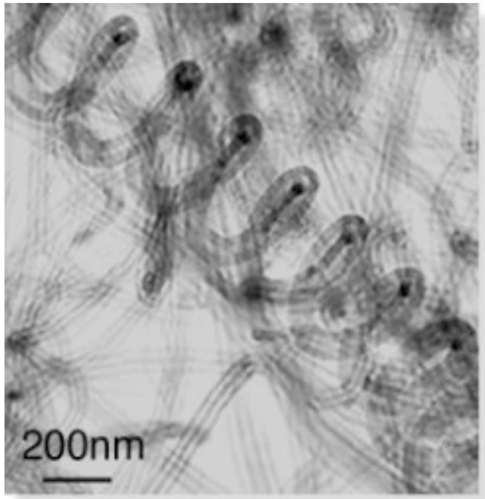
Nanotechnology

5th lecture



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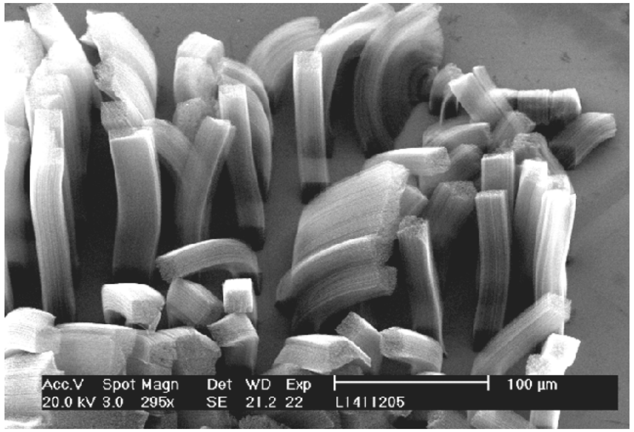

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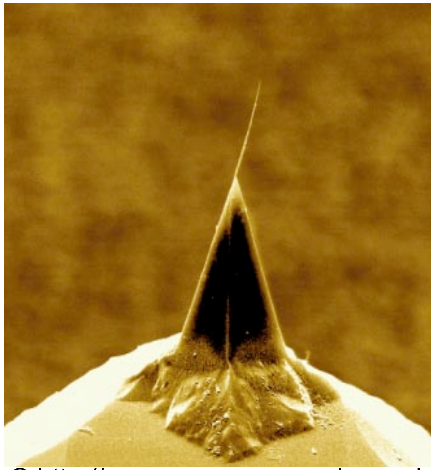
Plan for today:

3. Introduction to Carbon Nanotubes

3.4 Properties of Carbon Nanotubes

3.5 Carbon Nanotube based nano-objects

3.6 Applications of Carbon Nanotubes



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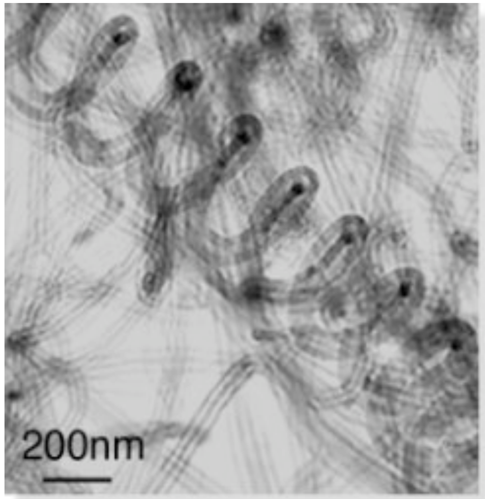

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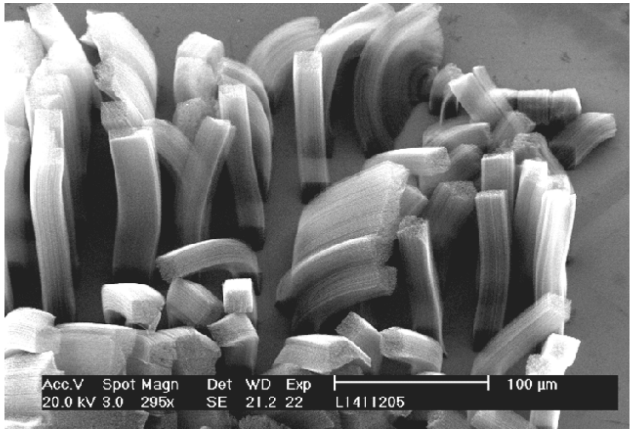

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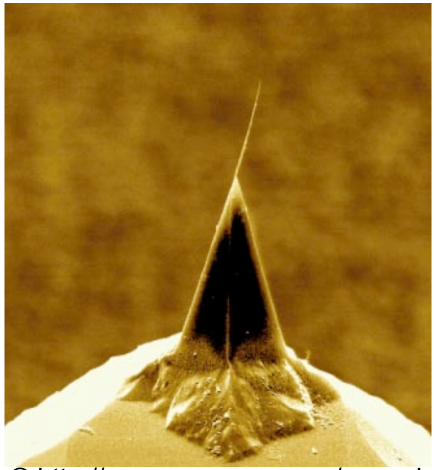

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Last time we had:

3. Introduction to Carbon Nanotubes

- ***3.1 Structure of Carbon Nanotubes***
- ***3.2 Synthesis of Carbon Nanotubes***
- ***3.3 Growth mechanisms of Carbon Nanotubes***

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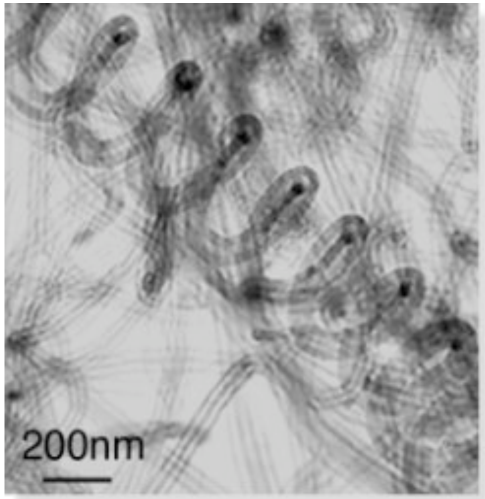

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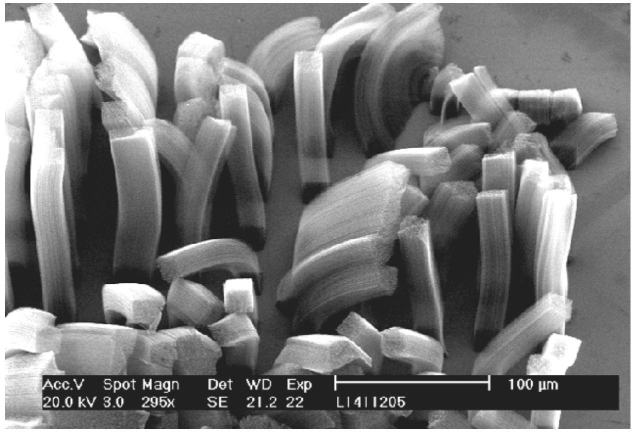

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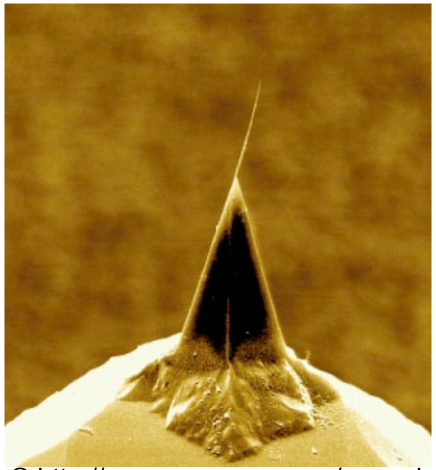
Plan for today:

3. Introduction to Carbon Nanotubes

- ***3.4 Properties of Carbon Nanotubes***
- ***3.5 Carbon Nanotube based nano-objects***
- ***3.6 Applications of Carbon Nanotubes***



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3.4. Properties of carbon nanotubes

- Carbon is a unique light atom that can form one, two-, or threefold strong chemical bonds.
- Properties of the carbon nanotubes may change drastically depending on whether SWNTs or MWNTs are considered.
- MWNTs are generally not much different from that of regular polyaromatic solids (polyaromatic solids are phases built with stacked graphenes instead of single graphenes).

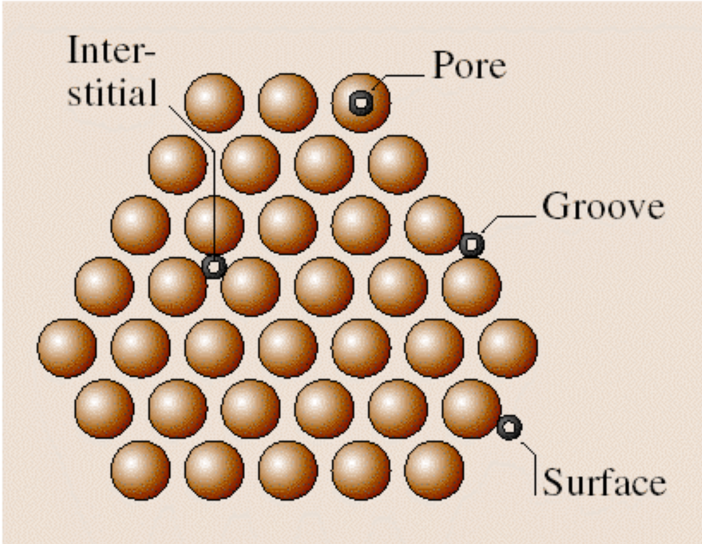
MWNT properties

- In stacked graphenes, the bond strength is quite different depending on whether the in-plane direction or the direction perpendicular to it is considered:
  - in-plane: very strong covalent bonds, only 0.142nm bond length
  - perpendicular: very weak van der Waals bonds, ~0.34 nm

SWNT properties

- SWNTs properties may change dramatically, depending on whether they are ropes or single tubes.
- SWNTs are narrower in diameter than the thinnest line able to be obtained by electron beam lithography.
- Stable up to 750°C in air, up to 1800°C in inert atmosphere (above: polyaromatic solids).
- In stacked graphenes, the bond strength is quite different depending on whether the in-plane direction or the direction perpendicular to it is considered:
  - in-plane: very strong covalent bonds, only 0.142nm bond length
  - perpendicular: very weak van der Waals bonds, ~0.34 nm

SWNT adhesion properties



- SWNTs have a very high surface area (the highest ever).
- Isolated SWNTs, with one end open, have a surface area of 2700m^2/g (accounting for both sides).
- 4 different binding sites.
- Binding energy 75% higher than on single graphene.

SWNT transport properties

- SWNTs are ideal quantum wires.
- Metallic SWNTs can transport huge current densities (max. 10^9 A/cm^2) without being damaged, i. e. about three orders of magnitude higher than in Cu.
- SWNTs are model systems to study one-dimensional charge transport phenomena.
- Visible light is strongly absorbed. It has been observed that flash illumination with a broadband light can lead to spontaneous burning of a macroscopic sample of agglomerated (i. e., ropes) carbon nanotubes in air and room temperature.
- SWNT thermal conductivitiy is comparable to that of high purity diamond.

SWNT mechanical properties

- The particularly strong threefolded bonding (sp^2 hybridization of the atomic orbitals) of the curved graphene sheet is stronger than in diamond (sp^3 hybridization) as revealed by their difference in C-C bond length (0.142 vs. 0.154 nm for graphene and diamond respectively).
- The tensile strength of SWNT is 20 times that of steel. It is even higher for MWNT.
- Defect-free carbon nanotubes could revolutionize the current panel of high performance fibrous materials.

SWNT reactivity

- Like any small object, carbon nanotubes have a large surface with which they can interact with their environment.
- The chemical reactivity of SWNTs (and c-MNWTs) is supposed to come mainly from the caps, since they contain six pentagons each.
- The reactivity of h-MWNT-type nanotubes is intrinsically higher, due to the occurrence of accessible graphene edges at the nanotube surface.

3.5. Carbon nanotube based nano-objects

1. Hetero nanotubes
2. Hybrid nanotubes
3. Functionalized nanotubes.

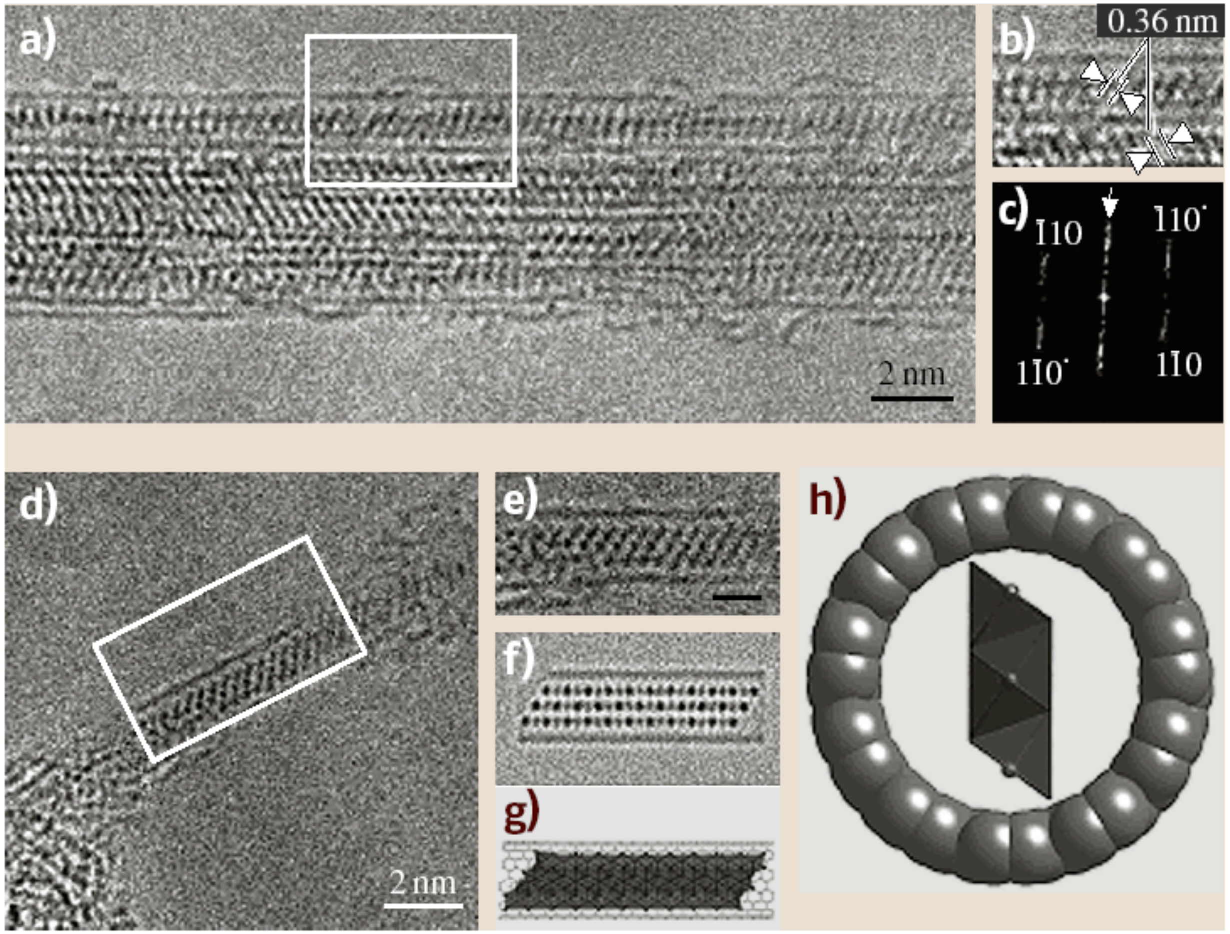
1. Hetero-nanotubes

- The carbon atoms are substituted with another element (like Boron and Nitrogen) while the overall honeycomb lattice-based graphene structure is maintained.
- Results:
  - new behaviors
  - improved properties
  - better control of the properties
- There exist “multilayered” c-MWNTs, i. e. MWNTs whose constituting coaxial tubes were alternatively made of carbon graphenes and boron nitride graphenes.

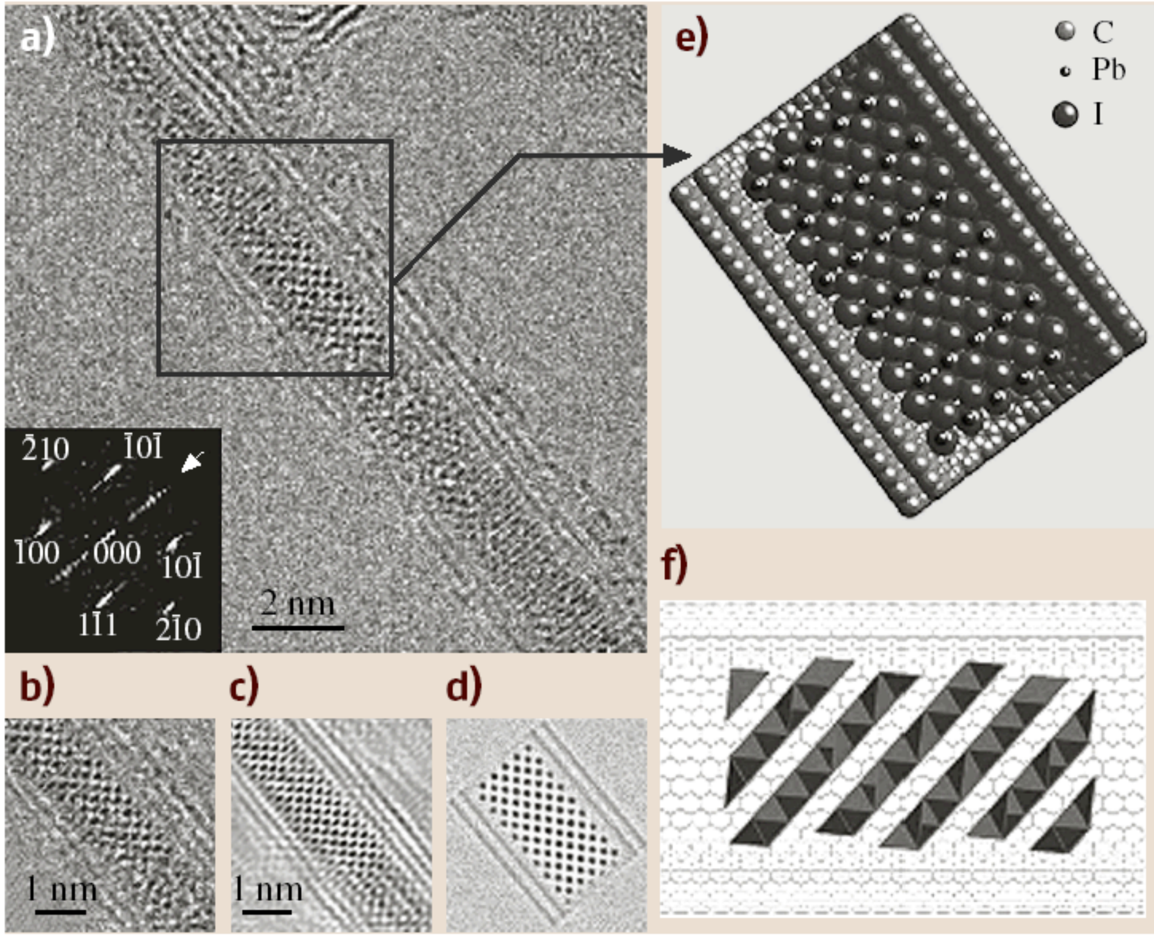
2. Hybrid carbon nanotubes

- SWNTs or MWNTs, whose inner cavity has been filled, partially or entirely, by foreign atoms, molecules, compounds, or crystals.
- Interesting possible applications as quantum wires.
- SWNTs are more difficult to fill, because of their smaller diameter.
- Filling methods:
  - in situ, e.g. MWNTs with Pb, Bi, TiC, etc.
  - wet chemistry method, via capillarity
  - sublimation filling methods (C_{60} into SWNTs)

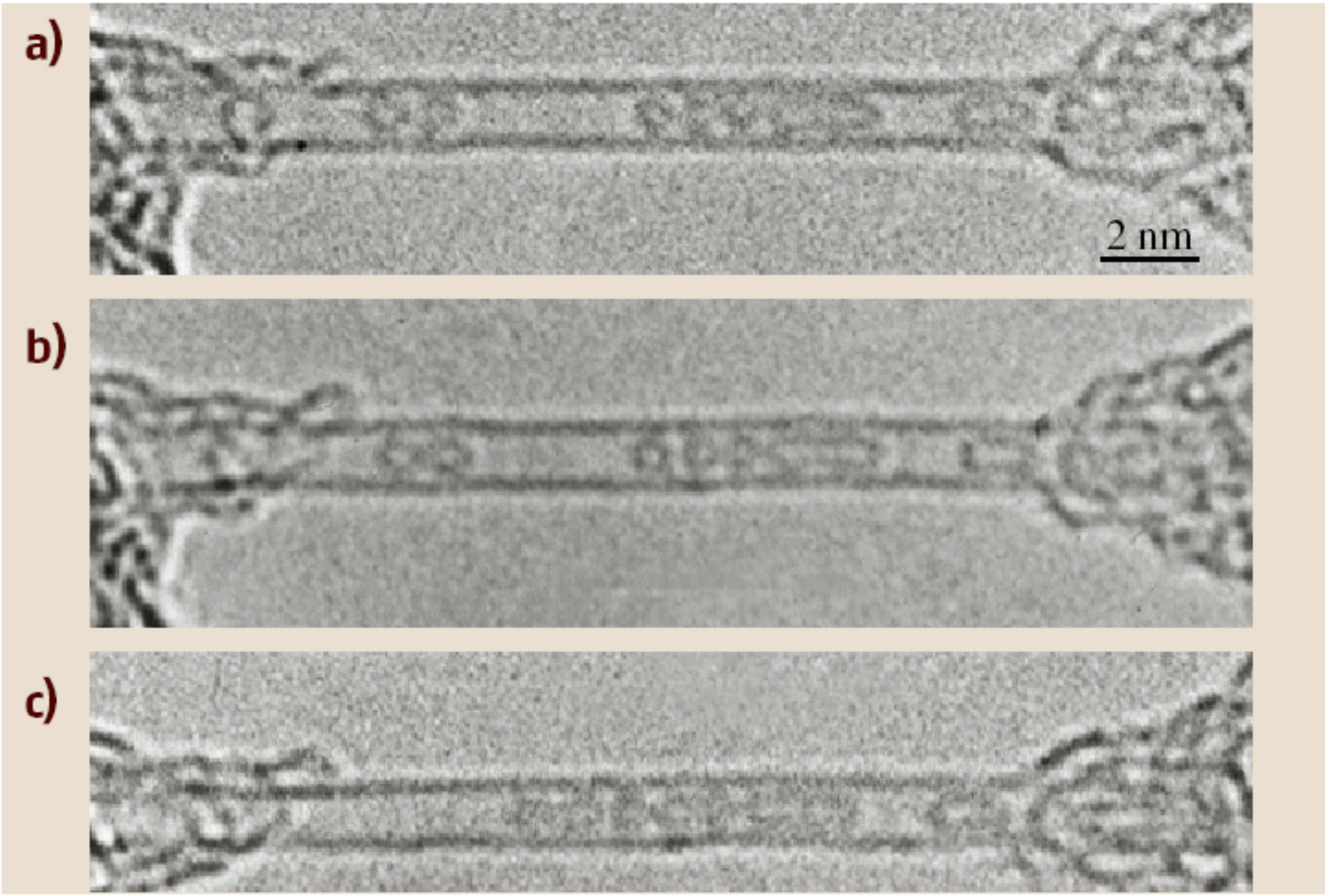
PbI_2 filled SWNT



PbI_2 filled DWNT



Peapod (C_{60} in SWNT)



3. Functionalized Nanotubes

- Via chemical oxidation and/or direct addition to the nanotube.
- Tips and sidewalls can be functionalized.
- Purified sidewall fluorinated SWNTs cost 900$/g (2003).

3.6. Applications of Carbon nanotubes

- Carbon nanotubes can be inert and can have a high aspect ratio, high tensile strength, low mass density, high heat conductivity, large surface area, and versatile electronic behavior including high electron conductivity.
- Their secondary structures such as ropes, fibers, papers, thin films with aligned tubes, etc., have their own specific properties.
- High quality single shell carbon nanotubes can cost 50–100 times more than gold.

Current applications

Current applications:

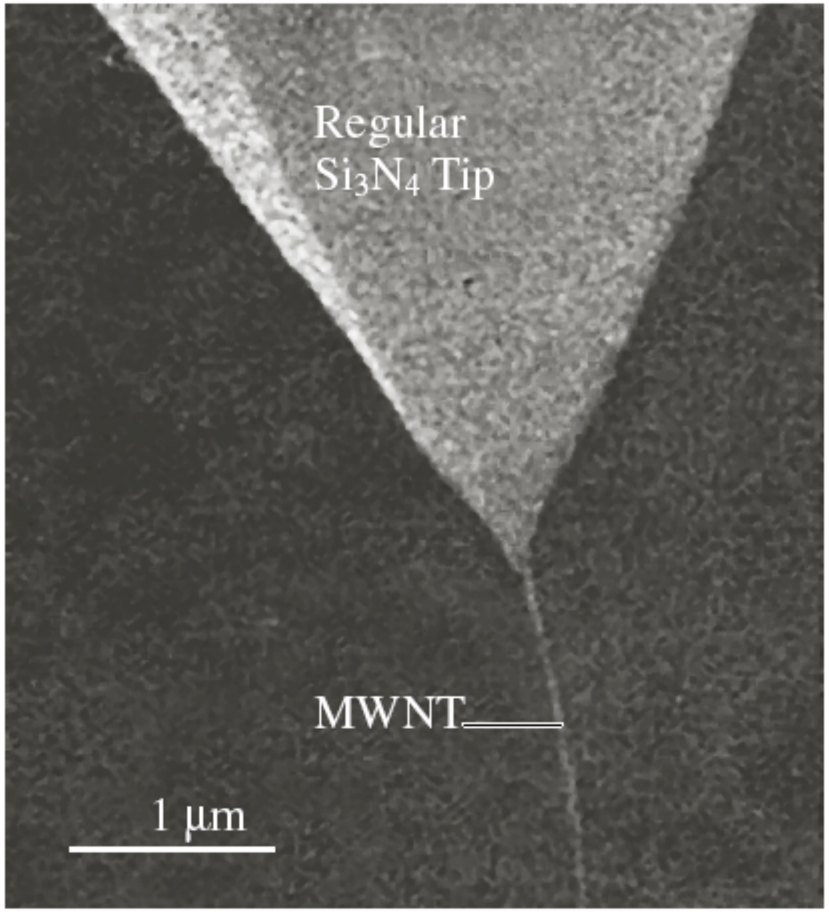
- Near field microscope probes
- Field-emission based devices
- Chemical sensors
- Catalyst support

Expected applications

Expected applications:

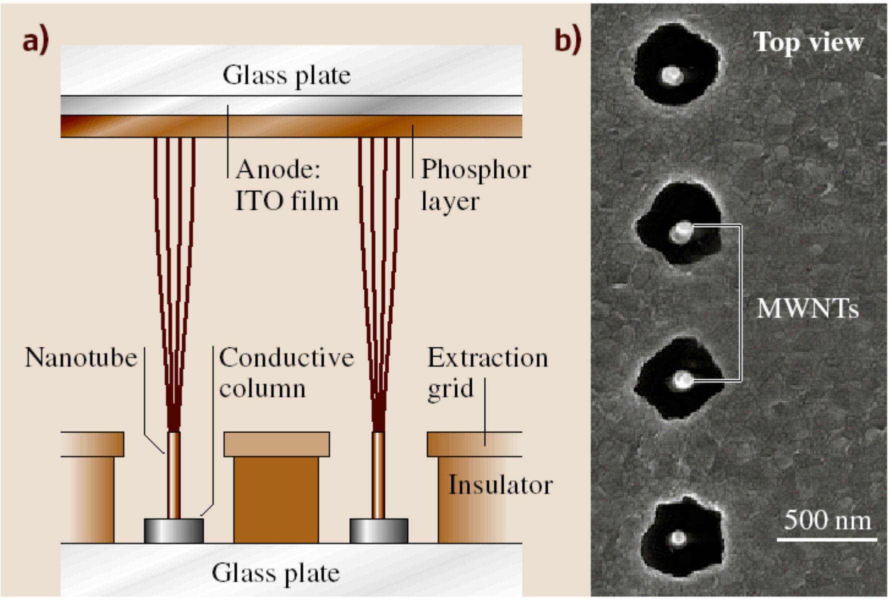
- Gas storage – hydrogen
- Gas storage – other gases
- Gas separation
- Absorbents
- Bio sensors
- Composites
- Metal matrix composites
- Ceramic matrix composites
- Polymer matrix composites
- Multifunctional materials
- Nano-electronics
- Supercapacitors

Current applications: Near field microscope probes



- MWNT tips are ideal force sensors in scanning probe microscopy (SPM).
- Can be functionalized very accurately (chemical force microscopy).
- Piezomax in Middleton, WI, produces commercial MWNT tips for AFM (200$/tip).
- Properties:
  - high mechanical strength
  - high lateral resolution

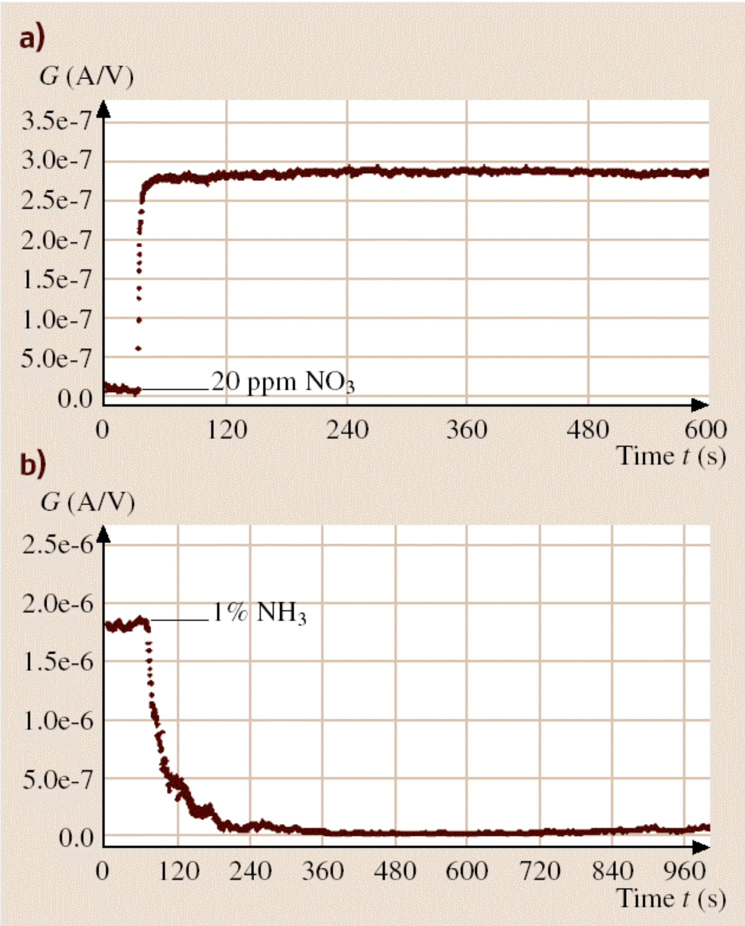
Current applications: Field emission based devices



- Carbon nanotubes are efficient field emitters.
- They are currently being incorporated in several applications, including flat panel display for television sets or computers (first prototype in 1999).

- Advantages of nanotubes as field emitters:
  - lower heating temperature
  - lower threshold voltage (produce same current density as conventional devices (Mo or Si tips) with only 3% threshold voltage)
  - Can also be used with flexible screens.

Current applications: Chemical sensors



- Semiconductor SWNTs are highly sensitive to the change in the chemical composition of the surrounding atmosphere at room temperature, due to the charges transfer between the nanotubes and the molecules from the gases adsorbed onto the SWNT surface.
- This adsorption is reversible.
- Extremely short response time.

Current applications: Chemical sensors

- The sensitivity of the new nanotube-based sensors is three orders of magnitude higher than that of standard solid state devices.
- Further advantages:
  - simplicity
  - very small size
  - can operate at room temperature
  - high selectivity
- Market situation: $ 1.6 billion by 2006.

Current applications: Catalyst support

- Their high surface area and stability at high temperatures (under not oxidizing atmosphere) makes CNTs perfect catalyst supports.
- h-MWNT type nanotubes with a poor nanotexture are the most suitable starting material for preparing such catalyst supports.
- MWNT-based catalyst-supports show significant improvements of the catalytic activity, in the case of liquid-phase reactions when compared to catalysts supported on activated carbon.
- Huge market.

Expected applications: Gas storage – hydrogen

- The development of lightweight and safe system for hydrogen storage is necessary for a wide use of highly efficient H_2-air fuel cells in transportation vehicles.
- Recently some articles or patents concerning the very high, reversible adsorption of hydrogen in carbon nanotubes or platelet nanofibers have aroused tremendous interest in the research community.

Expected applications: Gas storage – other than hydrogen

- Carbon nanotubes could become the world's smallest gas cylinders combining low weight, easy transportability, and safe use with acceptable adsorbed quantities.
- Due to their nano-size they could also be used in medicine, physically confining special gased prior to injection.

Expected applications:
Gas separation

Separation of gases to to different mobility of the molecules inside the nanotube.

Adsorbents

Adsorption of dioxin: Ecological consciousness has imposed emission limits on dioxin-generating sources in many countries, but finding materials that can act as effective filters, even at extremely low concentrations, is a big issue.

Expected applications: Bio-sensors

Attaching molecules of biological interest to carbon nanotubes is an ideal way to realize nanometer-sized biosensors.

Composites

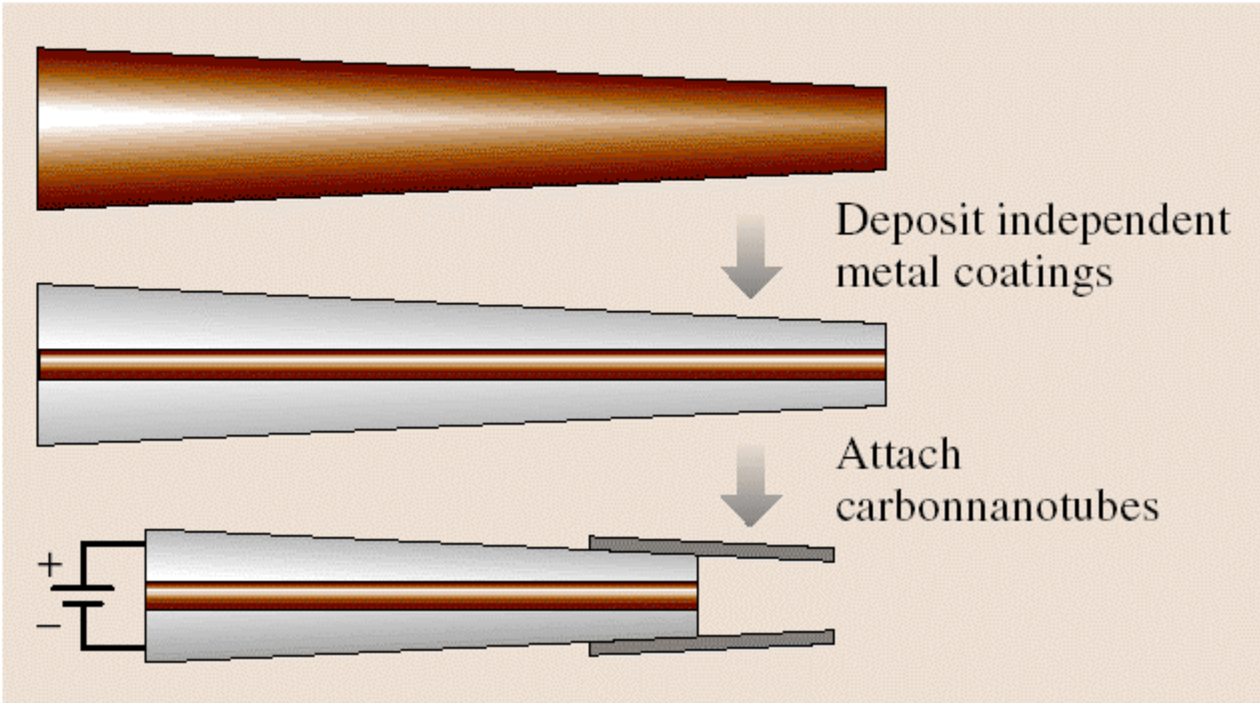
Because of their exceptional morphological, electrical, thermal, and mechanical characteristics, carbon nanotubes are particularly promising materials as reinforcement in composite materials with metal, ceramic, or polymer matrix.

Expected applications: Nano-electronics

- rectifying diodes, ballistic conductors, field-effect transistors.
- Key point: We cannot yet prepare selectively either metallic or semiconductor nanotubes.
- Another major challenge: fabricate at industrial scale integrated circuits including nanometer-size components that only sophisticated imaging methods (AFM) are able to visualize.

Expected applications: Nano-tweezers

Graphene expands slightly when electrically charged → use nanotubes as actuators.



Expected applications: Artificial muscles

- Two SWNT-based paper strips (“bucky-paper”) on both sides of an insulating doubleside tape.
- The two bucky-paper strips are previously loaded with Na^+ and Cl^-, respectively.
- When 1V is applied between the two paper strips, both expand, but the strip loaded with Na^+ expands a bit more, forcing the whole system to bend.

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Outlook to the 6th lecture

4. Nanowires

4.1 Synthesis

4.2 Characterization and physical properties of nanowires

4.3 Applications

That´s it for today.