Huge Sputtering of Alkali Halides in the Electronic Stopping Regime

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Alkali-halides, such as LiF or NaCl, are very sensitive to single electronic excitation. Numerous experiments demonstrated that classical sources of radiation, like electrons, gammas or neutrons are very efficient in damage creation. More recently [1], new results have been obtained when analyzing the defect creation of such class of materials under the irradiation of energetic heavy ions in the electronic stopping power regime. In LiF, the specific damage created under the dense and localized electronic excitation of the ions, does not result in amorphisation but leads to the formation of defect clusters along the ion trajectory. It was surprising to see that the size of the tracks as determined from small angle x-rays scattering experiments [1] is significantly smaller than in amorphisable crystals. This was in particular unexpected because such materials (as e.g., crystalline SiO2 quartz) are in most cases almost insensitive to single electronic excitations. In order to improve the understanding of the damage creation in ionic alkali halide crystals, earlier studies (e.g., chemical etching, swelling observations and atomic force microscopy) were complemented by sputtering experiments measuring the angular distribution and the total yield of the sputtered atoms. Such experiments provide data for a crucial test of track formation models such as for instance the thermal spike model or the pressure pulse model.

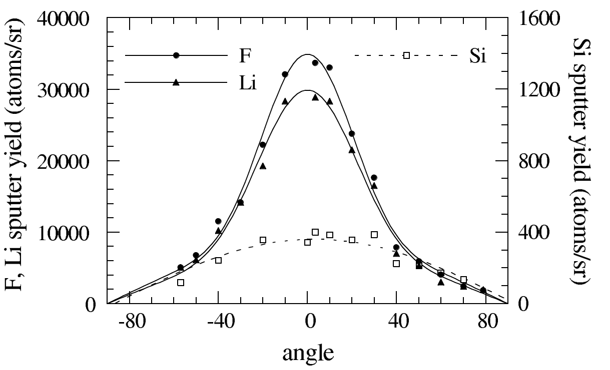

Fig. 1: Angular distribution of sputtered atoms from a LiF and SiO2 surface under irradiation of Au ions.

The experiments were performed on various ionic single-crystals (LiF, NaCl, CaF2, and RbCl) and on SiO2 quartz. The fast and efficient change of ion species and energies at the Munich Tandem accelerator allowed us to use several ions (S (50 MeV), Ni (70 MeV), I (150 MeV), and Au (210 MeV)) during one beamtime. The irradiations were carried out with the equilibrium charge state of the ions and under an incident angle of 71^o with respect to the surface normal. The sputtered particles were collected on arc-shaped catcher foils oriented perpendicular to the ion beam. Subsequently, the foils were analyzed by elastic recoil detection analysis (ERDA) at the same beamline using a 150 MeV Au beam. The technique allows the identification and quantification of the light elements deposited on the catcher arc on different positions corresponding to different angles.

As seen earlier for UF_4, an isotropic distribution is obtained for quartz (fig. 1 shows the data for a Au beam irradiation) corresponding to a cosine dependence. The situation is quite different for LiF. Here, pronounced sputtering occurs normal to the surface at small angles. The best fit to the Li and F data is composed of an isotropic cos plus a $\cos^8$ contribution. The total yield per incident ion, determined by integrating the angular data, exhibits for LiF (Y_{tot}(Li+F)=$8.3\pm1.3 \cdot 10^4$) a value by almost two orders of magnitude larger than quartz (Y_{tot}(Si)= $1.5 \pm 0.4 \cdot 10^3$). This huge yield has been confirmed by measuring the thickness decrease of a thin LiF layer on a Si substrate using the same irradiation conditions.

An important information can be obtained from the total sputter yield as a function of the electronic energy loss (fig. 2), because sputtering is only expected if the energy transferred to the atoms is large enough to surpass the surface cohesion energy. Although the data set is not yet complete, sputtering of LiF appears definitively at a lower energy loss than the threshold (10 keV/nm) for chemical etching of ion tracks [1].

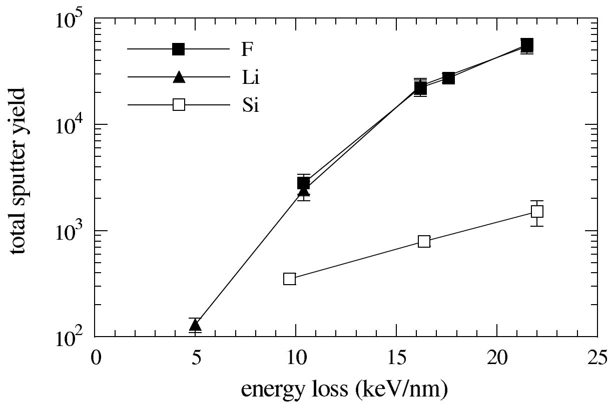

Fig. 2: Mean value of the total sputter yield per incident ion as a function of the electronic energy loss for LiF and SiO2.

In summary, compared with amorphisable materials such as quartz, LiF exhibits surprisingly large sputter yields combined with a highly non-isotropic angular distribution. For a theoretical description of our observations, thermal spike model calculations are in progress.

References

[1] Ch. Trautmann *et al.*, Nucl. Instr. Meth. **B146** (1998) 367