Structure Effects in Electronic Sputtering of SiO_2

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Bulk effects induced by energetic heavy ion irradiation are known to be more pronounced in the amorphous phase than in the crystalline phase of the same material [1]. The aim of the following study was to test whether this behavior also applies for surface effects such as sputtering. For this purpose amorphous and crystalline SiO_2 samples were irradiated with heavy ions in the electronic stopping regime.

As sputter targets we used 1 mm thick crystalline samples of α-SiO_2 quartz and thin films of around 500 nm thickness of vitreous SiO_2, thermally grown on silicon. The irradiation as well as the subsequent analysis was carried out at the Munich tandem accelerator. The fast and efficient change of ion species and energies allowed us to use several ions (Ni ions with 70 MeV, I with 150 MeV, Au with 210 MeV) of different stopping power within one beam time. All irradiations were performed with ions in their equilibrium charge state. The incidence angle of the beam was 20 degrees with respect to the surface. Sputtered particles were collected on arc-shaped ultra-pure Cu catcher foils mounted above the the sample surface and perpendicular to the ion scattering plane.

After irradiation, the catcher foils were investigated by elastic recoil detection analysis (ERDA) using 210 MeV Au ions and the same set-up as in our previous experiments [2]. In order to avoid re-sputtering from the catcher foils during analysis a 50 nm Cu over-layer was deposited on the catcher after the sputtering experiment. The particle identification detector system allowed the determination of the absolute number of sputtered atoms almost free of any background. However, inevitable oxidation of the catcher foil prevents quantification of the sputtered oxygen yield. By measuring the Si concentration at different spots along the catcher foil, we obtained the sputter yield as a function of the sputtering angle. Fig. 1 presents the angular distribution of sputtered Si atoms from crystalline and amorphous SiO_2. The data follow a slightly over-cosine function $cos^n\theta$ with n=1.3 (crystalline) and n=1.1 (vitreous).

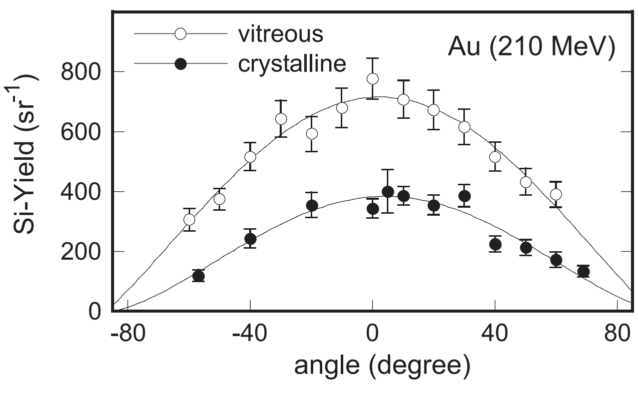

Fig. 1: Angular distribution of Si atoms sputtered with 210 MeV Au ions from SiO_2 quartz and vitreous SiO_2

The total sputtering yield of Si (at 20 degrees beam incidence) as deduced from integration of the angular distributions are plotted as a function of energy loss in Fig. 2. In addition to the catcher analysis, we also determined the thickness decrease of a vitreous SiO_2 thin film sample during ion bombardment by means of ERDA. This gives us an independent value of the sputter yield and thus allows us to estimate the sticking coefficient of Si atoms on the catcher to be 1.0±0.2. We also noticed that during sputtering the sample composition did not change indicating stoichiometric sputtering. To compare the sputtering yield shown with sputtering at normal incidence the yield values have to be multiplied by $\sin^{1.6}(20)$.

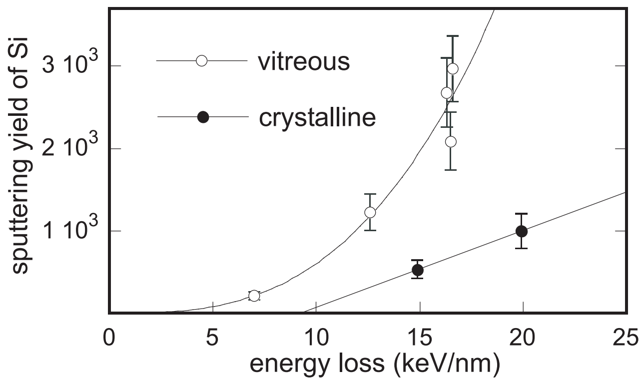

Fig. 2: Total sputtering yield of Si from vitreous SiO_2 and crystalline quartz for projectiles with different electronic energy loss.

Obviously, the sputtering yield for the amorphous SiO_2 is larger than for the crystalline quartz in agreement with corresponding observations for track formation in bulk material. For a theoretical description of these results, calculations with the thermal spike model are in progress. A consistent set of parameters can explain the quartz data assuming track formation as a quench of molten matter and sputtering as surface evaporation from the track area [2]. Within the model, increased sputtering of amorphous material can be ascribed to enhanced electron-phonon coupling during the track formation process.

References

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[2] M. Toulemonde *et al.*, Phys. Rev. Lett. **88** (2002) 057602