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Surface modifications on Si(111):H surfaces caused by the impact of multiply-charged ions

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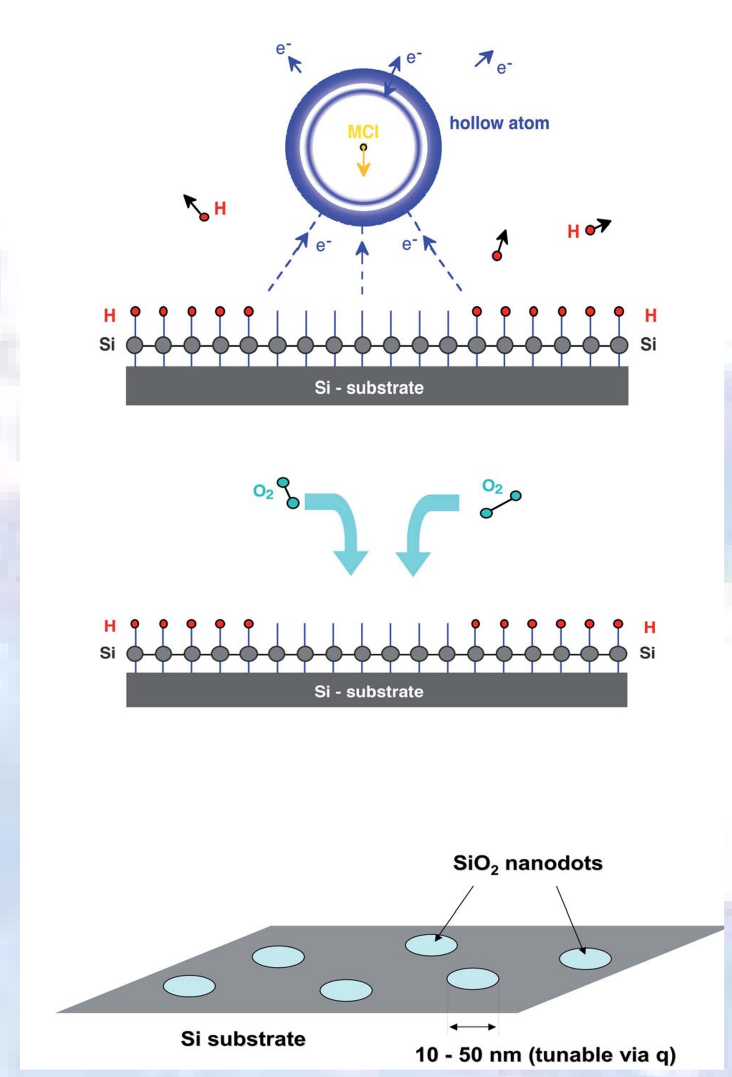
Overview

An important way of producing nanometre-scaled structures (nanostructuring) on surfaces is kinetic sputtering by fast ions. Potential sputtering (PS), *ie*, desorption induced by the potential energy of relatively slow multiply-charged ions (MCIs), holds great promise for more gentle nanostructuring [1]. It can cause high sputter yields even for such low ion impact energies where kinetic sputtering and defect creation in deeper layers is not possible. While the physical mechanisms of PS have been the subject of extensive investigation (see [1] and refs. therein), technical applications of slow MCIs have so far remained largely unexplored, despite the fact that slow MCIs provide unique opportunities for etching, ultra-thin film growth and nanostructure fabrication.
We are currently investigating whether beams of slow MCIs can be used effectively for nanostructuring. Slow MCI bombardment of various semiconductor and insulator surfaces will be applied under inert and/or reactive gas atmospheres in order to modify the surface around MCI impact sites. We will investigate the size of any produced structures and attempt to achieve control by varying the MCI impact conditions; e.g., the gas ion used, its charge state and kinetic energy. The investigations will be carried out with AFM and STM techniques working alternatively under UHV and ambient conditions. In this contribution we will discuss the present status of our project.

Basics and sample preparation

SiO_2 nanodot formation on Si

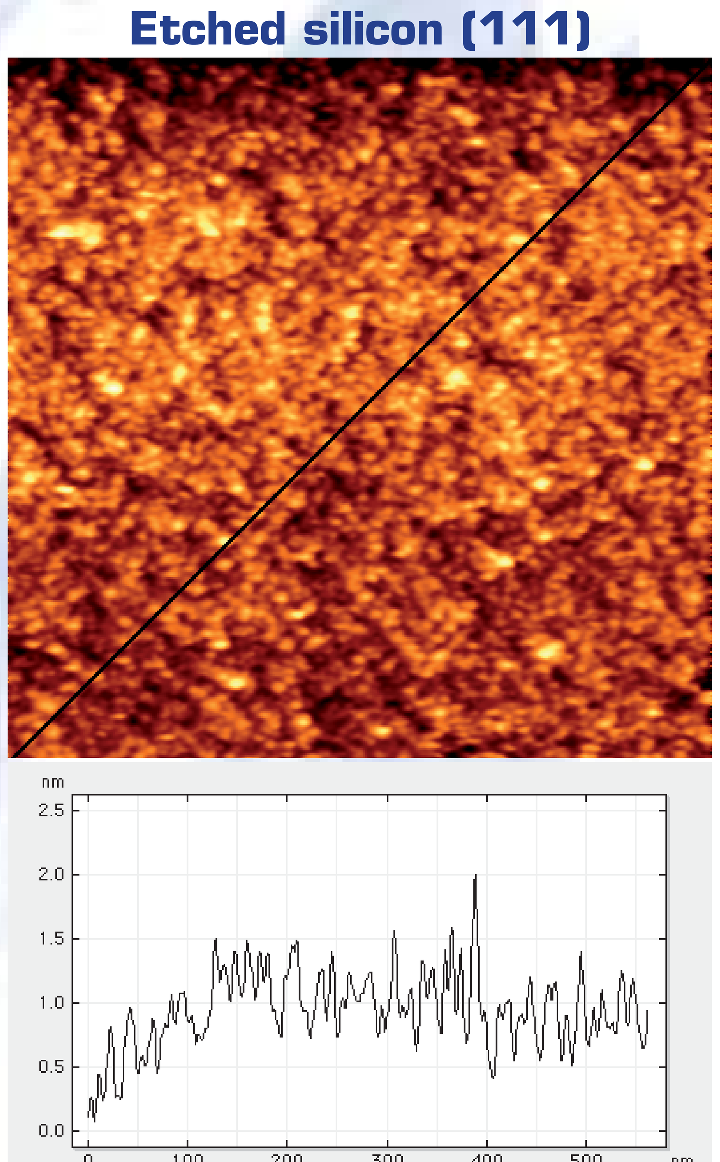


Sample Preparation

We used doped silicon (111) wafers, etched in an ammonia/hydrofluoric acid mix. STM pictures in vacuum and AFM pictures in air were collected.
Irradiation is performed with ions extracted from an ECR ion source, mass/charge ratio selected then directed and focussed onto the sample. Here we used 1.125 keV/amu Ar^{9+}. Dose is 1×10^{10} impacts per square cm unless otherwise stated. Oxidation is carried out by direct-current heating in an oxygen atmosphere. We heated at 2 W for 15 minutes in 10^{-6} mbar O_2.
Ambient AFM work used similarly prepared silicon, singly charged ions at 5 kV, the samples being removed into air for study.

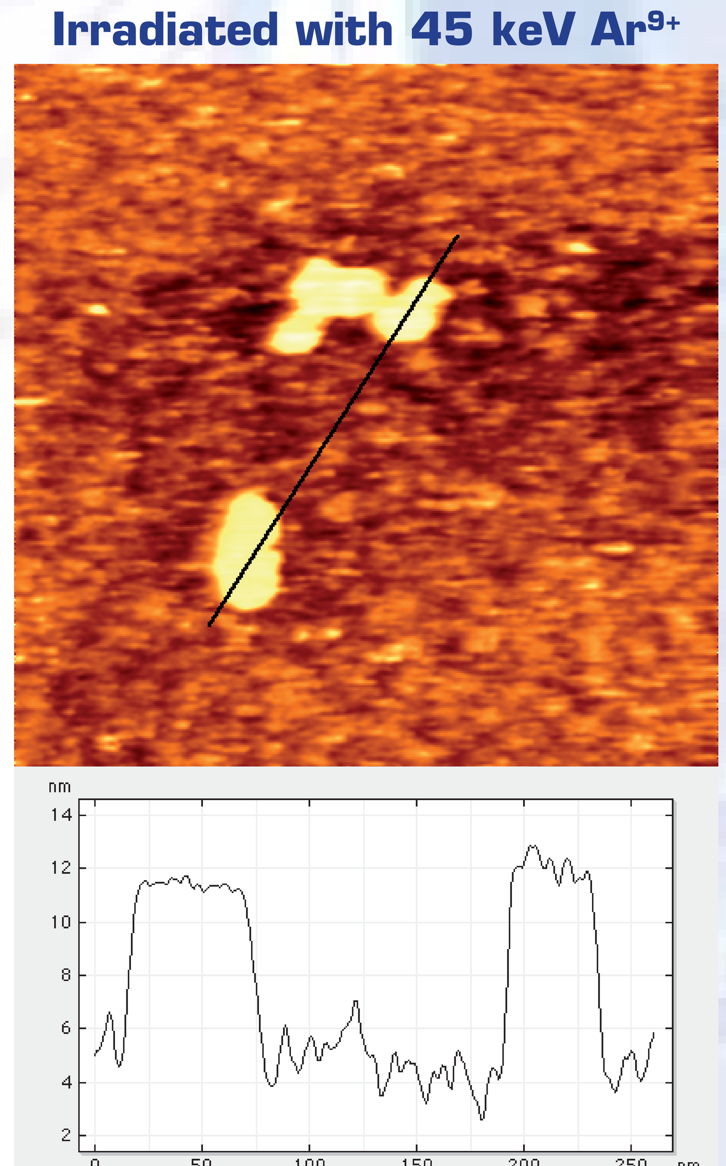
STM observations

Etched silicon (111)



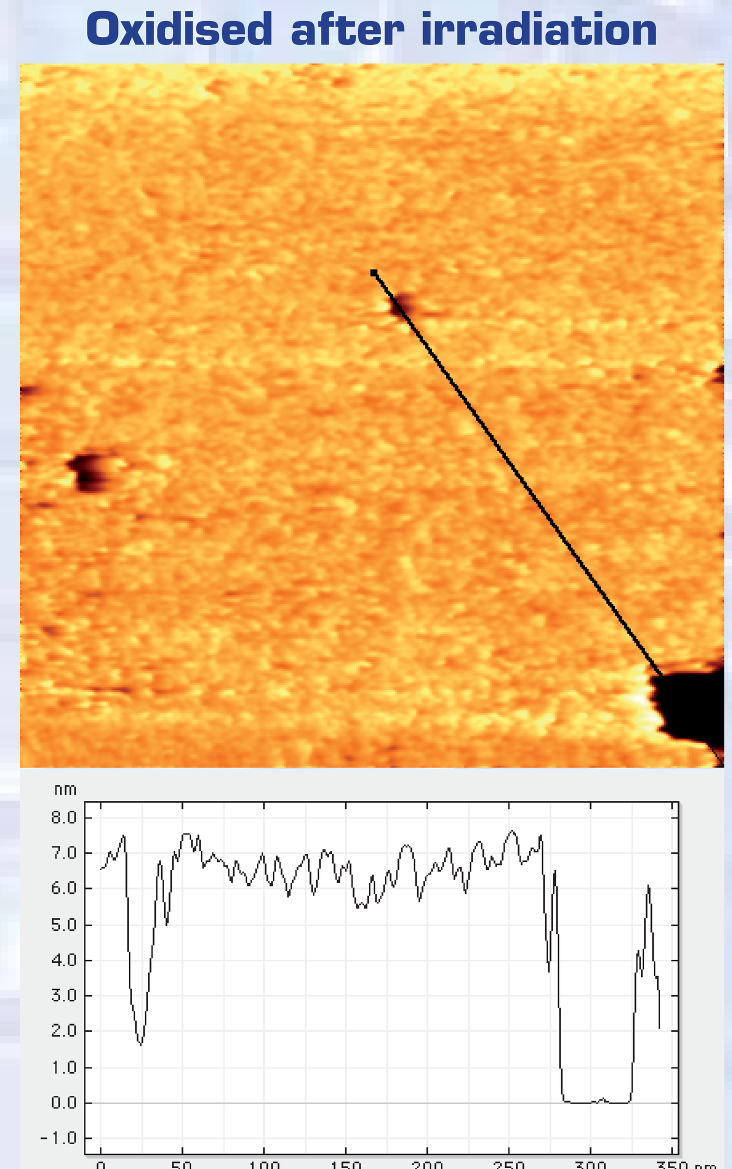
400 nm square, sample bias +1.5 V, 0.5 nA tunnelling current

Irradiated with 45 keV Ar^{9+}



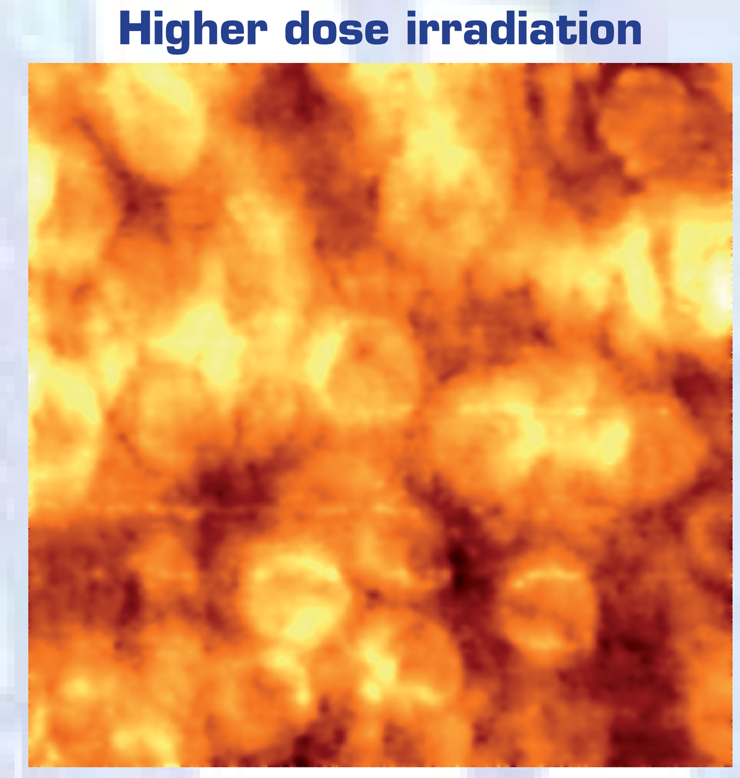
400 nm square, sample +1.03 V, tunnelling current 0.51 nA, 1×10^{10} ions/cm^2

Oxidised after irradiation



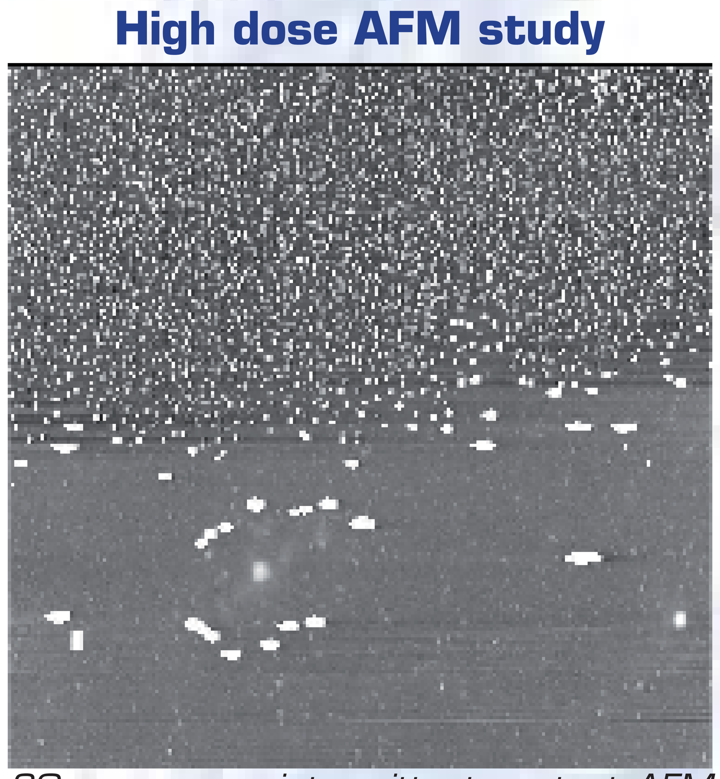
400 nm square, sample bias +2 V, 0.5 nA tunnelling current

Higher dose irradiation



400 nm square, sample bias +1.5 V, 0.2 nA tunnelling current, 5×10^{10} impacts per square cm with other parameters as in the image to the left before oxidation. The profiles of the apparent impact sites is essentially similar to those seen in the other picture and the number density is consistent with the increased dose; a raised area about 50 nm in diameter with a fairly flat top. More analysis has not been carried out; the image was collected last Thursday!

High dose AFM study



20 µm square intermittent contact AFM image collected in air. This sample was irradiated with 5 kV Ar^{+} at a dose of 10^{17} ions/cm^2. The lower half is in a region shielded from the ion beam. This work is a parallel line of research and verifies other results of ion interactions with surfaces.

Discussion and further work

After irradiation with MCIs, we see some raised areas in the images. It is known that dangling Si bonds appear higher than a surrounding hydrogen-terminated surface in STM and we suspect the features observed here are just that. At 45 keV impact energy, kinetic sputtering effects largely occur in deeper layers, away from the surface. The removal of hydrogen induced by the incoming MCI takes place before the impact. The argon then strikes the surface in the hydrogen-free area but does not disrupt the surface, leaving dangling bonds. Oxidation afterwards results in actual pits or an oxide layer with reduced tunnelling ability and therefore an apparent depression. Further studies are currently underway.
The high-dose work using singly-charged ions has afforded us better understanding of our equipment but it is not yet clear why the defects observed are so similar in size to those using higher energy MCIs.
Currently, our focus is on improving the etching method used. Producing atomically-flat hydrogen-terminated silicon is generally known to be difficult. We have carried out extensive tests and believe the silicon is limiting our abilities; the boron dopant and low step density, while good for the thermal manufacture of atomically flat silicon in vacuum, are mainly responsible for the roughness we have, until now, observed. We expect improved results within the next month.

References

[1] F Aumayr, HP Winter; Phil Trans R Soc Lond A **362**, 77 (2004)
See also: G. Borsoni *et al*, J Vac Sci Technol B **18**, 3535 (2000)
B Q Wei, Nature **416**, 495 (2002)

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