Surface nanostructuring of CaF_2(111) by irradiation with slow highly charged ions

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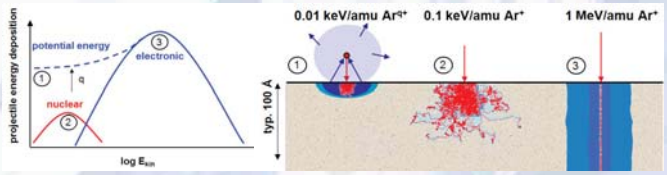
ABSTRACT

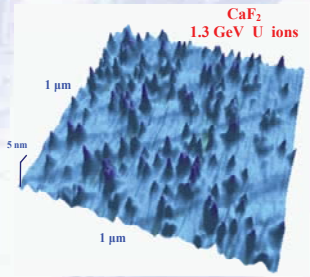
We have investigated the surface of CaF_2 (111) single crystals after irradiation with slow highly charged ions (HCI). Scanning force microscopy (SFM) reveals the creation of ion- induced surface nano-hillocks. These hillocks appear at a well-defined potential energy threshold of of about 14 keV. Estimations of the energy density deposited suggest that the threshold is linked to a solid–liquid phase transition ("melting") on the nanoscale. With increasing potential energy, both the basal diameter and the height of the hillocks increase, while no clear dependence of these parameters on the kinetic energy of the ion is observed. The present results reveal a remarkable similarity between this predominantly potential energy driven process and track formation by the thermal spike of swift (GeV) heavy ions.

SCENARIO

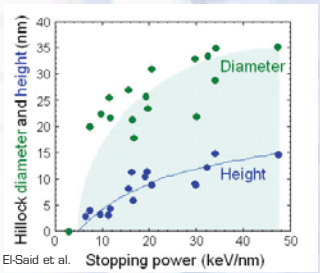


Slow highly charged ions (1) form „hollow atoms" in front of a target surface, leading to substantial electron emission [1]. Upon impact, their large potential energy is deposited mainly into the electronic subsystem (blue) of the target. In this respect, the interaction is closer related to swift heavy ion irradiation (3), which is dominated by electronic stopping, than to slower heavy ion irradiation (2) with dominant nuclear stopping (red). Using slow HCI, the interaction is limited to the surface of the target, eliminating the problem of radiation damage to the bulk.

SWIFT HEAVY ION TRACKS



GeV fast heavy ions create tracks in the bulk of various ionic fluoride single crystals [2], e.g. CaF_2, accompanied by hillock-like nanostructures protruding from the surface .



A minimum electronic energy loss $(dE/dx)_e$ of ~5 keV/nm is needed for the creation of surface nanostrucures on CaF_2 by swift heavy ion irradiation [3].

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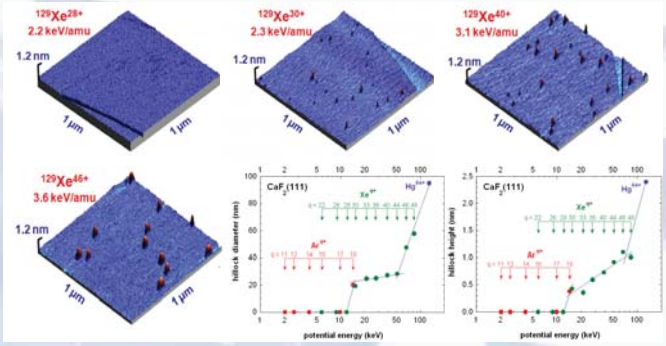
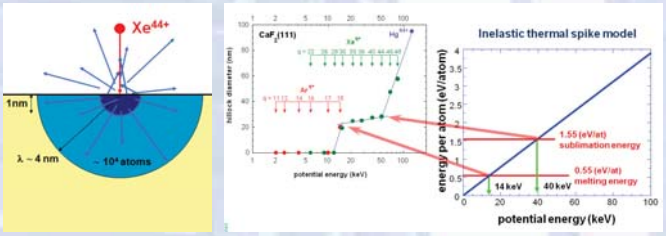
slow HCI on CaF_2

dependence on projectile potential energy



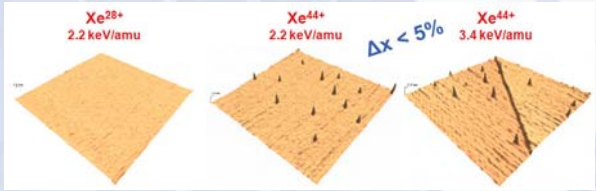
SFM measurements were performed after irradiation of CaF_2 single crystals with highly charged Ar, Xe, and Hg ions from the Heidelberg EBIT at kinetic energies between 2.2 and 3.6 keV/amu. The SFM micrographs show hillock-like nanostructures protruding from the surface. The size of the hillocks increases as a function of the potenetial energy carried by the HCI. A minumum potential energy of 14 keV has to be overcomed for the creation of these structures. A second threshold marking a steep increase in hillock size was found around 50 keV [4].

interpretation with the inelastic thermal spike model



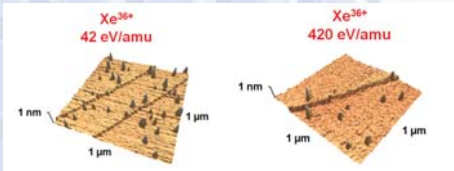
An extension of the inelastic thermal spike model [5] to the case of slow HCIs calculates the energy transferred to target atoms via phonon coupling of the hot electrons produced by the HCI impact [6]. The model calculations show that the observed thresholds for hillocks formation are correlated to the phase transitions of melting and sublimation.

dependence on projectile kinetic energy



The difference in hillock size produced by Xe^{44+} at 2.2 and 3.4 keV/amu is less than 5% (within statistical error bars). Xe^{28+} at 2.2 keV/amu did not produce any structures.

preliminary results at very low projectile velocity



At the Two Source Facility at FZD in Rossendorf, HCIs from an EBIT were decelerated to energies as low as 150 eV/q. Similar nanostructures are observed in this velocity regime, where the kinetic energy of the HCIs is much less than their potential energy.

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