Ambient AFM investigation of nanostructures on CaF_2 single crystals induced by slow highly charged Xe ions

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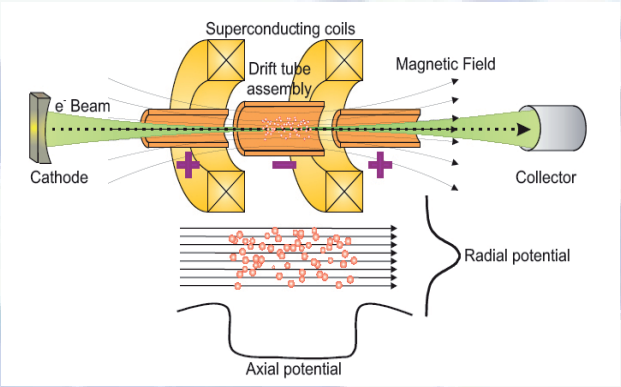
ABSTRACT

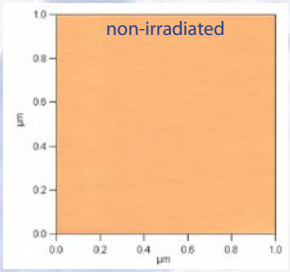
Upon interaction of highly charged ions (HCI) with solid surfaces a large amount of potential energy is deposited within a very short time (a few femtoseconds) into a nanometer sized volume close to the surface [1]. This unique action of HCI offers a promising way for surface nanostructuring of different materials [2]. We present first results on the generation of surface nanostuctures by HCI on CaF_2(111) cleaved surfaces. The CaF_2 single crystals were irradiated with slow (v < 1 a.u.) HCI from the Heidelberg-EBIT. Like for other ionic fluoride single crystals, ion-induced surface structures in CaF_2 are known to be stable under atmospheric conditions at room temperature [3,4]. After irradiation the crystals were investigated by scanning force microscopy (SFM) in ambient air. Topographic images show the generation of nano-scale hillocks protruding from the surface. The number of hillocks per unit area is in good agreement with the applied ion fluence. Comparison with observations for swift heavy ion irradiation of CaF_2 [4] surprisingly shows that slow Xe^{44+} ions (potential energy 51 keV) generate surface damages of larger diameter than for Xenon ions with a kinetic energy of about 1.5 GeV.

HIGHLY CHARGED IONS (HCI)

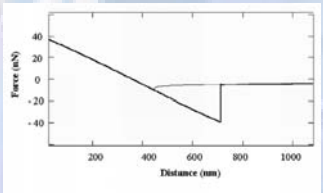
Principal of an electron beam ion trap (EBIT).



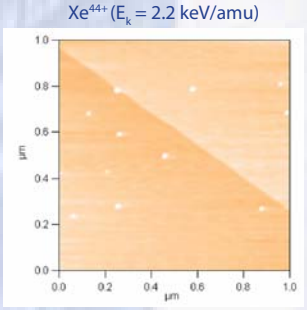
SFM of HCI-induced surface nanostructures



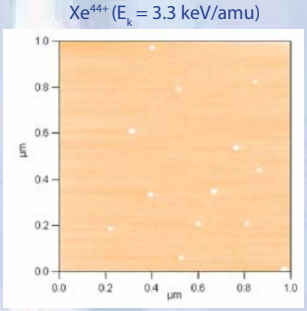
Force–distance curve on CaF_2 crystal surface.

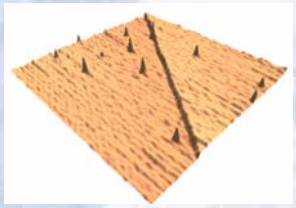


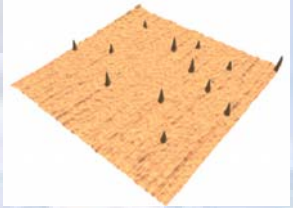
Xe^{44+} (E_k = 2.2 keV/amu)



Xe^{44+} (E_k = 3.3 keV/amu)





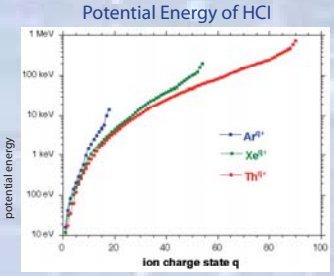


SFM topographic images of cleaved CaF_2(111) surface irradiated with Xe^{44} of two different kinetic energies.

Comparison with swift heavy ions

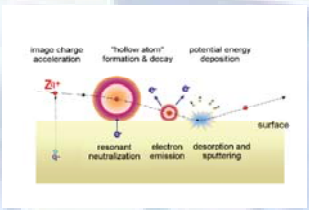
	Slow Xe^{44+}	Slow Xe^{44+}	Swift Xe
Specific energy (MeV/amu)	0.0022	0.0033	6.4
Ion range (nm)	84	117	46000
Electronic energy loss (keV/nm)	1.09	1.31	19.5
Nuclear energy loss (keV/nm)	2.85	2.56	0.02
Mean hillocks diameter (nm)	28.1 ± 0.4	28.3 ± 0.5	23.5 ± 0.4
Mean hillocks height (nm)	0.9 ± 0.1	0.9 ± 0.1	3.8 ± 0.2

Potential Energy of HCI

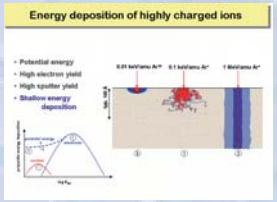


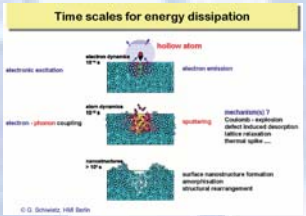
Total potential energy stored in highly charged Ar, Xe and Th ions versus charge state q. During a collision of the ion with a surface this energy is made available to induce surface modifications.

HCI - Surface Interaction



Scenario for impact of a slow HCI on a surface: The transfer of potential energy causes the transient formation of a so-called „hollow atom" and strong electronic excitation of the surface.





Conclusions and Outlook

- SFM topographic images show surface hillocks protruding from Xe^{44+}-irradiated CaF_2 single crystal
- No. of hillocks /cm² coincides with the applied ion-fluence
- Similar hillock diameters and heights were observed after irradiation with both Xe^{44+} (E_k=2.2 keV/amu) and Xe^{44+} (E_k=3.3 keV/amu) ions
- Larger hillock diameter induced by slow Xe^{44+} in comparison to swift Xe ions
- The results show that the potential energy plays a major role for CaF_2 (111) nanostructuring
- SFM investigations as a function of potential energy using various ion species of different charge states are in progress

References

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