Surface Damage of Silicon after Swift Heavy Ion Irradiation

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Synopsis In order to answer the long-standing question, if silicon surfaces can be damaged by swift heavy ions, a set-up to study ion-irradiation damage of reactive surfaces is presented. This set-up allows for the first time to avoid oxidization of the silicone surface during the experimental study. Scanning tunneling microscopy as well as low-energy electron diffraction was used to study the surfaces before and after irradiation. Silicon surfaces were prepared by flash-heating before irradiation with swift heavy ions (Xenon at 0.9 MeV/u). The targets stayed in ultra-high vacuum during preparation, irradiation and surface imaging. No surface damage was detected, at normal as well as at grazing incidence angle.

The radiation hardness of silicon is important for its wide-ranging applications, especially in environments with ionizing radiation. It is generally accepted that ions of atomic species, \textit{i.e.} not cluster ions, induce no surface modifications in silicon [1]. However, more recent measurements have indicated, that there may be damages in silicon due to swift heavy ions at electronic energy losses of about 15 keV/nm [2]. The general problem with the above-mentioned publications is that the targets were exposed to air in-between irradiation and observation of the surface. The protective silicon dioxide layer, which is produced each time the target is exposed to air, may alter the effects occurring due to the ion irradiation. We therefore mounted an experimental set-up to keep the target under ultra-high vacuum conditions along the study.

Targets were flash-heated in order to obtain atomically clean and properly re-constructed surfaces. We used Si(111) and flash-heated to 1200°C. The obtained surfaces were verified by means of low-energy electron diffraction and scanning tunneling microscopy.

The prepared targets were then irradiated at the IRRSUD beam-line of the GANIL facility in Caen, France. The chosen ion beam was Xenon at 0.9 MeV/u, leading to an energy loss of about 12 keV/nm. The beam-line allowed to work directly at the on-line STM. The obtained energy loss is lower than the above-mentioned possible threshold. As we are working at a smaller ion velocity, the threshold should also be lower [3]. Additionally, we irradiated the target not only under normal incidence, but also at grazing angle of 2 degree with respect to the surface. The threshold for surface damage should be even lower for grazing angle irradiation, compared to normal incidence irradiation [4].

After irradiation, the target was again studied by means of STM. The whole ensemble of preparation, surface study and irradiation chamber is mounted directly at the beam line, and we detected no oxidization of the surface after the irradiation. Mechanical and electronic noise from the accelerator was sufficiently dampened so that mono-atomic steps could clearly be seen. Atomic resolution, however, was not obtained.

At the given energy loss of 12 keV/nm, we saw no surface damage, besides a single line of hillocks, which is statistically not significant. Thus we estimate the damage probability to be smaller than 3x10\(^{-3}\), which is much smaller than the typical damage probabilities with swift heavy ions of about 1. Additionally, no change in surface roughness was detected.

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