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Electron emission for grazing impact of keV He atoms on an Al(1 1 1) surface

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Abstract

The energy loss of He atoms with energies $E \leqslant 28$ keV scattered from Al(1 1 1) under a grazing angle of incidence is recorded in coincidence with the number of electrons emitted in the collision. From our data we deduce the mean energies for emission of a specific number of electrons during impact of the atomic projectiles. We observe that only a fraction of some percent of the energy transferred to metal electrons results in their emission. The mean energy for emission of electrons in head-on binary collisions of He atoms with conduction electrons is estimated from a simple classical model which describes the data fairly well. For higher energies of the projectile motion with respect to the surface normal, i.e. collisions with surface atoms under smaller impact parameters, the mean energy transfer to emitted electrons is enhanced which is attributed to an electron promotion mechanism.

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1. Introduction

Electron emission phenomena for impact of atomic projectiles on solid surfaces play an important role for applications and in fundamental research. *Kinetic electron emission* (KE) is one of the important mechanisms where transfer of kinetic energy from incident atomic particles leads to electronic excitations and to electron emission [1–5]. Electronic excitation and emission phenomena are rather intricate subjects comprising the primary excitation process, subsequent transport and penetration of the solid vacuum boundary [6–8]. Different electronic excitation mechanisms are considered, where energy transfer in binary encounters of projectiles with conduction electrons

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[3–5] and electron promotion in collisions with atoms of the target surface [5,9] play an essential role. In the selvedge of the surface, excitations of conduction electrons dominate and are characterized by a kinematic threshold for electronic emission owing to the presence of a potential barrier (work function for Fermi electrons) at the solid vacuum interface [10,11]. Electron promotion in binary collision between projectile and target atoms proceeds only for sufficiently small impact parameters where the formation of molecular orbitals is effective.

Recently, kinetic emission of electrons was studied for bombardment of solid surfaces with atomic projectiles under a grazing angle of incidence. Under these conditions, projectiles are generally scattered in front of the topmost surface layer in the regime of surface channeling with well-defined trajectories [12]. Then interactions with the solid proceed primarily with the electron gas in the selvedge of the surface. Since most projectiles are specularly reflected from the surface, it is possible to study their energy dissipation and to relate their energy loss to the emission of a specific number of emitted electrons via coincident techniques [13,14]. A further important aspect in using grazing impact is related to the non-destructive nature so that the surface remains in a defined condition during measurements. A fair number of studies were performed with insulator targets – primarily alkali halide crystals – in the past years and provided a detailed understanding for the interaction scenario [13–15]. In particular, it could be shown that the formation of negative ions is the dominant precursor for electron emission from ionic crystals. This mechanism explains the at first glance surprising fact that total electron yields for bombardment of wide-band gap insulator surfaces are higher than for scattering from clean metal surfaces.

Recently, we have investigated the emission from metal surfaces in the grazing incidence collision regime. Total electron yields in the near threshold region could be consistently described by a model of electronic excitations in binary encounters of atomic projectiles with electrons in the selvedge of the surface. From simple phase space considerations we derived a threshold law for ion-/atom-induced electron emission from a free-electron gas metal and obtained the fractions of excited electrons that overcome the surface potential and reach vacuum [11]. In the present paper we will discuss studies on electronic excitation and emission at an Al(1 1 1) surface during grazing impact of keV He atoms. Our data are analyzed with respect to projectile energy loss, mean energy transfer for emission of a specific number of electrons, and total electron yields. We interpret our results in terms of a simple classical model of electronic excitation via binary encounter of atomic projectiles with electrons in the selvedge of an Al surface.

2. Experiment and results

Main components of the experimental setup have been discussed in previous papers [16]. In our UHV chamber (base pressure some 10^{-11} mbar) a chopped and well-collimated beam of keV He atoms is scattered from a clean and flat Al(1 1 1) surface under a grazing angle of incidence ranging from 1.3° to 5.5°. The scattered projectiles are recorded with a channelplate detector which provides the start signal for a time-of-flight (TOF) setup with an overall time (energy) resolution of typically 5 ns (5 eV). The number of emitted electrons is obtained from the pulse height of a surface barrier detector (SBD) biased to 25 kV with an overall efficiency of detection of electrons close to one (98%) [17]. By means of digital delays and a time-to-amplitude converter (TAC) we derive the number of emitted electrons for a specific TOF event. This procedure allows us to separate the TOF spectra with respect to a given number of emitted electrons, where particle coincidences with the noise of the SBD provides also those events related to the emission of no electron.

In Fig. 1 we show as a representative result TOF-spectra for the scattering of 12 keV He atoms from Al(1 1 1) under a grazing angle of incidence $\Phi_{in} = 1.68°$. The spectra are converted to an energy loss scale and are plotted for specific numbers of emitted electrons. Note that for a better comparison of data maxima are adjusted to the same heights. The well-defined spectra show a mean