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Emission of secondary ions after grazing impact of keV ions on solid surfaces

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ABSTRACT

We have scattered He^+ and Ar^+ ions with energies of 10 and 20 keV from solid surfaces and investigated by means of a quadrupole mass spectrometer the emission of secondary ions. Compared to the established method of secondary ion mass spectroscopy (SIMS), the impact of ions proceeds under a grazing angle of incidence of about 2°. In experiments with a Cu(100) target covered with an ultrathin Fe_3O_4 film as well as ZnO and ZnMgO surfaces we have explored some basic features of this variant of SIMS concerning the potential application as surface analytical tool.

1. Introduction

The detection of secondary ions after the impact of low energy ions on surfaces (Secondary Ion Mass Spectroscopy – SIMS [1–5]) is a powerful tool for the elemental depth analysis in surface science. In the established version of the SIMS method, the primary ions impinge on the surface along the surface normal or large angles with respect to the surface plane. The combination of the elemental analysis for secondary ions and the erosion via sputtering allows one to obtain the concentration of atoms as function of depth. In the application of SIMS it is still a substantial problem to quantify the secondary ion yields, since the charge of secondary particles depend in an intricate manner on parameters as work function or density of electronic states and the electronic structure of the emitted atomic projectiles. Therefore calibration standards with known elemental composition are of paramount importance for the quantitative analysis of samples.

In our experiments, we have performed SIMS studies on different targets where the impact of atomic and molecular ions with energies of up to 20 keV proceeds under a grazing angle of incidence of about 1–2°. The mass analysis and detection of the secondary ions were performed with a quadrupole mass spectrometer operated with a channeltron detector. The work reported here can be considered as an explorative study in order to investigate the properties of SIMS in this specific regime of ion-surface collisions. Similar as for studies on charge exchange or ion scattering, one would expect an enhanced sensitivity under these conditions to the topmost layer of the surface. Under grazing impact the collision of the projectile ions with the surface proceeds in the regime of surface channeling where the energy for the motion of projectiles normal to the surface is for keV ions in the eV regime so that a penetration of projectiles into the bulk is substantially suppressed [6–10]. Then preferential sputtering takes place at the topmost surface layer(s) so that the removed material and emitted secondary ions stem predominantly from this region. From this feature we expect an enhancement of the depth resolution for the SIMS method.

Studies on SIMS using grazing impact of projectiles are rare. As examples we mention here work by Alkemade and coworkers [11] on secondary ion emission from Ge layers induced by sub-keV O_2^+ ions at grazing angles down to 10°. Highly charged Ar ions under grazing impact at angles around 0.5° were used by Motohashi et al. for recording TOF(time-of-flight)-SIMS spectra from contaminated Al and GaN surfaces [12]. In the latter study the authors have concentrated on the emission of secondary protons as function of projectile charge, revealing a substantial increase of proton yield with charge. The secondary ion yields and the mass distributions have been studied for grazing impact of a number of MeV ions on a KCl(001) surface [13]. However, systematic studies in the typical SIMS regime using singly charged ions with keV energies cannot be found in literature.

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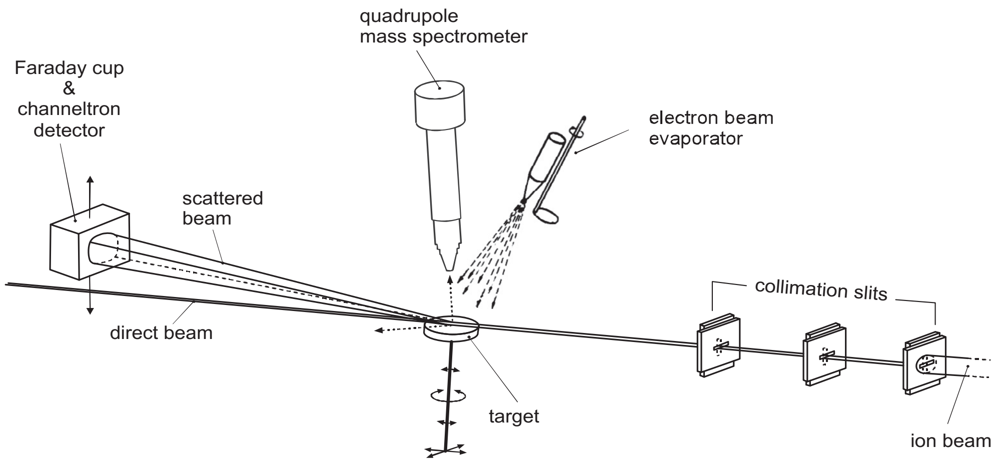

Fig. 1. Sketch of experimental setup for studies on emission of secondary ions after grazing impact of fast ions on solid target surface.

2. Experiment

In our experiments we made use of different sorts of singly charged atomic and molecular ions. We will limit our discussion here to He^+ and Ar^+ ions with an energy between 10 keV and 20 keV. The ions were produced in an Electron Cyclotron Resonance (ECR) ions source [14,15] and directed after mass analysis by a focusing magnet and collimation via sets of vertical and horizontal slits onto the surface of different targets mounted on a precision manipulator. A sketch of the experimental setup is given in Fig. 1. The grazing angle of incidence was adjusted to values of typically 2°. Depending on the experiments, the pressure in the target chamber was between 10^{-9} mbar and about 10^{-7} mbar. Possible contaminations of the target surface by atoms and molecules of the rest gas was tolerated, since it was also an issue of this work to explore their effects on the secondary ion yields and their transient behaviour during the sputtering process.

The ion beam was controlled via the target current and the current registered by a Faraday cup mounted downstream from the target. The angular distribution of scattered projectiles could be monitored by a channeltron detector with a 0.2 mm circular aperture which was mounted on a precision manipulator. Slow secondary ions with energies up to some 10 eV produced during ion impact were detected by means of a quadrupole mass spectrometer from Extranuclear Laboratories. The filament of this instrument, used for electron emission in order to produce ions from the rest gas in the vacuum chamber, was switched off so that ions analyzed after their passage through the quadrupole electrodes of the instrument had to stem from species produced during ion impact at the target surface. The voltages proportional to the intensities of ions at the detector were recorded by a 12bit ADC and the mass of the ions was controlled by the DC voltage fed to the instrument using a DAC output of a computer which served for recording of the mass spectra.

In our work we used a number of different targets. We started our investigations with a Cu(1 1 0) sample covered with an ultrathin Fe_3O_4 layer (several monolayers) which was produced in a different setup via reactive MBE (molecular beam epitaxy) in a O_2 partial pressure of some 10^{-8} mbar. The surface of the sample was initially contaminated because of storage at atmospheric pressure. In the second set of experiments we used ZnO and ZnMgO samples which were produced by MBE on a sapphire substrate. The Mg content relative to Zn for some ZnMgO samples was determined by an EDX (Energy Dispersive X-ray) analysis, samples with a low concentration of Mg of some % could not be calibrated by EDX and was evaluated in our studies.

3. Secondary ion emission from an ultrathin Fe_3O_4 film on Cu(1 1 0)

A typical secondary ion mass spectrum for the bombardment of a Cu(1 1 0) surface covered with an ultrathin Fe_3O_4 film by 10 keV Ar^+ ions under a grazing angle of incidence of 2° is shown in the upper panel of Fig. 2. The semi-logarithmic plot of ion yields as function of ion mass reveals a dominant contribution of Fe and an about two orders of magnitude smaller contribution from the

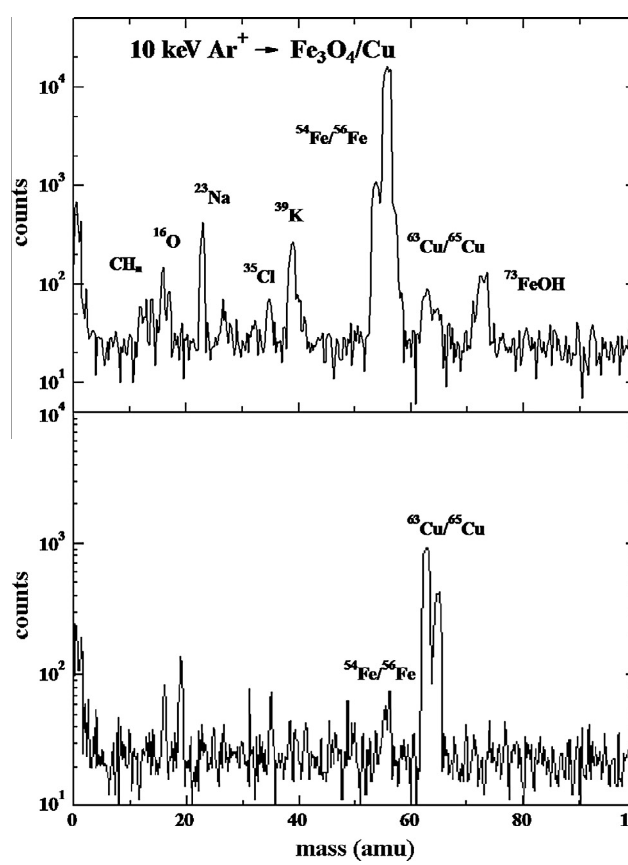

Fig. 2. Mass spectrum for scattering of 10 keV Ar^+ ions on Cu surface covered by Fe_3O_4 film of several monolayers under grazing angle of incidence of 2°. Upper panel: Spectrum taken at beginning of irradiation of target. Lower panel: Spectrum after sputtering over several hours.