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Review

Highly charged ion induced nanostructures at surfaces by strong electronic excitations

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ABSTRACT

Nanostructure formation by single slow highly charged ion impacts can be associated with high density of electronic excitations at the impact points of the ions. Experimental results show that depending on the target material these electronic excitations may lead to very large desorption yields in the order of a few 1000 atoms per ion or the formation of nanohillocks at the impact site. Even in ultra-thin insulating membranes the formation of nanometer sized pores is observed after ion impact. In this paper, we show recent results on nanostructure formation by highly charged ions and compare them to structures and defects observed after intense electron and light ion irradiation of ionic crystals and graphene. Additional data on energy loss, charge exchange and secondary electron emission of highly charged ions clearly show that the ion charge dominates the defect formation at the surface.

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Contents

1. Introduction

Ion beam modification and analysis of sample surfaces is nowadays a mature field in physics with a high technological relevance in e.g. semiconductor doping (electronic modification) or ion beam etching (topographic modification) as two out of many aspects. Slow highly charged ions (HCI) on the contrary are a new and exotic type of ions which allow efficient structuring of surfaces on the nanoscale. However, the interaction dynamics of HCI with surfaces and the mechanisms of the structure formation are not yet fully understood.

This article discusses nanostructuring on solid surfaces by strong electronic excitations induced by electron and slow ion irradiation. We focus on structures with nanoscale dimension, both in lateral as well as in vertical extension and therefore limit ourselves to low energy electron and slow HCI irradiation. The same type of excitations may also result from high power laser [1] or swift heavy ion irradiation [2], but on larger length scale in at least one dimension. The latter ones were already compared to slow HCI experiments in a recent review article [3].

To achieve modifications by ions just on the surface their velocity v has to be small (on atomic scale), i.e. we are referring here to slow ions with $v \ll v_0$ (Bohr's velocity: $v_0 = \alpha c \approx 2.19 \times 10^6$ m/s with $\alpha \approx 1/137$ the fine structure constant and c the speed of light). Nanostructures observed after slow HCI impact have diameters of about 5–20 nm and vertical extension of $\leqslant$2 nm. When these structures form due to single ion impact the power density initially transferred to the target's electronic system exceeds values of $10^{12} - 10^{14}$ W/cm^2 due to the high charge of the ions (e.g. $Q \leqslant 44$ in case of Xenon ions used in our studies). The ion charge state is associated with a potential energy, which is defined as the sum of the binding energy of all the released electrons. The potential energy with values of e.g. 51 keV (Xe^{44+}) is essentially released in the first nanometers of the surface on a femtosecond (fs) to 100 fs time scale. Since the underlying processes of nanostructure formation by slow HCI could successfully be identified with mechanisms such as defect mediated desorption [4] and local phase transitions (melting, sublimation) [5] we want to highlight in this review similarities between highly charged ion induced structures to structures obtained after low energy ($\leqslant$1 keV) electron irradiation.

In Section 1.1 we give an overview on different energy deposition mechanisms of slow ions, i.e. elastic and inelastic collisions with target nuclei and electrons. Chapter 2 refers to an additional type of energy deposition unique to slow highly charged ions, namely potential energy release. The