Swift Heavy Ion Induced Sputtering of CaF_2 Crystals Investigated by ERDA and TEM

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Sputtering experiments on insulators with heavy ion beams at energies where electronic stopping dominates show much larger yields than predicted by linear cascade theory (nuclear stopping). To better understand the electronic sputtering mechanisms systematic measurements on different insulating materials like SiO_2, LiF or CaF_2 crystals have been performed. Signatures of the underlying physical process are expected concerning the absolute yield, the threshold and energy loss dependence, and the angular distribution. The angular distributions of the sputtered particles can best be measured with the catcher technique. Most suitable for the catcher analysis especially for light elements is the heavy-ion elastic recoil detection analysis (ERDA).

Recent experiments on LiF crystals showed new and unexpected sputtering results concerning both, the total yield and the angular distribution [1,2]. The total sputter yield reaches values around 10^5 particles per incident ion. Moreover, Li and F are sputtered stoichiometrically exhibiting a sharp jet-like component symmetric around the surface normal. To see whether this jet-like component is a more general behavior of ionic crystals, additional sputtering experiments were performed with single crystals of CaF_2 using various heavy ion beams of energy around 1 MeV/u and different angles of incidence.

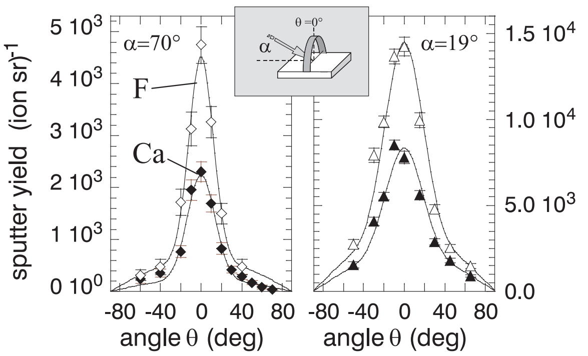

Fig. 1: Angular distributions of particles sputtered from a CaF_2 crystal under $\alpha = 70°$ and $\alpha = 19°$ with 210-MeV Au ions (Ca (closed symbols), F (open symbols)). Inset: scheme of irradiation set-up

In order to avoid surface damage, the sputtered particles were collected from several irradiation spots of limited fluence ($\leq 3 \times 10^{12}$ ions/cm^2). ERD analysis of the flattened catchers gives the number of Ca and F atoms along the originally arc-shaped catchers. As for LiF, the angular distributions exhibit a sharp jet-like component symmetric around the surface normal superimposed on a nearly isotropic cosine distribution. In the jet, the sputtered particles follow the stoichiometry of the crystal. By integrating over the full solid angle, the total sputter per incoming ion projectile is obtained (Fig. 2). The total sputter yield follows a power law with $\approx (dE/dx)^4$ and has a threshold of 6-8 keV/nm.

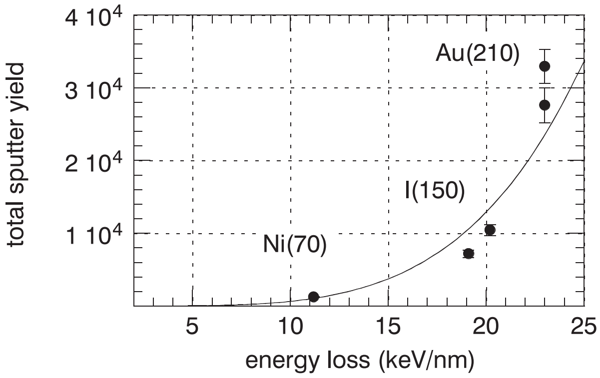

Fig. 2: Total sputter yield of CaF_2 as a function of the energy for an incidence angle $\alpha = 19°$. Solid line is a fit with $(dE/dx)^4$.

The large yield and the stoichiometry of the sputtering brings up the question whether the process is governed by the emission of larger clusters. We therefore mounted carbon-coated TEM grids at $\theta = 0°$ and inspected them by high-resolution transmission electron microscopy. We find individual, sometimes faceted, clusters of various diameters reaching up to 20 nm. Particles of suitable orientation exhibit lattice fringes corresponding to (111) and (200) CaF_2 planes. The height of the clusters as deduced from topographic scanning force microscopy also shows a large variation ranging from 1 to 12 nm with a mean value of 3 nm. The total number of atoms per cluster is in accordance with the sputtering yield measured by ERDA.

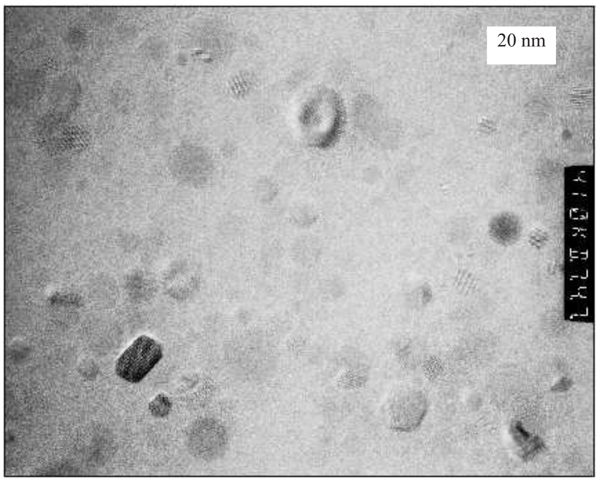

Fig. 3: TEM micrograph of sputtered CaF_2 nanoclusters collected on a carbon-coated TEM-grid during irradiation with 10^{12} Au-ions.

References

[1] W. Assmann *et al.*, Annual report 1999, p. 36
[2] M. Toulemonde *et al.*, Phys. Rev. Lett. **88** (2002) 057602