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BEAM INTERACTIONS WITH MATERIALS AND ATOMS

Electron emission yields from boron-like Ar ions impinging on Au(100)

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ABSTRACT

Using a new experimental station to be installed at the HITRAP facility at GSI we studied electron emission yields of Ar^{13+} ions impinging on a clean Au(100) surface. By taking data under different incidence angles and at different initial kinetic energies, contributions from kinetic and potential electron emission are separated. The number distributions of the emitted electrons exhibit signatures of specific trajectory classes contributing differently to the electron emission yields. Support for the identification of the different trajectory classes is obtained from SRIM simulations.

1. Introduction

Ever since the advent of sources for highly charged ions (HCI) the interaction of these ions with surfaces has been a field of very active research. One of the main interests is understanding the fundamental processes by which the large amounts of potential energy carried by the HCIs are dissipated at a surface within very short interaction times. For example the potential energy of an Ar^{13+} ion is already no less than 3.3 keV. The general trends of neutralization and relaxation mechanisms of such HCIs interacting with a surface can be described by the hollow atom scenario [1–3]. Upon approaching the surface, the HCI resonantly captures electrons from the surface into outer shells, leaving the inner shells empty and giving rise to the formation of a hollow atom. The highly, multiply excited hollow atoms will for one relax by fast Auger processes resulting in the emission of electrons driven by the ion's potential energy. At low kinetic energies at which kinetic electron emission is inhibited electron emission is a direct diagnostics of the dissipation of the potential energy of the HCIs.

In the near future the HITRAP facility (GSI, Germany) [4] will give access to fully stripped uranium U^{92+}, having a potential energy of almost 1 MeV and kinetic energies of approximately 0.5 MeV. To be able to use these HCIs for surface experiments at direct and lower beam energies we have designed and constructed an experimental user station to be installed at the HITRAP facility. The general features of the so called IISIS (Inelastic Ion Surface Interaction Station) setup will be presented here.

In this paper the capacity of IISIS will be demonstrated by means of detailed studies of electron emission from boron-like Ar^{13+} with kinetic energies of 4–91 keV impinging on a Au(100) single crystal to determine the role of potential and kinetic emission. The electron statistics spectra show indications of different trajectory classes contributing to the electron emission. In support of the identification of the trajectory classes, SRIM simulations have been performed.

2. Experimental setup

The newly designed and constructed experimental setup IISIS consists of a central CF-150 UHV chamber and is schematically depicted in Fig. 1. Below the chamber a 360 l/s turbo pump is mounted to pump down the system. A 400 l/s ion pump is used to bring the base pressure in the low 10^{-11} regime. In order to avoid interference with the electron statistic measurements the ion pump is switched off during data taking. During this time the turbo pump is used to maintain the pressure in the low 10^{-10} regime.

The ions enter the chamber via a six element deceleration and focusing lens system. The deceleration system is similar to a deceleration system used at another experimental setup at the KVI which is described in detail in [5,6]. This type of electrostatic deceleration using many-element lens systems has been applied for a long time and are widely used, e.g. [7–9]. The ions can be decelerated to virtually zero kinetic energy, which is achieved by floating the whole setup, including the electronics and pumps on the same

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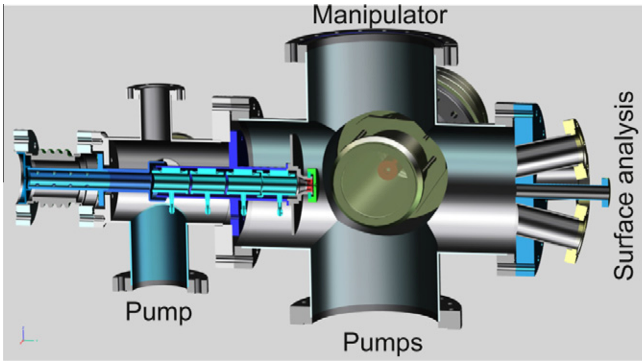

Fig. 1. Schematic view of the experimental setup. Indicated are the manipulator (top), pumps (differential pumping left side, main pumps of the chamber below the main chamber) and surface analysis tools. Also the diaphragms and lenses are shown, as well as the surface barrier detector and the grid in front of it. For further details see text.

high potential as the ion source, V_{source}. The final kinetic energy per charge unit is then set by applying a bias voltage, V_{bias}, on the setup, i.e. $E_{kinetic} = (V_{source} - V_{bias}) \times q$. The diameter of the final collimating diaphragm of the lens system is 1.5 mm. SIMION [10] trajectory simulations show that ion beams with an initial kinetic energy of 7 keV/q can be decelerated efficiently down to final kinetic energies of well below 100 eV/q, as can be seen in Fig. 2.

The transmitted ions will interact with the sample mounted on a VG Scienta manipulator equipped with a home built sample holder. The present design of the sample holder assures that the ion beam does not interact with the support material. This limits the rotation of the azimuthal angle. The sample can be rotated over 360° and moved in the X, Y and Z direction.

The Au(1 0 0) target used in the present experiments is prepared by cycles of sputtering with 7 keV Ar^{+} ions under grazing incidence angles and annealing at temperatures of up to 500 °C. The surface composition is checked by means of time of flight (TOF) low energy ion scattering. The time of flight system is mounted on the backside of the setup under an angle of 13° with respect to the incoming beam axis.

The electron statistics detector [11–13] is mounted under 90° with respect to the incoming beam. To collect all the emitted electrons on the electron statistics detector, the sample is surrounded by in total six electrodes. Five of the electrodes are biased negatively to optimize the electron collection efficiency. The sixth electrode, a positively biased highly transparent grid, is mounted directly in front of the electron statistics detector (see Fig. 1) and is biased positively to attract electrons. The surface barrier detector behind the grid is biased at +30 kV. The detector gives a signal proportional to the deposited energy [11]. Since all the electrons from a single impact event arrive at the detector within a few ps, which is orders of magnitude shorter than the inherent time resolution, the pulse height is a direct measure of the number of emitted electrons. On the other hand, the time between two ion impacts is sufficiently large to be distinguishable. The total average electron yield is determined from the electron number distribution, of which a thorough description can be found in [11].

To demonstrate the performance of IISIS, experiments have been performed using HCIs produced by the 14 GHz ECR ion source at the KVI ZERNIKELEIF facility. The energy at which the highly charged ions can be extracted range from 3 keV/q to 25 keV/q. The ions are mass over charge separated by means of a 110° bending magnet and guided towards and focused into the experimental setup by means of quadrupole magnets.

For the first experiments 12 keV/q Xe^{q+} ions were used. The measured electron yields are shown in Fig. 3 and compared to data from Meissl et al. [14] for higher charge states Xe ions of similar energy. The two data sets excellently connect to one another.

3. Results and discussion

3.1. Total electron emission yield measurements

In this work we are presenting total electron emission yield measurements of Ar^{13+} ions at kinetic energies of 4 up to 91 keV. These projectiles have velocities in the range from 1.4×10^5 m/s to 6.6×10^5 m/s, of which the latter is above the threshold for kinetic electron emission [15]:

$$v_{th} = \frac{1}{2} v_F \left(\sqrt{1 + \frac{W_\phi}{E_F}} - 1 \right) \quad (1)$$

with v_F the Fermi velocity and W_ϕ/E_F the ratio of the workfunction and the Fermi energy of the target. For Au one finds a threshold of 2.4×10^5 m/s which in the case of Ar projectiles corresponds to 12 keV kinetic energy. In order to cover the threshold regime, Ar^{13+} ions have been used with a kinetic energy ranging from 4 keV (1.4×10^5 m/s) to 91 keV (6.6×10^5 m/s). Fig. 4 shows the full compilation of the measured electron emission yields as a function of the velocity component perpendicular to the surface, $v_\perp$. For a

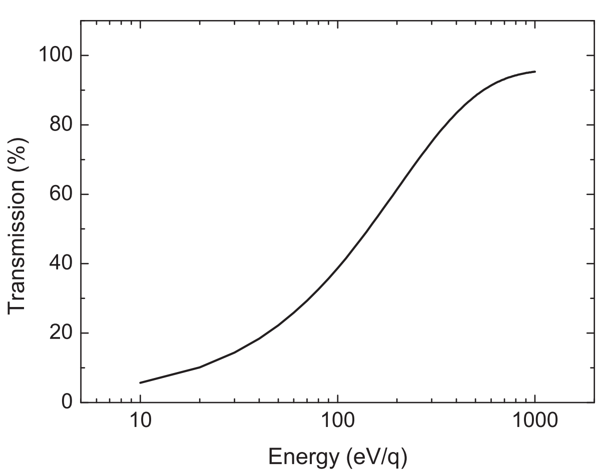

Fig. 2. SIMION simulation of the ion transmission through the deceleration and focusing lens system hitting the target within a 3 mm spot.

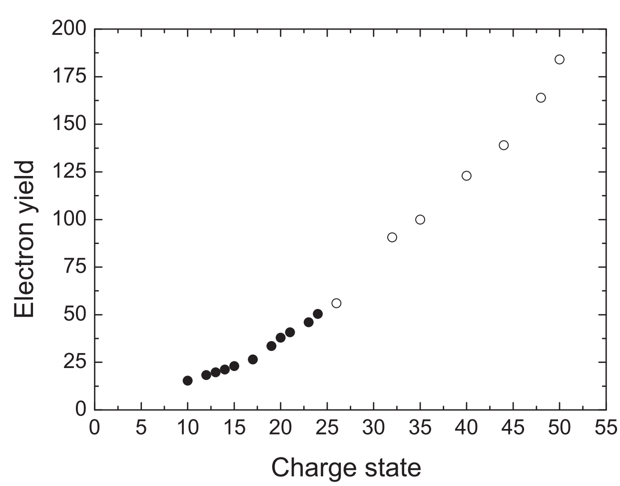

Fig. 3. Measured ion induced electron emission yield as a function of Xe^{q+} charge state: closed circles – present work and open circles – Meissl et al. [14].