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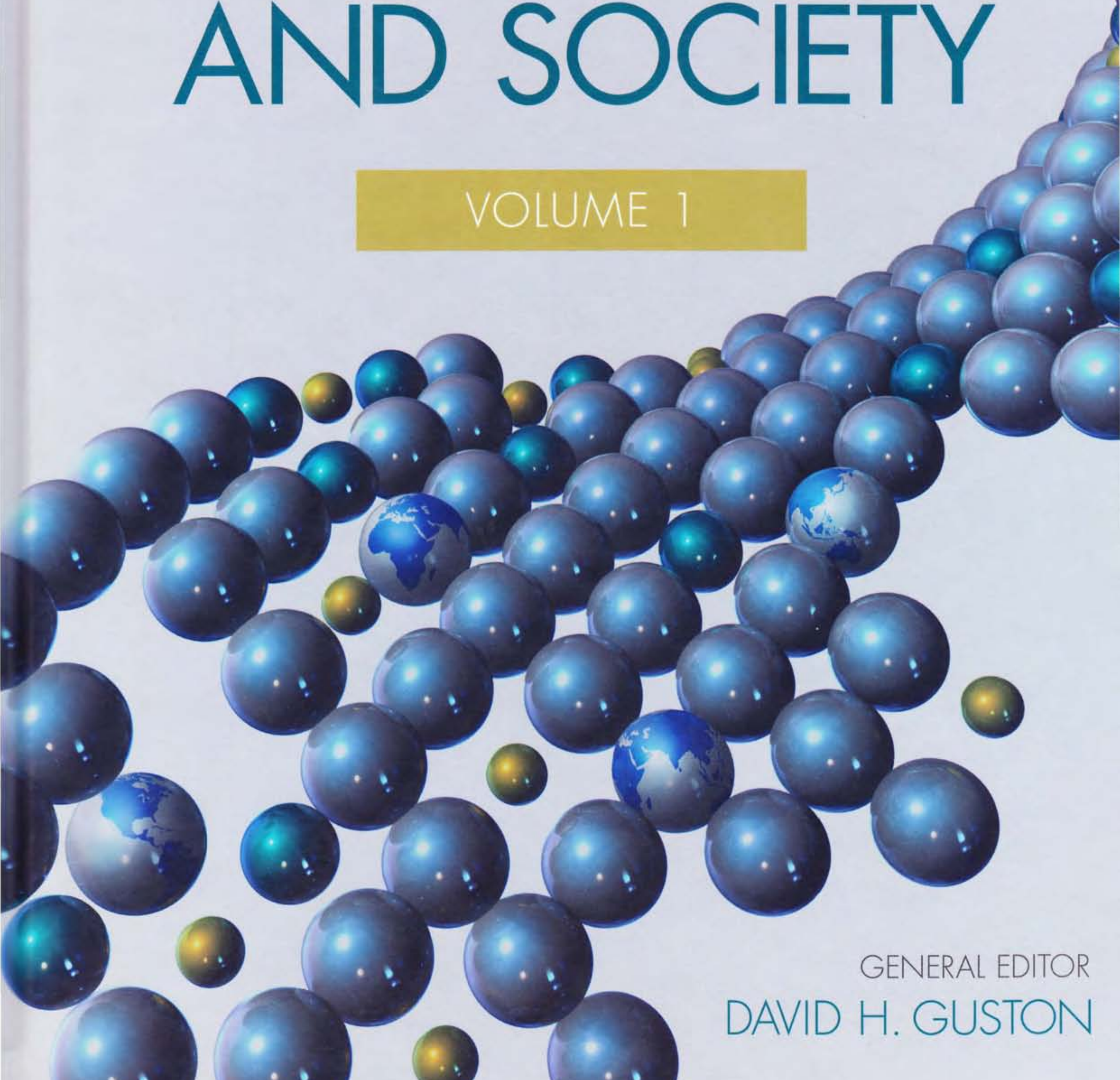

GENERAL EDITOR

DAVID H. GUSTON

ENCYCLOPEDIA OF NANOSCIENCE AND SOCIETY

VOLUME 1

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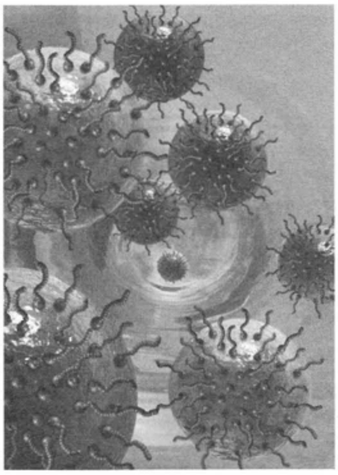

Contents

coordination of regional nanotechnology policy, encompassing education, research and development, industry, and business. Thus, the forum tries to address the need for a strong alliance across in the AP region in nanotechnology R&D and commercialization.

See Also: Australia; China; Japan; Singapore; Society for Nanoscience and Technology; South Korea; Taiwan.

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Association of German Engineers

The VDI (Verein Deutscher Ingenieure, or the Association of German Engineers) Technology Center (VDITZ) in Dusseldorf, Germany, is active in emerging technological fields. VDITZ combines technological competence with expertise in the interactions of innovations with economic, social and ecological dimensions, and is therefore a renowned partner of decision makers in the academic world, politics, industry, and society.

VDITZ supports implementing new key technologies through technology forecasting, monitoring and assessment, management of federal and state governmental research and technology project funding, enhancement of technology transfer from research to industry, neutral and problem-solving consulting, supporting technology management, as well as assisting new technology-oriented companies. VDITZ receives support from the German federal government, the Länder (German federal states), the European Union, and industry. The three main tasks of VDITZ are research funding, dealing with research questions, technology, and innovation, and consulting on emerging technologies.

VDITZ mainly functions as a project executing organization for the German federal ministry of education and research. VDITZ is active in drafting new research funding programs, consults with scientists, politicians and the industry, and tests and evaluates research and development projects. VDITZ also aims to accelerate innovations as its contribution to the dissemination and evaluation of research results. Further contracting authorities are the Landesstiftung Baden-Württemberg, the Berlin senate, and the European Commission. Technologies of interest to the organization are optical technologies, nanotechnology, electronics, and security research. VDITZ also serves as national contact point for project applicants.

VDITZ offers consulting and assistance in basic questions in research, technology and innovation concerning clusters and networks, international cooperation in education, research and innovation, as well as supplying research studies and expert opinions.

Emerging Technologies Consulting

VDITZ consults and supports decision makers regarding technological and societal issues for the future related to emerging technologies. It has more than 25 years of experience in technology forecasting and strategy development and a broad customer base in industry, politics, science, and the financial world. It is focused on information, consulting services, and technological and social issues. One of the core components of VDITZ comprises management of clusters and networks, as they provide the ideal environment for successful implementation of technological innovations. Furthermore, VDITZ offers target-oriented communication in order to provide key information. Additionally, studies and expert reports are offered to highlight possible options for actions.

In nanotechnology, the development speed has been so rapid that parallel basic research is carried out while nanoscale-related products are entering the world market. If one manages to control these products on the atomic and molecular scale, requirements are evolving to optimize the properties of products in the field of energy management (e.g., fuel cells, batteries, and solar cells), environmental technology (e.g., disposal, cleaning, and material flow), and information technology (e.g., media with high-density storage capabilities and high-end processors).

VDITZ promotes emerging technologies, such as microsystem technologies, multimedia, laser technology, plasma technologies, surface technologies, superconductors, and nanotechnology.

See Also: Germany; Nanoenabled Products in Commerce; Nanomaterials; Nanomaterials in Commerce; Spintronics.

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Australia

As a country with a proud history of development and adoption of scientific and technological advances, it is not surprising that Australia has recognized the competitive advantages and economic benefits of nanotechnology research and development (R&D) activities. The federal and state governments have made significant investments in the country's public and private nanotechnology capabilities.

Strategies and activities designed to foster innovation and the commercialization of nanotechnology-related applications have included the 2007 implementation of a National Nanotechnology Strategy (NNS), investment in infrastructure, education, metrology, and investigations into the adequacy of existing regulatory arrangements; a more recent focus has been on public awareness and engagement activities. The strategic importance of nanotechnology to Australia's future has also ensured that the country is now home to over 80 nanotechnology-focused businesses. Australia is also an active participant in international attempts at harmonization of societal and regulatory responses to nanotechnology, such as the International Standards Organisation and Codex Alimentarius Commission.

Nanotechnology as a field of scientific endeavor is not new to the Australian research or industry sectors, with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) having begun working on molecular composite materials during the mid-1980s. Commercial applications followed, with one of CSIRO's earliest nanoproducts, a food-packaging film using nanocomposite materials, entering the Australian marketplace in 1991. This pioneering work of CSIRO provided a strong foundation for other nanotechnology scientific and policy developments in Australia during the 1990s.

It was during this period that scientists from the Co-operative Research Centre for Molecular Engineering and Technology, with the support of the Australian government and industry, created a purpose-built functioning nanomachine (or synthetic biosensor) for use as a molecular sensor in, for example, the fields of medicine and food safety. Research into advanced supercapacitors undertaken by CSIRO and Energy Storage Systems gained momentum, resulting in the incorporation of Cap-XX (1999).

These advances, along with those made by, for example, the University of New South Wales's Semiconductor Nanofabrication Facility, showed the Australian government that nanotechnology had the capacity to be an enabling technology, and one that traditional sectors, such as the manufacturing industry, could benefit from. By the late 1990s, it was recognized that while Australia had the expertise and workforce to capitalize on nanotechnological advances, significant investment in infrastructure was needed. Also needed was a national strategy to encourage coordination between the states, the university sector, the research community and industry more generally in order to capitalize on the expertise and ensure maximum commercial impact and to position Australia as a global leader in fields in which nanotechnology could be utilized.

Nanotechnology Research

Despite the initial absence of a nationally coordinated strategy, federal and state support increased over the following years for nanotechnology-related research, commercialization, and policy development. Within the research community, key events included, for example, the establishment of CSIRO's Nanotechnology Centre (2001), the announcement by the Australian Research Council (ARC) that nanotechnology would be a priority area (2002), subsequent establishment of 24 nanotechnology-related research networks, and the nderline the tension between the gence and the two types of nanotechnology emergence that are prominent in the current debate. Bottom-up or self-organization emergence might be the only type that fits, at least to some extent, with the classic notion. The top-down type, on the other hand, might be better considered a certain kind of reductionism, namely a technological reductionism. Nevertheless, the mere fact that nanoresearchers refer to emergent properties can be regarded to indicate a shift in understanding and conceptualizing technology.

See Also: Converging Technologies; Drexler, K. Eric; Emerging Technologies; Feynman, Richard; Molecular Assembler; National Nanotechnology Initiative (U.S.); Nordmann, Alfred; Roco, Mihail; Self-Assembly; Self-Replication; Singularity; Smalley, Richard.

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Emerging Nanopatterning Methods

Highly integrated nanostructured devices call for advanced technical approaches to lithographic methods, which are capable of higher resolution and feature cheaper manufacturing costs than state-of-the-art optical lithography. Such approaches comprise, for example, nano-imprint-lithography (a major research topic and increasingly attracts industrial interest and activity), electron-beam-lithography, and multi-photon-based laser-lithography.

Multi-Photon-Based Laser-Lithography (MPLL)

MPLL is a direct-write nanostructuring method that uses a focused laser beam for fabrication of three-dimensional (3D) shapes in a photosensitive material. The laser focus is scanned through the volume of the material and alters material properties, such as solubility or refractive index, along its trace. Subsequent treatment (e.g., baking, development) removes the unexposed material. The photosensitive material is transparent to the laser wavelength, so that absorption and hence energy transfer from the laser to the material occurs only if more than one photon can be absorbed simultaneously from the laser beam (multi-photon-absorption). This non-linear optical interaction is confined to a small volume around the laser focus (voxel). The voxel size determines the resolution and the smoothness of a structure and depends on the laser properties, the focusing optics and the properties of the material under exposure. MPLL is a sequential method that builds a structure voxel by voxel. MPLL is applied for rapid prototyping of complex 3D shapes in the field of M(N)EMS/M(N)OEMS technology without any masks or further pattern transfer steps. Key benefits are flexibility and true 3D structuring capabilities.

Electron-Beam Lithography (EBL)

EBL is used for creating the ultrafine patterns required by modern nanotechnology. It is a direct write nanostructuring method using an electron beam for patterning a material sensitive to electron exposure (resist). The electron beam is scanned in a controlled manner, leaving a pattern in the resist. The electron impact locally alters the material solubility by either crosslinking (negative resist) or radiation degradation (positive resist).

Subsequent development removes the exposed regions (positive resist) or the unexposed regions (negative resist). EBL does not suffer from the diffraction limit known from photolithography and therefore nanometer-small features can be fabricated. Subsequent to the development, the pattern is transferred to the substrate material by etching. The main limitation of EBL is throughput, since it is a sequential single beam writing process. Key benefits include resolution and flexibility (maskless method).

Nanoimprint Lithography (NIL)

NIL is an advanced method for creating patterns from the micrometer down to the nanometer range at a low cost by means of replicating a master structure (NIL-stamp) in a suitable material. The material exhibits the inverse relief of the master structure (thickness contrast). The pattern transfer is conducted either by thermoplastic molding at high pressure/high temperature (hot embossing or thermal NIL) or by molding of a liquid resin at low pressure/low temperature and hardening by ultraviolet (UV) exposure (UV-NIL).

Thermal NIL requires hard stamps (e.g., Si-wafers) and temperatures above the glass transition temperature of the thermoplastic imprint resist for pattern replication and demolding at a temperature below the glass transition temperature. UV-NIL requires a transparent stamp (hard or soft) or a transparent substrate. Both methods allow either structuring of a resist polymer (acting as an etching mask as in conventional photolithography) or direct patterning of a polymer with specific optical and electrical properties. Due to the absence of heating/cooling cycles, UV-NIL is a faster process than thermal NIL. The residuum remaining after imprinting must be removed by, for example, etching. High quality master stamps are fabricated by an alternative method (EBL, MPLL) and are usually expensive. Key benefits are resolution (as detailed as 2 to 5 nm) and fast replication. Costs can be moderate when using cheaper working stamps made from the master stamp.

See Also: Electronics and Information Technology; Emerging Technologies; Nanoelectronics; Nanoscale Science and Engineering.

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Emerging Technologies

Nanotechnology is frequently identified as one of several powerful "emerging technologies," a category that is generally taken to also include biotechnology, robotics, information and communication technologies ("ICT," a category that includes equipment as well as services such as social networking and virtual reality offerings), and applied cognitive science, as well as the many hybrid technologies that arise from integration of these core technologies. Understanding the implications of these technologies is important in part because of the increasingly powerful role they play in helping to structure human institutions and behaviors, as well as regional and global natural systems.

Core Technologies and Innovation Waves

One useful concept for appreciating the implications of emerging technologies is provided by economic historians, who have identified and studied "long waves" of

In summer 2009, EPA announced the possibility of regulating nanosilver as a pesticide, because of its frequent use as an antimicrobial—often incorporated into a covering, such as for a computer keyboard or mouse, or in Samsung's Silvercare washing machines, which are designed to eliminate any bacteria in laundry. The decision to regulate nanosilver will require a number of other decisions—whether to establish new protocols for determining the hazards and efficacy of nanopesticides, which existing products (if any) will be required to be re-registered (for which there is precedent in the 1988 legislation), and how to evaluate whether a nanopesticide should be general use or restricted use.

A large number of products in recent years have reworded their claims and marketing copy in order to avoid language that specifically refers to antimicrobial properties, in an attempt to avoid an accidental violation of FIFRA; the new regulations mentioned by EPA are meant in part to clarify matters. In the last few years, it has been somewhat unclear which nanopesticide products require registration, and while erring on the side of caution may make sense from a legal standpoint, it represents a significant expense on the part of the company, as well as a delay in bringing the product to market.

See Also: *Consumer Reports*; Department of Agriculture (U.S.); Environmental Protection Agency (U.S.); Nanosilver; Regulation, U.S.; Samsung.

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Federal Institute for Occupational Safety and Health (Germany)

The Federal Institute for Occupational Safety and Health (FIOSH) in Germany acts as a center of competence and knowledge regarding matters of safety and health at work. FIOSH has its main office in Dortmund and offers advice and practical assistance to companies, the government, social partners (i.e., trade unions and employers, or their representative organizations engaged in social dialogue), and the general public. The main task of FIOSH is to research, analyze, inform, publish, coordinate, develop, train, and advise in providing humane work environments with safe, healthy, and competitive workplaces.

The aims and activities are reflected in the tasks assigned to FIOSH: they are oriented toward the basic concern of maintaining and improving safety and health at work. The approaches adopted to achieve this goal are the safe design of technology and humane designs of working conditions. An essential element is the maintenance and promotion of health and work ability on the basis of the notion of health and health-based behavior. The Institute is committed to the safety and health of people in their working and living environments.

FIOSH helps to ensure a high quality of work and competitive companies. It advises and supports the German Federal Ministry of Labor and Social Affairs, as well as other ministries, and implements sovereign tasks, conducts research, and develops practical solutions.

As an important future technology, nanotechnology presents an opportunity for positively influencing economic development in the long-term through intensive research, and for the effective translation of research results into innovative products. In many areas, it is not currently possible to assess the toxicological and ecotoxicological risks associated with this emerging technology. It is expected that the prevalence of nanotechnology will continue to increase and that workers, consumers, and the environment will increasingly be exposed to it.

Hence, an important goal of FIOSH is to monitor the development of this new technology, to assess the opportunities and risks in a transparent process, and to compare them with established technologies. According to present knowledge, insoluble and poorly soluble nanomaterials are of particular toxicological relevance. Current German chemical legislation does not provide for a specific procedure for testing and assessing nanomaterials, such as titanium dioxide, zinc oxide, iron oxide, silicon dioxide, or carbon black, which represent a nanoscale modification of an existing high production volume (HPV) substance with the same chemical abstract service (CAS) number. Regulations have not yet been created for nanomaterials in food, consumer products, or cosmetic products. For example, particle sizes have not been defined in the purity criteria for the authorized food additives silicon dioxide (E 551) and titanium dioxide (E 171).

See Also: Germany; Health and Environmental Risks (Netherlands); Nanomaterials; Nanosilver; Nanotoxicology; Titanium Dioxide; Zinc Oxide.

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Federal Institute for Risk Assessment (German)

The German Federal Institute for Risk Assessment (Bundesinstitut für Risikobewertung, or BfR) is an agency under public law with the task of strengthening consumer health protection, and heavily engaged in the area of possible risks of nanotechnology in consumer-relevant areas and in health. The Institute reports to the Federal Ministry of Food, Agriculture, and Consumer Protection, but is independent when it comes to its scientific assessments and research. BfR has the statutory remit of identifying potential risks to consumers from foods, substances and products, of assessing them scientifically, and of involving all the stakeholders in an active communication and information process. In 2008, for example, more than 6 million euros were earmarked for research.

In 2005, the Institute established an internal expert group for nanotechnology. In 2006, the Institute was actively involved in investigating respiratory problems suffered by more than 100 consumers, caused by a sealing spray called Magic Nano, which did not actually contain any nanoparticles. Together with the Federal Office for Health and Safety and the Federal Environmental Agency, a research strategy to identify the potential risks of nanotechnology was published in 2007. Furthermore, BfR is active in the scientific bodies that deal with the regulation of nanotechnology at a national or European level.

BfR has also conducted and funded a series of dialogue and research activities on the risks of nanotechnology. In order to determine how nanotechnology is perceived by the German population, one BfR project conducted research into the public perceptions of nanotechnology by means of a representative population survey, coupled with a qualitative psychological study. Parallel to this, BfR conducted a consumer conference, an expert survey and a media analysis of the subject. This was followed by consumer- and product-orientated studies on the risk perception and the framing of nanotechnology in spontaneous online discussions (in online forums and weblogs), as opposed to organized online dialogues.

All these activities share the common goal of providing orientation and, by extension, maintaining the ability of society to respond in an informed manner to a new, complex technology and guaranteeing the safe, responsible handling of nanotechnology and its products. BfR research activities are also designed to identify risks or risk areas that are present in the public perception in a manifest, latent or potential manner, and to describe factors that impact risk communication in this new area. The Institute's research and dialogue activities play an important role in Germany's overall strategy for dealing with the health, environmental, and safety issues and the ethical, legal, and societal implications of nanotechnology.

See Also: Federal Institute for Occupational Safety and Health (Germany); Germany; Magic Nano; Nano Initiative—Action Plan 2010 (Germany).

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Federal Ministry for Transport, Innovation, and Technology (Austria)

The Federal Ministry for Transport, Innovation, and Technology (BMVIT) is one of several Austrian ministries with responsibility for research and technology, mainly focused on innovative research and development. As such, it is the main funding body for the Austrian nanotechnology research program "NANO Initiative." The ministry is divided into five departments:

- Department I: executive committee and international affairs
- Department II: roads and aviation
- Department III: innovations and telecommunications
- Department IV: rail, water transport, and transport labor inspectorate
- Department V: infrastructure planning and financing, coordination

The Role of the BMVIT in the Austrian Innovation System

Research, development, and technological innovation provide the basis for economic growth, competitiveness, employment, and, ultimately, the prosperity of the country and its citizens. The BMVIT promotes research at all levels, from basic research to the industrial application of research results. The BMVIT manages the largest share of the public budget earmarked for applied research. It owns 50 percent of the Austrian Research Promotion Agency (FFG), the body through which the Ministry channels the major part of its application-oriented research funding, and holds the majority of the Austrian Research Centers (ARC). Moreover, the BMVIT is responsible for the Austrian Science Fund (FWF), Austria's central body for the promotion of basic research.

Besides efficient research promotion, a forward-looking approach of the most important components of the innovation system is essential—among the people engaged in research, and within the structures and funding systems which make European and national research possible. The main activities of the BMVIT in the field of research are cooperation between industry and the scientific community, orientation toward key technologies, building on the strength of Austrian research, support to business start-ups in the high-technology sector, and providing an attractive location for international research centers.

The department for innovation and telecommunication coordinates several research areas with at least one associated nationwide research program. These research and development areas are transport and mobility, sustainable development, aeronautics, space, information technology, ambient assisted living (AAL), nanotechnology, human resources, and security research.

The Austrian NANO Initiative

The Austrian NANO Initiative is a multi-annual funding program for Nanoscale Sciences and Nanotechnologies (NANO for short) in Austria. It coordinates NANO measures on the national and regional levels and is supported by several ministries, federal provinces and funding institutions, under the overall control of the BMVIT. The program is managed by FFG on behalf of the BMVIT. The orientation and structure of the Austrian NANO Initiative have been developed jointly with scientists, entrepreneurs, and intermediaries. The NANO Initiative addresses all NANO players from university and non-university research, as well as enterprises located in Austria. International partners are welcome to participate in all program action lines.

See Also: Innovation; Interdisciplinary Research Centers; NANO Initiative (Austria); NanoTrust Project (Austria); Research and Innovation Assessment.

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he sheer nature of nanotech- ve rise to a revolution in human existence. The first version of a nanotech factory is likely to be a diamond- (carbon-) based one, which will lead to the creation of compact and strong versions of extant technology at an astonishing pace. For example, in a nanotech era, computers would become nearly a 1,000 times smaller and use a mere fraction of the power that they now use, and materials could be about 100 times stronger.

While these are promising advances for the future, extant nanotechnology can address several 21st century worldwide issues. Poor water quality in the third world could be improved using nanosorbents, nanocatalysts, bioactive nanoparticles, nanostructured catalytic membranes, and nanoparticle enhanced filtration, and nanotechnology-derived products could dramatically reduce the concentrations of toxic compounds in water. In the area of energy storage, nanocatalysts can be used for hydrogen generation, and carbon nanotubes can be used in composite film coatings for solar cells. In the field of agricultural technology, nanocapsules can be used for the effective delivery of heribicides, and nanomagnets for the removal of soil contaminants. Nanosensor arrays, based on carbon nanotubes, can be used in the detection of disease, while nanocomposites in plastic sheets used for wrapping food can ensure greater freshness for longer periods of time.

In fact, nanotechnology is being considered to attain the Millennium Development Goals (MDGs) at a greater pace, with newer applications in agricultural nanotechnology, such as nanosensors to monitor the quality of the soil and plant health helping humanity eradicate extreme poverty, nanomedicine helping to reduce infant mortality rates, improve maternal health, and combat human immunodeficiency virus (HIV) and other infections, and applications such as gas separation nanodevices to reduce air pollution and ensure environmental sustainability.

See Also: Artificial Intelligence; Green Nanotechnology; National Nanotechnology Initiative (U.S.); Next Industrial Revolution.

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Global Value Chains

The globalization of knowledge, technology, and capital is rapidly changing the way companies compete in the market. Competition in the field of nanotechnology is not among companies, but among global supply chains and business networks. High-tech companies—especially those in the nanotechnology sector—increasingly develop competitive advantages through intellectual property, open innovation approaches and global exploitation of technology.

The "globalization of innovation" is driving the global value chains in the field of nanotechnology. A value chain can be understood as a series of activities that leads to the creation of a product. Products pass through all activities of the chain in order, and at each activity the product gains some value. Also the gross margins generally increase with every step of the value chain. The chain of activities gives the products more added value than the sum of added values of all activities. The general structure of nanotechnology value chains reaches from nanotools via nanomaterials and nanointermediates to nanoenabled products.

In the case of nanotechnology, and due to the fact that newer technologies are far more influenced by globalization, the value chains are extending to global value chains. Inter-company processes and specific design rules that used to be an advantage for big companies are losing importance and are being replaced by common international standards and methods. The size of a company is not a key factor anymore—what matters more is the company's access to resources, wherever they may be located.

Nanotechnology is not a single technology, it is actually a cluster of different technologies that have one thing in common: they are influenced or controlled by structures of matter at the nanoscale. It is unlikely that nanomaterials will dramatically alter the nature of a product or lead to a new product if an entire value chain from nanomaterial to end product has to be developed, since the time to market would probably be too long or the return on investment too low. Success is most likely in areas where suitably tailored nanomaterials can be integrated seamlessly into an existing value chain, while simultaneously preserving the benefits of the nanoengineered property.

Problems in the nanotechnology sector arise mainly in companies that still cling to conventional thinking patterns. The "sell what you have" and the "go-it-alone" strategies are only partly effective in markets that are based on innovation-based global value chains. The focus of most nanotechnology companies has primarily been on materials phenomena and incremental improvements to existing markets. The results are low-value chain nanoproducts that are not contributing attractive gross margins, thereby making sales volume the vital ingredient for profitable operations. However, realizing high sales volume from low-value chain offerings is arduous, dependent in most instances on the marketing efforts of other companies who may have different priorities. A company with offerings higher on the nanotech value chain has a higher gross margin per unit and is less dependent on sales volume of other companies. Ergo, nanotech companies need to productize their way up the nanotechnology value chain to gain higher gross margin.

The challenge for the coming years will be the set-up of value chains with a high margin nanotechnology share. This requires an accelerated transition of the advances in nanoscience into commercial applications. To achieve this, a proper nanomanufacturing infrastructure will be needed. It is most likely that such an infrastructure will only be established when it is catalyzed at a global level. The speed of establishment of such a nanomanufacturing infrastructure will determine the impact of nanotechnology on our future life.

See Also: Nanoenabled Products in Commerce; Nanomaterials; Nanomaterials in Commerce.

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Governance

It is expected that widespread social and economic impacts will be made by nanotechnology and nanosciences, thus these emerging and enabling technologies pose a new set of challenges to policy and regulation. These challenges are being tackled by diverse political players and institutions on the national, supranational, and international level. This group includes politicians and

Several inventions in the 1980s made nanotechnology and the use of nanomaterials a reality.

Among these are the scanning tunneling microscope (STM), which provided the first images of individual atoms on the surfaces of materials, and won the German scientist Gerd Binnig and his colleague, the Swiss scientist Heinrich Rohrer, the Nobel Prize in Physics in 1986. In 1990, Dr. Donald M. Eigler and Dr. Erhard K. Schweizer of the IBM Almaden Research Center at San Jose, California, demonstrated for the first time the ability to build structures at the atomic level by spelling out "I-B-M" with individual xenon atoms. Other nanomaterials, such as the discovery of fullerenes, a new crystalline form of carbon C_{60} that could emerge as the building blocks of molecular machines, and carbon nanotubes that are extremely strong and flexible that give nanotechnology its raw material, the properties of semiconductors of nanocrystals, and the atomic force microscope. In 1987 researchers at Bell Labs in the United States created the first single electron transistor based on the idea of Konstantin K. Likharev, a scientist at Moscow State University that it would be possible to control the flow of single electrons. Similarly, today biotechnologists can create DNA sequences and artificial viruses, which can be considered an example of molecular manufacturing.

See Also: Definitions of Nanotechnology; IBM; Indigenous Nanotechnology; Nanomanufacturing; Quantum Dots.

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History-in-the-Making

The History-in-the-Making project, started in 2006, attempts to understand the history of nanotechnology as it emerges. The project, funded by the National Science Foundation (NSF), is handled by a research group based at the Center for Nanotechnology in Society at the University of California, Santa Barbara (UCSB). Heading the project is W. Patrick McCray, Co-director of the center and Associate Professor in the UCSB Department of History. The center is collaborating with the Kimberly Jenkins Chair for New Technologies and Society at Duke University (Timothy Lenoir), and the Center for Contemporary History and Policy at the Chemical Heritage Foundation in Philadelphia (Cyrus Mody). The goal of the project is to make policy makers, scientists and engineers, and the general public understand the opportunities and the risks that the nanoenterprise affords.

The wide range of possible applications makes the understanding of the development and its impact on society a complex task. New technologies do not enter society on their own; ultimately people and societies make technologies and decide how they are used. The History-in-the-Making concept focuses on the historical and social developments around this purely technological area. It acknowledges that social sciences and humanities have significant roles to play in nanotechnology beyond addressing the issues of public perception and media coverage.

One problem that needs to be addressed is that scientists and engineers do not have the time, expertise, or resources to survey the influence their research has on the markets and society. They also have little information of how their research results are implemented and commercialized. Historians, social scientists and humanities scholars have the insights and methods that can help to monitor and document the impact of nanotechnology on society as "history in the making."

One problem the project will have to deal with is the growing amount of information that in combination with the limited ability of the human mind to process data leads to a collective memory loss (stored to forget). A proper documentation and structuring of the events will have to be established to help future historians extract the actual chain of events out of the huge amounts of raw data stored. Otherwise, electronic mail, Websites, conversations, and experiments about the emerging field of nanotechnology might quickly slip into the past.

This is especially problematic, as the public perception of nanotechnology does not reflect its importance. For example, government support for nanotechnology—some $6.5-billion thus far—is on a similar scale as the U.S. space program was in the early 1960s, when a large infrastructure for science and technology was established. But public awareness of nanotechnology is low. People are accustomed to innovation and the importance of this technological revolution might be underestimated.

A key project of the center is the historical context of nanotechnology. A first step was a case study focusing on the nascent field of Spintronics, basing on interviews with participants of a research conference in 2006 on the topic at UCSB's Kavli Institute for Theoretical Physics. The work is directed toward understanding the development of nanoelectronics, temporally and spatially, and includes aspects such as research funding, patents, publications, and research groups. In this context, the team of Duke University applied tools they had developed for data mapping and visualization.

Another area of nanoresearch that appears most exciting to scientists, commercial firms, and government patrons is the development and implementation of nanoelectronics as a replacement for systems based on microelectronics. The potential economic and social effects of this transformation may be profound. Monitoring these events might bring a better understanding of when and how technological changes happen.

See Also: Center for Nanotechnology in Society (UCSB); National Science Foundation (U.S.); Risk-Benefit Perceptions of Nanotechnology; Risk Communication; Social Science.

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Human Enhancement

Human enhancement technology is any physiologically incorporated device, pharmaceutical product, or medical procedure that improves an individual's physical or cognitive abilities beyond the uppermost boundary for the species in terms of either the number or the strength of those abilities. This article will first unpack the lexical and logical difficulties inherent in the definition offered above. What constitutes a technology, a relevant trait for enhancement, or the appropriate boundary for the line between therapy and enhancement are far from settled issues and will require some discussion. It will include a brief discussion throughout of the theoretical and historical underpinnings of human enhancement by way of explanation of the choices made in forming the definition above.

Technology's roots are embedded in action rather than in artifacts. The Greek *techné* means art or skill and *technologia* refers to the study of an art or skill. The etymology of the word makes no mention of the material or social artifacts of *technologia,* but today that is perhaps the most common understanding. Technology is no longer conceived of as something you do or you study in order to do, but rather as something you hold, possess, and use to your advantage.

Thus, defining human enhancement technology only in terms of devices or procedures represents something of a departure from historical definitions but it does conform to contemporary convention. It serves a further analytical purpose in distancing human enhancement technology from social technologies and learned skills—as already noted these definitions seem obscure to most—and confining it to devices and medical procedures.

Defining Human Enhancement

Social technologies—the modern state system for example—have certainly served to enhance human capacities, but such a statement is uncontroversial and seems to belie the energy with which many oppose what has come to be known as human enhancement technology. The same can be said of learned skills and arts; it is not unusual to describe these things as enhancing our natural abilities.

Further, it is likewise uncontroversial to argue that mundane—and perhaps even cutting edge—commercial material technologies enhance our natural abilities.

nomic powers but, rather, toward needs that are economically not as powerful, such as those prevalent in developing or threshold countries.

Future-Oriented Shaping of Innovation

Especially in the case of innovation in cross-sectoral fields, such as nanoscale, S&T can be characterized by its distributed structure—i.e., a sharing of roles among actors from different organizations and even institutional domains. Distributed innovation requires that the different components that constitute an innovation come together in a particular manner. This, for example, applies to new knowledge, methods and techniques; financing of R&D and markets; innovation policy frameworks and regulatory procedures; and public or private needs and preferences. In addition to generating innovations, it is critical how they are implemented into different societal contexts and appropriated by various actors. In the case of emerging S&T, assessing what is needed to appropriately generate, regulate, and apply innovations is particularly difficult. As the future of emerging fields of S&T is uncertain, the various transitions from present scientific and technological potentials to future innovations are still undetermined. The future characteristics of society are uncertain as well, as is the development of the relationships between S&T and society.

This constellation gives rise to numerous challenges that affect those who are concerned with the practical development of innovations as well as those who analyze such processes as social scientists. Since emerging innovations are neither fully crystallized nor established in society, and since their trajectories are subject to at times abrupt shifts, what is needed are capacities to cope with dynamic change at various levels—such as preparedness to cognitively and practically master unforeseen developments in S&T and society. It is therefore important to enhance the process of innovation with reflexive, deliberative, and anticipatory capacities. Emerging fields of S&T that are considered to result in revolutionary innovations tend to boost controversial—promissory and fearsome—expectations. Not least for this reason it is important to institutionalize future-oriented assessments of emerging S&T in society as well as forums that facilitate communication among actors from various backgrounds.

It would be illusionary, though, to expect that improved communication across diverging disciplinary or societal cultures will result in consensual understandings of the significance of new and emerging S&T. Nevertheless, exploring and discussing what the probable or potential consequences of such innovations may be will help envision different scenarios of S&T in society, as well as identify zones of consent and dissent. This seems particularly important in areas that carry the potential to affect fundamental values and norms of a society, such as those concerning the identity and welfare of human beings (as well as other forms of life). However, not only are emerging fields of S&T subject to dynamic change but also to shifting public perceptions and attitudes. Therefore, what may be considered undesirable today because of unknown risks or assumed moral quandaries might become part of common sense and everyday culture in the future—which again demonstrates the interdependency of technological and societal change.

See Also: Anticipatory Governance; Commercialization; Competitiveness and Technonationalism; Disruptive Technology; Emerging Technologies; Reflexive Governance; Science Policy; Social Science; Societal Implications of Nanotechnology; Technology Assessment; Uncertainty.

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InnovationSpace

InnovationSpace is a transdisciplinary education and research lab that teaches students how to develop products that create market value while serving real societal needs and minimizing impacts on the environment. The program is located at the Center for Nanotechnology in Society at Arizona State University (ASU).

It is one of several design programs or courses in the United States that focus on equipping students with the skills to collaborate and the ambition to innovate. The team approach is being focused as a way to supercharge innovation. Further courses in this field are the Integrated Product Development at Carnegie Mellon University; the Center for Innovation in Product Development at the Massachusetts Institute of Technology (MIT); the Institute of Design at the Illinois Institute of Technology; and Stanford University's new Institute of Design.

InnovationSpace conducts applied projects with university researchers, corporations, and other private sector groups. The topic and scope of projects are negotiated in advance and often based either on an existing invention (for instance, an engineering prototype) or an open-ended interest in exploring new opportunities. While the focus of projects may vary widely, all projects are shaped by integrated innovation: they aim at meeting user needs in unexpected ways, create value in the marketplace and improve society and the environment.

Once a project is defined and fees negotiated, students are recruited from the business, engineering, product design, and graphic design programs. Typically, students sign up for a yearlong, two-semester course that is cross-listed and satisfies program requirements in all the disciplines. As an alternative, students may also be hired by InnovationSpace as research assistants to work on shorter-term and more targeted projects. In either case, faculty members from each of the four disciplines collaborate to provide instruction and support.

InnovationSpace projects are normally conducted in six phases. During each phase, integrated innovation is used to develop and present concepts and plans. This model has proven to be very useful and effective in helping teams of students target and explore specific areas of interest. During the fall semester research is organized, design concepts are generated and the respective business plans evaluated. In the spring, with concepts and plans more clearly understood and articulated, "new venture proposals," which fully describe the proposed design concept (including engineering specifications) and an integrated business, marketing, and communication design plan are created.

As final step, the teams are required to present their new venture proposals at a trade-show exhibition and in front of a public audience that typically includes a diverse group of ASU faculty, university intellectual property managers, students, venture capital groups, investors, and corporate partners. During these events, each team discuses its proposal and assesses its value (i.e., the quality of its innovation) by measuring it against integrated innovation. By design, this last step forces the teams to make a compelling argument for how their proposal satisfies consumer demand in a unique way, improves society and the environment, and creates measurable value in the marketplace.

Nanotechnology Projects

Numerous InnovationSpace projects have included nanotechnology. For instance, three product ideas from the 2007 to 2008 academic year that have been submitted to Arizona Technology Enterprises imagine new uses for nanotechnology to enhance human life. These include a scanner that translates printed text into Braille, a device that enables cancer patients to observe their progress on a computer screen, and a cast or brace that can change rigidity in response to certain wavelengths of light. In the 2008 to 2009 academic year, InnovationSpace's focus was on the use of nanotechnology to solve energy problems. Projects included a solar powered portable transportation device called the Tangent, a temporary shelter that regulates its inner temperature using solar energy, and the Everwell system, used to collect drinking water from the air. InnovationSpace has also sponsored public dialogues on various issues relating to nanotechnology, including nanotechnology and religion, using futuristic scenarios to spark responsible debate about nanotechnology and its social implications, and equality and inequality in nano- and other emerging technologies.

While most undergraduate and graduate educational programs shy away from the legal complexities of intellectual property, InnovationSpace assigns co-inventor rights on all projects to the participating students.

The prospects for InnovationSpace are good. It is planned to expand the undergraduate program and to develop an ambitious graduate offering, with emphasis on global issues. An alliance of research labs at ASU is being established with faculty in assistive technology, nanotechnology, architecture, robotics, and other areas. A network of off-campus relationships with inventors, intellectual property consultants, and corporations is being set up. InnovationSpace aims to promote transdisciplinary collaboration and invention as being essential to 21st-century innovation.

See Also: Center for Nanotechnology in Society (ASU); Design and Construction; Innovation.

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Institute for Technology Assessment and Systems Analysis (Germany)

The Institute for Technology Assessment and Systems Analysis (ITAS) was among the first research institutes investigating the societal dimensions of nanotechnology. This work started in 2000, partly motivated by an early study for the German Parliament via its Office of Technology Assessment, operated by ITAS. Current ITAS work on nanotechnology focuses on risk characterization and communication of nanoparticles and ethical aspects of converging technologies. The mission of ITAS is much more broad, and covers issues such as sustainable development, energy systems analysis, and sociology of risk.

The Institute

ITAS is a public-funded research institute of the Karlsruhe Institute of Technology. The mission of ITAS is creating and communicating knowledge at the many interfaces between science and technology and society. Its work focuses on environmental, economic, social, and political-institutional issues.

ITAS supports politics, science, business, and the general public in decision making on the basis of the best available knowledge and transparent assessments. For this purpose, ITAS applies and upgrades methods of technology assessment (TA) and systems analysis. Knowledge provided by ITAS can be characterized by the following aspects:

Pragmatic Orientation. The Institute produces knowledge against the background of societal expectations, problems, and debates concerning technology. Relevant societal actors are involved in the research and communication process. Research results are integrated into different alternative options for action and shaping.
Future Orientation. The Institute's research regularly includes a prospective part. The focus is on forecasting the consequences of human action, both as a foresight of sociotechnological developments and as an assessment of the future impacts of current decisions, taking into account specifically the uncertainties necessarily involved.
Value Orientation. ITAS approaches the normative dimension of TA by analytical as well as by participatory means, involving applied ethics and social sciences. In particular, a model of sustainable development work has been developed by ITAS.

ITAS focuses on the following research fields:

Strategies of Sustainable Development. Based on the integrative concept of sustainable development, strategies for a variety of problems are developed and assessed, for example in the fields of mega-cities, land use, and scarce materials.
Energy—Resources, Technologies, and Systems. New technologies in the energy field are investigated with respect to their ecological, economic, and social impacts in the context of energy systems. Current focus is on the use of biomasses not competing with nutrition requirements, and on efficiency strategies.
Key Technologies and Innovation Processes. Potentials and impacts of key technologies as well as unintended side effects are identified and characterized. Options for action concerning innovation, dealing with risks and for public debate are developed. Focus is on nanotechnology and on communication technology.
Knowledge-Based Decision Making in Society. Decision making in modern society is, on the one hand, more and more expected to be knowledge based, but on the other hand increasingly faced with far-ranging uncertainties. This dilemma is investigated in depth, and strategies of dealing with it are developed.

ce at the University of Ba- r for Atom Technology in Japan; and the Nanoelectronics Research Center at the University of Glasgow.

Interdisciplinary research centers are, in many ways, the institutional backbone of nanotechnology. With no single recognized nano journal or professional society, the local interdisciplinary nanoscale research center represents many scientists' most extended contact with the nanotechnology enterprise. This is partly because nanotechnology organized in an historical moment when interdisciplinary academic centers were the preferred mechanism for implementing many nations' science policy frameworks. However, the standard interpretation of what nanotechnology is also lends itself to the interdisciplinary research center concept. Nano is usually seen as a convergence of many disciplines; of university, industry, and government; and of scientists and the public. All these forms of convergence fit easily within the rubric of the interdisciplinary research center.

See Also: Interdisciplinarity; National Nanotechnology Infrastructure Network (U.S.); National Science Foundation (U.S.); Trading Zones.

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International Center for Technology Assessment

The International Center for Technology Assessment (ICTA) is a nonprofit, nongovernmental organization (NGO) dedicated to analyze the impact of technology on society in terms of economic, ethical, social, environmental, and political perspectives. ICTA's main focuses concern the environment, global warming, patent watch, nanotechnology, human biotechnology, corporate accountability, and economics. ICTA mainly focuses its efforts in the United States.

ICTA has repeatedly challenged the Environmental Protection Agency (EPA) on environmental issues. In 1999, it petitioned that carbon dioxide should be declared a pollutant that threatens public health and welfare. In 2009, EPA finally complied with the 2007 Supreme Court decision. Furthermore, in coalition with other environmental, consumer, and health groups, they filed a complaint concerning unregulated nanotech pesticide pollution against EPA. Pollution is by far not the only environmental threat ICTA is addressing and warning about. Invasive species pose a non-negligible danger to ecosystems all over the world. Genetically engineered plants may pose a threat to original plants. Genetically engineered plants that were not intended for humans may find their way into human food through contamination of other species.

Biopollution from genetically engineered organisms is particularly dangerous because it exists on the genetic scale, making it nearly impossible to control or clean up. ICTA and its sister organization, The Center for Food Safety, seek to educate policy makers and the public on the dangers of biopollution and invasive species, and to encourage stronger policies to prevent their spread. Another controversial topic that ICTA tackles is the profit-driven acquisition of patents of genetic material of plants, animals and even humans by pharmaceutical companies called "bioprospectors" in this context. This biopiracy potentially poses a great threat to countries in the third world, whose knowledge on traditional organic remedies could be bought by international companies, resulting in the poor rural population in these regions of the world losing access to their ancient cures.

ICTA's Patent Watch Program seeks to identify pernicious patents granted by the U.S. Trademark and Patent Office. Such patents include human cloning techniques as well as invasive surveillance methods or biological weapon delivery systems. In the United States, no patent can be refused due to ethical or public interest concerns. ICTA encourages grassroots activities against such patents, initiates and supports legal challenges against existing and future pernicious patents, and helps to raise awareness. In their view, the U.S. patent system poses a dual threat to society. First, it encourages development of pernicious technologies and inventions, even those likely to cause substantial harm to people and the environment. Second, it allows private ownership of basic resources that should belong to everyone. The activities in this field clearly target mainly the United States, but since the United States encourages other governments to adopt these policies and make them the global norm, international implications cannot be denied.

Concerning nanotechnological applications beyond research, ICTA opts for a more thorough and profound evaluation of products containing nanoparticles, and seeks to shift the burden of proof onto the producers by halting commercialization of products containing nanoparticles until they have been proven safe. ICTA seeks to force federal regulatory agencies to adopt an accurate and standardized definition of nanotechnology, and to regulate emerging nanotechnologies as they would other materials whose safety has not been determined. NanoAction is a nanotechnology-focused advocacy project of the ICTA.

Recent advocacy campaigns organized by the ICTA include two calls for further regulation of nanotechnology by the U.S. Environmental Protection Agency. The first study, conducted in conjunction with the Center for Food Safety, concerns nanoparticle silver, which is used in many consumer products (often advertised using claims of its germ-killing ability). It is not yet known if nanosilver threatens human and aquatic health, and its germicidal properties are debatable. The second study called for the National Organic Standards Board of the U.S. Department of Agriculture to prohibit the use of nanotechnology in organic products.

In their efforts targeting developments in human biotechnology, ICTA seeks to keep policy makers, activists, and the public informed about developments in human biotechnology. ICTA also encourages a strong regulatory framework to ensure that human genetics research proceeds only under strict ethical standards. The center's main actions in this field are set against all kinds of cloning, be it animal cloning or techniques that might enable cloning of humans.

ICTA is also a founding member of the Center for Corporate Policy, an organization that advocates in the field of corporate responsibility and accountability.

See Also: Anticipatory Governance; Codes of Conduct, Corporate; Federal Institute for Risk Assessment (Germany); Food; Genetically Modified Food; Governance; Nanoparticle Occupational Safety and Health Consortium; Nanosilver; NanoTrust Project (Austria); Nanotechnology Safety for Success Dialogue (Food Industry); National Industrial Chemicals Notification and Assessment Scheme (Australia); Research and Innovation Assessment; Risk Assessment; Risk Governance; Technology Assessment.

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International Council on Nanotechnology

Justifications for nanotechnology research are often predicated on the importance of different kinds of diversity: diversity of disciplines contributing to the field; diversity of nations competing and cooperating in the commercialization of nanoscience; and diversity of stakeholders (i.e., corporate, academic, government, nongovernmental organizations, and the media). Diversity usually requires institutions to confer coherence, however—otherwise, participants are likely to fracture into their respective constituencies. Disciplinary diversity in nanotechnology has largely been fostered by government-funded academic interdisciplinary research centers, for which there is a long history of institutional models. International and stakeholder diversity, however, has required new kinds of institutions. One of the first and most important of these has been the International Council on Nanotechnology, a semiautonomous spin-off of the Center for Biological and Environmental Nanotechnology at Rice University.

benefit. Nanotechnology could still only benefit affluent [illegible] in rural communities, the most powerful members of a village, or men and not women in a household. Furthermore, from a critical perspective, risks cannot be so easily predicted and controlled. Technologies have unexpected consequences. Developing countries which often have less sophisticated regulatory systems may be more be susceptible to risks to environment and health caused by nanotechnologies.

Overall, the critical view focuses on the contexts of nanotechnology creation and use. Poverty is seen as social. Nanotechnology is not seen as inevitable, and there is a focus on local technologies as alternatives and on local knowledge and participation in development interventions. Nanotechnology has clearly reinvigorated debates about the relationship between technology and international development. Despite some variation in positions, discussion remains highly polarized. All parties would benefit from more empirical evidence about how specific nanotechnologies in specific developing areas are actually being developed and used.

See Also: Brazil; China; Equity; India; United Nations Millennium Goals.

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International Dialogue

International Dialogue can be described as interactions with various institutions and agencies all over the world, which by their position in society and by the force of their ideas can unite many areas of interest. International dialogue in nanoscience aims toward a global cooperation in nanotechnology; it enables and maximizes the beneficial contributions of nanotechnology to society and natural systems, as well as addresses the concerns of the public to reduce risks that may be associated with nanotechnology.

Nanoscience and nanotechnology are assumed to play an increasingly important role in technological and societal developments over the next decades, giving rise to a high level of expectation among the scientific community, the industry, and the general public at large. This means that communication between nonscientists is difficult because of the large number of parties involved in this topic. That is why proper access to knowledge, defining common databases, and Websites, as well as workshops, conferences, joint publications, and research activities are needed in different countries to achieve international dialogue in this topic. Education and training for research is also essential, and the need for new multidisciplinary skills is crucial.

As history has shown, scientific discoveries can benefit humankind, but can also be used for evil purposes. At an international meeting with experts from 25 countries, organized by the U.S. American Meridian Institute and the U.S. National Science Foundation (NSF) in June 2004, the clear and urgent need for ongoing international dialogue, cooperation, and coordination in the area of responsible nanotechnology was stated. It was concluded to establish an informal preparatory group to proceed with four terms of reference:

1. Continue and intensify an international dialogue and cooperation on responsible research and development of nanotechnology to respond to the expectations and concerns of citizens.
2. Constitution of a small preparatory group to explore possible actions, mechanisms, timing, institutional framework, and principles for this dialogue and cooperation.
3. Preparation of a draft plan of action and a joint declaration, along with the procedure for their adoption.
4. Composition of the preparatory group (North and South America, Europe and Africa, Asia and Oceania) and its functioning.

The "Exploratory Meeting for Responsible Research and Development in Nanotechnology" in Brussels in 2005 declared the following points of global relevance:

- Exchanging results of research and developments between different countries
- Generating and sharing data on the fundamentals of nanoscience and nanotechnology,
- Generating and sharing data on toxicology and ecotoxicology
- Developing common methodologies for statistical analysis and risk assessment in this field
- Supporting research in nomenclature and metrology for future possible regulatory actions
- Developing common tools and exchanging good practices to increase public awareness and social acceptance for nanotechnology

In the 2007 Brussels workshop titled "Communication Outreach in Nanotechnology: From Recommendations to Action," the European Commission was drafting a set of recommendations on how to engage the European civil society into dialogue and appropriate communication on nanotechnology. Important points are identifying and surveying target publics, developing new models and tools for communication, fostering dialogue and engagement addressing both professional and leisure time, as well as ensuring access to reliable and high-quality information on ethical, social, and legal dimensions of nanotechnology and its potential implications on daily life.

Various International Research Projects

Demos NanoDialogues is a London-based think tank that explores how social intelligence can inform decision making in nanotechnology funding and diffusion. The NanoDialogues project includes four experiments in public engagement to foster interaction between scientists, government and the public on impacts of science and technology.

The British Interdisciplinary Research Centre in Nanotechnology, the University of Cambridge, Greenpeace UK, the Guardian, and the Policy, Ethics and Life Sciences Research Centre of the University of Newcastle set up NanoJury UK. A citizens' jury comprising 25 members hears evidence from a range of experts about future potential applications, risks, and benefits of nanotechnology. A panel of experts chooses the witnesses and oversees the jury's activities; furthermore, there is a science advisory panel.

Nanologue is a European Commission–funded joint project (of Wuppertal Institute for Climate, Environment and Energy, Forum for the Future, triple innova, EMPA) that brings together leading researchers from across Europe to facilitate an international dialogue on the social, ethical and legal benefits, and potential impacts of nanoscience and nanotechnologies.

See Also: Ethics and Risk Analysis; International Nanotechnology and Society Network; Law; Nanoethics Group; Nanotechnology Issues Dialogue Group (UK); Societal Implications of Nanotechnology.

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International Nanotechnology and Society Network

The International Nanotechnology and Society Network (INSN) is a coalition of researchers and institutions exploring the relationship between society, social change, and nanoscience research. Members from 37 institutions in 11 countries participate in the network, which is headquartered at Arizona State University (ASU) in Tempe , and additionally affiliated with the University of California at Santa Barbara (UCSB). Both ASU and UCSB are homes to Centers for Nanotechnology in Society created by 2005 National Science Foundation (NSF) grants, and ASU's CNS is the largest such research center in the world.

The INSN's stated mission is to "advance knowledge, promote institutional innovation, engage policy processes, and improve decisions related to the societal impacts of nanotechnologies and other areas of innovation that nanotechnology may help to enable." The

ritten by Renn and Rocco, is tar-
d offers a conceptual framework for the risk governance of nanotechnology that can help address risk issues that are not addressed by any single authority because they involve multiple stakeholders and/or involve global, long-term and cross-boundary risk. Also in 2006, IRGC co-organized with the Swiss Re Centre for Global Dialogue the project's concluding conference, "The Risk Governance of Nanotechnology: Recommendations for Managing a Global Issue," of which a full report was published. In 2007 the project was concluded with the publication of a Policy Brief, "Nanotechnology Risk Governance—Recommendations for a Global, Coordinated Approach to the Governance of Potential Risks."

In 2008, the IRGC started a nanotechnology project, with the support of the Austrian Federal Ministry for Transport, Innovation and Technology, and the Korean National Program for Tera-Level Nanodevices, that focused on risk governance strategies for nanotechnology applications in food and cosmetics. Antje Grobe, Ortwin Renn, and Alexander Jaeger are linked to the Dialogik GmbH, a nonprofit research institute founded in 2003 by Professor Ortwin Renn and Dr. Hans-Peter Meister, were the co-leaders of this project.

A workshop was held in April 2008. Invited panelists came from the Directorate General for Health and Consumer Affairs, European Commission (DG Sanco), the Confederation of the Food and Drinks Industries of the EU (CIAA), L'Oréal, Ion Bond Ltd. (producer of thin-film PVD, PA-CVD and CVD coating technologies), the International Standard Organization (ISO), Friends of the Earth, Unilever, the Max-Rubner Institute, the Federal Research Institute of Nutrition and Food, Germany, the Swiss Federal Laboratories for Materials Testing and Research (EMPA), The Coca-Cola Company, the Swiss Centre for Technology Asseussment (TA-Swiss), the Federal Institute for Risk Assessment, Germany (BfR), Nestlé, the Consumer Association in the United Kingdom, the OECD, the U.S. Food and Drug Administration, Verband der Chemischen Industrie e.V, Germany (VCI), Friends of the Earth Germany (BUND), the EU Commission, the Nanotechnology Industries Association (NIA), Environmental Defense, BASF, and Swiss Re. In December 2008, the IRGC published the report "Risk Governance of Nanotechnology Applications in Food and Cosmetics."

See Also: Anticipatory Governance; Food; Governance; Nano-Ethics; Social Risk.

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International SPM Image Competition

The biannual International Scanning Probe Microscopy Image Competition (ISPMIC) honors excellent scanning probe microscopy images. The idea for this contest stems from Spanish government officers and researchers; financing comes from Spanish institutions and private companies.

All images submitted to the ISPMIC competition are judged by an international panel of scanning probe microscopy (SPM) researchers, as well as by experts in scientific photography and scientific dissemination. The jury takes into account both scientific and artistic merits. Images are judged on the basis of their scientific quality, originality, imagination, visual impact, and the ability to capture relevant aspects of the nanoscale. ISPMIC is open to individuals from institutions, research organizations, or companies. The ISPMIC is restricted to scientific images obtained using SPM techniques—scanning tunneling microscopes (STMs), atomic force microscopes (AFMs), magnetic force microscopes (MFMs), and scanning near-field optical microscopes (SNOMs), among others—that are processed using a special version of the SPM freeware software WSxM. Theoretical simulations of SPM images are also welcome.

The SPMage 2007 competition drew more than 300 submissions. The first prize went to A. Fuhrer from ETH

Zürich (Switzerland) for his image titled "Nano Rings." Second place went to L.P. Silva from EMBRAPA Recursos Genéticos e Biotecnología Brasilia for "The Surface of Human Red Blood Cells After Treatment With Antibiotic Peptide." Third place went to K. Demidenok from the Leibniz-Institut für Polymer Forschung (Germany) for "Root." Fourth place went to C. Krull from the Freie Universität Berlin (Germany) for "Thymine Integrated Circuits Grown on Silver Terminated Silicon (111) R3xR3," and fifth place went to C. Munuera from ICMM-CSIC, Madrid (Spain), for "Daisy Flowers in the Nanoworld."

The SPMage09 first prize went to L. Ang from NUS (Singapore) for "Human Malaria (*Plasmodium malariae*) Infected Red Blood Cells." S. Otte from NIST (the United States) won second prize for "Atom Spangled Patchwork." The third prize (1,250 euros) went to S. Abetkovskaia from the A.V. Luikov Heat and Mass Transfer Institute (Belarus) for her "Winter-Time Nanofishing." The fourth prize went to F. Mantegazza from the Universita' degli studi di Milano-Bicocca (Italy) for his "Venis of Coral," and the fifth prize went to M.C. Redon from the Centre d'Investigació en Nanociencia i Nanotecnologia (Spain) for "Looking for the Summer Ice."

See Also: Images; Microscopy, Atomic Force; Microscopy, Scanning Probe; Microscopy, Scanning Tunneling; Nanotools; Tools.

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International Standards Organization

The International Standards Organization is the foremost nongovernmental organization (NGO) that develops international standards across product sectors and services, with the exclusion of electrotechnology (which is the responsibility of International Electrotechnical Committee, or IEC) and most of the telecommunications technologies (the responsibility of the International Telecommunication Union). The aim of a development of international standards is to facilitate the exchange of goods and services, and to eliminate technical barriers to trade. The national members of the ISO are a mix of private sector organizations that are recognized by their governments for their work on standardization, among others who are part of the governmental setup. The ISO international standards are voluntary, but a number of them have been enforced by states within their regulatory framework. Apart from international standards, ISO also publishes what it calls "new deliverables." These refer to different categories of specifications, such as technical reports, that represent varying level of consensus on the subject. These documents are usually published at the intermediate stage of standard development and do not have the same status as an international standard. However they enable flexibility to be incorporated into the standard development process, especially in a rapidly developing field like nanotechnology.

In June 2005, the ISO established the ISO/TC229 (Technical Committee on Nanotechnology) with the aim of standardizing the field of nanotechnology. The next year in June 2006, the IEC TC 113—nanotechnology for electrical and electronic products and systems—was established, focusing on technical issues in this field. Within the ISO-TC 229, four Joint Working Groups have been established:

JW1: Terminology and Nomenclature
JW2: Measurement and Characterization
JW3: Health, Safety and Environment
JW4: Material Specification

These four aspects reflect the primary aspects of terminology, nomenclature, measurement, and characterization within standards development in any field of technical activity. There was an international agreement between the ISO and IEC to join efforts on these themes, creating the first two ISO/IEC working groups. There are currently 32 participating members and 10 observer members within the ISO/ TC 229. Developing country representatives make up more than 40 percent of the participating members and almost all of the observer members.

[illegible]nology research projects are being [illegible]ted in the laboratories of the Departments of Electrical Engineering, Physics, Materials Science and Engineering, and Chemistry and Chemical Engineering. For example, silver nanoparticles are being used on fibers for application in antibacterial textiles. Research in nanoelectronics includes studying the thermoelectric effect in carbon nanotubes that can be further used for various applications, such as electrical circuits.

One of the leading academic groups in nanotechnology, the Nano-Coating Group, is currently researching new classes of inorganic nanomaterials to produce phase-change nanostructured films by chemical routes, such as solution-phase deposition. These films will be used and evaluated in electronic devices. INST reports producing 10 to 50 publications on other nanotechnology related topics, depending on the year.

An example of work in nanomedicine and nanobiotechnology being pursued in Iran can be found at Shahid Beheshti University of Medical Science. Considered one of the top five universities in Iran, its research and postgraduate programs are technically robust with a strong emphasis in nanotechnology research. One example of nanobiotechnology research work is the reported synthesis of a nanotechnology-based vaccine for multidrug-resistant tuberculosis. A single nanoparticle was found to alter the structure of a mycobacterium that causes tuberculosis, and to subsequently destroy the pathogen. Researchers claimed to have developed a form of nanoencapsulation, which they call nanocups, that specifically target a drug or any other compound to an infected organ and indicate success with clinical trials in patients.

In conclusion, the research group and the universities described are prime examples of Iran's efforts toward expanding on nanotechnology. Iran has made a considerable leap in terms of scientific achievements in the past few years. More institutions have been built and more limited foreign free zones have been established. This suggests that scientifically there is segment that is trying to become more involved abroad. Although the vast majority is still government funded, it is gradually becoming more open to private institutions as a way to increase competition between companies and in return, the goal is to increase the innovation leading to more prestige for Iran's science and technology sector.

See Also: International Development; Nanobiotechnology; Nanomedicine; Nanosilver.

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Iran Nanotechnology Policy Studies Committee

The Iran Nanotechnology Policy Studies Committee was established in 2001 and was renamed the Iranian Nanotechnology Initiative Council (INI) in 2003. It is a committee for studying nanotechnology trends and defining a direction for nanotechnology development in Iran. Iran began its activities to develop nanotechnology early in 2001, when then Iranian president Mohammad Khatami made the Technology Cooperation Office (TCO) responsible for the coordination of developmental activities for nanotechnology in the country. In 2003, after extensive studies and analysis, TCO recommended creation of a council and was given the task of defining a direction for nanotechnology development in Iran. INI was established to advice on new directions. They mobilized quickly and introduced the first national nanotechnology development plan titled, "Future Strategy." The plan was then adopted by the cabinet ministers. Its mission was to gain access among the 15 advanced nations in nanotechnology in order to achieve economic development for the country.

Since 2001, and especially after formation of the INI council, numerous activities were organized in nanoscience and nanotechnology, with the following being the most prominent ones:

- Networking between local laboratories with instruments of common interest
- Recognizing Iranian scientists active in nanotechnology and supporting their activities

- Providing financial incentives to Iranian scientists to publish nanotechnology articles in international scientific journals
- Identifying international partners for research and scientific collaborations
- Publicizing advances in nanotechnology in Iran and other countries
- Offering of advanced nanotechnology courses in master's and Ph.D. programs throughout Iranian universities

INI aims to gain access to a fair share of the international trade using nanotechnology, laying the proper groundwork for enjoying the benefits of nanotechnology, to upgrade the Iranian quality of life, and to institutionalize sustainable and dynamic development of science, technology, and nanoindustry.

INI is headed by the vice president (as of July 2009, the deputy president for science and technology affairs) and the head of the Management and Programming Organization and comprises the ministers of agriculture, economics, and finance affairs, health and medical education, industry and mines, petroleum, science, research and technology, as well as five senior nanotechnology experts chosen by the head of the council. The councils' secretary is the head of the presidential office for technological cooperation.

The main duties of INI include passing goals, approaches, strategies, and national plans for developing nanotechnology in the country. Its major tasks are allocation between sectors and synchronizing them inside the framework of the national long-term plan. INI has complete supervision on the realization of the defined goals and plans.

TCO/INI suggested the National Iranian Nanotechnology Initiative (NINI) Program (approved by the Iranian cabinet in July 2005) that subsequently established the Nanotechnology Laboratory Network (NBN) supporting researchers and industries in the field.

See Also: Anticipatory Governance; Democratizing Nanotechnology; Global Value Chains; Innovation; Iran; Nanomanufacturing; Science Policy.

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Israel

The development of nanotechnology in Israel has a similar timeline to the development of nanotechnology in other industrialized nations. However, for a nation of such limited population (7.4 million in 2009) and size (8,000 mi^2), Israel is a disproportionally productive player in several key nanotechnology research fields. Nanotechnology in Israel is characterized by highly managed cooperation between the government, universities, and private industry (including finance) and has been focused as much on applications and commercialization as on fundamental research. As in a number of other nations, nanotechnology has been seen as way to leverage, reorient, and reorganize research function around multidisciplinary shared facilities. As a small nation, Israel has been more successful than many at creating these synergies.

In the late 20th century, Israel emerged as a strong competitor in the high-tech industries, particularly information and communication technology (ICT), defense and security, and biotechnology. Israel's focus on and support for nanotechnology in the 21st century is a natural development from that earlier success. The reasons for Israel's successful high-tech sector include its highly developed research culture and institutions, its well-organized and globalized venture capital (VC) sector, one of the most highly educated workforces in the world with a greater percentage of scientific workers than almost any other nation, a long tradition of powerful and highly integrated science and technology policy and technology assessment in the Israeli government, and tight cultural and institutional connections

KOSHA's major functions consist of providing technical support in various forms, stimulating and offering educational and training activities, providing for financial support (when necessary), preventing labor illnesses and accidents, and being actively involved in research and development (R&D) activities. In compliance with its purpose, KOSHA, as reported in an Organisation for Economic Co-operation and Development (OECD) paper from 2008, conducted several projects to develop biomarkers for the exposure to silver nanoparticles; monitor the effects of multi-walled carbon nanotubes (MWCNT) exposure; carry out research studies on nanotoxicity; and perform risk assessment of nanoparticles.

As a necessary complement to the guidelines being elaborated by KOSHA, KATS adopted Korea's first guidance for safe handling of nanomaterials in May 2009. The standard was designed to ensure the safety of workers and researchers dealing with nanomaterials, and takes into consideration the current conditions of national workplaces and laboratories.

The national standard is the result of prior discussions among various regulatory agencies that solicited the adoption of a standardized framework to avoid the potential emerging risks associated with handling nanomaterials. The standard, named KS A-6202, provides safety measures that should be followed by workers, researchers, and entrepreneurs. The standard also provides for a checklist that can aid its implementation.

The standard consists of different articles, which, among other things, provide that workers must wear protective clothing to prevent exposure, and states all nanomaterial-related processes should be isolated. Additionally, the standard specifies that facilities where nanomaterials are handled should be clearly indicated, as well as any zones in which there is a risk of contamination.

As a consequence of its importance, the KS A-6202 will probably be utilized as a term of reference in the development of the workplace environmental management guidelines by KOSHA, and it will be likely used by other agencies and ministries in the preparation of a uniform framework, which will address all concerns related to the safe handling of nanomaterials. The introduction of the standard has been seen very positively from the stakeholders involved in a sector in which Korea has already heavily invested.

See Also: Ministry of Environment (South Korea); Ministry of Science and Technology (South Korea); Occupational Safety and Health Administration (U.S.); National Nanotechnology Development Plan (South Korea); Regulation (Europe); South Korea.

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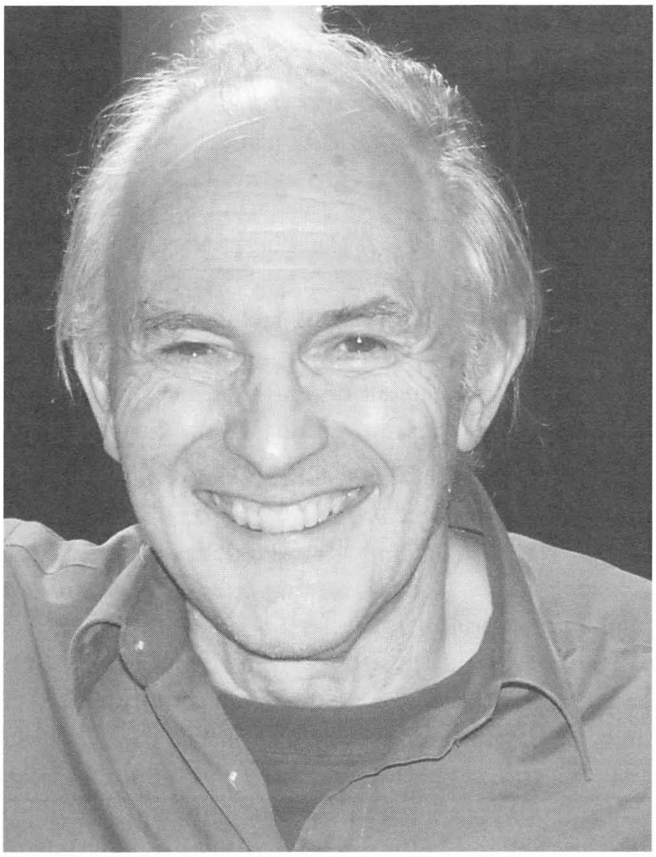
Kroto, Sir Harry

The British chemist Sir Harold (Harry) Walter Kroto (1939–) was one of the three winners to share the 1996 Nobel Prize in Chemistry for the discovery of fullerenes, which are carbon atoms bound in the form of a structure that resembles a soccer ball. Kroto is currently a member of the Chemistry Faculty at Florida State University.

Sir Harry Kroto was born on October 7, 1939, in a small city called Wisbech in Cambridgeshire, England. Both of his parents were born in Berlin, Germany. His surname at birth was Krotoschiner; in 1955, his father changed it to Kroto. This name has its origins in the Polish town of Silesia. Because his father was Jewish, the family had to leave Berlin in 1930s with the onset of World War II, and moved to Britain. In 1955, his parents set up a small balloon factory in Bolton, Lancashire, and he spent much of his school vacations working at the factory. Although his parents were poor, they did everything they could to further Harry's education, and he attended Bolton School, with (in his own words) "exceptional facilities and teachers." Kroto's favorite toy was a Meccano set, which he stated was a true engineering kit and teaching toy. "This is the sensitive touch needed to thread a nut on a bolt and tighten them



Sir Harold (Harry) Walter Kroto is a British chemist and a winner of the Nobel Prize in Chemistry.

with a screwdriver and spanner just enough that they stay locked, but not so tightly that the thread is stripped or they cannot be unscrewed," he stated.

Kroto calls himself a devout atheist. Early in life, he enjoyed art, geography, gymnastics, and woodworking. Later, he gravitated toward chemistry, physics, and math. His classes with Dr. Wilf Jary increased his interest in chemistry, and this fascination grew when he was introduced to organic chemistry by chemistry teacher Harry Heaney, now Professor at Loughborough in the United Kingdom. At the University of Sheffield, he played on the university tennis team, but left because he wanted to continue some form of art. He designed the covers of the student magazine, *Arrows*. Kroto was introduced to spectroscopy by Richard Dixon, and became interested in quantum mechanics. Kroto received a first-class honors B.Sc. degree in chemistry from the University of Sheffield in 1961, and his Ph.D. (on the spectroscopy of free radicals produced by flash photolysis) from the same university in 1964. In 1963, he married Marg (Margaret) Henrietta Hunter.

In 1964, the couple moved to Ottawa, Canada. Kroto did his postdoctoral research at the National Research Council in Canada, and at Bell Laboratories in the United States. In 1967, he began working at the University of Sussex, earned a full professor title in 1985, and was Royal Society Research Professor from 1991 to 2001.

In the 1970s, Kroto's research group searched for carbon chains in interstellar space. Between 1975 and 1978, they found two long molecules: cyanobutadiayne, and cyanohexatriyne. Kroto grew interested in laser spectroscopy, and joined Richard Smalley and Robert Curl at Rice University in Texas. He decided to use Rice's apparatus to simulate the carbon chemistry that occurs in the atmosphere of a carbon star. In September 1985, they found that carbon stars also produce C_{60} species, along with long carbon chains. For this finding, Kroto, Curl, and Smalley received the Nobel Prize in chemistry in 1996.

See Also: Canada; Fullerene; Smalley, Richard.

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Kurzweil, Ray

Raymond Kurzweil (1948–) is an American inventor, entrepreneur, author, and futurist. He is also a proponent of rapid technological advancement in genetics, y into the lungs and can impair

In spring 2006, German newspapers published articles titled "Poisoning by Sealing Spray" or "Household Spray Brings Six Consumers to Hospital." The message of poisonings by a nanoproduct quickly spread worldwide. The newspaper headlines became more and more dramatic: "Fear of Nano on the Shelf" and "How Toxic Are Nanoparticles?" *The Economist* asked "Has All the Magic Gone?" Suddenly the entire field of nanotechnology was under suspicion. Nanotechnology as a whole was blamed for endangering consumer health. The ETC Group demanded a general nanotech moratorium. In addition, other nongovernmental organizations such as Friends of the Earth U.S.A. and Australia referred to the Magic Nano case as evidence of the risks of nanoproducts.

Retrospectively, Magic Nano became a symbol for possible risk of nanotechnology and the necessity of a broad risk debate. The case showed that nano fears in the population can easily be triggered by news linking nanotechnology to concrete hazards or media reports of human suffering and harm. Moreover, perceived risks could undermine consumer acceptance of products, even if they pose no actual danger. It might not even matter to consumers if products actually contain nanoparticles. If something bad happens to an item that has "nano" in its name, attention will immediately focus on the whole category of nanoproducts.

See Also: Federal Institute for Risk Assessment (Germany); Nanomaterials; Nanomaterials in Commerce; Public Attitudes Toward Nanotechnology; Public Well-Being.

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Market Projections

Products based on nanotechnology are expected to impact nearly all industrial sectors in the years to come, and will enter consumer markets in large quantities. Considering the future prospects of nanotechnology, countries across the world are investing heavily in this sector. Many factors influence the success or failure of any singular technology venture, and in the case of nanotechnology, so much is unknown that attempts to predict the future in this field are particularly subject to caution. However, some people believe that nanotech has the potential to trigger revolutions in, among other areas, materials, information and communication technology, medicine, and genetics. Over 1,000 consumer products incorporating nanotechnology are on the market as of 2009, according to the Project on Emerging Nanotechnologies, and the number is expected to continue to grow.

While no one can predict the future, it is a normal business practice to try to estimate the future value of technologies. The value of the nanotechnology market is estimated to grow from $14.5 billion in 2009 to over $30 billion in 2013, assuming a compound annual growth rate (CAGR) of around 20 percent per year, fueled in part by massive investment in nanotechnology research and development (R&D) by governments and corporations worldwide. Under these assumptions, the market for nanotechnology incorporated in manufactured goods will be worth $1.6 trillion, representing a CAGR of more than 49 percent in the forecast period (2009–13).

Globally, the Asia-Pacific region will experience the fastest growth in the market for nanotechnology enabled goods, with a CAGR projected of around 52 percent in the forecast period, followed by Europe and the United States. Recent gains by emerging markets in India, China, and Russia in the field of nanotechnology R&D will continue to grow. Of course, all these figures are estimates based on assumptions which may or may not hold true in the future.

The greatest growth in market share is expected from sales of products incorporating nanotech rather than from the sales of the materials themselves. In 2014, 4 percent of general manufactured goods, 50 percent of electronics and IT products, and 16 percent of goods in healthcare and life sciences by revenue are estimated to incorporate emerging nanotechnology. The sales of products incorporating emerging nanotechnology is estimated to rise from less than 0.1 percent of global manufacturing output in 2004 to 15 percent in 2014, totaling $2.6 trillion, more that the combined values of the information technology and telecom industries, and 10 times more than biotechnology revenues.

Currently, electronics and IT applications dominate the nanotechnology market: microprocessors and memory chips already have new nanoscale processes implemented. It is expected that nanotechnology will become commonplace in manufactured goods by 2014. Healthcare and life sciences applications will become significant as nanoenabled pharmaceuticals and medical devices emerge from lengthy human trials. It is projected that 10 million manufacturing jobs worldwide in 2014 (11 percent of the total manufacturing jobs) will involve building products that incorporate emerging nanotechnology. Nanotechnology will shift market shares and introduce new unconventional competitors in conventional markets with a high entry barrier.

Currently available market size forecasts deal with what is called "evolutionary nanotechnology" (top-down approaches). The goal of evolutionary nanotechnology is to improve existing processes, materials, and applications by scaling down into the nanoscience realm, and ultimately fully exploit the unique quantum and surface phenomena that matter exhibits on the nanoscale. Due to this ever continuing trend of "smaller, better, cheaper," the number of companies that are, by the same definition, "nanotechnology companies," will grow quickly and soon make up the majority of all companies across many industries. By contrast, truly revolutionary nanotechnology envisages a bottom-up approach, where functional devices and entire fabrication systems are built atom by atom.

Projections about the future value of nanotech are hampered by the fact that nanotechnology is more frequently incorporated into products and is not an industry unto itself. It is also difficult to track because corporations sometimes attach the "nano" label to products that make little or no use of nanotechnology (e.g., the cleaning product Magic Nano, which was removed from the market in Europe). Even if nanotechnology is actually used in a product, it may add relatively little added value and in analysis, the market value for the entire value chain is attributed to nanotech, exaggerating the potential of nanotechnology. A breakdown of the market forecast figures for nanomaterials, nanointermediates, and nanoenabled products shows that nanomaterials will probably contribute less than 0.5 percent of the market (which would still total $3.6 billion) by 2010.

See Also: Commercialization; Drexler, K. Eric; Emerging Technologies; Enabling Technology; Global Value Chains; Nanoenabled Products in Commerce; Nanointermediaries in Commerce; Nanomanufacturing; Nanomaterials in Commerce; Nanotechnology in Manufacturing.

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Market Resistance and Acceptance

Market resistance is the resistance of consumers (or other businesses, in the case of business-to-business activity) to a product or service, while market acceptance is the reverse. Sometimes resistance eventually gives way to acceptance, but sometimes it doesn't. Predicting how the market will respond to a product or service is historically an unreliable practice, even with the extensive focus groups and marketing research available for corporations and other interested parties.

Recent history is full of examples of products that thrived or failed seemingly independent of merit or practical concerns. DVDs caught on quickly despite complaints within the industry about its technical specifications and limitations, while the Laserdisc never emerged from its obscure niche; the Minidisc player and other formats that offered much of what the CD did but with further advantages that never caught on significantly; digital cable and the promise of hundreds of television channels were discussed for at least two decades before held at the California Institute of Technology (Caltech), in Pasadena—was first published in Caltech's *Engineering and Science* journal in February 1960, and was hailed as the "invitation to enter a new field of physics." At its inception, the journal had the support of the University of South Carolina's Nanocenter, as well as the NIRT. The first paper, published by Alex Lee, was on "Nanotechnology and Patents: Shaping the Brave, New Intellectual Property Frontier," and the second, by Ashley She, was on "The Changing Sciences," outlined the National Nanotechnology Initiative (NNI).

These were followed by Evan Michelson writing "Calling the Shots: Regulating Nanotechnology From the Bottom Up"; Maria Connelly, "How Can We Predict Society's Acceptance of Nanotechnology and How Should We Manage This Acceptance?"; and Nidhi Kumar, "The Brain-Machine Interface." The journal has since changed its name to *Minus 9*, although it is still edited by students from the University of South Carolina and elsewhere.

The hope was that *Minus 9* would encourage more published research on aspects of nanotechnology. This soon became the case, and it was not long before the journal became a discussion paper for students at all levels, lecturers, researchers, and for others in the field. The journal solicited articles, included papers of varying length on "the societal, ethical, legal, epistemological, and sociological implications of nanotechnology," and included information on "other emerging technologies." Soon *Minus 9* became one of the major players in the field of nanotechnology journals, with many issues made available online to help encourage discussion and debate on a range of fields. As of 2009, the editor was Brad Steinwachs, and the associate editor was Andrew Graczyk. The journal encourages students from around the United States and elsewhere to submit entries for online publication. As of 2008, the journal also began to accept and publish submissions on other emerging technologies along with nanoscience.

See Also: Emerging Technologies; Feynman, Richard; Journals; NanoEthicsBank.

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Molecular Assembler

A molecular assembler is a hypothetical machine that can manipulate and assemble single atoms with atomic precision. In the book *Engines of Creation,* K. Eric Drexler proposed such a machine as the ultimate goal of nanotechnology; however, many scientists still think that creating such a machine would be impossible. The molecular assembler could also replicate, which would hypothetically be the first task of such a machine.

The assemblers would then start to produce atomically tailored structures, machines, materials, and devices. Drexler was also the first to propose the so-called "Grey Goo" scenario, which is a highly speculative scenario describing self-replicating nanomachines that can no longer be controlled by humans, continuing to replicate, converting more and more energy and increasingly drawing resources from the environment, ultimately covering the planet with their "Grey Goo," leading to global epiphagy (eating of the environment) and the end of the biosphere.

However, a completely autonomous self-replicating assembler would not only be harder to develop and would work less efficiently, but it would also be less efficient than a specialized molecular assembler; therefore, it would be less appealing for someone to produce for economic reasons. Expanding the scope of atomic precision will dramatically improve high-performance technologies of all kinds, from medicine, sensors, and displays, to materials and solar power.

According to Drexler, a single assembler would consist of about 1 million atoms and some 10,000 moveable parts, each made from a couple of atoms. A complex machine, distinctively different from current industrial robots, this machine would grab single atoms and molecules and mount them, with chemical bonds acting as glue. Molecular assemblers are envisaged as purely mechanical constructs, with gears, motors, and levers.

Richard Smalley, who was awarded the Nobel Prize for his contributions to nanotechnology, stated the physical impossibility of molecular assemblers because of what he termed the "sticky fingers" problem (the atoms would stick to the atoms of the assembler, and it would be impossible to release them) and the "fat fingers" problem (an assembler would have to assemble atom by atom with "fingers" that themselves are made of single atoms, and therefore have a certain minimum thickness; and not only one atom would have to be grabbed, but all the atoms in certain volumes would have to be manipulated and the single fingers would prevent each other from doing so).

Life itself shows us that biological pendants of molecular assemblers are indeed possible. Bacteria, for example, are self-replicating assemblers that are controlled by DNA. Also, single biomolecules, such as the ribosome (a biological nanomachine made of ribosomal RNAs and proteins that synthesize proteins), could be referred to as biological assemblers. However, the use of the term generally implies a man-made nanomachine.

The two predominant views about molecular assemblers (the utopic dreams and the apocalyptic scenarios) currently dominate ethical debates about future perspectives of nanotechnology, and cause various unnecessary conflicts and emotional reactions. Both views are single minded; however, many believers still adhere to the concern of nanotechnology creating self-replicating molecular assemblers. Contrary to widespread treatment in popular culture and science fiction, it is not believed that molecular assemblers will play a central role in nanotechnology in the near future.

See Also: Drexler, K. Eric; *Engines of Creation*; Ethics and Risk Analysis; Foresight; Foresight Institute; "Grey Goo" Scenario; Joy, Bill; Molecular Nanotechnology; Nano-Ethics; Self-Assembly; Self-Replication; Smalley, Richard.

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Molecular Motors

Aristotle believed that motion distinguishes between living and nonliving organisms. Only living organisms can move without external driving force, he summarized his insight by the Aristotelian proverb "Life is motion." It is now known that living organisms are built up from cells that have complex structures with different functionalities and different length scales. Molecular structures have scale that spans between nanometers to micrometers.

A motor is a device that converts energy to mechanical motion. Molecular motors refer to biological structures that transform chemical energy released by the hydrolysis of nucleotides (mainly adenosine-5'-triphosphate [ATP] and its analogues) into mechanical motion. A well-known example of a molecular motor is the muscle protein, myosin that is responsible of the muscle contraction.

There are several classes of molecular motors that provide different functionalities for a living cell. Motors are typically function in groups. A typical velocity for a motor is in the order of 1 micro m/sec and the stalling force is in the order of piconewtons. The energetic efficiency of these motors exceeds 50 percent. Both linear stepping and rotary spinning motors have been identified.

Examples of these motors include (1) myosin in muscles that uses actin filament as track to cause muscle contraction; (2) DNA and RNA polymerases which move along the strands of DNA to replicate the DNA or transcribe it to RNA; and (3) F1-ATPase which are rotary motors for cell locomotion and ATP synthesis.

Inspired by the desire to produce nanomachines, nanoscientists took interest in the biological molecular motors trying to synthesize nanoscale motors made of synthetic stimulus responsive polymers that emulates the molecular motors functionality. These motors are composed of a discrete number of atoms and produces motion of its component parts. These motors respond to input energy and produce cyclic motion. The input energy is usually from light, heat, chemical reaction or electrical potential stimuli. Inducing actuation at the nanoscale with little number of parts and with nanoscale actuators is challenging. Both artificially autonomous and hybrid systems have been synthesized recently by scientists to produce nanoscale motion. The performance of bimolecular motors is several orders of he utility fog, consists of a swarm of " that can take the shape of virtually anything, and change their shape on the fly.

A nanowire is a connecting structure that has a diameter in the range of 10^{-9} meters, a one-dimensional nanostructure having a lateral size constrained to less than tens of nanometers and an unconstrained longitudinal length. It is also known as quantum wires. These connectors are used to connect tiny components together into very small circuits. Nanowires are experimental and are not available in commercial or industrial applications. The conductivity and tiny size make them ideal for future computer processors and connectors. This technology is a necessary stepping stone to the creation of molecular computers. Nanowire-based detection strategies could be used in the analysis of health parameters and thus significantly affect the healthcare sector. Nanowire assembly and integration with microchip technology is emphasized as a key step toward the ultimate goal of multiplexed detection at the point of care using portable, low power, electronic biosensor chips.

Risks and Potential Social Impacts

The rapid commercialization of nanotechnology requires thoughtful environmental, health, and safety research, meaningful, an open discussion of broader societal impacts, and urgent toxicological oversight action. Toxicity of MNT systems may induce cytotoxicity and/or genotoxicity, but also other toxic effects.

See Also: Molecular Assembler; Molecular Motors; Nanomedicine; Nanoscale Science and Engineering.

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Monash Centre for Regulatory Studies

Monash University, established in 1958, is Australia's most internationalized university. The Monash Centre for Regulatory Studies (MCRS) was founded in May 2009, and aims to provide a better understanding of the nature, extent, and implications of contemporary regulatory environment. The debate on nanotechnology's possible negative effects is a concern that Monash University shares. MCRS research in nanosciences and nanotechnology focuses on the possible impacts to Australia's regulatory frameworks. The establishment of MCRS was motivated by the need to better understand the various factors that comprise contemporary regulation at both national and international levels, and to provide practitioners and scholars with a core set of ideas, theories, and skills to apply to their activities the field.

MCRS aims to integrate theory and practice through a broad, cross-disciplinary approach by addressing regulatory issues using flexible postgraduate teaching and research programs. MCRS was established as a joint initiative between the faculties of law, business and economics, arts, medicine, nursing and health sciences, and pharmacy and pharmaceutical sciences. The director of MRCS, Professor Graeme Hodge, continues to stress the importance of regulatory studies in nanosciences and nanotechnologies. At the 2009 one-day symposium "Nanotechnology: Science, Policy & Public Perspective" (hosted by Monash University Institute for Nanosciences, Materials and Manufacture, MCRS, and the Faculty of Arts School of Political and Social Inquiry), scientists and players from the industry discussed the basics of the field, as well as policy, perceptions, and prospects, and held an industry panel, thereby helping to expand the public's understanding of the social, economic, and cultural consequences of nanotechnology.

The diverse backgrounds of the researchers at MCRS allow for investigating and teaching various aspects of regulation in nanoscience and nanotechnology: risk management, risk governance, regulatory challenges, governing nanotechnologies with civility, and the possible establishment of transnational codes and public registries as tools. Case studies comprise biomedical nanotechnology, as well as nanotechnologies in cosmetics (such as sunscreens), foods and food contact materials, and environmental health and safety.

The regulatory sector in Australia is extensive and complex, with over 60 major regulatory bodies. Apart from the federal and state governments, considerable funds are committed by businesses and industry toward regulatory processes. Although the regulatory sector at the state, national and international level is extensive and complex, the study of regulation in itself is a relatively new discipline in Australia.

See Also: Anticipatory Governance; Berkeley, California, Local Regulatory Efforts; Cambridge, Massachussetts, Local Regulatory Efforts; Governance; International Risk Governance Council; Regulation (Europe); Regulation (U.S.).

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Monsanto

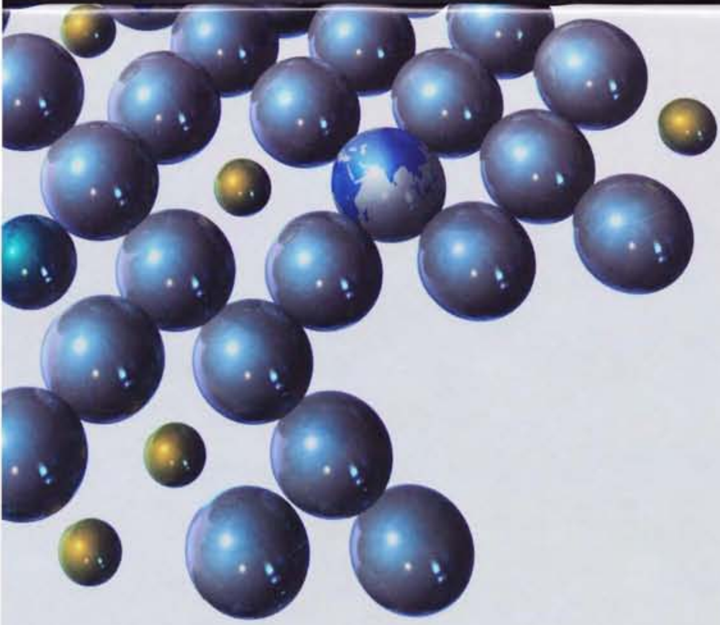
One of the world's most prominent and controversial companies, Monsanto Company is a multinational agricultural biotechnology corporation headquartered in St. Louis, Missouri. Its signature product is the world's best-selling herbicide, glyphosate, marketed under the trademark Roundup. However, the company is also extremely controversial, most notoriously for having produced the chemical defoliation material, (herbicide) "Agent Orange" during the Vietnam War, polychlorinated biphenyls (PCBs)—one of the world's most dangerous fertilizers, and more recently for its aggressive efforts to promote and protect Monsanto's rights to genetically engineered seed, and push genetically modified (GM) food. Monsanto began as a chemical company in 1901, but in the 1990s, through a series of mergers, splits, and acquisitions, reinvented itself as an agricultural company. According to the company Website, Monsanto invests almost $1.5 million in research and marketing that spans genomics, breeding, crop analytics, chemistry, and biotechnology.

The company identifies its key areas of interest as genomics, the discovery and identification of the functions of genes, biotech transformation—input (weed, disease, insect control) and output (quality, nutrition, yield), a key focus on seeds, with an attempt to establish dominant positions in canola, corn, and soybeans, and finally, new Roundup formulation research.

Monsanto is active in the use of nanotechnology in genetic engineering that has been termed *synbio* (also known as synthetic genomics, constructive biology, or systems biology) that is inspired by the convergence of nanoscale biology, computing, and engineering. Essentially, this is the design and construction of new biological parts, devices, and systems that do not exist in the natural world and the redesign of existing biological systems to perform specific tasks. Such engineering would allow gene synthesis to create new microbes and biological samples, sequenced and stored in digital form, to be transferred instantly across laboratories. Monsanto scientists became the first to genetically modify a plant cell in 1982, and in 1987, the company conducted the first field tests of genetically engineered crops.

Littigation and Lobbying

The company is also noted for its aggressive litigation, intense lobbying practices, and the intense anger it provokes among environmental activists and the antiglobalization movement. Genetic manipulation has awakened fears in the public, especially in Europe. Monsanto has been blamed for the failure of genetically modified crops, as for example in 2009, when South African farmers were hit by millions of dollars in lost income when 82,000 hectares of genetically manipulated corn failed to produce seeds despite an outwardly green and lush appearance. Monsanto has claimed that "underfertilization processes in the laboratory" were responsible for this, and has offered to compensate the farmers. Similar problems of crop failure have affected Monsanto seeds in India. Moreover, genetically modified products have led to paradoxical results, as for example, the inadvertent creation of evil pigweed, a "super weed" that is resistant to RoundUp. Pigweed can produce 10,000 seeds at a time, is drought resistant, and has very diverse genetics. It can grow to 3 meters high and easily smother young cotton plants.



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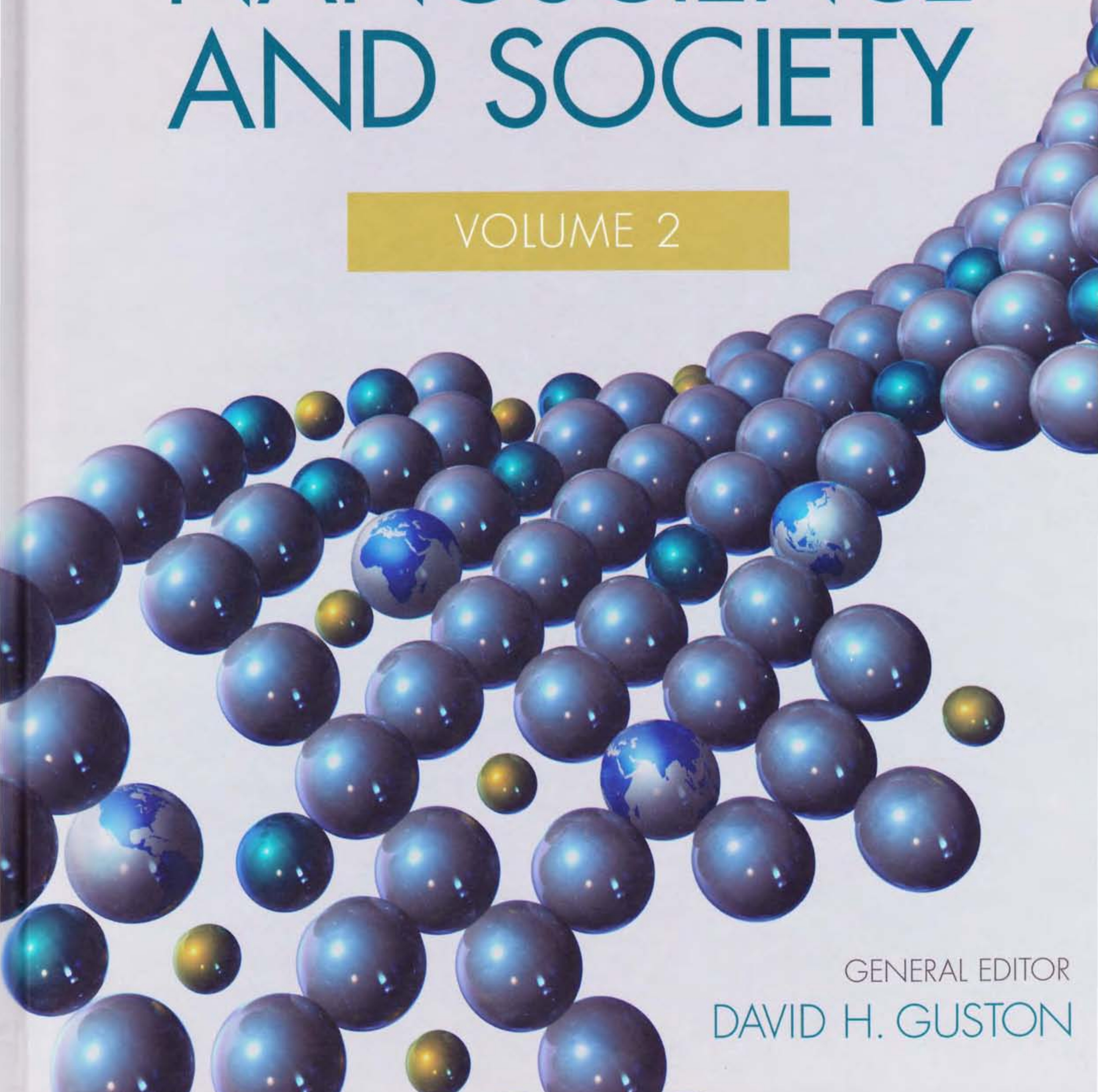

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Nano-Bible

In 2007, scientists at the Technion-Israel Institute of Technology in Haifa, Israel, reproduced the entire Hebrew Bible on a silicon chip measuring less than 1/1,000th of an inch, demonstrating recent advances in miniaturization technology. The silicon chip, which is the size of a grain of sugar, was first coated with a layer of gold 20 nanometers (nm) thick, whereupon a focused ion beam (FIB) generator used gallium ions to etch away the gold layer in order to reveal the silicon base, thus inscribing the text on the chip.

The idea for the project was conceived by Uri Sivan, a physics professor and director of the Russell Bernie Nanotechnology Institute. Ohad Zohar, a physics education advis\eor with the Institute, and Alex Lahav, former head of the FIB lab at the Wolfson Microelectronics Research and Teaching Center, managed the project and conducted the experiment.

The project was part of an educational program intended to raise public awareness about and interest in nanotechnology, particularly among young people. The experiment investigated ways that miniature structures could be created and imaged at the nanoscale. To make the intent of the project more accessible to the public and to capture the layperson's imagination, the project posed the question, "How small can the Bible be?" The ion particle beam could have used any pattern of points to demonstrate its inscription capabilities, but using a pattern of points that specifically represent text helped the researchers to concretize the project's focus on miniaturization techniques and the potential harbored therein for high-density data storage. The Bible in particular was chosen because it contains approximately 10 million bits of data. According to Sivan, the creation of the Nano-Bible is a step toward the eventual goal of using DNA and other biomolecules to store information.

It took 90 minutes for the computer-guided ion beam generator to etch patterns of points that would ultimately comprise the text's 308,428 Hebrew words, complete with vowel indications. Each point measured approximately 40 nm in diameter and can be read under a scanning electron microscope.

Researchers subsequently photographed the Nano-Bible and displayed it in the faculty of Physics at 10,000x magnification (measuring 23 feet x 23 feet) where its 3mm-high letters can be read with the naked eye. The original Nano-Bible, occupying an area smaller than a pinhead, is displayed alongside the photograph. The accomplishment has also been used to highlight Israel's contribution to advances in nanotechnology.

See Also: Innovation; Israel; Public Attitudes Toward Nanotechnology.

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Nanobioconvergence

One of the fascinating aspects of nanotechnology is that on the nanometer scale all the natural sciences meet and intertwine. Physics meets life sciences as well as engineering, chemistry, materials science, tribology, and computational approaches, which altogether communicate and are closely linked. The methods, concepts, and goals of the respective fields converge. This inherent interdisciplinarity of nanotechnology poses a challenge and offers an enormous potential for fruitful cross-fertilization in specialist areas. Nanobioconvergence denotes the merging of life sciences, especially biology and bionanotechnology, with nanoscience and nanotechnology, focusing on the technical connection of these particular technologies as well as on the unified opportunities and challenges they present to human nature and our values. Nanobioconvergent technologies are most useful when applied to specific problems where innovative solutions can be provided through leveraging varieties of technologies.

General Description

The emergence of nanobioconvergence happens in an atmosphere of dissolution of the strict borders between classical disciplines. New findings in the natural sciences and the development of new technologies enhance the possibilities and range of interference with matter in general. New observation tools such as the atomic force microscope allow for investigation of matter on an ever-decreasing length scale. Biomolecules can be investigated in action. The new tools and methods also allow for manipulation on the scale of nanometers. Engineering at the molecular level, tailoring new structures and materials, and even building of machine-like devices at this scale is increasingly becoming possible. The basis for such technological applications is the knowledge revealed in the biosciences as well as in nanoscience. Similar themes are now approached from different perspectives and disciplines, resulting in a fruitful exchange of concepts, methods, and tools. As the tools of investigation can also be used for manipulation and generation of structures, new areas of application are attracting interest from manufacturers.

Biotechnology includes genetic engineering and engineering of proteins, which is done with methods from pre-nanotechnology times. With the tools of nanotechnology a molecule-by-molecule or even atom-by-atom manipulation is possible. Nanotechnological methods are slowly introduced in traditional chemistry and integrated in production processes. The enhanced understanding of nanoscale processes, for example the functioning of self-organization, brings forward new production methods.

Bionanoscience focuses on the molecular building blocks of living cells. Nanotechnology enables the study and control of biomolecules, delivering new insights into surface properties as well as into the working of biological cells themselves. Nanobioconvergence potentially will revolutionize our understanding and practice of medicine. The integration of new molecules into cells allows for extended manipulation of cellular functions, such as gene regulation. These new possibilities are further investigated in the emerging new field of synthetic biology.

The complexity of the human body far exceeds any engineered devices: the information flows from macromolecules through cells, organs, and to the human body. The biological cell is a magnificent self-organized system and a complex information-processing network. Key attributes making it a complete system are its abilities to sense (monitor its biological surroundings and responses), decide (process incoming signals and trigger an optimal response through information processes), and actuate (modify its nanometer-scale environment to a more suitable one for survival). The cell's activities are carried out by biomolecules, such as the millions of proteins with sizes ranging from 1 to 20 nm. In each cell millions of molecules maintain internal operations and communicate with the external environment. The nanoscale assembly of organic and inorganic matter leads to the formation of cells and to the most complex known systems—the brain and human body.

Biomimetics

Distinct from biotechnology but also connected to nanobioconvergence is biomimetics. Here, principles found in biology, such as nanoscale properties of organisms, are utilized for technical applications, which are not necessarily in the organic realm. Biomimetic materials processing is just one example; further examples are synthesizing of new functional materials by refining knowledge and understanding of related biological products, structures, functions, and processes. Biomimetic materials processing follows a combination of process–mimetic and function–mimetic approaches. Its final goals are to create functional materials using harmless substances under normal temperature and pressure, and to develop materials functionalities through the control of properties and form at the nanoscale. Mankind has just begun to mimic the complex relationship of structure and function as it appears in natural materials, optimized at different length scales, yielding extraordinary performance.

Examples and Application Fields

Bionanoconvergent approaches comprise a broad variety of issues and some efforts yielded successful products on the market. For the goal of the improvement of human conditions major application areas include expansion of human cognition and communication, improvement of human health and physical capabilities, enhancement of group and societal outcomes, strengthening of national security and competitiveness, and unification of science and education. Some examples: biomineralization is investigated for synthesis of material mimicking the controlled crystallization process found in nature.

Drawing lessons from nature was also the basis to manufacture artificial materials with precisely engineered characteristics, for example water-repellent surfaces inspired by the microscopic roughness of the lotus leaf that allows it to effectively repel water and show self-cleaning properties. Molecular nanoelectronics is inspired by biological signal transduction at the level of protein molecules. Functionalized layers of molecules, nanomembranes, are used as filters for medical as well as biotechnological and environmental purposes, as well as in sensors.

They can connect with organic matter. Engineered surface characteristics are particularly important in medical devices. Also in medical diagnostics, high-throughput screening and drug delivery, nanobioconvergence has a strong influence. Molecular machines could be used for the transport of small amounts of substances for lab-on-a-chip systems. Precise manipulation of biological particles in fluids, and real-time monitoring of a single living cell are further important achievements. Functionalized biomolecules are investigated for the generation of energy mimicking natural photosynthesis.

Governance, Risk, and Societal Implications

In manipulating the building blocks of matter, nanobioconvergence has implications on various areas—including health, environmental, and social issues. Therefore, prospects, problems, and potential risks are important issues. Technological, environmental, societal, health, and safety issues must be addressed in research, societal studies, regulatory measures, and government policies.

The world's first major conference to consider the societal implications of nanotechnology, held in September 2000 at the National Science Foundation near Washington, D.C., raised awareness of the importance of technological convergence, with nanotechnology regarded more as a toolset for many other fields of science than as an isolated specialization. In subsequent conferences investigating the convergence of the four co-called NBIC fields (Nanotechnology, Biotechnology, Information technology and Cognitive science), it was concluded that introduction and management of converging technologies must be done with respect for immediate as well as longer-term concerns, at the national and global levels.

Societal implications of converging technologies should be judged using a balanced approach between the goals (leading to envisioned societal benefits) and unexpected consequences (which could be a combination of unexpected benefits and risks).

Future Perspectives

To fully exploit the potential of nanobioconvergence, scientists and engineers will have to substantially change their methods and concepts of thinking, especially on the level of fundamental research. Interdisciplinary scientific principles and concepts that allow specialist scientists to understand complex phenomena need to be developed. The specialist results that currently appear in increasingly specialist journals need to be rearranged and connected across fields.

See Also: Microscopy, Atomic Force; Nanobiotechnology; Nanoelectronics; Nanomaterials.

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'he first is the bottom-up ap- scenario, the chemical properties of the material are utilized to assemble into a useful structure. Scientists have shown through computational schemes that self-assembled components can be arranged into gears and mechanical structures. The energy needed to move the components is provided through the potential energy, or electrostatic energy provided at the tips of the movable components.

The second approach to building NEMS devices is called the top-down approach, which uses fabrication techniques utilized in the MEMS and electronic industry, such as optical and electron beam lithography. These techniques suffer from the lack of necessary resolution necessary for NEMS devices. Most known NEMS devices built using the top-down approach integrate nanoscale components, such as carbon nanotubes, to make transistors that can be integrated into miniaturized actuators, such as motors or pumps, that can perform a physical work. Conventionally, the output of an electromechanical device is the movement of a mechanical element. These motions can be expressed as a deflection in the mechanical component, linear motion, or rotational motion of the mechanical components. Vibrational motion, from a change in the amplitude or the frequency of the vibration, also constitute an output of the electromechanical device. Detection of these changes is recorded by highly sensitive transducers.

Motion of small components can be induced by an applied electric field and can be observed by optical interference or angular deflection of laser beam. Both static displacements and dynamic resonant motion can be actuated and detected using this technique. A recently demonstrated technique uses a scanning tunneling microscope (STM) as an actuator and a scanning electron microscope (SEM) to detect the motion.

In addition to enhancements in electronic and computational power as a result of the development of NEMS, it is anticipated that molecular displacements and forces will be detected using future NEMS devices. The possibility of engineering structures that can interact and probe materials at the molecular levels will open a new era for scientists to explore material characteristics at the molecular level. NEMS devices are expected to advance applications, such as the creation of ultrahigh density data storage, sensitive and portable chemical and biological sensors, and high-frequency device components for wireless communication. Resonators with frequencies above 10 GHz can now be built using nanolithography techniques. As a result, the sensitivity of the NEMS devices is orders of magnitude higher than bulk and micro devices. Due to their small size, NEMS devices dissipate very small amounts of energy.

A class of NEMS devices that integrates the sensing or actuation in a fluid environment has recently emerged as a new area of NEMS. In the nanofluidic systems, the diffusion and particle interaction with the fluidic surface become dominant. New analytical systems that integrate the actuation and sensing on a single chip have recently emerged for biological and chemical evaluation of markers. It is anticipated that in the near future, NEMS devices will be made that can rapidly and reliably detect a single molecule.

See Also: Electronics and Information Technology; Microscopy, Electron (Including TEM and SEM); Microscopy, Scanning Tunneling; Nanoelectronics; Nanomaterials; Nanoscale Science and Engineering.

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Nanoelectronics

The term *nanoelectronics* refers to electronic devices with dimensions of functional elements below 100 nanometers in size. The prefix *nano* comes from the Greek word *nanos*, meaning "dwarf." The term *nano* in more technical terms means 10^{-9} or one-billionth of something. One nanometer (nm) equals one-thousandth of a micrometer (μm) or one-millionth of a millimeter (mm). The diameter of a strand of human hair is 50,000 nm.

Roots of Nanoelectronics

The microelectronics industry, since the beginning of the 1970s, has followed Moore's Law, which indicates that the performance of semiconductor devices doubles roughly every 18 to 24 months. The increase in performance has been achieved mainly by shrinking the feature size of the individual transistors, enabled by the optimization and improvement of existing technology. It is believed that the integrated circuit industry will continue to follow "Moore's Law" until the year 2010, leading to metal oxide–semiconductor transistors with a minimum feature size of 10 nm in the next decade. In this case, the switching charges comprise only 1,000 or less electrons.

After 2010, there is a general feeling that evolutionary strategies based on Moore-like projections will gradually become obsolete, due to physical limits such as quantum effects and nondeterministic behavior of small currents and technological limits, such as power dissipation, design complexity, and tunneling currents. These limits may hinder the further progress of microelectronics on the basis of conventional circuit scaling. Technological problems, together with strongly increasing investment costs for conventional complementary metal-oxide semiconductor (CMOS) technology, may reduce the entry barriers for alternative device concepts.

Nanoelectronics is often considered a disruptive technology, because present candidates for nanoelectronical functional elements are significantly different from traditional transistors. Nanoelectronics presents the opportunity to incorporate billions of devices into a single system. Nanoelectronics is often regarded as the successor of microelectronics because it is capable of extending miniaturization further toward the ultimate limit of individual atoms and molecules. At this scale, some of the classical laws of physics can no longer be applied. Its properties need to be defined by quantum physics.

Quantum effects may present challenges for conventional semiconductor technology, but may also offer opportunities for new technologies. Despite the challenges, nanoelectronics hold the promise of making computer processes more powerful than what is possible using conventional semiconductor fabrication techniques. A number of approaches are currently being researched, including new forms of nanolithography, as well as the use of nanomaterials, such as nanowires or small molecules, in place of traditional CMOS components. Field-effect transistors (FET) have been made using both semiconducting carbon nanotubes (CNTs) and heterostructured semiconductor nanowires. Key issues and challenges that need to be addressed comprise the scalability of the device concept, the potential to operate at high temperatures (ideally at room temperature), the potential to offer an interface to the macroscopic world, and to consume little power. A further challenge is to find adequate architectures to integrate the nanoscale devices for efficient information processing or storage. Such architectures are far more demanding than the traditional CMOS ones. Fault tolerant concepts, as well as self-testing approaches, may have to be included.

Carbon Nanotubes

CNTs are a very popular material in the field of nanoelectronics. Since their discovery in early 1991, a lot of research work has been done on the material. CNTs are a unique material in which the electronic, thermal, and structural properties change depending on the arrangement of the carbon atoms, as well as the length and the spin orientation of the nanotubes. CNTs can behave like semiconductors, metals, or insulators. The longest conductive nanotube reported to date (by the University of Cincinnati) is 2 centimeters long. University of Cincinnati researchers have also developed a process to build extremely long aligned carbon nanotube arrays. They have been able to produce 18 millimeter–long carbon nanotubes that might be spun into nanofibers.

CNTs have the desirable mechanical property of being 100 times stronger than steel. Various applications of CNTs in the field of electronics can be found. CNTs can be used as interconnection materials between transistors in IC, sensors, probes, transmitter tips for displays, and energy storage devices, such as supercapacitors. The uniform and symmetrical structure of carbon nanotubes allows larger electron mobility, that is, faster electron movement in the material, a higher dielectric constant (higher frequency), and symmetrical electron/hole characteristics. This allows for more transistors to be packed into a single chip.

Nanofabrication

Because of the dimensions in which nanoelectronics operates, there are two possible approaches to the fabrication of nanoelectronic devices, namely, top down or bottom up. The present-day route to the fabrication of nanelectronics devices relies on the top-down approach, utilizing high-throughput optical lithography for feature sizes down to 180 nm, and electron beam lithography for feature sizes down to 30 nm with a low throughput (for masks).

The top-down approach is the extension of established methods of engineering and microelectronics processing that relies on a selective patterning process, often described in terms of depositing, patterning, and etching layers of material to define the circuitry and active elements. This approach continues with the miniaturization of electronic components by the development of strongly improved production processes and materials, starting from current practices. These methods are amenable to mass manufacturing, which has resulted in reduced costs (per transistor) for high-end electronics products. This approach enables developers to profit from the low-cost mass manufacturing expertise already acquired with silicon-based systems. However, exponentially increasing fabrication costs and fundamental physical limitations remain significant challenges for continued top-down miniaturization over the next decade. Top-down approaches rely on control of damage, and as the structures become smaller, the defects make device operation increasingly problematic.

In addition to the top-down approach of fabricating nanoelectronics devices, nanoscientists are also employing a bottom-up approach that is based on the self-assembly techniques of atoms and molecules. Self- and directed-assembly mechanisms are phenomena often found in nature, from the growth of crystals to the formation of complex functional biological systems, including the cells of the human body. Therefore, in attempting the bottom-up method, nature was used as a model, and the assembly of complex structures was approached by starting with single atoms and molecules. However, the mechanisms of such processes are still not well understood and research and development in this field represents a formidable challenge.

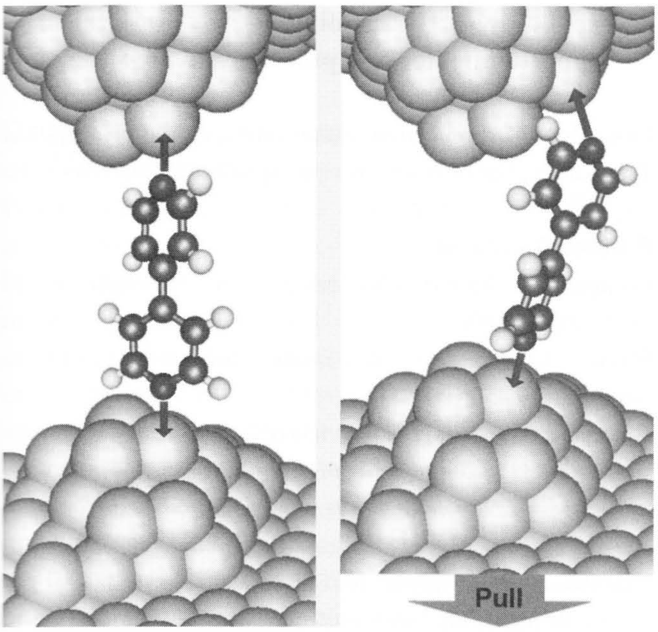
Bottom-up nanofabrication refers to device fabrication on an atom-by-atom basis. Bottom-up processes use chemically or biologically inspired routes for synthesis and assembly of nanoscale building blocks into complex nanoarchitectures with novel electronic or optical properties. Molecules, which are prefabricated arrangements of atoms in a functional form, are also appealing for bottom-up fabrication. The advantage of the bottom-up approach lies in the design and chemical synthesis of functional molecules by the billions, which can then be assembled into nanoelectronic devices. Such an approach will drastically reduce fabrication costs. However, development of controlled assembly strategies for integration of bottom-up nanostructures and nanoarchitectures into electronic devices and circuits remains a significant long-term challenge. In the medium-term, development of hybrid top-down/bottom-up fabrication strategies for electronics represents a key opportunity.

Progress along both of these avenues will entail a massive amount of research effort and investment in resources. Expert opinion is that eventually the top-down and bottom-up approaches can both be combined into a single nanoelectronics manufacturing process, where certain manufacturing steps can then be carried out using the top-down approach and others using the bottom-up approach. Such a hybrid method has the potential to lead to a more economical nanomanufacturing process.

Emerging Devices

A single-electron transistor (SET) is a three-terminal device that has switching properties controlled by the addition or subtraction of one electron, or through which only one electron may be transported at a time. The single-electron transistor is an example of a three-terminal device in which the charge of a single electron is sufficient to switch the source-to-drain current. SET devices are perceived by some to be the natural successor to the metal–oxide semiconductor field-effect transistor (MOSFET) although the research is also perceived by some companies as a method to investigate the ultimate limits of the MOSFET itself, as single electron effects will limit normal transistor action at the smallest length scales. SET devices are predominantly aimed at high-density, low-power applications.

There are a number of designs for low-power SET logics, but they do not look very encouraging due to large time constants limiting the operation at very high speeds. The SET, however, shows promise for memory, probably not in the form of a single electron transistor, but more likely in the form of a nanoflash memory, since a number of the designs are a miniature version of conventional flash-type memory devices. The SET seems to be a natural extension for conventional flash-type memory devices, and may even take over for static random-access memory, possibly bridging the gap between more standard CMOS and the single-electron



Researchers found that nanoelectrical resistance can be turned "off" by pulling the configuration vertically.

transistor. Whether the single-electron transistor will ever make it to the marketplace will strongly depend on future developments in device fabrication, both in respect to feature size (2 nm range) and uniformity, along with the control of background charges.

Resonant tunneling diodes (RTDs) are the most mature of all the nanoelectronic devices. RTDs have been successfully demonstrated in numerous applications and potential markets include digital-to-analog converters (DACs), transmitters, and ultralow power memory for portable applications. RTDs may be designed for much higher speeds than CMOS for DACs, etc., typically in the speed range between 10 and 100 GHz, or for much lower power than CMOS, such as Static Random Access Memory (SRAM) technology. III/V semiconductor alloys, such as the pair gallium arsenide and aluminum arsenide, are expected to be on the market in the near future.

Research on si-based devices still requires further development before marketable devices can be realized. The major concern remains wafer uniformity, especially for large integration levels. It should be noted that the intrinsic multistability of RTDs also enables the implementation of compact and elegant architectures for logic circuitry, although these areas are not yet as mature as the lower integration level applications. Another asset of resonant tunneling diodes is their potential to operate at room temperature without the need for nanoscale patterning. Like all two-terminal devices, however, their major disadvantage is a lack of signal regeneration. A combination of RTDs with classical transistors, such as MOSFETs or modulation-doped field effect transistors, is therefore desirable to increase the fan-out.

Outlook for the Future

Nanoelectronics and silicon technology are two important areas that will shape the future of the integrated circuit industry. Despite enormous recent progress in the fabrication and demonstration of nanoelectronic devices, many challenges remain. For solid-state nanoelectronics, one of the most important challenges is to be able to reliably and uniformly produce in-silico the characteristic nanometer-scale features required for nanoelectronics: nanometer-scale islands, barriers, and "heterojunctions" between islands and barriers

While the CMOS continues to dominate the semiconductor industry, it appears that several nanoelectronic devices originally conceived as successors to the CMOS are now finding their way into niche markets. The performance of computers used to be dependent on the amount of transistors. This has changed. Moore's Law, concerning the exponential increase in density and performance increase that CMOS has enjoyed for over 30 years, cannot be maintained forever. Moore's Law is no longer valid regarding computer performance: the data core can only administer a certain maximum amount of transistors.

Current multiple core technology makes "Moore's Law" obsolete, with the main task being the linking of several cores. Simple hardware focused development is increasingly replaced by multiple-core systems that are not driven by miniaturization but by cooperative software. The development of ever-smaller structures in nanoelectronics is necessary to establish small path lengths, but the physical limits are soon reached. The two limiting factors in nanoelectronics are miniaturization and the complexity of processors. The complexity of processors issue can be countered via standardized processors acting in concert via sophisticated software. The new "Moore's Law" correlates the amount of transistors per unit area with the number of core processors.

For the nanoelectronics field to mature further, there is a necessity to bring novel devices more on a par with CMOS by developing the necessary fabrication processes, simulation tools, and design rules that are required for any industrial electronic manufacturing process.

NanoMarkets, a leading advanced technology analysis firm in the United States, forecasts developments in the emergence of a large market for nanomemory products. The market for such products is expected to grow to \$65.7 billion by 2011, with the main driver being demand for high-performance, nonvolatile memory for mobile communications and computing. Nanoengineered display technology, such as roll-up displays using plastic electronics and other platforms, are also areas with predicted opportunities, and have attracted leading electronic firms such as Xerox and Philips. Displays have been a focal point of computer engineering in recent years. Using carbon nanotubes to replace scanning electron guns, manufacturers like Samsung are shrinking these screens and reducing power consumption. It is even possible that these screens will be small, bright, and efficient enough for use in laptop computers.

Nanoelectronics is now coming of age, and it appears to be the right time to develop these production tools. Up to now, solid-state nanoelectronic devices largely have been fabricated in III/V semiconductor compounds, such as gallium arsenide and aluminum arsenide.

It is believed, however, that silicon nanoelectronics would greatly contribute to the inexpensive mass manufacture of nanoelectronic devices. Hence, as the result of the industry's adoption of new materials and technology platforms—such as spintronics, plastic electronics, molecular electronics, nanotube/nanowire electronics, and low- and high-k dielectric materials—a new demand for novel manufacturing modes is now emerging. As transistors shrink, leakage current problems occur at the gate. This problem could potentially be fixed by using high-k materials, such as hafnium dioxide, zirconium dioxide, or titanium dioxide, as a replacement for typically used low-k material, such as silicon dioxide, in transistor dielectric gate.

In order to fulfill the promise of nanoelectronics, it will be necessary to greatly refine both fabrication techniques and architectural concepts to permit the useful assembly of small, low-power computing structures that contain trillions of nanoelectronic switching devices. Research in nanoelectronics is important and rewarding, and is vital for the community to encourage this economically valuable line of research. While nanoelectronics has challenges in its own right, it plays an important role in the convergence with areas of materials and applications. These will pose their own challenges and opportunities for new products and processes.

See Also: Carbon Nanotubes; Electronics and Information Technology; Nanomanufacturing; Nanomaterials.

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Nanoenabled Drugs

One of the greatest impacts of nanotechnology is taking place in the context of drug delivery. Nanoenabled drugs offer potential solutions to fundamental problems in the pharmaceutical industry ranging from poor water solubility of active agents (i.e., drugs or genes), toxicity issues, low bioavailability or a lack of target specificity (e.g., delivering the active to a specific "target" site). As a result, active agents are delivered more efficaciously while minimizing side effects, which lead to better patient compliance. Numerous U.S. Food and Drug Administration (FDA)-approved nanoenabled drugs are on the market and are already affecting medicine and promise to alter the healthcare landscape. To date, numerous nanoenabled drugs including luminescent quantum dots, magnetic nanoparticles, gold nanoshells, dendrimers, and block copolymer micelles have been developed for drug delivery. However, as these products move out of the laboratory and into the clinic, federal agencies like the FDA and the U.S. Patent Office struggle and saturation solubility, which frequently correlates to improved in vivo drug performance. In some cases, the pharmacokinetic behavior of nanoenabled drugs may help minimize peak plasma levels (which may be toxic) as well as prevent a drop below the targeted therapeutic range (which may reduce efficacy).

Finally, it should be noted that imaging or sensing agents might additionally be incorporated into a nanoenabled drug delivery system to generate multifunctionality (e.g., drug-loaded quantum dots).

See Also: Abbott Pharmaceuticals; Food and Drug Administration (U.S.); Nanobiotechnology; Nanomedicine, Ethical Issues of; Nanomedicine, Toxicity Issues of.

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Nanoenabled Products in Commerce

Nanotechnologies are becoming increasingly economically important worldwide. Today, numerous products already include nanotechnological components or are made using nanotechnologies. Signs for a broad industrial process of transformation through nanotechnologies have been apparent from a scientific point of view since the 1980s. Looking at consumer projects alone, the Project on Emerging Nanotechnologies lists 1,015 products or product lines using nanotechnology, versus 54 when the inventory began in 2005. The United States is the leading manufacturer of nanoenabled products listed on this inventory, followed by East Asia, and Europe. In all, 24 countries are included, representing every continent except Africa. A consensus prevails that nanotechnologies will have an impact on virtually all areas of life, and thus on the economy, in the mid- and long-term. Unlike many other high technologies, nanotechnologies have a cross-sectional character, and therefore possess a very broad potential of applications in many areas of the economy.

Consumer Nanoproducts

Health and fitness is the largest category in the 2009 consumer products inventory of the Project on Emerging Technologies. It contains 605 products or product lines (out of 1,015 total) while the next largest category is home and garden, with 152 products. Within health and fitness, the largest product category is personal care (193 products) followed by clothing (155) and cosmetics (137). Examples of products in the personal care category include the Clearly It! skin care products from Kara Vita (Complexion Mist, Spot Treatment, and Acne Treatment Lotion), a line of hairdryers and hair straighteners produced by Conair, and a nanosilver toothbrush produced by Summitek, Inc. Clothing products incorporating nanotechnology include antibacterial socks produced by the Sharper Image, the LZR Racer swimsuit produced by Speedo, and a line of wrinkle-free, stain-resistant nanocare trousers produced by Lee Jeans.

The home and garden category, the second largest in the consumer inventory, includes home furnishings, cleaning products, construction materials, luggage, paint, pet care goods, and luxury items. Products in this category include Apollo diamonds (grown in a lab, rather than mined, using a derivation of the chemical vapor deposition process), antibacterial/antifungal towels from AgActive that are designed to remain free of odor and bacteria, and the Dr. Mobile air purifier produced by Airo Co. that uses a nanosilver filter to trap germs and viruses.

The third largest category in the consumer products inventory is food and beverages. This includes food, items used in cooking and storage, and nutritional supplements. Products in this category incorporating nanotechnology include Canola Active Oil produced by Shemen Industries, which uses nanodrops or micelles to inhibit transportation of cholesterol into the bloodstream, FresherLonger plastic storage bags produced by Sharper Image, which are infused with silver nanoparticles to inhibit the growth of bacteria, mold, and fungus, and cookware from GreenPan, which uses a hybrid polymer nanocomposite nonstick technology.

Automotive Engineering

Nanoscaled fillers, such as sooty particles, are applied in car tires, for example. The nanometer-sized dimensions of functional layers or particles allow a drastic improvement in performance of catalysts and air filter systems that clean air inside and outside of the car. Optical layers for reflection reduction on dashboards, or hydrophobic and dirt-repellent "easy-to-clean" surfaces on car mirrors are further examples of applications using nanotechnologies in automobiles. Currently, profits amounting to billions of dollars are being generated using such high-end products, where nanotechnologies are incorporated into the product or into production technologies. In the production technology of future automotive engineering, nanotechnological adhesives have an enormous economic potential since they allow energy savings in assembly processes. An interesting application relates to adhesives that are modified with magnetic nanoparticles. The coupling of thermal energy in the form of microwave radiation induces the chemical reaction necessary for the gluing process.

Certain nanoadditives in plastics can lead to distinct improvements concerning processing properties in injection-molding machines. Here, energy savings of up to 20 percent are possible. Alternatively, the cycle time can be reduced by up to 30 percent, thereby increasing the throughput. Molding tools can be designed more easily and new components can be built with thinner walls, allowing for substantial material savings. Furthermore, the number of rejects is reduced, particularly in highly stressed parts such as housings and the functional elements of electric drives, in windscreen wiper arms, door handles, reflectors, mirror systems, joining elements, sunroof elements, in boxes of locking systems, and in many more applications.

Practically all of the physical and chemical properties of polymers can be modified using fillers. The motivation behind this is to considerably improve properties, such as scratch resistance, or to achieve higher mechanical stability. The latest developments make it possible to replace conventional car windows with plastic, coated on the nanometer scale. In doing so, the focus is placed on the development of transparent, light, scratch-resistant, and, at the same time, stiff materials. Another possibility to reduce fuel consumption and emissions and to increase energy efficiency is to coat cylinder tracks nanotechnologically. Thus, the high loss resulting from friction in today's engines can be significantly reduced. Almost all automotive manufacturers are currently performing research and development regarding fuel cells as alternative drive and supply unit for car electronics. Here, nanotechnologies can also give decisive advantages. Examples include the cell electrode, the diffusion membrane, or systems for hydrogen storage.

Sensors based on the Giant Magneto Resistance (GMR, that is, a significant decrease—typically 10 to 80 percent—in electrical resistance in the presence of a magnetic field) are currently used in increasing amounts due to the realization of a noncontact measurement. They can rather sensitively identify the strength and direction of magnetic fields, and are therefore capable of being incorporated into automobiles for the determination of a rotational speed by counting ferromagnetic marks, such as the teeth of a passive gear wheel, of the number of magnetic elements of a magnetized ring (rotation of wheels). Additionally, GMR-based sensors can act as position sensors (for example, on a valve actuator stem, the turn of the steering wheel, or pedal position) and linear sensors (e.g., liquid level indicator).

Environmental Technology

Until recently, environmental technology did not represent a direct driving force concerning nanotechnology research. Nevertheless, many technological innovations are envisaged to occur due to the particular properties of nanoscaled objects. Their mechanical, chemical, and biological functionalities, as well as geometrical properties, are capable to improve various applications of environmental technology, such as in filtration, catalysis, or sensor technologies. Additionally, environmental technology can indirectly benefit from different fields of application, such as surfaces with recognized environmentally friendly, easy-to-clean properties.

Nanoproducts in Medicine

Nanoscaled products in medicine become relevant in fields where molecular understanding of cell functions and controlled fabrication of materials on the nanoscale are systematically combined. This combination results in the development of new therapies and medical/technical products. Nanoscaled objects are also used for medical technology: nanomembranes are utilized for dialysis, nanocomposites find application in dental prostheses, and nanocrystalline coatings inprove implants.

The fields of application for nanoproducts in medicine are numerous. Nanoparticles are used in order to selectively accumulate agents within diseased tissue for the reduction of side effects, or to overcome biological barriers, such as the blood-brain barrier. Agents can be formulated as nanoparticles to control solubility, and thus bioavailability. Nanoparticles allow the development of completely new therapies. Magnetic hyperthermia is a promising form of cancer therapy, aside from the well-known methods of surgery, chemotherapy, and radiotherapy. Magnetic nanoparticles are used as mediators for magnetic hyperthermia. In broad terms, magnetic hyperthermia involves dispersing magnetic particles through the targeted tissue, and then applying an alternating magnetic field of sufficient strength and frequency to cause the particle to heat. This heat conducts into the immediately surrounding diseased tissue. Hyperthermia treatment of cancers is based on the observation that some cancer cells are more sensitive to temperatures in excess of 41 degrees Celsius than their normal healthy counterparts.

The first generation of contrast agents consists of high-spin paramagnetic ions that are at present routinely used as magnetic resonance imaging (MRI) contrast agents. Paramagnetism is a form of magnetism that occurs only in the presence of an externally applied magnetic field. MRI is a medical imaging technique used in radiology to visualize the internal structure and function of the body. Contrast agents enhance the appearance of blood vessels, tumors, or inflammation. Recently, superparamagnetic nanoparticles represent an advanced class of MRI contrast agents. A superparamagnetic material is not magnetized, except in an externally applied magnetic field—in this way, it is comparable to a paramagnetic material.

Magnetic drug delivery by particulate carriers is a very efficient method of delivering a drug to a localized disease site. Very high concentrations of chemotherapeutic or radiological agents can be achieved near the target site, such as a tumor, without any toxic effects to normal surrounding tissue or to the rest of the body. It is thus possible to replace large amounts of freely circulating drugs with much lower amounts of drugs targeted magnetically to localized disease sites, reaching effective drug levels with high local concentrations.

In magnetically targeted therapy, a cytotoxic drug is attached to a biocompatible magnetic nanoparticle carrier, such as albumin-coated magnetite. (Albumin is protein with water solubility, which is moderately soluble in concentrated salt solutions, and experiences denaturation at elevated temperature.) When the particles are administered intravenously, external, high-gradient magnetic fields are used to concentrate the complex at a specific target site within the body. The process of drug localization is based on the competition between forces exerted on the particles by the blood compartment and magnetic forces generated from the magnet, that is, the applied field. Magnetic particles have been used for many years in biological assays. The magnetic beads are subsequently coated with a chemical or biological species, such as DNA, or antibodies that selectively binds to the target analyte. Primarily, these types of particles are applied to separate and concentrate analytes for offline detection. As an improvement, the distinct selectivity of sample and target can be used as a rapid sensitive detection strategy with the online integration of a magnetic detector. This integration is facilitated by the development of GMR sensors as the magnetic detectors. These sensors have the unique advantage of being compatible with silicon integrated circuit fabrication technology resulting in a single detector, or even multiple detectors, that can be made on a single chip along with any of the required electrical circuitry.

Nanoproducts in Manufacturing Processes

Nanoscaled products support different tasks and functions of the process-oriented production such as industrial engineering, logistics, materials management, and occupational and quality safety. The means of production and maintenance are oriented toward cutting costs, improving quality, protecting the environment, enhancing the efficiency of manufacturing processes, extending the life cycle of components, and maintaining safety in the factory. Various targeted features within the manufacturing process become realized by using nano-objects: clean surfaces, easy pollution control, preservation of resources and environmental protection, using passively and actively functionalized surfaces, thermal protection layers and friction minimizing layers, enhancement of operational safety against electrostatic and magnetic fields as well as fire protection, heat and sound insulating layers, increase of impermeability, enhancement of quality and quality assurance, and innovative and optimized process technology.

Nanoproducts in Architecture

Even in a conventional and rather conservative commercial sector like architecture, nanoenabled products offer high potential for the optimization of materials and processes with respect to functionality, safety, design, maintenance of value, profitability, and environmental protection.

The spectrum of nanotechnology-driven improvements already covers nearly all sectors of architecture. Concerning structural work, nanotechnology allows for optimization of construction materials containing cement-like grout. Nanotechnology enables stability to be increased by a factor of 10. The quality of insulating material for outside facades and roofs can be significantly enhanced. The contamination of facades and walls can be efficiently suppressed using self-cleaning coatings based on the lotus effect (e.g., a coating that mimics the way lotus leaves repel water droplets and particles of dirt). Nanoparticles allow for antimicrobial behavior. Coating of glass can result in properties such as self-cleaning and adjustable shading. The latter one allows the use of the window as a sunscreen. Nanoparticles as additives in polymers can be used as improved flame-retardant materials. Nanotechnologically based coating techniques also allow the production of scratch-resistant tiles.

Nanoproducts in Textiles and Optics

"Nanowhiskers" attached to individual cotton fibers have led to new and improved properties of breathability, stain resistance, water repellence, and wrinkle resistance. The whiskers are hydrophobic, and water remains on the top of the whiskers and above the surface of the fabric. Titanium dioxide nanoparticles are applied for ultraviolet (UV) protection of textiles.

Optical technologies are cross-sectional technologies that contribute to technological advances in various areas of commerce. The 21st century is, therefore, also called the century of the photon (a photon is a quantum of light). Smart and reactive nanocolors focus on enhancing the usability of products, such as the surface of papers, packaging films, molded plastics, metals, among others, are suited for designer products. These smart colors, set up by chemically responsive optically resonant multilayer nanostructures, incorporate one or more of the following features: capabilities to respond to an external stimulus or control, surfaces that indicate the status of a material or product, or sensors or actuators embedded within material or bonded to the surface. The Austrian company Attophotonics, in collaboration with Mondi, developed a variety of innovative color materials with various functions (i.e., sensory function, or reactive color) based on its nanocolors and nanocoating technologies. Multi-nanolayers indicate, for example, humidity levels and/or water contact via a distinct reversible or irreversible color change coated on paper, polymer, or metal films, as well as printed via nanocolored inks. Potential applications have excited interest in the industrial, commercial, medical, automotive, military, and aerospace fields.

Foturan photosensitive glass is a photostructurable glass ceramic manufactured by the Schott Glass Corporation. Foturan is used as a substrate for micro-electro-mechanical systems (MEMS). Microfabrication in Foturan is achieved through patterning by a pulsed UV laser, a follow-up heat treatment step, and chemical etching. In Foturan, the exposed areas experience a selective phase change in which the native amorphous glass phase converts to a crystalline lithium silicate phase. The degree and type of crystallization are both responsive functions of the irradiation and thermal processing procedures. Under high exposure, the crystallized areas etch up to 30 times faster than the unexposed material in high frequecy, with the etch rate varying with irradiation dose. Because Foturan is transparent at visible through infrared wavelengths, three-dimensional (3D) direct-write exposure with a pulsed laser can detail complex 3D structures within the Foturan material. Foturan combines unique glass properties, such as transparency, hardness, and chemical and thermal resistance, with the opportunity to achieve very fine structures with tight tolerances and high aspect ratio (hole depth/hole width). Very small structures of 25 microns are possible with a roughness of 1 micron.

Zerodur glass ceramic from Schott AG is made from a mixture of crystallites, 30 nm to 50 nm in size, embedded inside a glass matrix of lithium, aluminum, and silicon oxides, and does not expand when subjected to heat or shrink at low temperatures. Zerodur is isotropic (i.e., invariant with respect to direction), homogeneous, and can easily be polished. Zerodur glass ceramics are applied in high-precision optics and in the manufacturing of semiconductor chips. The semiconductor industry has been increasingly working with mirror systems made from this material to expose the wafers. Furthermore, Zerodur glass ceramic is used for the mirror optics in the manufacturing of liquid crystal display (LCD) flat-screen monitors for televisions, laptops, and cell phones.

A photonic crystal (PC) is a new type of a manufactured material with refractive index periodically modulated on the scale of optical wavelengths. PCs can be utilized for realizing devices of novel or improved functionality. Photonic crystal fiber (PCF) can provide characteristics that ordinary optical fiber cannot, such as single mode operation from the ultraviolet to the infrared and bending insensitivity. Applications for photonic crystal fibers include spectroscopy, metrology, biomedicine, imaging (e.g., optical coherence tomography, a method yielding high-resolution 3D images from within biological tissue), telecommunication, industrial machining, and military uses.

Organic light-emitting diodes (OLEDs) are light emitting diodes that generate light in a film of organic compounds. A significant benefit of OLED displays over traditional LCDs is that OLEDs do not require a backlight to function. An OLED display can therefore be much thinner than an LCD panel. OLED-based display devices also can be more effectively manufactured than LCDs and plasma displays. Currently, OLEDs are used in small-screen devices, such as cell phones, PDAs, and digital cameras. But degradation of OLED materials has limited the use of these materials. OLED television sets are not expected to be available until at least 2010.

See Also: Energy; Fate and Transport of Nanoparticles; Manufactured Goods; Manufacturing and Materials; Nanoenabled Drugs; Nanogate (Tribological Coating for Automobiles); Nanomanufacturing; Nanomedicine; Nanoscale Science and Engineering; Nanotechnology in Manufacturing; Next Industrial Revolution.

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Nano-Ethics

Nano-ethics concerns the ethical issues associated with emerging nanotechnologies. Nanoscale science and engineering enables technologies in areas ranging from textiles and agriculture to medicine and computing. As a result, nanotechnology is implicated in a diverse array of ethical issues involving everything from privacy and environmental justice to synthetic organisms and human enhancement. However, different nanotechnology fields, research programs, and applications have different ethical profiles. For this reason, case-by-case ethical assessment for nanotechnology is crucial.

Defining Nano-Ethics

A frequent argument against the notion of nano-ethics is that there is nothing novel about ethics as it relates to nanoscale science and engineering. In this view, the issues, concepts, basic principles, and critical perspectives involved are those from bioethics, environmental ethics, medical ethics, and other established areas of applied ethics. Thus, nano-ethics is indistinct from or reducible to these other areas.

In response, proponents of nano-ethics argue that what is crucial is not that it constitutes a distinct field, but that there are significant ethical issues associated with nanoscale science and engineering, and that the extent to which nanotechnology promotes human, environmental, and social goods depends in part on whether these issues are identified and addressed.

In addition, it may be that nanotechnology, due of its distinctive features, what those features enable, the ways in which it is being promoted or disseminated, or the sheer rate and volume of innovation, raises familiar ethical issue in particular compelling, complex, urgent or novel forms. Moreover, just as nanoscale science and engineering is enhanced rather than diminished by being

This allowed it to have a legal status to enable it to enter into contracts with other parties, as well as be eligible for EU-funded projects. Operating from its headquarters at the Institute of Nanotechnology in central Glasgow, Scotland, with Dr. Mark Morrison as the Nanoforum EEIG manager, the Website states that it has more than 15,000 registered users, and attracts 100,000 visits each month. The main emphasis for the Website was to allow free access to information on nanotechnology, much of it only published online, allowing an organized search for information. Although much of the information involves work in the member states of the EU, it does include Canadian, U.S., and other researchers, and is by no means limited to work by or of interest to people within the EU. The result is that the site has been very useful for following new developments and inventions connected with nanoscience, and allows information access easily and quickly.

In addition, it has been particularly important to study the development of nanoscience, with users able to study how the field has been totally transformed. The earliest articles available are from the 1990s, although the vast majority were posted in the late 2000s. There are some similarities with NanoEthicsBank, although NanoEthicsBank tends to specialize in issues connected with moral, philosophical, and ethical issues in the field of nanoscience, whereas the Nanoforum includes a much wider range of material, including press releases and "works in progress" by researchers. One section of the Nanoforum Website is devoted to the Nanotechnology Education Tree, which has helped simplify the study of nanotechnology by dividing it into a number of fields: health, the environment, energy, electronics, and "modern life." Because of the number of users, the site also has attracted advertising and news about nanoscience-related events and research programs, allowing the site to be used for easy networking and the sharing of news.

See Also: European Union; Foresight Institute; *Minus 9*; NanoEthicsBank.

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Nanogate (Tribological Coating for Automobiles)

Environmental requirements demand that car combustion motor exhaust gases are thoroughly reburned in exhaust gas recirculation systems instead of being simply emitted into the atmosphere via the exhaust pipe. Condensate deposits from the exhaust gases of the combustion chambers are tar-like sooty residues that can agglutinate on valves in exhaust gas recirculation systems, resulting in larger force to lift from seat to open the valves, a subsequent loss of function, and the need for replacement.

The German company Nanogate developed a ceramic surface coating system for the valves in such systems that prevents agglutination of condensate deposits and that can successfully be applied in series production, resulting in exhaust recycling systems with improved performance. The metal valve has the valve plate and/or the valve seat provided with a ceramic coating with a layer thickness between 10 and 1,000 nanometers (nm), especially effective are coatings between 100 and 220 nm thick. The coating materials comprise zirconium oxide (ZrO_2) for general applications, and oxides of metals of the third, fourth and/or fifth main and auxiliary groups of the periodic system of chemical elements for specific high-temperature applications.

The valves have to be operative in the temperature range between 400 and 450 degrees Celsius (between 750 and 850 degrees Farenheit), in some cases (for specific motors) between 700 and 800 degrees Celsius (between 1300 and 1400 degrees Fahrenheit). The partial pre-cooling of exhaust gases in more recent motors can lead to enhanced buildup of condensate in the valve.

The coating of the metallic valve decreases the force to lift from seat if condensate deposits contaminate the valve disk and/or seat, and prevents or decreases condensate attachment. Because of the high operating temperatures, the coating material is ceramics. Nanogate coatings between 100 and 220 nm reduce the force to lift from seat of valve disks compared to uncoated valve disks by up to 30 percent. The coating is especially suited for double-disk system valves. Therefore an additional motor to open the valves can be dimensioned smaller or might be not necessary at all.

Closed and continuous coatings are of uttermost importance. Coatings thicker than 1,000 nm exhibit cracks that allow the condensate to establish direct contact with the metal or oxidized metal surface of the valve disk, resulting in strong adhesion of the valve disk to the sealing surface of the valve disk.

For effective reduction of the force to lift from seat, the coating is applied to at least one sealing surface of the valve. The coatings can be applied via physical or chemical vapor deposition in vacuum, via painting with metallic alcoholate solutions and subsequent drying at elevated temperature, or via spray coating methods. To reduce the amount of coating material and to make the process more economically, only the sealing surfaces are coated. The valve has increased lifetime and better closing properties if the valve disk is made of a harder material than the valve seat, for example, if steel is used for the valve disk and aluminum for the valve seat.

The Nanogate coating technology is not limited to metallic valve systems in exhaust gas recirculation systems, but can also be applied in all valves that have to be high temperature resistant and run the risk to become agglutinated. The coating can be applied on any metallic surface that comes into contact with exhaust gases, especially in exhaust pipes, exhaust gas coolers, pistons, compressor blades, or throttles.

See Also: Nanomaterials; Nanomaterials in Commerce; Nanotechnology in Manufacturing; Zinc Oxide.

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Nanohazard Symbol Contest

The Nanohazard Symbol Contest was initiated by the action group on Erosion, Technology, and Concentration (the ETC Group), a global science and technology governance nongovernmental organization (NGO). The symbol is meant to increase the visibility of a nanoscale science and technology safety discourse. The winning symbols of the 2007 Nanohazard Symbol Contest were Dimitris Deligiannis (Greece), Shirley Gibson (Scotland), and Kypros Kyprianou (England).

Sixteen 2007 contest winners were chosen from the 482 designs submitted by people from 24 countries.

The ETC Group was one of the first NGOs, if not the first, to question medical and environmental health safety issues with existing nanoscale materials, as well those in development and envisioned. The ETC Group initiated the Nanohazard Symbol Contest, feeling that a common, internationally recognized symbol warning of the presence of engineered nanomaterials was overdue. The ETC Group also used the term *nanohazard* to highlight social hazards, such as what would happen to the livelihood of people, particularly in low-income countries, if nano products replaced natural products. The ETC Group has called for a moratorium on nanoparticle production and release to allow for a full societal debate and the development of regulations and nanogovernance structures to protect workers, consumers, and the environment, and to minimize possible negative consequences.

Details of the Competition

The ETC Group and other involved parties sent out notice of the competition through their global networks, which included artists, designers, scientists, students, regulators, and members of the public. Entries were judged on their conceptual as well as artistic merit. All submitted entries were treated as copyright-free, and entries submitted with copyright conditions (other than creative commons) were not considered. An independent panel of judges selected by the ETC Group selected 16 finalists. The second stage was the public judging which took place at the World Social Forum in Nairobi, Kenya, in January 2007. Winners of Nanohazard Symbol Contest were announced at the World Social Forum. The compe-

Nanologues

The Nanologue project was a 21-month endeavor, funded in 2005 by the European Commission within the 6th Framework Programme. Nanologue was formed to build a common understanding concerning social, ethical, and legal aspects of nanotechnology applications, and to facilitate a Europe-wide dialogue among science, business, and civil society about its benefits and potential impacts. The Nanologue project was performed by a consortium led by the Wuppertal Institute (Germany), and included the Swiss Federal Laboratories for Materials Testing and Research in Switzerland (EMPA), the Forum for the Future in the United Kingdom (UK), and the German applied research and consulting organization that focuses on corporate and social responsibility, Triple Innova.

As the public's ongoing rejection of genetically modified organisms (GMOs) shows, when public trust in a new technology is lost, regaining it is incredibly difficult. The aim of the Nanologue project was to promote an open and honest dialogue between scientists, policy makers, and the public about both the potential benefits and pitfalls of nanotechnologies.

The Nanologue project had three phases. In the first phase, discussion began concerning the ethical, legal, and social aspects of nanoscience and nanotechnologies, specifically food, energy conversion and production, and medical diagnostics. The second phase aimed to start a discussion on the benefits and risks of nanotechnology between representatives between research and society. Interviews with researchers and members of civil society were conducted about the social, ethical, and legal impacts of nanotechnology, as related to environmental performance, human health, privacy, access, acceptance, liability, regulation, and control. The consortium reported on the interviewees' recommendations and suggestions to increase the benefits and reduce the risks of nanotechnology. During the third phase, several products were developed to enhance the dialogue on the social, ethical, and legal aspects of nanotechnology applications.

One of the products of the Nanologue consortium is called "Three Scenarios of How Nanotechnology Will Have Developed by 2015." The three cases were developed by experts, and are the outcome of variations in key drivers that are likely to influence how the technologies develop and are used in the future. Drivers include the legal and political framework, prices of raw materials, the speed of scientific progress in nanotechnologies, and environmental pressures. In each scenario, nanotechnologies have been put to quite different uses, and have varying levels of public acceptance.

The scenarios are meant to assist people interested in nanotechnology to think about its place in society in a more structured way. Scenario 1 is called "Disaster Recovery." This scenario describes a possible world that exists in 2015 where a lack of regulation has resulted in a major accident. Public concern about nanotechnology is high, and technology development is slow and cautious. Scenario 2 is called "Now We're Talking." In this scenario, strong regulation and accountability systems are in place in 2015. The technology has been shaped by societal needs and strong health and safety concerns. Scenario 3 is termed "Powering Ahead." Scientific progress has moved faster than expected and nanotechnology is making a real impact, particularly in energy conversion and storage.

An additional product of the Nanologue consortium is the NanoMeter, an Internet-based tool assessing the societal implications of nanotechnology. The NanoMeter addresses researchers and product developers, and aims to help understand the societal impacts of nanoapplications during product research and development in a quick and easy way. Offering the most relevant societal implications identified during the Nanologue project, the NanoMeter serves as a useful starting point to guide the internal discussion during the development phase of new products and technologies.

Further projects aiming to enhance the dialogue between researchers and society are the 2006 European Communication Project "Nano Dialogue: Enhancing Dialogue on Nanotechnologies and Nanosciences in Society at the European Level," and "DECIDE: Deliberative Citizens Debate," initiated by the European science center and museum network.

See Also: Environmental Ethics/Philosophy and Nanotechnology; European Union; International Dialogue; Nanojury; Nanotechnology Issues Dialogue Group (UK); Social Movements and Nanoscience; Societal Implications of Nanotechnology; United Kingdom.

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Nanomanufacturing

Nanomanufacturing refers to the fabrication and production of materials, physical structures, or devices with at least one of their dimensions in the range of 1 to 100 nm, in order to produce functional and controllable devices with new properties, phenomena, and behavior.

Nanomanufacturing can be understood as large-scale production of uniform nanoscaled materials, structures, and complex molecular devices, which is realized by implementing the nanotechnology in numerous aspects of the manufacturing processes while maintaining their unique properties. Those properties may be different from the properties of bulk material, single atoms, or molecules because of the unusual physical, chemical, and biological properties that emerge in materials on the nanoscale. Nanomanufacturing refers to industrial-scale manufacturing of nanotechnology-based objects, with emphasis on low cost, precision, and reliability. Nanomanufacturing is distinct from molecular manufacturing, which refers specifically to the manufacture of complex nanoscale structures by means of nonbiological mechanosynthesis and subsequent assembly.

Nanomanufacturing is a hereditary technology from micro-manufacturing, which has been exceedingly successful in many aspects. The most obvious example is microelectronics. Microelectronics entered the nanometer scale in the late 1990s when scientists at IBM's Almaden Research Center in California demonstrated the possibility to control the position of individual atoms. Subsequently, scientists at IBM's Zurich research laboratory showed how to move and precisely position molecules at room temperature using a scanning tunneling microscope (STM) in 1996. These pioneering researchers proved that individual atoms and molecules can directly be manipulated and controlled, and laid the basis for manufacturing materials with improved properties, such as superior strength, higher magnetism, and good thermal conductivity.

With the rapid development of nanotechnology, researchers and engineers are forced to figure out how to scale up the production of promising nanostructures to a commercially useful scale without loosing their unique and valuable properties. To this, a different set of fundamental research issues have been addressed, such as scale-up of assembly processes to production volume, controlling the processes with the reproduction ability of the nanoscaled process techniques, and the reliability and integration of turning nanoscaled structures and devices into large-scaled products. Successful integration of nanomaterials and nanostructures into final products typically entails resolving fundamental issues of physics and chemistry. Therefore, nanomanufacturing may require interdisciplinary cooperation to transfer the technology from the laboratory to commercial products.

The National Nanotechnology Initiative Grand Challenges and the National Science Foundation Workshop on Three Dimensional Nanomanufacturing, held in Birmingham, Alabama, in January 2003, addressed three important issues for nanomanufacturing:

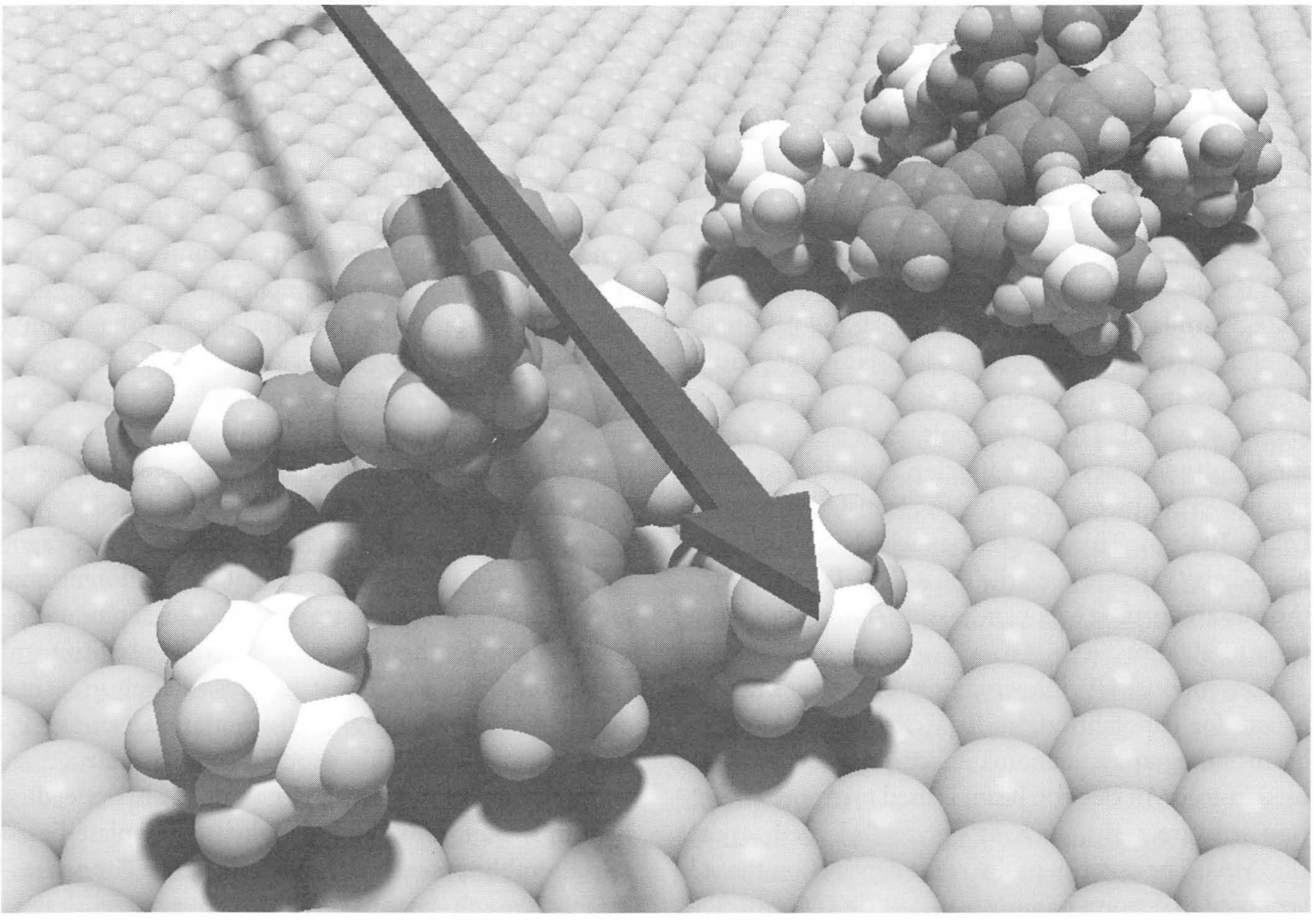
1. Control of the assembly of three-dimensional (3D) heterogeneous systems, including the alignment, registration, and interconnection in 3D, and with multiple functionalities.
2. Handling and processing nanoscale structures in a high-rate/high-volume manner, without compromising beneficial nanoscale properties.
3. Testing the long-term reliability of nanocomponents; and detect, remove, or prevent defects and contamination.

For these three issues, precise control of size, shape, alignment, and integration of nanostructures is fundamental. The fabrication and growth process of the nanostructures must be fully controllable and reproducible. Properties of the final integrated nanodevices need to have well-functioning behavior within an acceptable range. It must be possible to commercialize and mass-produce the products without losing the unique properties. Good and reliable metrological devices for quality control need to be developed and used for testing and checking nanocomponents.

Today, nanomanufacturing is leading the next industrial revolution, and providing the manufacturing base with a radically precise, less expensive, and more flexible way to reduce energy consumption for production. The rapid development of nanotechnology will have impacts on almost every industry sector, and through the generation of new products and systems, on society in general. The availability of a broad range of new consumer and industrial products, including sensors, actuators, displays, and healthcare diagnostics, will revolutionize the lives of future human beings.

It took about 10 years for carbon nanotubes to evolve from their discovery in 1991 to a mature and stable product in 2000. Based on this, the development of nanomanufacturing could be divided into four stages. The first stage is the development of functional nanostructures (which includes synthesis of functioning nanopowders, nanowires, nanobelts, nanorods, nanostars, nanoneedles, nanostructured thin-films for coatings, and passive nanoenabled products). This phase can be expected to last from 2000 to 2010. The next stage will see the era of nanocircuit fabrication, that is, the development of active nanofunctioning transistors, actuators, sensors, and adaptive devices, and should last until 2015. The third stage involves the use of nanorobots, nanosystems, and 3D functioning nanodevices, expected to evolve from 2010 to 2020. When entering the fourth stage, technology will comprise inorganic–organic hybrid nanosystems, in situ construction of bio-robots, self-assembled nanorobots and functioning devices. This stage is envisaged to start in 2015.

The two major approaches for nanomanufacturing or nanofabrication are the top-down and the bottom-



Nanocars consist of a chassis and four alkyne axles that spin freely. The axles are spherical molecules of carbon, hydrogen, and boron. When light hits the nanocar, the motor rotates, moving the car similar to a paddlewheel.

up methods. In top-down approaches, nanoobjects are constructed from larger entities without atomic-level control. Top-down approaches comprise lithography, deposition, and etching. In bottom-up approaches, materials and devices are built from molecular components that assemble themselves chemically by principles of molecular recognition. Bottom-up methods include (self-) assembly of atomic and molecular building blocks to form nanostructures. This method is widely used in sol-gel and chemical vapor deposition. In nature, self-assembly has existed for billions of years, from simple biomolecules to complete organisms.

Top-Down Approach

The top-down approach proved successful in the field of microelectronic technology and microelectromechanical systems (MEMS). While new resolution limits continue to be achieved, the production cost per device is continuously rising. Conventional tools and equipment reach their limitations in the sub-00 nanometer (nm) range. The concept of Moore's Law is continually being challenged. Novel methods, such as nanomolding, nanopatterning, extreme ultraviolet (EUV), X-ray, and electron-beam lithography, have been developed to fulfill the need for increasingly higher resolution. Nanopatterning and nanomolding manufacturing involve the use of an e-beam-fabricated hard mold template to stamp the pattern onto a polymeric resist on top of a working piece.

It is often followed by a dry etching process to generate a similar pattern onto the substrate. A complimentary pattern is formed on each stamping process. The stamping or imprint process is fast, repeatable, and economical. The same mold or template can be used multiple times before it deteriorates. This process has proven to be excellent for the transfer of patterns below 100 nm. This process has widely been used in high-density digital versatile discs (HD-DVDs), where the pits are formed by an embossing stamp with structures of 400 nm.

Conventional UV lithographic processes are not adequate for nanofabrication. EUV, X-ray, and electron-beam lithographic nanomanufacturing methods are used instead. An electron beam is used to expose an electron-sensitive resist, such as polymethyl methacrylate (PMMA). The polarity of the resist depends on the solvent used to dissolve it.

For example, PMMA dissolved in trichlorobenzene is a positive resist, while PMMA dissolved in polychloromethylstyrene is a negative resist. The resolution limit is 10 nm. The subsequent processes after lithography, such as etching and deposition, lead to creation of the nanostructures.

Bottom-Up Approach (Self-Assembly Process)

The bottom-up approach is a spontaneous process where atoms and molecules are assembled into stable structures that are at thermodynamical equilibrium. Functional structures are assembled from physical or chemical nanoscale building blocks. The final products created from self-assembly normally have smaller energy to minimize defects. Biological organisms are self-assembled entities: guided by the genetic code, proteins and macromolecules assemble to functioning biological systems. The carrier of the genetic code, DNA itself, is also built by self-assembly. Nanomanufacturing processes based on self-assembly require reliable and repeatable large-scale self-assembly processes. The ultimate goal of technological self-assembly is to develop biologically inspired assembly/molecular manufacturing processes. Technological self-assembly is considered the ultimate solution for the manufacturing of nanodevices operating in a living body without any adverse effects.

The currently-known self-assembly methods that can be used in a controlled way are limited and primitive. Most involve inorganic materials and are limited to fabrication processes, resulting in basic shapes on a laboratory scale.

Current technological self-assembly processes comprise one-dimensional growth, due to the anisotropic crystallographic of a solid, template-based self-assembly processes, cap reagent, or catalyst-induced growth and random direction 3D self-assembly process. Vapor solid processes basically dominate one-dimensional growth due to the anisotropic crystallographic properties of a solid; this process is generally used to form crystalline structures. The structures will only grow in a certain direction in a preferred orientation. Nanostructures formed with this process comprise structures with high aspect ratio, such as nanowires, nanoneedles, nanotips, nanorods, and nanobelts. Template-based self-assembly processes are used to guide the self-assembly growth process in order to achieve desired shapes and patterns. Aluminum oxide (Al_2O_3) is a typical template used for this process. In cap reagents or catalyst-induced growth, catalysts are used to induce the growth. Catalyst beads are generally located on the tip of the grown nanowires or nanostructures. Solid-liquid-solid or vapor-liquid-solid processes are used in this method. Random-direction 3D self-assembly processes yield 3D nanostructures such as nanostars, nanodendrites, and nano-fish-bone structures.

Materials Aspects of Nanomanufacturing

In terms of materials, nanomanufacturing can be divided into three major categories: carbon nanotubes (CNT), inorganic-, and organic-based materials.

Since the first discovery of single wall CNTs by Ijima and his coworkers in 1991, CNTs have been widely studied both theoretically and experimentally. Reliable production of CNTs is considered the distinct border and milestone for entering the era of nanofabrication. Various methods are currently used to synthesize CNTs; however, most of them are still at the experimental stage. The company CNano Technology (founded in 2007) recently announced the ability to produce of 500 tons of multiple wall CNTs per year; this is currently considered the world's largest production capacity. CNT-based materials are rapidly developing and already yielded pioneering applications, and are currently the leading nanomanufacturing products.

A wide variety of inorganic-based nanostructured materials have been synthesized and manufactured in the large scale, including nanopowers of zinc oxide (ZnO), tin oxide (SnO_2), and zinc selenide (ZnSe). A recent startup company, named SeaShell Technology, produces silver nanowires and nanorods with uniform diameters as thin as 50 nm and in lengths up to several hundred micrometers at kilogram scale quantities. Inorganic nanowire devices can already be assembled in a systematic and predictable manner. The electronic properties, their size, and interfacial properties can be precisely controlled during synthesis.

Organic based 2D nanomaterials, such as organic thin-films, have been intensively studied for the past 50 years. Commercial organic thin-film has already been used for applications and devices such as sensor products, solar cells, and organic transistors.

Current Status and Future Prospects

Nanomanufacturing involves various economic sectors that are closely connected in their engineering, industrial design, and technological processes. For example, nanomanufacturing provides materials for subsequent use in energy sectors. Recognizing the value of the unique material properties achievable through nanotechnology, the U.S. government has led global investment in finding new manufacturing products based on high-quality new materials and precise structures through the Industrial Technologies Program of the Department of Energy. Major implementations of nanomanufacturing for energy include nanocoating for efficiency in gas turbine, lubricants for reducing energy emissions in generator turbines, nanocatalysts for petroleum processing, microchannel assisted nanomaterials for photovoltaic material production, supercapacitors for high-speed electrical energy, and long-life lithium batteries and fuel cells.

The United States is now advancing the capability to efficiently incorporate nanomaterials in commercial processes and products. In the Internet technology and electronics sectors, nanomanufacturing plays an important role in the development of new generations of computers. Nanomanufacturing provides the tools for realizing superhigh-density microprocessors and memory chips. It is believed that a data bit could be stored in a single atom, which means that a single atom might be able to represent a bit or a single word of data. This could replace the use of transistors and capacitors as the media of data storage in conventional circuit chips.

Another important nanomanufacturing goal is the development of compact instrumentation for use in medical engineering and biotechnology. Manufacturing nanoscaled biochips led to a goal of creating diagnostic tools and drug discovery systems with significantly reduced energy consumption.

Nanomanufacturing could increase the product performance of DNA analysis systems, where accurate and fast analysis time is highly important. Furthermore, the advantageous properties of nanomaterials, such as lighter composite materials, and increased reactivity, yielding more reactive and less pollutant fuels and automated systems enabled by nanoelectronics, will prove useful for the automotive, aircraft, and aerospace industries.

Nanopowder

Powdered materials, such as nanopowdered metal, semiconductor, ceramics, glass, and high-strength steel, have proved to be among the most valuable products in nanomanufacturing. Nanopowders are powders composed of nanosized particles with an average diameter of less than 100 nm. Nanopowder is a new industrial product, with excellent properties for use in various applications, including microelectronics, integrated cicuit packaging materials, dielectric materials, wear and corrosion resistance, thermal conductive material, chemical deposition coating, as a refining agent for alloys or catalyst, for surface protection, and as an additive for lubricant oil.

The preparation of commercial quantities of nanosized powder is crucial. Several processes are being developed for the preparation of the powders. Although nanomaterials with functional application can currently be prepared by chemical processing, the practical process control is still difficult. Some methods developed to prepare nanopowders in the last decade involve self-propagating high-temperature synthesis, electric explosion of wires, plasma chemical synthesis, flame synthesis via combustion chemical vapor deposition, thermal synthesis in a plasma reactor, and burning in a laminar dispersion flame. Nanopowders can also be synthesized by the spray pyrolysis method, in order to attempt to create a homogenous nanosized spherical particle shape. Spray pyrolysis is a process in which a thin film is deposited by spraying a solution on a heated surface, where the constituents react to form a chemical compound.

Priority areas of research and development include processes to obtain better control of matter at the nanoscale; creating materials with new behavior; a greater focus on nanostructures and complex nanosystems; crating silicon nanoelectronics; nanomanufacturing from molecules; developing instruments for nanoscale measurement and standards; establishing major new nanocenter facilities to train skilled workers to carry this revolution forward into an exciting new future.

The most advanced generation of products will approach the way in which biological systems work, and involve nanomanufacturing of heterogeneous molecular nanosystems, where each molecule has a specific structure and function.

See Also: Carbon Nanotubes; Commercialization; Microscopy, Electron (Including TEM and SEM); Microscopy, Scanning Tunneling; Molecular Nanotechnology; Moore's Law; Nanoelectromechanical Systems; Nanoenabled Products in Commerce; Nanomaterials; Nanomaterials in Commerce; Nanotechnology in Manufacturing; Nanotools; National Nanotechnology Initiative (U.S.); Zinc Oxide.

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Nanomaterials

Nature is full of scales both in space and time where a variety of structures, that is, materials of different characteristics, find their home. These structures, either from nature or human-made, are not only physically and/or biologically interesting, but also technologically relevant if one can use them in different applications. Such a multitude of scales encompass the smallest at the quantum level, 10^{-11}-10^{-8} (m) in length and 10^{-16} -10^{-12} (s) in time, next to the atom/nano level, 10^{-9}-10^{-6} (m) in length and 10^{-15} -10^{-10} (s) in time, *mesoscale,* 10^{-6}-10^{-3} (m) in length and 10^{-10} -10^{-6} (s) in time, and the macroscopic one, less than 10^{-3} (m) in length and less than 10^{-6} (s) in time.

In addition, in the domain of the continuum mechanics, the so-called microscopic (few microns) scale is also important for many engineering applications. In fact, the classic textbook *Transport Phenomena* by R. Byron Bird et al., has an excellent introduction to multiscale process by using three of the scale levels mentioned above: the molecular, the microscopic, and the macroscopic scales. The authors actually suggest that an understanding of the "bulk" behavior can be systematically obtained by an up-scaling or "bottom-up" approach based at the molecular level. Thus, "macroscopic transport equations" are suggested based on knowledge at the molecular and microscopic level. This upscaling or bottom-up approach is what is now frequently nanoproducts was in the past on the order of three to four products per week and that, by August 2008, approximately 800 manufactured-based nanoproducts were available. The project maintains an inventory where a list of consumer products is available. A large majority of these products are within the family of passive nanomaterials (first generation), including cosmetics, sunscreen, food products, clothing, surface coating, paints, and catalysts.

To the first generation of nanomaterials, described above, three additional generations have been envisioned, that is, active nanostructures, systems of nanosystems, and molecular nanosystems. Each one of these generations implies an increasing knowledge of the fundamentals of nanomaterials and how they may be manufactured. For example, the use of nanoparticles in drug delivery directly to tumors minimizes the potential toxic effects of the drug; the use of new nanomaterial in MRI and CAT scans leads to a better image and safer procedures; and nanosensors may be able to detect pathogens in food in the near future. The list is long, but these few examples make the case for a very promising future.

Finally, the federal government has established a National Nanotechnology Initiative (NNI) that coordinates the efforts of about 25 agencies in promoting the development of nanotechnology. The efforts of these agencies are focused on advancing a world-class nanotechnology initiative on research and development programs leading to new products, medical devices and new drugs, effective educational resources to support the formation of a skilled work force, and a supporting infrastructure. This infrastructure should also include the understanding and managing of the potential environmental, safety, and health impacts of the nanotechnology products.

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See Also: Consumer Products Inventory; Nanoenabled Drugs; Nanoenabled Products in Commerce; Nanomedicine; Nanosilver; National Nanotechnology Initiative (U.S.); Woodrow Wilson International Center.

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Nanomaterials in Commerce

Nanomaterials such as carbon nanotubes, carbon aerogel (a material that is composed of nanosized carbon fibers), ferrofluids, nanodiamonds, nanosilver, and titanium oxide nanoparticles are becoming increasingly important in commerce. Such nanomaterials can already be found in products as diverse as batteries, chemical sensors, cleaning products, computer parts, electronic devices, fabrics, food, fuel cells, medical applications, solar cells, and sporting goods. As nanotechnology develops, new products are brought to the market that are more user friendly, portable, and flexible in their applications. It is expected that the utilization of nanoparticles in technological applications will continue to show dramatic growth in the foreseeable future.

Carbon nanotubes are molecular nanopipes with a diameter of between 1 and 50 nanometers (nm) and a length up to some millimeters made from carbon. They are used, for example, in transistors, displays, metrology, conducting polymers, and transparent electrical current and heat conductors.

Pure nanoscale chemical elements such as silver, gold, aluminum, zinc, iron, nickel, palladium, cobalt, and copper have broad uses in nanotechnology, and nanooxides (in powder form or in a suspension) of the main group elements, transition metals, and rare earth metals are used for catalysis, skin cream (ultraviolet [UV]-blockers), pastes, paint, glue, batteries, fuels cells, or in microelectronics. Ferrofluids are magnetic fluids, and fluids that react to a magnetic field, respectively. Based on iron oxide, nanoparticles combined with other atoms or nanooxides fluids, for example, find applications in medical and military technology.

Health and Medical Usages

When silver comes in contact with water, silver ions are released. Silver ions have, even at the smallest concentrations, antibacterial effects, while also being nonpoisonous, noncarcinogenic and have a low tendency to cause allergies (as opposed to other bactericides). Nanoparticles of silver (nanosilver) have much larger surface-to-volume ratio than macroscopic particles, and therefore provide faster combined ecological and economic benefits as less resources are needed. The small size of nanosilver particles also allows for production of novel materials that would otherwise not be possible, for example in synthetic polymer fibers. Nanosilver can be used to sterilize medical instruments and equipment. It is also used in food production, as a antimicrobial wound dressing, in household items, such as washing machines or refrigerators, and kills bacteria and reduces odors in cosmetics and in textiles.

Iron nanoparticles are used in cancer therapy. They are injected in tumors, an electric field is applied, and the nanoparticles heat up, destroying the tumor cells. Manufactured targeted drug delivery solutions offer enhanced absorption rates and bioavailability.

Nanoparticles are used for targeted delivery of drugs to tumors and diseased cells. They are furthermore utilized to improve drug delivery performance using oral, inhaled, or nasal delivery methods. Antimicrobial nanoemulsions are used for nasal delivery to fight viruses (such as the flu and colds) and bacteria, drug delivery through the skin using micellar nanoparticles, oral drug delivery with propriety structures called novasomes, and targeted oral drug delivery to diseased cells using a nanocrystalline structure called a cochleate.

Catalysts with platinum nanoparticles embedded on carbon nanotubes reduce platinum usage and increase catalyst lifetime, and catalysts with platinum nanoparticles embedded in a carbon aerogel reduce platinum usage. Catalysts composed of manganese oxide nanoparticles for use in removal of volatile organic compounds (VOCs) in industrial air emissions are capable of destroying VOCs down to the part per billion scale.

Batteries with chemicals isolated from the electrode by "nanograss" when the battery is not in use yield increased shelf life. Lithium-ion batteries with an anode composed of lithium titanate spindel nanoparticles and with nanocomposite electrodes, and silver-zinc batteries using nanoparticles in the silver cathode yield higher power density and a quicker recharge.

Carbon nanotube-based sensors are used for detecting low levels of industrial gas, to monitor carbon dioxide and nitric oxide levels in a patient's breath (used to provide a quick evaluation of patients respiratory status) and palladium nanoparticle-based sensors can effectively detect hydrogen.

Spray on film containing titanium oxide nanoparticles kills bacteria and reduces odors. Liquid cleaners using nanoparticles called micelles remove oils and dirt, replacing solvents with lower level of VOCs and other pollutants. Liquid in which polymer molecules will align with each other, when applied to a surface such as a windshield, to bond with the glass and form a very thin, strong polymer film, repels water and dirt and increases visibility with longer lifetime than conventional films.

Nanomaterials in Industry

Nanodiamonds have industrial applications, such as being used as a cutting material in drilling, cutting and polishing tools, as additives in polishing pastes, and as carrier substances for bioactive material. Nanodiamonds can also be utilized in a water treatment and used to aid cooling. Silica is a material that can be used to change viscosity in paints, polymers, synthetic rubber, binding materials, and gaskets. Amorphous nanoscale silica particles are increasingly being used by the cement industry in the development of more flexible and harder types of cement, and as additives for polymers and resins. Silica improves rigidity, impact strength, performance, UV stability, and consistency.

Nanoemmissive displays, magnetoresistive random access memory, nanochips, memory chips that use nanoscale probe tips to read and write data, self-assembled nanostructures, organic light-emitting diode (OLED) displays, and nanophotonics and integrated circuits with nanosized features are just some examples of nanomaterials used in electronics.

Nanowhiskers can make fabrics resistant to water, bacteria and stains. Nanopores insulate against hot or cold temperatures, and silver nanoparticles reduce odors. Liquid containing nanoparticles can be sprayed on textiles to form a hydrophobic film that repels water and resists soiling.

Clay nanocomposite used to produce bottles, cartons, and films provide a more efficient barrier to gasses or odors, and plastic film containing silicate nanoparticles provides a barrier to gasses or moisture. Nanoparticles are also used for delivery of vitamins or other food and beverages without affecting the taste or appearance.

Nanocatalysts used in the conversion of coal to liquid fuels and in the upgrading of low-grade crude oil yield additional raw material for producing gasoline, diesel, and other liquid fuels. Nanoparticle cerium oxide catalysts for diesel fuel increase mileage and reduce air pollution. Nanoclusters help gasoline and diesel fuels burn more completely by breaking the fuel into smaller droplets.

Various types of solar energy cells utilizing nanomaterials are already commercially available. These include cells using nanoparticles imbedded in plastic film, solar cells made with copper-indium-diselenide semiconductor ink, organic solar cells, and solar cells made with silicon nanocrystalline ink.

In sporting goods, various nanomaterials are already being applied. Examples are nanocomposite barrier films that prevent the loss of air in tennis balls, strong, lightweight carbon nanotubes used to strengthen bicycle components, nanoparticles filling voids in golf shafts, enabling a more consistent golf swing, nanoenhanced polymers in golf balls, yielding improved energy transfer from the golf club to the ball, stiffer tennis racquet frames containing carbon nanotubes to provide more power, and racquet frames containing silicon dioxide nanoparticles for increased strength, stability, and power.

Iron nanoparticles are applied to treat groundwater pollutants directly at the source of pollution. This method is less expensive than pumping water out of the ground for treatment. Water deionization methods, using electrodes made from carbon aerogel, yield lower energy usage and operating costs than conventional methods for converting salt water into drinking water. Furthermore, nanotechnology enhanced membranes are used as a means of less costly water desalination. Filters made from nanofibers are capable of removing viruses from the water at a lower cost than conventional filters of equivalent performance.

See Also: Carbon Nanotubes; Energy; Fate and Transport of Nanoparticles; Manufactured Goods; Manufacturing and Materials; Nanoenabled Drugs; Nanogate (Tribological Coating for Automobiles); Nanomanufacturing; Nanomedicine; Nanomedicine, Ethical Issues of; Nanomedicine, Toxicity Issues of; Nanoscale Science and Engineering; Nanosilver; Nanotechnology in Manufacturing; Next Industrial Revolution.

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Nanomedicine

Nanomedicine is an emerging field that seeks to apply nanotechnology to medicine to image, diagnose, monitor, treat, repair, and regenerate biological systems. Often referred to as the most promising offshoot of nanotechnology, nanomedicine has recently secured its position as a key site for global research and development, acquiring academic and commercial legitimacy. Funding for nanomedicine research comes both from public and private sources, and the leading investors are the United States, the European Union (EU), and Japan. Working at the molecular-size scale, nanomedicine is animated with promises of the seamless integration of biology and technology, the eradication of disease through personalized medicine, targeted drug delivery, regenerative medicine, as well as nanomachinery that can substitute portions of cells. Although many of these visions may and California's Department of Toxic Substances Control (DTSC) has initiated a mandatory reporting program for manufacturers and users of carbon nanotubes under the authority of recent state legislation.

The NMSP is thus part of a pattern of information-gathering efforts by governmental authorities, all of which are acting under conditions of profound uncertainty with respect to the potential hazards of nanomaterials. EPA rates the program as a success, while acknowledging that data gaps remain. Critics point to the poor response level to this and other voluntary initiatives as evidence that such efforts are inadequate. The NMSP, and programs like it, are probably the beginning of larger conversations, rather than ends in themselves.

See Also: Carbon Nanotubes; Environmental Protection Agency (U.S.); National Nanotechnology Initiative (U.S.); Risk-Benefit Perceptions of Nanotechnology.

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Nanoscale Science and Engineering

Nanoscale science and engineering deals with the study and development of systems with functional structures on the nanoscale—typically between 1 to 100 nanometers (nm). Whereas nanotechnology (NT) refers to the engineering of functional systems at the molecular scale, nanoscience (NS) depicts the study of nanoscale materials with the primary goal of gaining insight into their properties and nanoengineering refers to the practice of engineering in the field of nanotechnology.

Nanoscale science and engineering play a crucial role in the goal-oriented development and improvement of nanoproducts. NS and NT encompass a range of techniques rather than a single discipline, and stretch across the whole spectrum of science, touching medicine, physics, engineering, and chemistry. They will offer better built, safer, cleaner, and smarter products for the household, for information and communication, for healthcare, for agriculture, for transportation, and for industry in general.

Classical disciplines such as physics, chemistry, and biology meet at nanoscale systems. Physicists entered microelectronics with the invention of the transistor. A further reduction of the size of electronic systems led to applications of quantum effects, for example, in ultrathin layers. Biologists came from large structures down to molecular biology and to functional molecular design. Chemists, on the other hand, created complex systems (e.g., within polymer chemistry) by starting from simple atoms or molecules. Supramolecular chemistry uses the principle of self-organization to produce nanosystems, a strategy that forms the base for many biological processes. The combination of the fundamental principles of different fields leads to new interdisciplinary techniques for the fabrication of nanosystems for useful products.

In order to build nanomaterials, a thorough understanding of the properties of the fabrication processes as well as of the nanosystems themselves is necessary. Many natural and biological systems are scaled in the region from 1 to 100 nm. In this mesoscopic transition region from atoms or molecules to macroscopic systems, materials show considerable changes of their physical (i.e., mechanical, electrical, optical) properties. Some nanoscale effects are: the increase of surface to volume ratio altering mechanical, thermal, and catalytic properties of materials, quantum effects, such as the tunneling effect, confinement, spin effects, and quantum coherence.

Historical Background, Conceptual Origins, and Experimental Advances

Humans have employed nanotechnology for thousands of years, for example in making steel, in coloring glass by using metallic nanoparticles of gold and silver (e.g., the 4th-century Lycurgus cup, which was made from dichroic glass that changes color when held up to the light), or more recently in vulcanizing rubber. Each of these processes rely on the properties of stochastically formed atomic ensembles with some nanometers in size and are distinguished from chemistry in that they do not rely on properties of individual molecules. Techniques for the production of nanoparticles are quite old, but there was no understanding of the processes in ancient times.

Nanoscience developed fast in the second half of the 20th century, but the fundamentals were established earlier (accompanied by the development of quantum physics and quantum theory). Important steps in the development of NT and NS were the determination of the size of molecules in 1905, the invention of the electron microscope in 1931, large-scale production of nanoscale silicon dioxide particles as a substitute for soot in car tires in 1942, Feynman's visionary lecture about possible future developments in nanotechnology in 1959, the development of the theory of quantum confinement with effects of nanoscaled structures to electrical and optical properties of materials in 1962, Moore's Law in 1965, the development of molecular beam epitaxy (MBE) enabling the production of monoatomic layers on surfaces in 1968, and the development as well as subsequent patent registration of the process of atomic layer deposition for depositing uniform thin films one atomic layer at a time in 1974.

Norio Taniguchi first defined the term *nanotechnology* in 1974: "Nanotechnology mainly consists of the processing of, separation, consolidation, and deformation of materials by one atom or one molecule." The birth of cluster science, the invention of the scanning tunneling microscope (STM) in 1981, and the discovery of fullerenes in 1985 also boosted NT and NS.

K. Eric Drexler described and analyzed nanoassemblers and molecular engines in his futuristic books, *Engines of Creation: The Coming Era of Nanotechnology*, and *Nanosystems: Molecular Machinery, Manufacturing, and Computation*, leading to molecular nanotechnology and molecular manufacturing in 1986.

Supramolecular chemistry and self-organization form the foundations of the bottom-up approach in NT, first utilzed in 1987. The discovery of the Giant Magnetoresistive Effect (GMR) in 1988 was the basis for modern hard disk drives in personal computers (PCs). In an historic attempt, 35 xenon atoms were used to write the IBM logo on the surface of a nickel single crystal (the positioning of the xenon atoms took 22 hours at a temperature of minus 269 degrees Celsius) in 1989. In 1991, carbon nanotubes (CNTs) with many interesting mechanical and electrical properties were rediscovered. The construction of a "quantum corral" of 48 iron atoms on a copper surface by using an STM tip, and the visualization of a two-dimensional electron gas, the basic concept of a "quantum mirror" with applications for information technologies occurred in 1993. Single molecules representing electric switches formed the base for molecular electronics in 1999. The first integrated circuit made of CNTs in 2003, the development of a nanoresonator made of nanotubes and a hydraulic nanosystem as a pre-stage for nanomachines in 2008 were further important milestones.

Nanomaterials, Design Methods: Top-Down and Bottom-Up

Nanomaterials have unique properties arising from their nanoscale dimensions. A nanomaterial is either a nanoobject, that is, it is confined in one, two, or three dimensions at the nanoscale (less than 100 nm), or it is nanostructured. End products simply containing nanomaterials (for instance, electronic equipment) are not considered nanomaterials.

Taking examples from biology, a relevant system forms DNA, which is a nanoscale and functional system with size-dependent effects (primary, secondary, and tertiary structures), or a magnetobacterium that finds its orientation via nanosized magnetic iron oxides. Further biological nanomaterials are enzymes and proteins, ultrafine particles, clusters, colloids, nanocrystals, quantum wells, quantum dots, fullerenes, and CNTs.

Top-down and bottom-up are two approaches for the manufacture of products. The bottom-up approaches build up smaller (e.g., atomic or molecular) components into more complex assemblies (going from the small to the large), while top-down approaches seek to create nanosized devices by using larger ones to direct their assembly (from the large to the small).

The top-down approach often uses the traditional microfabrication methods that descended from solid-state silicon techniques for building microprocessors and are now capable of creating features smaller than 100 nm, used in cutting, milling, etching, nanolithography, nanoimprinting, sputtering, and chemical (CVD) and physical vapor deposition (PVD) in general. Solid-state techniques can also be used to create devices known as nanoelectromechanical systems (NEMS).

Bottom-up approaches, in contrast, use the chemical properties of single molecules to cause single-molecule components to automatically arrange themselves into some useful conformation. These approaches utilize the concepts of chemical synthesis, self-organization, molecular self-assembly and/or molecular recognition. Well known examples are found in biology, for example, in the formation of cell membranes and the replication of cells by division and growth. DNA nanotechnology utilizes the specificity of Watson-Crick base pairing to construct well-defined structures out of DNA and other nucleic acids. Most of the bottom-up approaches to nanotechnology are based on principles of supramolecular chemistry. Another variation of the bottom-up approach is molecular beam epitaxy (MBE). MBE allows scientists to lay down atomically precise layers of atoms and to build up complex structures (for example, devices for spintronics).

Bottom-up approaches should produce devices faster and much more cheaply than top-down methods. Top-down methods, on the other hand, are much more promising techniques when the size and complexity of the desired assembly increases. To combine their positive features, hybrid approaches have been proposed, employing a combination of a top-down approach for a coarse definition of the pattern and a bottom-up technique to realize short-range ordered nanoscale structures that align to the coarser structures, but in long-range order.

Scanning probe microscopy (SPM) techniques have developed into important tools for surface physics and the characterization and synthesis of nanomaterials. Two early versions of scanning probes are the STM and the atomic force microscopes (AFM) that can both be used to move atoms, carve structures on surfaces, and help guide self-assembling structures. Various further types of scanning probe microscopy basically only differ by probing different sample properties, such as temperature distributions (scanning thermal microscopes), acoustic properties (scanning acoustic microscopes), and optical properties (scanning near-field optical microscopes).

Miniaturization and Ultraprecision Convergence With Other Technologies

Nanotechnology promotes the unification of many fields of science and technology based on the unity of nature at the nanoscale. In 1965, Gordon Moore, one of the founders of Intel Corporation, observed that silicon transistors were undergoing a continuous process of scaling downward, a phenomenon that became known as Moore's Law: the idea that the number of transistors that could be fit into a given area would double every 18 months for the next 10 years. This trend has even continued until this day, going from just over 2,000 transistors in the original 4004 processors of 1971 to over 700,000,000 transistors in the Core 2. Thereby the transistor minimum feature sizes have decreased from 10 micrometers to the 45–65 nm range in 2007; one minimum feature is thus roughly 200 silicon atoms long. Today, microelectronics has already met nanoelectronics.

At the same time, chemists and biochemists were moving in the other direction. It became possible to direct synthesis, either in a test tube or in modified living organisms. Directed synthesis might prove useful for fabrication of multifunctional nanoparticles for biomedical applications, for example, as contrast media for X-rays and magnetic resonance, to identify cells, and to dose active pharmaceutical ingredients.

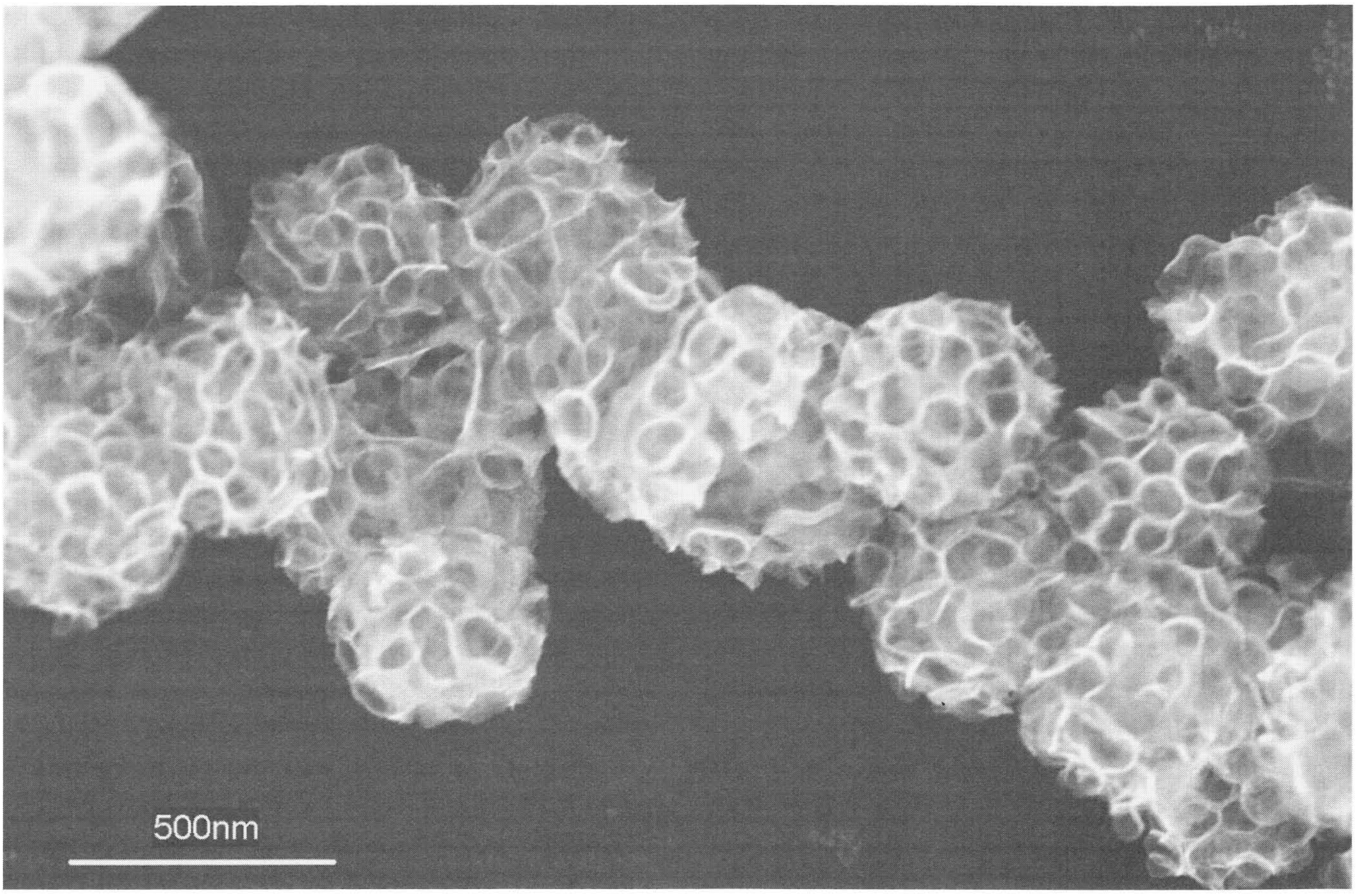
The interaction of matter with light is of fundamental importance for humans and for many technical applications, such as light emitting diodes (LEDs) or lasers. Nowadays, we can control and manipulate light, we can generate light pulses as short as a few femtoseconds. Nano-optics studies the interaction of nanoscale objects with light and the application of nanoscale objects for optical devices (nanophotonic). Structures of the size of the wavelength of the light are already in the nanoscale region. An active layer of a commercialized semiconductor laser has a thickness of 10 nm, the accuracy of coatings of ultraprecise optical systems is smaller than one atomic monolayer (less than 0.5 nm).

Thus powerful technologies now meet on a common scale, the nanoscale. By the application of the principles of physics, biology, and chemistry to nanosized structures, many systems with new valuable properties and powerful functionality may be created.

Nanoscale Effects

Nanoscale effects deals with the study of nanoscaled systems and their properties. A thorough understanding of fabrication processes and the functionalities of nanoscaled structures is crucial for goal-oriented development of nanoproducts.

An important aspect of NT concerns particle size, since the volume of an object decreases as the third power of its linear dimensions, but the surface area only decreases as its second power. The increased ratio of surface area to volume present in nanoscale materials leads to new effects, for example the quantum confinement ("quantum size effect"), where the electron properties of solids are altered with great reduction in particle size. Materials can suddenly exhibit very different behavior compared to their behavior on the macroscale. For instance, opaque substances become transparent (copper); metals and



Platinum's properties can be changed at the nanoscale by a method similar to photosynthesis. Instead of manufacturing sugar, a platinum ion can change to neutral metal atoms, allowing metal to be deposited repeatedly.

ceramics become superplastic (copper); stable materials turn combustible (aluminium); solids turn into liquids at room temperature (gold); and materials that chemically inert at normal scales start to exhibit catalytic properties (platinum). This leads to numerous new applications.

The increased ratio of surface area to volume in nanosized particles has huge effects. This is illustrated by the following example: by dividing a material, for example, a cube of iron, into two, four, eight cubes, and so on, more and more atoms become located at the surface. When the size of the cubes gets smaller than 50 nm, the number of atoms on the surface suddenly increases very quickly, and when the length of the cube is around 1 nm, then all atoms are placed on the surface. Therefore, many effects attributed to particle size do not come into play by going from macro to micro dimensions; however, they become pronounced when the nanometer size range is reached.

The field of surface physics, which was an exotic area of physics before the age of nanotechnology, is now increasingly gaining importance. Atoms on the surface of a grain have fewer neighbors than atoms of the inner volume and only feel the unbalanced attracting forces of the inner atoms. Therefore their energy is higher than that of inner atoms. The contribution of the surface energy to the total energy of a grain may be huge, a reduction of the size of grains leads to an increase of the specific surface area and consequently of the specific surface energy (for example, from 0.00007 J/g for macroscopic sodium chloride to 500 J/g for 1nm-sized sodium chloride nanoparticles). Nanoscaled particles have a very high surface energy and therefore they are very reactive. Even the influence of a single atom becomes important.

The specific surface energy also plays an essential role for the large diffusion of particles in nanoscaled materials, and as a consequence furthermore influences properties and processes that happen on surfaces, for example, catalysis, the separation of different kinds of molecules, or transport of charge carriers in batteries and fuel cells.

Reactive atoms on the surface are an advantage for processes with interactions with the surface (surface coating) or with grain boundaries (composite materials), but they may become a disadvantage when the nanoscale particles tend to reduce their energy by forming clumps (agglomerates). The prevention of unwanted aggregation is a challenge for nanotechnology in the production and stabilization of nanoparticles. The high surface energy has greater influence on thermodynamic properties of a nanoscaled material (reduction of the melting point and of the thermal conductivity) and on its mechanical properties (increase of tensile strength and ductility).

A characterization of nanosystems can be also carried out via dimensionality and confinement: film systems are nanoscale (less than 100 nm) in one dimension and extend into two dimensions (quantum well); fibers and tubes are nanoscale in two dimensions and extend into one dimension (quantum wires); and quantum dots are nanoscale in three dimensions, so that in quantum dots, the movement of charge carriers is restricted in all three dimensions.

The quantum confinement effect can be observed once the spatial extent of the confined extension is of the order of the wavelength of the electron wave function. This depends on the electron density: in metals, the wavelength is of the order of 1 nm, whereas in moderately doped semiconductors it reaches values of about 10 to 100 nm; therefore semiconductors are more easily used to study confinement effects. An electron behaves as if it were free when the confining dimension is large compared to the wavelength of the electron. However, as the confining dimension decreases and reaches a certain limit, typically in the nanoscale, the energy spectrum turns to discrete. As a result, the bandgap becomes size dependent. This ultimately results in a blue shift in optical illumination as the size of the quantum dots decreases. Quantum dots have properties between those of bulk semiconductors and those of discrete molecules. The influence of confinement on nanosystems becomes evident in optical, electric and magnetic systems.

Besides their electrical charge, electrons show another fundamental property that can be utilized in information technology and nanoelectronics: a spin with its associated magnetic moment. The discovery of the very pronounced effect of the spin orientation on electronic transport properties in thin metallic ferromagnetic/non-ferromagnetic/ferromagnetic multilayers, the Giant Magnetoresistive Effect (GMR), led to highly sensitive, fast, and very small magnetic field sensors, that are used, for example, in the read heads of hard disk drives. The spin dependence of the tunneling current through ultrathin insulating films (1–10 nm), the tunnel magnetic resistance effect is utilized, for example, in magnetic random access memories. The research field of spintronics, also known as magnetoelectronics, studies the spin properties of electrons in addition to their fundamental electronic charge in solid-state devices.

Nanomaterials

Materials referred to as nanomaterials are generally classified into two categories: fullerenes, and inorganic nanoparticles. The fullerenes are a family of allotropes (modifications) of carbon that conceptually are graphite planes (graphene) rolled into tubes, spheres, or ellipsoids. Spherical fullerenes are also called buckyballs, and cylindrical ones are called carbon nanotubes (CNTs) or buckytubes. CNTs are usually only a few nanometers wide (between 1 and 10 nm), but they can range from less than a micrometer to tens of micrometers in length. The ends may be open or capped with, for example, half of a fullerene molecule. Besides single-wall nanotubes (SWNTs), there are multiwall nanotubes (MWNTs), which consist of numerous cylinders tightly stuck into one another.

In addition, ropes of CNTs are frequently encountered. These ropes are self-assembled bundles, typically of SWNTs, in which the tubes line up parallel to each other. CNTs have extraordinary macroscopic properties: high tensile strength, high ductility, high resistance to heat, high electrical conductivity, and relative chemical inactivity. Superconductivity has also been attracting intense research. CNTs already have many interesting applications, such as for integrated circuits in nanoelectronics, field emission displays, light sources, actuators, sensors and batteries, bulletproof vests, and materials that block electromagnetic waves. Another proposed use in the field of space technologies and science fiction is to produce the type of high-tensile carbon cables that would be required by a "space elevator."

Nanoparticles or nanocrystals made of metals, semiconductors, or oxides are of particular interest for their mechanical, optical, electrical, magnetic, chemical, and other properties. Nanoparticles are effectively a bridge between bulk materials and atomic or molecular structures. They show size-dependent properties, such as quantum confinement in semiconductor particles. But the change in properties is not always desirable: for example, ferroelectric materials smaller than 10 nm can switch their magnetization direction using room temperature thermal energy.

Industrial Applications

In nanotechnology, a large set of materials and improved products rely on a change in the physical properties when the feature sizes are shrunk. The Project on Emerging Nanotechnologies from the Woodrow Wilson International Center for Scholars estimates that over 800 manufacturer-identified nanoproducts are publicly available, with new products hitting the market at a pace of three to four per week.

Nanoproducts that are already on the market include products for energy, resources, and the environment, for the refinement of surfaces and thin films, for textiles, for electronics, for optics, and for pharmaceutical industries. In the areas of energy, resources, and the environment, surfaces made of nanopowders help to save materials (e.g., noble metals in catalysis).

Further examples of nanoproducts in the marketplace are improvements to an effective energy storage in hydrogen technologies (CNT, zeolites); higher energy densities in batteries via ultrathin films and nanopores; energy savings via thermal insulation with materials with very low thermal conductivity (such as aerogel); antireflective optical coatings for solar cells; portable nanomembranes and easily cleaned systems that purify, detoxify and desalinate water. In the electronics field, innovations include high density of data storage of optical and magnetic materials; read heads (GMR) for hard disk drives; electronics based on solid-state silicon with structures of less than 65 nm; flash memory (e.g., USB sticks); magnetic random access memory (MRAM); polymer electronics (organic transistors, organic light-emitting diodes [OLEDs], OLED displays); CNT field-emission displays; and quantum dot displays.

In optics, we see transparent material replacing glass with increased stability and reduced weight; scratch-resistant surface coating of eyeglass lenses based on nanocomposites; antireflective ultrathin optical coatings; ultraprecise optics for telescopes; two-dimensional photonic crystals; OLEDs; and highly efficient nanoscale light sources, such as quantum dots. In the healthcare industry, nanoparticles are used as a contrast medium for clinical diagnostics, and biochips are used for in vitro clinical diagnostics and nanomembranes for dialysis. NT covers many branches of technologies (sometimes it is referred to as a general-purpose technology) and it has or will have much influence on all of them.

See Also: Carbon Nanotubes; Converging Technologies; Drexler, K. Eric; Feynman, Richard; Fullerene; Historical Examples of Nanomaterials; IBM; Microscopy, Atomic Force; Microscopy, Electron (Including TEM and SEM); Microscopy, Scanning Probe; Microscopy, Scanning Tunneling; Moore's Law; Nanobioconvergence; Nanoelectromechanical Systems; Nanoelectronics; Nanoenabled Products in Commerce; Nanomaterials; Quantum Dots; Quantum Information Processing and Communication; Self-Assembly; Societal Implications of Nanotechnology; Spintronics; Woodrow Wilson International Center.

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Nanoscale Undergraduate Education Program

Rapid advances in nanoscience and nanotechnology research indicate a need for corresponding science, engineering, and medical education efforts. In terms of K–12 education (primary and secondary education from Kindergarten through 12th grade), scientific and technological literacy have become even more pressing concerns, given the extent to which advances in nanoscience and nanotechnology are expected to impact all aspects of human experience, including healthcare and medicine, transportation, electronics, and environmental sustainability. Around the world, efforts are being undertaken in the field of nanoscale science and engineering education, with noteworthy examples already showing solid integration of nanotechnology in undergraduate education (college education taken prior to earning a degree), such as in chemistry, physics, biological sciences, engineering, environmental science, and technology. Many institutes and organizations now offer nanoscale education programs, most of them in the United States and in European countries.

Although nanotechnology has received a great deal of attention in the popular media in the United States, appropriate educational materials about nanotechnology for both the general public and university students have been less readily available. To address this need, the U.S. National Nanotechnology Initiative (NNI) set goals to meliorate nanotechnology education at all levels, develop educational resources, develop a skilled workforce, develop the needed supporting infrastructure, and develop a nanoscience module for college students.

NSF Programs

The U.S. National Science Foundation (NSF) introduced the program Nanoscale Science and Engineering Education (NSEE) to enhance formal and informal education in nanoscience, engineering, and technology. Its goals are to develop strong partnerships, linking science educators with nanoscale science and engineering researchers, and to increase knowledge in advances in nanoscale research and technology and their impact on society. To attain the overarching program goals, NSEE encompasses two independent components.

The first is the Nanoscale Informal Science Education Network, intended to foster public awareness, engagement, and understanding of nanoscale science, engineering, and technology through establishment of a network. It is a national infrastructure that links science museums and other informal science education organizations with nanoscale science and engineering research organizations. Numerous resources, including downloadable educational materials, news of upcoming conferences and events, and notification of funding opportunities, are available at the program's Website (www.nisenet.org).

The second program, Nanotechnology Undergraduate Education (NUE), aims to introduce nanoscale science, engineering, and technology through a variety of interdisciplinary approaches into undergraduate education, particularly during the first two collegiate years. The program provides educational opportunities for undergraduate students and K–12 educators. It also provides indirect funding for students at this level, or educational development, such as curricula development, training, or retention. The NSF Website also maintains a partial listing of courses on nanoscale science and engineering offered by U.S. universities. As of 2010, these included courses in subjects such as nanostructred materials (Clarkson University), chemistry and physics of nanomaterials (University of Washington) and nanomanufacturing processes (University of Arkansas), as well as summer workshops such as those offered at Northwestern University and Rice University.

The first NSEE grant proposals were solicited in 2005: at that time, one award was available for NISE, for up to \$4,500,000 per year for five years, and 15 for NUE at up to \$200,000 total for up to two years. The programs continue, with most recent NUE grants being awarded in 2010: winning researchers were located at a variety of institutions, including The University of Wisconsin-Milwaukee, Union College, Rensselaer Polytechnic Institute, and North Carolina Agricultural and Technical State University. The NISE Award is also active, and proposals are being solicited (note that only a single five-year award is available: the first grantee was Lawrence Bell of the Boston Museum of Science). Projects in nanoscience and nanoscience education are also eligible for numerous other grants available through various federal agencies. The NNI lists some of these on their Website, along with advice on locating grants.

Mihail C. Roco is the senior advisor for nanotechnology at the NSF, and is one of the strongest advocates of educating the nanotechnology workforce. Based on the 2001 market for instruments, he estimated that 2 million people will be needed to ensure success in nanoscience and nanotechnology in the years from 2010 to 2015: 800,000 to 900,000 in the United States, 500,000 to 600,000 in Japan, 300,000 to 400,000 in Europe, 100,000 to 200,000 in Asian-Pacific countries outside Japan, and 100,000 elsewhere.

The NNI's Centers and Networks of Excellence also play a major role in nanoscience education, because many are located within universities, and often provide practical and classroom training along with funding opportunities for students and junior researchers.

See Also: Innovationspace; *Journal of Nano Education*; National Center for Learning and Teaching in Nanoscale Science and Engineering; National Science Foundation (U.S.).

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Nanoscience and Society Research Group

Researchers in the Science, Technology and Society (STS) Initiative, based in the College of Social and Behavioral Sciences (CSBS) and the Center for Public Policy and Administration at the University of Massachusetts Amherst, work with the National Science Foundation (NSF) Center for Hierarchical Manufacturing (CHM) to examine societal implications of nanotechnology with a focus on emerging industry and university networks, risk management, environmental health and safety (EHS), and public policy.

The Nanoscience and Society Research Group (NanoSRG) brings together faculty from five research centers and seven departments and programs, including political science, sociology, economics, psychology, anthropology, communication, legal studies, natural resources conservation, and history. NanoSRG faculty are focusing on two activities: (1) organization and leadership of three national research and policy workshops and (2) an industry study of risk management behavior of nano scientists and firms in light of EHS challenges and opportunities for innovation.

Workshops

The STS Initiative held its first workshop, "Nanotechnology and Society: The Organization and Policy of Innovation," in May 2007 at the University of Massachusetts Amherst. This workshop brought together national and international faculty, public officials, scientists, and students to examine a range of societal implications of emerging nanoscale technologies, including technology innovation and dispute resolution, the role of the media in forming public opinion and informing public policy on emergent technologies, visual perception of nanoscale phenomena, and organization and economics of the nanotechnology research and development enterprise.

Using themes developed from the workshop, the NanoSRG also organized a half-day Policy Roundtable that brought together policy makers and researchers on the day after the May 2007 workshop. Discussions at the Roundtable were designed to build dialogue that could enhance both research and policy, as well as identify potential topics for upcoming nanotechnology and society workshops. The driving questions behind the Policy Roundtable were (1) what are the most pressing challenges for continued advancement of the nanotechnology research and policy agenda?; (2) how can governments encourage innovation and competitiveness in this emerging technological arena and at the same time safeguard the public good?; and (3) what distinctive dimensions of nanotechnology need to be considered in crafting responses to these questions?

Working closely with CHM and the National Nanomanufacturing Network (NNN), the STS Initiative conducted a second workshop, "Nanotechnology and Society: Emerging Opportunities and Challenges," in sector in the broader economy. According to PCAST, citing Lux Research figures, global funding for nanotechnology in 2008 totaled $18.2 billion for research, 46 percent of which was supplied by government. In 2009, some $224 billion of products making some use of nanotechnology components were sold. But the value of these components was only $29 billion, $11 billion of which were manufactured in the United States. Of global products, the majority—some 55 percent—were in the materials and manufacturing segments of the auto, industrial equipment, building and construction sectors, and included coatings, composites, and electronic components. Another 33 percent were in the form of batteries, displays, and coatings in electronics and information technology, and 12 percent were in healthcare and medical sciences sectors. Only 1 percent were in environmental and power applications.

In the first decade of the 21st century, nanomanufacturing was one of the lowest of the NNI's research priorities. Since 2008, annual spending in this area has averaged around $55 million out of total budgets averaging around $1.6 billion in that period. However, the NNI's fiscal year 2011 budget did increase funding for nanomanufacturing research by $26 million, a 34 percent increase over 2009. In its 2010 review, PCAST emphasized the necessity of commercializing nanoscale science and engineering, recommending that five leading agencies in the NNI (Department of Defense, Department of Energy, National Science Foundation, National Institutes of Health, and National Institute of Standards and Technology) double spending on nanomanufacturing over the next five years, while maintaining or increasing the level of basic research funding in nanotechnology.

See Also: Carbon Nanotubes; Nanomaterials; National Nanotechnology Initiative (U.S.); Quantum Dots; Self-Assembly; Spintronics.

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Nanotechnology Institute (ASME)

The American Society for Mechanical Engineers (ASME) Nanotechnology Institute (NI) was established in 2001. ASME, founded in 1880, is a not-for-profit professional organization promoting the art, science, and practice of mechanical and multidisciplinary engineering and allied sciences. The aim of the ASME NI is to advance the art, science, and practice of nanotechnology. The ASME NI is entrusted to carry out ASME activities in nanotechnology and to arrange interdisciplinary programs and activities to bridge science, engineering, and applications. While the ASME NI contributes to the development of nanotechnology, the adoption of nanotechnology in ASME's scope, in turn, provides the latter with the opportunity to modernize itself. ASME recognizes that nanotechnology, being highly interdisciplinary in nature, cuts across major divisions, including heat transfer, fluid engineering, applied mechanics, dynamics and controls, microelectro-mechanical systems (MEMS), and bioengineering, and hence the ASME NI draws representatives from each of these divisions. The activities of the ASME NI are organized through five committees. Each of the committees concentrates on specific activities:

- *Education Committee*: educational infrastructure and delivery in the area of nanoscale science, engineering, and technology.
- *Nanomanufacturing Committee*: manufacturing techniques related to nanotechnology such as synthesis and integration.
- *Devices & Systems Committee*: functional devices and systems that exploit nanoscale phenomena. Systems of interest: energy, information, and biomedical technologies.
- *Nanoscale Phenomena Committee*: fundamental understanding of nanoscale science that could have relevance in engineering: solid/fluid mechanics; heat transfer; thermodynamics.
- *Government/Venture/Social Impact Committee*: foster dialogue and interactions between the science/engineering communities and government, private investment and media.

Any individual, such as faculty, postdoctoral researcher, graduate student, personnel from industry, government, the media interested in any aspect of nanotechnology can become a member of the ASME NI committees. Members have the opportunity to shape ASME NI programs and to offer a collective voice to nano leaders in Washington, through ASME's Government Relations Operations. Since its inception, the ASME NI has been organizing numerous programs related to nanoscience and technology. These include major regular events such as the Integrated Nanosystems Meetings, two-day conferences that bring in participants from research, government, venture and media. Nano Training Bootcamps are also important ASME NI events. The Bootcamps are four-day training programs involving classroom and laboratory sessions.

They are designed to offer a detailed tutorial-based account of advances in fundamentals of nanoscience in different fields, and prospects for translating these advances into practical nanotechnologies. The ASME NI bootcamp topics include nanostructure properties, nanodevices, synthesis of nanostructures, nanostructural characterization, societal impacts, etc. Further ASME NI conferences/meetings organized so far include topics related to applications of nanotechnology in energy, medicine, electronics, and commercialization of nanotechnology. The ASME NI also organizes nanotechnology events overseas with international partners. The ASME NI arranges and participates in meetings with congress members and lawmakers updating them on nanotechnology.

The ASME NI Website provides a one-stop resource for intended researchers and practitioners about ASME nanotechnology activities, as well as links to other sites.

See Also: Nanomanufacturing; Nanoscale Science and Engineering; Nanoscale Undergraduate Education Program; Nanotechnology in Manufacturing; Social Movements and Nanoscience; United States.

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Nanotechnology Issues Dialogue Group (UK)

The Nanotechnology Issues Dialogue Group (NIDG) is a British nanoscience and nanotechnology organization. Its purposes are to coordinate British government activities involving the opportunities and challenges of nanotechnology; provide a platform from which to monitor the government's activities; and ensure that the government's activities and those of Research Councils are integrated with the Nanotechnology Research Co-

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Nanotechnology Victoria

Nanotechnology Victoria Ltd (NanoVic) operates in Australia with the support of Austrade, an arm of the Australian government, and was established to help focus attention on the field of nanoscience research. Its aim was to help exploit the commercial potential of the field, especially in relation to "improved drug delivery, medical imaging, and diagnostic systems." To achieve this, it established two separate entities with different roles.

The first of these was Interstitial NS, a specialist development company "for novel therapeutic nanoparticle delivery systems." It concentrated on the manufacture of existing pharmaceutical products, improving on the processes, and formulating ways to improve new pharmaceutical products and vaccines. The other entity was Quintain NS, which focused on researching the development of nanoengineered contrast media for the improvement of products used in the medical imaging market. This would assist medical personnel, especially radiographers, in diagnosing and monitoring diseases. Both of these entities were active in seeking additional investment capital and joint research projects.

NanoVic has reported some initial successes. A number of projects include research into therapeutic nanoparticle delivery, through Interstitial NS, with plans to transform the nature of the transdermal delivery of nanostructured therapeutics and vaccines. Nanotechnology Victoria is collaborating with Monash University on a new product for adults and children suffering from diabetes, and improving inhalers for delivery of medications.

This has led to the development by Paul Charlwood and colleagues of a prototype pulmonary inhaler that could have greatly improve insulin dosing. As Charlwood said, "the core of the nanotechnology development and inhaler design was to reduce the complexity, risk, and discomfort involved with injecting insulin for the world's growing number of insulin-reliant diabetics." Although the product has not been finalized, the prototype was exhibited in Boston in May 2007, and received much positive attention, both for the device itself and for other projects funded by NanoVic. Quintain NS has led many advances on medical imaging using the products qBright, to detect prostate cancer, and qTrack, to detect vulnerable plaques.

See Also: Australia; Australia Nanobusiness Forum; Australian Office of Nanotechnology; Nanomedicine.

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Nanotools

A plenitude of tools are used in nanotechnology for characterization, manipulation, and fabrication of matter at the nanoscale. Such tools provide data regarding optimization for production and quality assurance, and yield characteristics for specific applications and interaction with biological systems and behavior in the environment.

Characterization tools are used to determine the size and shape of particles, the state of dispersion of nanoparticles in a solution, physical and chemical properties, and surface area and porosity, among other surface properties. Manipulation tools are utilized to manipulate single atoms, molecules, or larger structures, up to several hundreds of nanometers (nm) in size.

Micro- and nanofabrication tools enable production of materials, physical structures, or devices with at least one of their dimensions in the range of 1 to 100 nm in order to produce functional and controllable devices with new properties, phenomena, and behavior.

For characterization, manipulation, and fabrication, important surface methods and methods that deal with bulk material below the surface comprise electron beam (e-beam) nanolithography, electrospray, imprinting systems, ion beam nanolithography, photoresist nanolithography, plasma processing technology, scanning electron microscopy, and scanning probe microscopy, as well as computer-based simulation and design tools (e.g., *ab intio* methods, molecular CAD tools, and nanodesign software tools). The major tools can be categorized as optical, electron microscopy-based, scanning probe microscopy-based, and additional tools.

About 20 years ago, Don Eigler and his coworkers from the IBM Research lab in Almaden succeeded in the tailored manipulation of single atoms. They arranged with the tip of their scanning tunneling microscope (STM) 35 xenon atoms on a single crystal to have them spell the three letters of their company, which were subsequently imaged with the same tip. This ability to morphologically characterize and manipulate objects on the nanometer scale with scanning probe microscopy techniques was an important achievement, contributing to large-scale production of nanoscale structures.

Microscopy

The STM was just the beginning of a now large family of scanning probe microscopes. Related instruments include atomic force microscopy, which allows for imaging and manipulation of electrically conductive as well as insulating material (e.g., living cells or single biomolecules in solution) at unprecedented resolution, as well as investigation of nanomechanical parameters such as stiffness and viscoelastic forces; scanning near-field optical microscopy; and scanning capacitance microscopy.

Besides these important and powerful techniques, various linear and nonlinear spectroscopy techniques are used to provide data. Electron and atom diffraction methods yield important additional information concerning the coherence of the investigated nanostructures. Electronic properties of nanostructures are often investigated via conventional emission methods such as electron, X-ray, or optical spectroscopy.

The optical methods comprise optical microscopy, confocal microscopy, X-ray microscopy, ultraviolet-visible (UV/VIS) spectroscopy, infrared spectrometry, terahertz spectroscopy, Raman spectroscopy, and surface enhanced Raman spectroscopy. Electron microscopy includes scanning electron microscopy and transmission electron microscopy. Additional methods include point-projection microscopes, low-energy electron diffraction, reflection high-energy electron diffraction, X-ray spectroscopy and diffraction, nuclear magnetic resonance, electron paramagnetic resonance, Auger electron spectroscopy and Mössbauer spectroscopy.

Surface Science Techniques

Surface science techniques currently applied in nanotechnology are manifold and comprise Auger electron appearance potential spectroscopy, Auger electron spectroscopy, Auger photoelectron coincidence spectroscopy, atom probe field ion microscopy, appearance potential spectroscopy, angle resolved photoelectron spectroscopy, angle resolved ultraviolet photoelectron spectroscopy, attenuated total reflection, ballistic electron emission microscopy, Bremsstrahlung isochromat spectroscopy, chemical force microscopy, concentric hemispherical analyzer, cylindrical mirror analyzers, contact potential difference, chemical vapor deposition, diffraction anomalous fine structure, disappearance potential spectroscopy, diffuse reflectance infrared Fourier transform, extended appearance potential fine structure, energy dispersive X-ray analysis, electron energy loss spectroscopy, ellipsometry, electron momentum spectroscopy, electron probe microanalysis, electron spectroscopy for chemical analysis, electron stimulated desorption, electron stimulated desorption ion angle distributions, extended X-ray absorption fine structure, and field emission microscopy.

Also employed in nanotechnology is field ion microscopy, Fourier transform infra red, Fourier transform reflectance-absorption infrared, Helium atom scattering, hemispherical deflection analyzer, high energy ion scattering, high resolution electron energy loss spectroscopy, inelastic electron tunneling spectroscopy, k-resolved inverse photoemission spectroscopy, ionization loss spectroscopy, ion neutralization spectroscopy, inverse photoemission spectroscopy, infrared absorption spectroscopy, ion scattering spectroscopy, low energy electron diffraction, low energy electron microscopy, low energy ion scattering, lateral force microscopy, molecular beam epitaxy, molecular beam scattering, magnetic circular X-ray dichroism, medium energy ion scattering, magnetic force microscopy, metastable impact electron spectroscopy, multiple internal reflection, metal organic chemical vapor deposition, magneto-optic Kerr effect, normal incidence X-ray standing wave, near-edge X-ray absorption fine structure, positron annihilation Auger electron spectroscopy, plasma enhanced chemical vapor deposition, photo emission electron microscopy, photoelectron diffraction, proton induced X-ray emission, photon-stimulated desorption, reflection absorption infrared spectroscopy, reflectance anisotropy spectroscopy, Rutherford back scattering, reflectance difference spectroscopy, reflection extended X-ray absorption fine structure, retarding field analyzer, reflection high energy electron diffraction, and reflectometric interference spectroscopy.

The long list of techniques also includes scanning Auger microscopy, scanning electron microscopy, scanning electron microscopy with polarization analysis, surface enhanced Raman scattering, surface extended X-ray absorption spectroscopy, second harmonic generation, second harmonic magneto-optic Kerr effect, secondary ion mass spectrometry, scanning kinetic spectroscopy, surface magneto-optic Kerr effect, sputtered neutral mass spectrometry, spin polarized inverse photoemission spectroscopy, spin polarized electron energy loss spectroscopy, spin polarized low-energy electron diffraction, scanning probe microscopy, surface plasmon resonance, spin polarized ultraviolet photoelectron spectroscopy, spin polarized X-ray photoelectron spectroscopy, soft X-ray appearance potential spectroscopy, surface X-ray diffraction, thermal desorption spectroscopy, thermal energy atom scattering, total internal reflectance fluorescence, temperature programmed desorption, temperature programmed reaction spectroscopy, total reflection X-ray fluorescence, ultraviolet photoemission spectroscopy, X-ray absorption near-edge structure, X-ray photoelectron diffraction, X-ray photoemission spectroscopy, X-ray reflectometry and X-ray standing wave. Ellipsometers, film thickness measurement tools, and surface profilometers also add to the list.

Nanofabrication Tools

Nanofabrication tools include electron beam lithography systems, sputter coaters, scanning electron microscopy (SEM) and SEM e-beam for maskmaking; resist spinners, nanoimprint systems, contact aligners, (programmable) ovens and ultraviolet (UV) cure systems for optical photolithography, tools for chemical vapor deposition (low pressure and plasma enhanced), atomic layer deposition systems for epitaxial growth, evaporators and sputter systems for metallization and sputtering, plasma etchers and reactive ion etchers for dry etching, furnaces and rapid thermal annealers for annealing, oxidation, and doping, and tools for wafer bonding and sawing.

The large number of tools currently used for characterization, manipulation and fabrication in nanotechnology shows that there is "no best technique." Since nanotechnology itself is at the meeting point of biology, engineering, chemistry, physics, biology, materials science, among others, its methods are also plentiful.

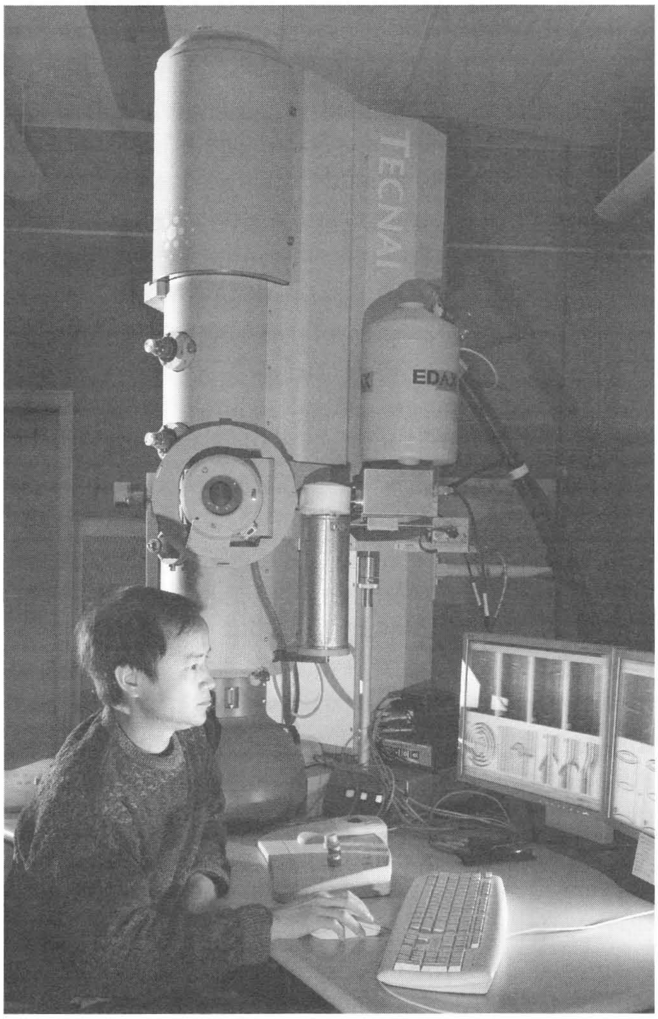
Characterization and Detection Techniques

Characterization and detection techniques can be used for manipulation and fabrication. The invention of the scanning probe microscopes in the 1980s ultimately opened the nanocosmos for man-made technology. Determination of the size and of physicochemical properties provides the basis for subsequent manipulation and fabrication. Size and shape as well as surface properties can be measured by ensemble analytical techniques or single particle techniques, respectively. Ensemble analytical techniques comprise dynamic light scattering, laser diffraction/static light scattering, low pressure impactors, electrical low pressure impactors, scanning mobility particle sizers, differential mobility analyzers, field flow fractionation, centrifugal sedimentation, specific surface area and time of flight mass spectroscopy.

Single particle techniques comprise scanning electron microscopy, transmission electron microscopy, field emission gun scanning/transmission electron microscopy, energy dispersive spectrometry, electron energy loss spectroscopy and atomic force microscopy. The many different physical principles used are the reason for current issues in size measurement: the use of multiple techniques where each type of measurement needs different sample preparation yields a measured "size" that is defined differently for the different methods.

For the determination of physical and chemical properties, ensemble analytical techniques as well as single particle techniques are applied. Ensemble analytical techniques comprise investigation of the atomic and/or chemical structure, of surface charge and surface reactivity. The atomic and/or chemical structure is probed with Fourier transform infrared spectroscopy, Raman scattering, X-ray absorption spectroscopy, extended X-ray absorption fine structure X-ray absorption near edge structure, X-ray and neutron diffraction and circular dichroism. Surface charge can be probed via measurement of the zeta potential, whereas comparative microcalorimetry is used for information about surface reactivity. Singe particle techniques that probe the surface composition comprise electron spectroscopy for chemical analysis (X-ray photoelectron spectroscopy) and secondary ion mass spectroscopy.

In 2006, the Organisation for Economic Co-operation and Development (OECD) established the Working Party on Manufactured Nanomaterials. Its objective is to promote international cooperation in human health and environmental safety related aspects of manufactured nanomaterials, in order to assist in the development of rigorous safety evaluation of nanomaterials. The relevant material properties as defined by Steering Group 3 of the OECD Working Party on Manufactured Nanomaterials comprise agglomeration/aggregation, water solubility, crystalline phase, crystallite size, dustiness, representative TEM pictures, particle size distribution, specific surface areas, Zeta potential, surface chemistry, photocatalytic activity, pour density, porosity, octanol-water partition coefficient, redox potential, radical formation potential and other relevant information of representative nanomaterials such as fullerenes, single-wall carbon nanotubes (SWCNTs), multi-wall carbon nanotubes (MWCNTs), silver nanoparticles, iron nanoparticles, carbon black, TiO_2, Al_2O_3, ZnO, SiO_2, polystyrene, dendrimers, and nanoclays.



A researcher views nanocylinder flaws on a combo transmission electron–scanning tunneling microscope.

All of these elaborated techniques yield important information. A current hot topic of research is the acquisition of data on the biological effects of the nanoparticles and nanosystems investigated, for example, regarding translocation from portal of entry to target organs, protein binding, cellular uptake, accumulation and retention as well as cell/tissue response.

Currently, a large set/combination of techniques is necessary and available for nanotechnological characterization, manipulation and fabrication. Nanotechnological tools are in rapid development. There is strong need for further harmonization and standardization as well as for the development of more refined methods for detection and characterization of nanomaterials in matrices such as food, cosmetics and environment, as well as the development of well-defined reference materials.

See Also: IBM; Microscopy, Atomic Force; Microscopy, Electron (Including TEM and SEM); Microscopy, Optical; Microscopy, Scanning Probe; Microscopy, Scanning Tunneling; Nanomanufacturing; Nanoscale Science and Engineering; Next Industrial Revolution; Tools.

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Nanotoxicology

Nanotoxicology is a branch of science that investigates the effects of nanoparticles (particles less than 100 nm in size) on human health. The increase in production of nanomaterials for various manufacturing, biomedical, and consumer products has attracted the attention of the scientific community worldwide to study the potential benefits of nanomaterials on our daily lives. It is estimated that the production of nanoparticles will increase from an estimated 2,300 tons produced in 2009 to 58,000 tons by 2020.

Compared to larger size particles, the extremely small size of nanoparticles affords them easy entry into the human body. Furthermore, the small volume-to-surface area ratio of these particles imparts them with the potential to induce toxic health effects. Currently, with the increase in use of nanomaterials in commercial products ranging from cosmetics to tennis balls, it is extremely important that toxicologic evaluation of these nanomaterials receive greater attention than ever before. In addition to consumer products, emerging biomedical applications of nanoparticles as drug-delivery agents or biosensors involve direct ingestion or injection of nanoparticles into the body, indicating the importance of evaluating the toxicity of these nanoparticles along with their potential benefits for usage in drug delivery.

Nanomaterials and Toxicity

The main characteristic of nanomaterials is their size, depending on which, modification of the physiochemical properties of the material takes place. This creates an opportunity for increased uptake and interaction with biological tissues, and generates an adverse effect in biological organisms that would not otherwise be possible with the same material in larger forms. Experimental evidence has indicated that their small size, large surface areas, and the ability to generate reactive oxygen species (ROS) play a role in the ability of these nanoparticles to induce damage. ROS production has been observed in a variety of nanomaterials, ranging from carbon fullerenes, carbon nanotubes, and nanoparticle metal oxides. Further, it has been found that as the particle size decreases, there is a tendency for toxicity to increase, even if the same material is relatively inert in bulkier form (e.g., carbon black, titanium dioxide). ROS and free radical production is one of the main mechanisms of nanoparticle toxicity and results in oxidative stress, inflammation, and damage of cell membranes and DNA.

Due to the small size of these particles, they readily gain access to the cell by crossing the cell membranes. Inhalation and ingestion are the main routes of entry of these particles into the body. In addition, these particles also have the ability to penetrate the skin, especially broken skin, indicating that skin conditions like acne, eczema, wounds, and sunburn could accelerate the uptake of these nanoparticles. Once in the blood stream, they are transported to various parts of the body and taken up by tissues like the brain, heart, liver, kidneys, and bone marrow. In addition to size, other properties of nanoparticles that influence toxicity include their chemical composition, shape, surface structure and charge, solubility, aggregation, and the presence of functional groups.

Air Pollution and Nanoparticle Toxicity

With the increase in air pollution, the potential effects of human exposure to airborne nanosized particles (also known as ultrafine particles (UFPs) by toxicologists) have increased dramatically. Several epidemiological studies have found that exposure to UFPs have resulted in adverse respiratory and cardiovascular effects. A strong association between UFPs as a predictor of mortality and morbidity of adults was documented in six polluted and less polluted cities of United States. Further, these particles have also been associated with increased cardiovascular mortality. An increase in blood pressure and heart rate was reported to be associated with increased exposure to UFPs.

Exposure to ambient air pollution (especially UFPs) has also been shown to cause increasing incidence of ion Agency (U.S.); Food Standards, l; National Health and Medical Research Council (Australia).

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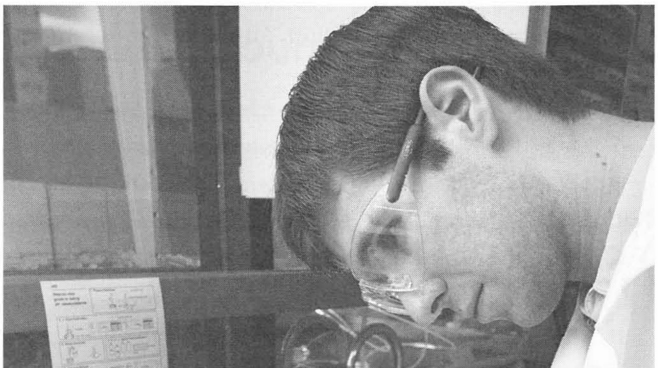
National Institute for Occupational Safety and Health (U.S.)

The National Institute for Occupational Safety and Health (NIOSH) is the U.S. federal agency responsible for conducting research and making recommendations for the prevention of work-related injury and illness. The institute, which was created by U.S. Congress (in the Occupational Safety and Health Act of 1970), is part of the Department of Health and Human Services. The mission of NIOSH is to develop and establish recommended occupational safety and health standards. This goal is achieved through scientific research, development of guidance, authoritative recommendations, dissemination of information, and response to requests for workplace health hazard evaluations.

In 1996, NIOSH launched the National Occupational Research Agenda (NORA). NORA is an innovative public–private partnership to establish priorities for occupational safety and health research both at NIOSH and throughout the United States. NORA's research focus is on the problems of highest relevance to U.S. workers, employers and occupational safety and health practitioners in the major industrial sectors of agriculture, construction, healthcare, manufacturing, mining, services, trade, and transportation. NIOSH stands at the forefront of U.S. research in researching the occupational health implications of nanotechnology.

The institute identified 10 critical topic areas to guide in addressing knowledge gaps, developing strategies, and providing recommendations. The critical areas represent core active research programs designed to investigate ultrafine and nanoparticle behavior, health risks associated with nanomaterials, and field evaluations of potential nanoparticle emissions in the workplace. The NIOSH Nanotechnology Research Center (NTRC) was created in 2004 to coordinate institute-wide nanotechnology-related activities. NIOSH works closely with other federal agencies and private sector organizations to plan, conduct, and facilitate research that will support the



Part of the Centers for Disease Control and Prevention, NIOSH is responsible for occupational safety reearch.

responsible development and use of nanotechnology. NIOSH co-chairs the interagency working group on Nanotechnology, Environmental and Health Implications with the Food and Drug Administration. Building on these initiatives, NIOSH updated its strategic plan for nanotechnology in 2008 to address immediate and long-term issues associated with nanotechnology and occupational health in partnership with other federal agencies, research centers, and industry.

Capitalizing on its 38 years of research experience in occupational safety, NIOSH created the NTRC to identify critical issues, create a strategic plan for investigating these issues, coordinate the research effort, develop research partnerships, and disseminate information gained. The NTRC is comprised of nanotechnology-related activities and projects consisting of and supported by more than 30 scientists from various NIOSH divisions and laboratories.

Through the NTRC, NIOSH has identified 10 critical research areas for nanotechnology research and communication. These 10 critical research areas are (1) exposure assessment; (2) toxicity and internal dose; (3) epidemiology and surveillance; (4) risk assessment; (5) measurement methods; (6) engineering controls and personal protective equipment; (7) fire and explosion safety; (8) recommendations and guidance; (9) communication and information; and (10) applications. By working in these critical research areas, NIOSH has comprehensively begun to address the information and knowledge gaps necessary to protect workers and to responsibly move nanotechnology forward so that its far-reaching benefits may be realized.

See Also: Federal Institute for Occupational Safety and Health (Germany); Health and Environmental Risks (Netherlands); Healthcare and Life Sciences; Laboratory Safety; Nanoparticle Occupational Safety and Health Consortium; Nanotechnology Safety for Success Dialogue (Food Industry); National Institutes of Health (U.S.); Occupational Safety and Health Administration (U.S.); Occupational Safety and Health Enforcement (U.S.).

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National Institute of Environmental Health Sciences (U.S.)

The U.S. National Institute of Environmental Health Sciences (NIEHS), located in Research Triangle Park, North Carolina, is one of 27 research institutes and centers that comprise the National Institutes of Health (NIH) and the U.S. Department of Health and Human Services (DHHS). The NIEHS studies the impact of the environment on the development and progression of human disease. The institution can be traced back to 1966, when the U.S. Surgeon General announced the establishment of the Division of Environmental Health Sciences within the NIH. In 1969, the division was elevated to full NIH institute status. NIEHS has been at the forefront of environmental health sciences, with an impressive record of important scientific accomplishments and remarkable institutional achievements and growth.

The NIEHS director and scientific staff are advised by a number of advisory boards and councils drawn from among scientists and the public. The National Advisory Environmental Health Sciences Council (NAEHSC) recommends grant awards for research projects and training. The Board of Scientific Counselors is an external peer review committee that evaluates Division of Intramural scientists on the basis of accomplishments since their last peer review. The National Toxicology Program (NTP), under the NIEHS, also relies upon advice from external groups and ad hoc panels.

One key organization of the NIEHS is the institutional review board (IRB), which is concerned with human research subjects. The group ensures that research meets high ethical and scientific standards and is designed, reviewed, approved, and implemented in accord with accepted ethical principles and the DHHS (45 CFR [illegible] ir research works. There are, [illegible] concerning the carcinogenic nature of titanium dioxide nanoparticles.

See Also: Occupational Safety and Health Administration (U.S.); Precautionary Principle; Quantum Dots.

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Tools

Analytical tools for nanoscale materials (engineering and biological) have rapidly developed since the 1980s, concerning improvement of resolution and efficiency of existing techniques and development of new tools. The four major groups of nanoscale probing tools are Scanning Probe Microscopy (including scanning tunneling microscopy, atomic force microscopy and near field scanning optical microscopy), electron microscopy, X-ray methods and optical techniques. Emerging techniques include nanoimprint-lithography, electron-beam-lithography, and multi-photon-based laser-lithography. Theoretical approaches include atomistic simulations and nanodevice modeling, and various computer modeling packages are available to predict the structures of complex materials, to model surface structures and properties, to predict nanoparticles structures and properties, and to model reactivity.

Scanning Probe Microscopy

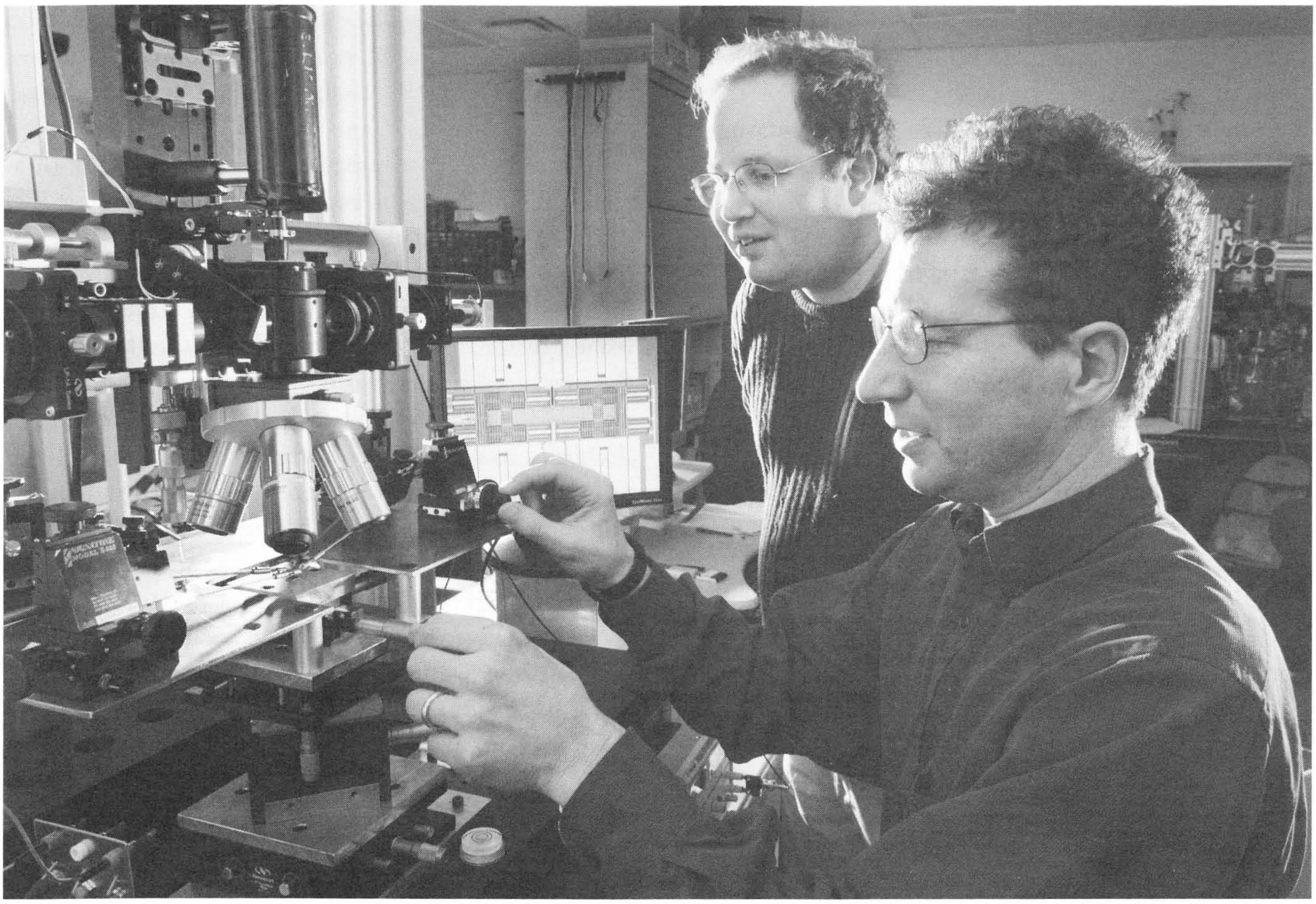
Scanning probe microscopy (SPM) is a branch of microscopy that covers various techniques for surface imaging. In this type of microscopy a physical probe scans the specimen line-by-line, recording and analyzing interactions between a sharp probe and the surface, and forming an image of the respective parameter(s) of the surface. Starting with the invention of the scanning tunneling microscope (STM) in 1981, SPM revolutionized many areas of science and engineering by offering a wide range of resolution from the subatomic level up to few hundreds of micrometers. Some scanning probe microscopes can record several interactions simultaneously. The three most common SPM techniques are atomic force microscopy (AFM), scanning tunneling microscopy (STM), and near-field scanning optical microscopy (NSOM).

Atomic force microscopy (AFM) became the most widely used tool for imaging, measuring, and manipulating matter at the nanoscale. Depending on the application and the tip used, AFM experiments can characterize the surface in terms of van der Waals forces, capillary forces, chemical bonding, electrostatic forces, magnetic forces, thermal or photothermal properties. AFM techniques employ a very sharp tip, normally 3 to 50 nm of radius, attached to a flexible cantilever. The cantilever bending resulting from the interaction forces between the tip and surface during yields the data.

STM measures the electronic density of states of a material with an electrical current between the tip and surface. When the STM tip is brought sufficiently close to the surface, interactions between the electron cloud on the surface and that of the tip atom induce the flow of an electric tunneling current when a small voltage is applied. At a separation of a few atomic diameters, the tunneling current rapidly increases as the distance between the tip and the surface decreases. The technique can provide 0.1 nm lateral and 0.01 nm depth resolution. NSOM uses an optical fiber probe to scan the surface. The light, generally a laser, is emitted thought the aperture in the probe, and the signal is detected after interacting with the surface in transmission, reflection or fluorescence mode.

Electron Microscopy

Standard electron microscopes reach a magnification of 2 million times and provide information about topography, morphology, composition, and crystallographic properties of tested materials. A focused beam of electrons, which is accelerated toward the material's surface by an electrical potential, is used to characterize the surface. A high-resolution image is formed by using magnetic lenses and recording interactions between the electron beam and irradiated surface. Trans-



Sandia National Laboratory researchers examine friction at the microscale. Nanoscale probing tools include scanning probe microscopy, electron microscopy, X-ray methods, and optical techniques.

mission electron microscope (TEM) and scanning electron microscope (SEM) are the two most widely used techniques.

TEM is a precursor of electron microscopy. The first type was developed in 1931 in Germany and the initial design was entirely inspired by a light microscope. During the experiment, an electron beam is transmitted through the sample interacting with the material structure. Part of the beam leaves the specimen carrying information about its structure and an image is formed, showing dark (dense structure) and light (less dense structure) regions of the sample. A new generation of TEMs with improved aberration correctors (HRTEM) offers high-resolution images at magnifications of up to 50 million.

SEM techniques do not rely on transmission processes but rather on the interaction of the electron beam scanned over the specimen surface, where electrons lose some energy generating low-energy secondary electrons, light emission or X-ray emission. The SEM image is obtained by analyzing one of those signals and relating it to the position of the beam on the specimen surface. SEM method offers much lower resolution than TEM but is capable of generating three-dimensional (3D) images of entire samples up to several centimeters in size.

X-Ray Methods

X-ray methods are a family of analytical techniques to study crystallographic structure, chemical composition and physical properties of materials. The wavelength of X-rays is comparable to the size of atoms, which allows for probing the structural morphology of single atoms. Moreover, due to their energy and ability to penetrate deep into the material, X-rays can provide information about the bulk structure. When the X-ray beam hits a sample, it interacts with the electrons bound in an atom and either the radiation will be scattered by these electrons, or absorbed and excite the electrons. Hence, two important X-ray methods include experiments based on (i) scattering and (ii) absorption of the X-ray beam.

In terms of scattering techniques, X-ray diffraction is one of the major characterization tools used in materials science, where single crystal and polycrystalline (or powder) methods can be distinguished. The single crystal method is used mainly to elucidate the molecular structure of novel compounds, while powder diffraction is mainly used for "fingerprint identification" of various solid materials. Powder diffraction is an established way of identifying unknown substances, by comparing experimental diffraction data with a universal database, which is maintained and constantly updated by the International Centre for Diffraction Data.

Unlike the X-ray diffraction method, X-ray absorption spectroscopy (XAS) is used to probe local properties of the structure. XAS provides information about the nature of empty molecular orbitals of the absorbing atom. The number of empty molecular orbitals and their energy positions are characteristic for different chemical species; therefore, XAS is a suitable technique for identifying different molecular species.

Optical Techniques

Confocal Microscopy has been designed to overcome some limitations of classical wide-field optical microscopy and allows to obtain high-resolution optical images with good depth selectivity. 3D images are recorded by using a spatial pinhole to eliminate out-of-focus light in samples that are thicker than the focal plane. Because a confocal microscope uses point illumination, imaging can be time consuming as it requires scanning over a surface. A fluorescence microscope is a light microscope widely used in life sciences, which uses the phenomena of fluorescence instead or in addition to optical reflection and absorption. Epifluorescence microscopy is a specific fluorescence microscopy method yielding improved signal to noise ratio. Fluorescent stains are commonly used to obtain selective images of protein or other molecule of interest.

Raman spectroscopy is a light scattering technique to study vibrational, rotational, and other low-frequency modes in a system. The sample is illuminated with a laser beam and the photons interact with the sample, producing scattered radiation of different wavelengths. Raman spectroscopy is extremely rich in information and is commonly used in chemistry, since vibrational information is specific to the chemical bonds and symmetry of molecules.

Infrared spectroscopy studies the absorption of infrared light by substances and is based upon the fact that different molecules absorb light energy at different frequencies. A popular fast technique is Fourier transform infrared (FTIR) spectroscopy, which is a measurement technique for collecting infrared spectra. In this method, the measured signal is subjected to mathematical Fourier transformation resulting in a spectrum identical to that from conventional infrared spectroscopy.

Optical traps (or tweezers) use light to manipulate objects as small as a single atom and have been used mainly in biological sciences to trap viruses, bacteria and living cells. In fact, an optical trap is a tightly focused laser beam providing attractive or repulsive force and capable of holding microscopic particles stably in three dimensions.

Computer-Aided Design of Nanodevices

The development of novel devices at the nanometer scale with potential for large-scale integration and room temperature operation is a challenging task. Nanotechnology computer-aided design provides a tool for detailed modeling of molecular and nanoelectronic devices.

Computer Simulation Techniques

Computer simulations techniques are an integral component of current materials science. Various software packages such as the nanoXplorer IDE Software for designing, visualizing and simulating nanoscale components, HARES (High performance fortran Adaptive grid Real space Electronic Structure), EDIP (Environment Dependent Interatomic Potential), SETE (Single Electron Tunneling Elements), ANEBA (Adaptive Nudged Elastic Band Approach), MIT Photonic Bands (MPB), CPMD (Carr-Parrinello Molecular Dynamics code), and PARSEC (Pseudopotential Algorithms for Real Space Energy Calculations) are used to predicting the structures of complex materials, model surface structures and properties, predict nanoparticles structures and properties and model reactivity.

Other Techniques

Magnetic resonance spectroscopy (NMR) is a primary technique for determining the structure of organic compounds. It is a nondestructive technique, which provides much better contrast between different materials (soft tissues) then other spectroscopic methods. It uses a powerful magnetic field to align the nuclear magnetization of hydrogen atoms in water in the body. Diseased tissue, can be detected because the protons in different tissues react differently to the electromagnetic field. By changing the parameters on the scanner this effect is used to create contrast between different types of body tissue.

Angular resolved photoemission spectroscopy is the most direct experimental technique to probe electronic structures. This method is based on the photoelectric effect. Depending on the excitation energy of the photons, either the valence band structure or the core levels can be probed. The excited free electrons retain information about the energy and momentum they had in the solid, which are analyzed and used to map the band structure of the system. The field ion microscope was the first instrument that yielded atomic resolution (1951). A needle-sharp tip in a vacuum chamber is pointed toward a fluorescent screen. A small amount of an imaging gas is released into the chamber and applying a high positive voltage to the tip creates a high electric field around the tip. As the image gas atoms approach the tip they are ionized and accelerated toward the fluorescent screen, where they form an image that is representative of the surface of the tip.

Emerging Techniques

Highly integrated nanostructured devices call for advanced technical approaches to lithographic methods, which are capable of higher resolution and are cheaper concerning their manufacturing costs than state-of-the-art optical lithography. Such approaches include nanoimprint lithography (a major research topic and increasingly attracts industrial interest and activity), electron-beam-lithography and multiphoton-based laser lithography.

See Also: Emerging Nanopatterning Methods; Images; Microscopy, Atomic Force; Microscopy, Electron (Including TEM and SEM); Microscopy, Optical; Microscopy, Scanning Probe; Microscopy, Scanning Tunneling; Nanotools.

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Topless Humans Organized for Natural Genetics

THONG is the acronym for a Chicago-based group calling itself "Topless Humans Organized for Natural Genetics." While this may seem to many like a Monty Python-esque joke, THONG takes its work seriously and has had media impact by staging guerrilla-style public protests against emerging technologies in consumer products. The group uses the shock tactics of public nudity to highlight its opposition to genetically modified (GM) crops and nanotechnology, for environmental and health reasons.

This opposition to new technologies is often tied to ecological, antiglobalization, antiwar, and global equity issues. THONG activities peaked between 2003 and 2006, when public fears about GM and nanotechnology were at their highest, appearing at scientific conferences, meetings and chain stores with protestors in varying degrees of undress. It can be seen as part of a novel public resistance to nanotechnology and genetic modification technologies using street "guerrilla" tactics.

Naked Resistance

While there is growing support in scientific and business circles for nanotechnology, opposition has often emerged in unexpected ways. Prince Charles became an ally to green movements in 2003 when he spoke about the dangers of nanotechnology in an article in *The Guardian*, following the publication of the ETC [illegible] to a situation where scientists and [illegible] could learn enough of a common language to acknowledge and even accommodate each others' perspectives and method.

A trading zone can remain a multidisciplinary exchange, but it can also evolve into an interdisciplinary collaboration that might, in turn, lead to a new expertise embodied in a new discipline. Future research should focus on developing techniques for graphing trajectories in trading zones, permitting comparison, and capturing lessons learned from both successful and unsuccessful collaborations.

See Also: Multidisciplinarity; Research and Innovation Assessment; Scientists' Attitudes Toward Nanotechnology.

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Transdisciplinarity

Nano- and miniaturization technologies stand at the forefront of beneficiaries from a transdisciplinary approach of problem solving. Transdisciplinarity as a principle of integrative forms of research is an emerging model of learning and problem solving, the core idea of which is the amalgamation of different academic disciplines and practitioners in a joint effort to solve real-world problems. The inception of this cross-collaborative model was prompted by modern needs of problem solving. As such, transdisciplinarity may be viewed as a by product of the economic trends and technical globalization tendencies that dominated within the past few decades along with related sociopolitical and cultural impacts. The shifting scientific landscape from disciplinary to interdisciplinary to transdisciplinary can be attributed to different factors, such as the increasing dependence of economic growth and competitiveness on knowledge, an ever-increasing environmental awareness, and an increasing (and better educated/informed) population that is more demanding with respect to knowledge creation.

Complexity and unpredictability are two influential motivations for a transdisciplinary model of problem solving. Modern scientific views infer that many phenomena and processes are uncertain, even unpredictable. Such notions, advanced by the fledgling science of complexity, are the essence of transdisciplinarity. Thus, in general, one may think of transdisciplinarity as a methodology to manage, and perhaps harness, complexity in order to reach a solution of a multifaceted problem. Such a problem, or rather a lack of a solution, meanwhile, may affect many constituents (also called stakeholders) of a given population (e.g., society, science, universities, economic establishments).

In a transdisciplinary collaboration, people from different disciplines work jointly not only to address a specific research problem, but to have a deeper dialogue on how their specific knowledge and approaches can interact and be assimilated into new models and methodologies that apply beyond the scope of the research problem. Key requirements for development of a successful transdisciplinary initiative are institutional support, selection of a proper team with expertise in all necessary disciplines, the presence of a common goal, and constructive communication between all parties.

A transdiscplinary approach can achieve minimal entanglement between constituents while keeping them better informed about cross views and how such views may affect their parts. Transdisciplinarity ensures improved collective learning and synchronicity of thought processes when spending minimal effort in solving a given problem. Transdisciplinary approaches of problem solving are important for nano- and miniaturization technologies. This is because nanosciences and nanotechnologies, which attempt to probe the building blocks of matter, have far reaching consequences that may potentially impact every aspect of human life. In the United States, recognition of such a potential was manifested through the

National Nanotechnology Initiative which involved several federal funding agencies focusing on research efforts that probe societal impact of nanotechnology. Similarly the European Union Framework Programs promote the formation of international transdisciplinary consortia focusing on the nanosciences. Nanotechnology is interdisciplinary by its very nature.

At the nanoscale traditional boundaries between sciences overlap, if not disappear. Thus, successful research relies not only on constructing an interdisciplinary architecture, but also on implementing an efficient methodology to manage the interaction between the various active elements. One area within the realm of nanotechnology where transdisciplinarity is essential is medical and health related applications. Here a methodological approach consolidating the scientific fields of genomics, diagnostics, and drug formulation/production, in combination with social studies in disease background, as it relates to environment and other factors, will be a major factor in improving societal health.

See Also: Converging Technologies; Interdisciplinarity; Interdisciplinary Research Centers; Multidisciplinarity; Nanobioconvergence; National Nanotechnology Initiative (U.S.); Technoscience.

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Transhumanism

Transhumanism is a social and philosophical movement devoted to promoting the research and development of robust human enhancement technologies. Human enhancement technologies are any material or social technologies which produce an increase in human sensory, emotive, or cognitive capacity as well as technologies geared toward producing a marked increase in human health and longevity. It is important, then, that in the definition of transhumanism it is *robust* human enhancement technologies which are at issue. Robust is intended to designate those technologies which are strictly material, more or less permanent, and—with the exception of artificial intelligence which represents something of a special case—integrated into the human body. Though directly related to the topic of human enhancement, transhumanism is not the particular hardware or technology, but the concept, the philosophy, and the movement. The concise definition of transhumanism offered above, will be expanded the through a theoretical and historical examination.

The term *transhumanism* was originally coined by Julian Huxley in his 1957 essay by the same name. Huxley refers principally to the use of social and cultural technologies to improve the condition of humanity but the essay and the name have been adopted as seminal to the movement that is principally focused on material technology.

Huxley held that while man was a naturally evolved species it was now possible through the complex social institutions he had developed for man to assume many of the responsibilities of the evolutionary mechanism in refining and improving the species. The ethos of Huxley's essay—if not its letter—can be located in transhumanism's commitment to assuming the work of evolution through technology, rather than society.

The movement's adherents are overwhelmingly male, libertarian, and employed in the high technology sector of the economy or the academy. Its principle proponents over the decades have been prominent technologists like Ray Kurzweil, scientists like roboticist Hans Moravec and nanotechnology researcher Eric Drexler, with the addition of a small but influential contingent of philosophers like James Hughes and Nick Bostrom. The movement has evolved over time having begun was a loose association of groups dedicated to "extropianism" or the desire to leave the Earth and colonize space.

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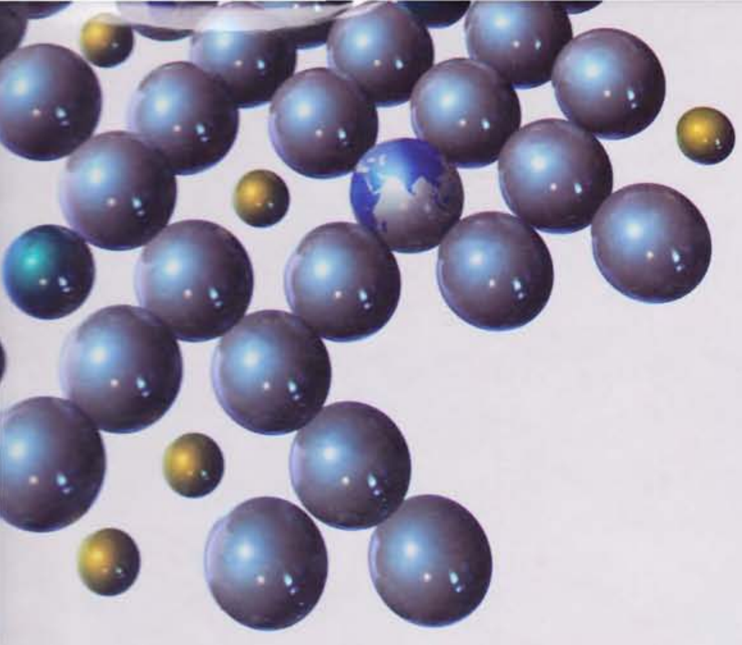

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