To cite this version:

G. Lakits, F. Aumayr, H. Winter. STATISTICS OF ELECTRON EMISSION FROM METAL SURFACES BOMBARDED BY IONS IN DIFFERENT CHARGE STATES. Journal de Physique Colloques, 1989, 50 (C1), pp.C1-533-C1-539. 10.1051/jphyscol:1989156 . jpa-00229355

HAL Id: jpa-00229355
https://hal.archives-ouvertes.fr/jpa-00229355
Submitted on 1 Jan 1989

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
STATISTICS OF ELECTRON EMISSION FROM METAL SURFACES BOMBARDED BY IONS IN DIFFERENT CHARGE STATES

G. LAKITS, F. AUMAYR and H. WINTER

Institut für Allgemeine Physik, Technische Universität Wien Wiedner Hauptstr. 8-10, A-1040 Wien, Austria

Résumé - La statistique des électrons émis par impact d'ions mono ou multichargés sur des surfaces métalliques est étudiée afin de différencier les contributions de l'émission potentielle. En particulier, nous discutons du nombre d'électrons émis dans le cas d'impact d'ions Ar$q^+$ ($q = 1-4$) sur de l'or polycristallin.

Abstract - The statistics of electrons emitted due to impact of singly and multiply charged ions on metal surfaces is investigated in view of different contributions from potential emission. As an example we discuss the number of electrons emitted for impact of Ar$q^+$ ($q = 1-4$) on polycrystalline gold.

1. Introduction

Bombardment of metal surfaces with atomic projectiles (neutral and/or ionized atoms and molecules) leads among other processes to electron emission, an important phenomenon for plasma wall interaction, particle detection, gaseous electronics, etc. Although such electron emission processes have received considerable attention for many years, up to now the underlying mechanisms are still not sufficiently well understood. For particle-induced electron emission usually two mechanisms are distinguished. For positive (ground state) ion bombardment at rather low impact velocity only potential emission (PE) is expected, if the potential energy of the ion exceeds twice the work function of the metal surface $^1$. Above a threshold projectile velocity of typically $10^5$ ms$^{-1}$ kinetic emission (KE) contributes as well $^2$ and becomes eventually the dominant source of electron emission toward higher velocities. For impact velocities well below 1 a.u. both emission processes are assumed to act independently of each other, because the PE processes are practically terminated before the projectile particles have reached the surface to initiate the KE processes.

In chapter 2 we summarize our knowledge on electron emission from clean metal surfaces under impact of slow multicharged ions, for which PE is the dominant process. In chapter 3 investigations of the emission statistics for both KE and PE processes induced by singly - and multiply charged ions are reported.

2. Electron emission yield and electron energy distribution

A number of studies on slow multicharged ion bombardment of different metals $^1,3,4$ have established an apparently linear relationship between total electron yield $\gamma$ and the available primary ion potential energy $W_q$. The proportionality factor was shown to depend primarily on the ion velocity $^5$ and for given ion species and charge state the PE yield generally decreases with
increasing projectile velocity. This linear relationship breaks down, however, if the primary ion charge state is increased such that the projectiles during their neutralization develop an inner shell hole, e.g. for N^{6+} or Ar^{9+}, in which cases fast electrons from projectile Auger emission have been observed. However, this Auger contribution towards higher impact energy becomes relatively less important in the observed electron energy spectra.

The observations referred to are explained in the following way. A multicharged ion which slowly approaches the surface captures rapidly electrons from the solid (primarily via resonance neutralization/RN), thus forming multiply excited projectile states which are subject to fast autoionization/AI. As a result of these sequential processes, slow (≤30 eV) electrons are emitted, with their number depending on the available time for the projectile to reach the surface. If an inner shell vacancy develops (e.g. K-shell vacancy for N^{6+}), at least one electron has to reach the next higher shell in the course of the autoionization processes, before the inner shell vacancy can be filled by means of transitions leading to Auger electron emission (e.g. KLL, KLM, etc. for N^{6+}). At higher impact velocity the available neutralization time decreases and thus observation of Auger electron emission becomes more and more unlikely. The comparably fast Auger electrons carry away an important part of the available total potential energy \( W_q \). This explains at least in part the deviation from the linear relationship of electron yield vs. \( W_q \). Furthermore, the available time for executing the RN-AI steps decreases with increasing impact velocity, which explains the observed gradual decrease of the electron yield.

3. Electron emission statistics

We have constructed an experimental setup for investigation of electron emission statistics induced by different projectile species \( Z_q^+ \), irrespective of their charge (neutral particles as well as singly- or multiply charged positive ions or negative ions), being suitable for impact energies above \( = 0.5 \) q keV. With this method the total electron yield \( \gamma \) can be determined either by conventional current measurements or from the statistics of electron emission (henceforth called ES), i.e. the probabilities \( W_n \) for ejection of 1, 2, ..., \( n \) electrons per incident projectile, from which \( \gamma \) results as

\[
\gamma = \sum_{n=1}^{\infty} n \, W_n , \quad \sum_{n=0}^{\infty} W_n = 1 \quad (1)
\]

With these relations the total electron emission coefficients \( \gamma \) can be determined also for cases where current measurements are not feasible, e.g. for neutral projectiles or too small ion fluxes. However, for evaluation of \( \gamma \) it is necessary to determine the (not directly measurable) probability for emission of no electrons \( W_0 \). If \( W_0 \) cannot be calculated from \( \gamma \) -values obtained by current measurements (see above), to a first approximation it may be obtained from a least-squares fit of Poisson- or Polya-distributions to the ES as described below (see e.g. ref. 11).

Moreover, comparing ES for given projectile species in different charge states (e.g. Ar^{+} vs. Ar^{8+}, \( q \geq 1 \)) provides information about the emission statistics of the extra PE processes, which so far are unknown but can be expected to yield useful hints on the PE mechanisms involved.

3.1 Experimental setup

Our first experiments (cf. fig. 1) have been performed under UHV conditions at a base pressure below \( 10^{-9} \) mbar. Ar^{q+} (\( q = 1 - 4 \)) and Ne^{q+} (\( q = 1 - 3 \)) ions with impact energies of 2 - 20 keV...
have been used as projectiles. A polycrystalline Au target was sputter-cleaned by Ar$^+$ bombardment with the total electron emission coefficient being frequently checked. After applying a dose of typically $10^{16}$ ions/cm$^2$ no further change of $\gamma$ was noticeable. Comparison with published $\gamma$-values showed however, that our $\gamma$ remained typically 20% higher, indicating that the target preparation was not yet sufficient to result in an atomically clean surface. Anyhow, during the measurements it was checked repeatedly that these target conditions remained constant.

Consequently, the present results apply to a stable partially gas-covered Au surface, but in further work atomically clean targets will be prepared by means of additional standard cleaning procedures.

Fig. 1 shows the experimental configuration for measuring ES spectra (see below) as well as the currents of primary ions $I_i$ and emitted electrons $I_e$. The target is mounted within a highly transparent cage. For the current measurements a cage potential of +350 V was applied, with the resulting target current $I$

$$I = I_i + I_e = I_i + \frac{I_i}{q} \gamma \rightarrow \gamma = q \left(\frac{I_e}{I_i} - 1\right)$$

The ion current $I_i$ was measured by directing the primary ions into a Faraday cup. For measuring ES spectra the cage potential was set to -20 V to prevent the emitted electrons from leaving the cage except through the extraction aperture. With the extraction electrode set to +3.5 kV, all electrons were extracted through the aperture and accelerated toward a solid state detector (Canberra Passivated Implanted Planar Silicon detector) connected to +30 kV.

Ray trace calculations have been carried out to optimize the extraction geometry. Fig. 1 also shows some calculated trajectories for electrons starting from the target with energies of 20 eV into a solid angle of $2\pi$.

The PE process lasts not longer than $10^{-13}$ s and subsequent KE events are terminated within $10^{-12} - 10^{-11}$ s. Therefore, all electrons emitted due to impact of a particular projectile arrive at the solid state detector within its resolution time of $\geq 10^{-9}$ s. Consequently, the total energy of a group of electrons ejected by impact of a single particle corresponds to the number $n$ of these electrons.

The pulses produced by the detector are amplified, transformed to ground potential and pulse-height analyzed by a multichannel analyzer, from which ES spectra as shown in fig. 2 are obtained.

![Fig. 1. Experimental setup for measuring electron emission statistics. Typical electron trajectories have been indicated.](image-url)
3.2 Data reduction and evaluation

To a first approximation the peak areas of the ES spectrum correspond to the probabilities $W_n$. However, between the main peaks (the typical energy resolution is 7 keV FWHM) we observe a structured "background" (c.f. fig. 2) which can be attributed to electrons backscattered from the detector surface. Current measurements were performed with a dummy collector made of Al (which behaves similarly as Si with respect to electron backscattering) and mounted at the same position as the Si detector. These measurements showed that about 15% of the electrons impinging on the detector surface are backscattered. For Si the backscattered electrons deposit only about 40% of their initial energy into the detector.

To derive the emission probabilities $W_n$ from the measured ES spectra more precisely, the following procedure has been applied. If $n$ electrons reach the detector, their deposited energy is not only represented by the "full energy peak" ($n \times 30$ keV), but also by a number of individual peaks corresponding to cases for which $0, 1, 2, ..., m$ electrons have been backscattered from the detector surface.

The probability $P_n(m)$ for backscattering of $m$ electrons out from a group of $n$ electrons arriving at the detector surface obeys the binomial statistics (Lakits et al., to be published), i.e.

$$P_n(m) = \binom{n}{m} p^m (1 - p)^{n-m}$$

(3)

In our model the following assumptions are included.

* The probability for backscattering of electrons has been chosen as $p = 0.17$ according to measurements for a Si surface.

* Backscattered electrons carry away a mean energy of $0.6 \times 30$ keV $= 18$ keV (see above) with a Gaussian energy distribution of 12 keV FWHM.

Fig. 2 compares an experimental ES spectrum (open circles) with the results of a fit (solid line) using the above described model. The experimental data can very satisfactorily be reproduced by this fitting procedure, which gives a quantitative explanation of the structures observed between the main peaks in the ES spectra.

**Fig. 2.** Measured ES spectrum for 16 keV Ne$^{2+}$ impact on partially covered Au (circles) with fitted spectrum (solid line) and individual contributions including electrons backscattered from the detector surface (dashed lines).
To obtain $y$ we also need the (not directly measurable) probability for emission of no electrons $W_0$. To a first approximation $W_0$ can be derived from a least-squares fit of Poisson- or Polya distributions to the areas $A(n)$ resulting from the above described fitting procedure (see e.g. ref. 11). Subsequently the such derived $y$ values may be compared with those resulting from the current measurement.

However, if current measurements are feasible, we can proceed the other way around and investigate whether the ES obey a particular statistics or not. To check this we use the results of the current measurements for calculation of $W_0$ according to equs. (1) and (2) and then compare the obtained $W_0$ distribution with various statistical functions.

### 3.3 Typical results

Figs. 3 a - d show experimental ES spectra for impact of 16 keV $\text{Ar}^{q+}$ ($q = 1, 2, 3, 4$) on gold. The above described fitting procedure delivered the different ES (fig. 4 a), from which a deconvolution technique described in detail elsewhere (Lakits et al., to be published) permitted the evaluation of ES for PE - contributions due to different $\text{Ar}^{q+}$ ($q = 2, 3, 4$) projectiles in comparison to $\text{Ar}^{q+}$, see fig. 4b.

It is clearly visible, that with increasing charge state $q$ PE becomes relatively more efficient. Whereas proceeding from $\text{Ar}^{q}$ to $\text{Ar}^{2+}$ does not show remarkable differences, for $\text{Ar}^{3+}$ and especially for $\text{Ar}^{4+}$ the probability for emission of $n \geq 2$ electrons has considerably increased due to additional PE processes.

Measurements with variable ion impact energy showed a tendency for increasing the relative importance of PE toward lower impact energy, as expected $^1,4,5$.

---

**Fig. 3.** Measured ES spectra for 16 keV impact of $\text{Ar}^{q+}$ ($q = 1 - 4$) on a polycrystalline Au surface.
Fig. 4. a. Statistical electron emission distributions for bombardment of polycrystalline Au with 16 keV Ar$q^+$ (q = 1, 2, 3, 4).

b. ES derived for extra potential emission for Ar$q^+$ (q = 2, 3, 4) over Ar$^+$ (E = 16 keV); "error margin" indicates conservatively calculated total experimental uncertainty.

4. Conclusions

We have developed a method for determination of electron emission statistics resulting from impact of various projectile species (both neutral and charged) on a metal surface.

As a first example, measurements are presented for 16 keV Ar$q^+$ (q = 1 - 4) impact on polycrystalline gold, from which a difference of emission statistics is clearly visible. This permits derivation of both the potential emission surplus and the statistics related to this extra potential.
emission. So far, only one comparable study has been made\textsuperscript{16}, measuring ES for bombardment of different metals by 1 - 20 keV Ar\textsuperscript{+} and Ar\textsuperscript{4+}. Further systematic measurements involving lower impact energies and other projectile species in different charge states are in progress.

Acknowledgements This work has been supported by Fonds zur Förderung der wissenschaftlichen Forschung (Projekt Nr. 6381). Useful communications by Dr. W. O. Hofer (KFA Jülich/FRG) are gratefully acknowledged.

References

\textsuperscript{1/} H.D. Hagstrum, Phys.Rev. 96 (1954) 336
\textsuperscript{2/} M. Kaminsky, in: Atomic and Ionic Impact Phenomena on Metal Surfaces (Springer, Berlin 1965)
\textsuperscript{3/} U.A. Arifov, L.M. Kishinevskii, E.S. Mukhamadiev and E.S. Partis, Sov.Phys.-Techn.Phys. 18 (1973) 118
U.A. Arifov, E.S. Mukhamadiev, E.S. Partis and A.S. Pasyuk, Sov.Phys.-Techn.Phys. 18 (1973) 240
\textsuperscript{7/} S.T. de Zwart, PhD thesis, University of Groningen, The Netherlands
\textsuperscript{11/} L.A. Dietz and J.C. Sheffield, Rev.Sci.Instr. 44 (1973) 183
\textsuperscript{14/} H. Kulenkampp and W. Spyra, Z. Physik 137 (1954) 416
\textsuperscript{16/} P. Schackert, Z. Physik 197 (1966) 32