2

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INCIDENT ION CHARGE STATE DEPENDENCE OF ELECTRON EMISSION DURING SLOW MULTICHARGED ION-SURFACE INTERACTIONS*

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Characteristic variations in the total electron yield γ as a function of crystal azimuthal orientation are reported for slow N^{2+},N^{5+} and N^{6+} ions incident on a Au(011) single crystal, together with measurements of γ as a function of incident ion velocity. Kinetic electron emission is shown to arise predominantly in close collisions between incident ions and target atoms, and potential electron emission is found to be essentially constant within our present velocity range. The incident ion charge state is shown to play no role in kinetic electron emission. Extremely fast neutralization times of the order of 10^{-15} secs are needed to explain the observations.

INTRODUCTION.

The total electron yield γ, defined as the average number of electrons emitted per incoming ion, arising in the interaction of multicharged ions with a metal surface may be composed of contributions from several distinct production mechanisms. Traditionally it has been useful to define electron emission as kinetic electron emission (KEE) or potential electron emission (PEE), depending on whether the ejected electrons are liberated by the conversion of kinetic or potential energy of the incident projectile. While KEE can occur only after the incident ion has impacted the target surface, PEE which can contain contributions from interatomic Auger processes such as Auger neutralisation (AN), and Auger deexcitation (AD), as well as from projectile-based intraatomic Auger processes such as autoionization (AI), can begin when the ion is at relatively large distances above the surface[1]. Recently it has been shown[2,3] that the completion of the complex cascade of Auger processes responsible for multicharged ion neutralization above the target surface requires time scales of the order of 10^{-12} to 10^{-13}s. This time scale is accessible only at very low incident ion velocity or under extreme grazing incidence conditions. For longer above surface interaction times PEE will continue after the ion has entered the target material. Indeed in a recent paper we have shown that the major part of PEE observed in experiments to date has occurred after the ion has impacted the target surface[2]. Thus a second distinction can be made depending on whether the electrons are emitted above the target surface or from within the target material. Three categories of electron emission may thus be identified; (i) KEE, which consists solely of below surface emission, (ii) above surface PEE, and (iii) below surface PEE. We present an analysis of the total electron yield for N^{2+}, N^{5+} and N^{6+} ions in the velocity range 0.25au - 0.55au, incident on a Au(011) single crystal. The total electron yield for each charge state is found to increase linearly with incident ion velocity. Characteristic variations in γ are reported as a function of the incident azimuthal angle. These variations allow us to unambiguously separate the contributions of PEE and KEE to the total electron yield. The PEE is shown to be essentially constant within our present energy range. Using computer simulations of the projectile energy loss within the target we

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have been able to reproduce the observed variations. The results of our simulations are consistent with the conclusion that KEE arises predominantly in close collisions between incident ions and target atoms. The amplitude of the observed variations is found to be independent of initial charge state. The implications of this observation for the neutralisation of the incident ion are considered.

MEASUREMENTS.

We have carried out a range of measurements of the total electron yield for N^{2+}, N^{5+}, and N^{6+} ions incident on a clean Au(011) single crystal surface. The details of our apparatus and technique have been given elsewhere[2]. In Fig 1 we present our measurements of the total electron yield as a function of incident ion velocity for N^{5+} and N^{6+} ions incident at 20^0 along the [100] direction. It can be seen that the total yield for a given incident charge state increases linearly with the incident ion velocity. In addition the slopes of the total electron yield curves in Fig 1 appear to be independent of the initial incident ion charge state. The additional emission for N^{6+} as compared to N^{5+} could be due to either PEE or an increase in KEE due to the charge state of the incident projectile. The equal slopes in Fig 1 suggest that this additional emission is independent of projectile velocity within our present velocity range, and would thus appear to be PEE.

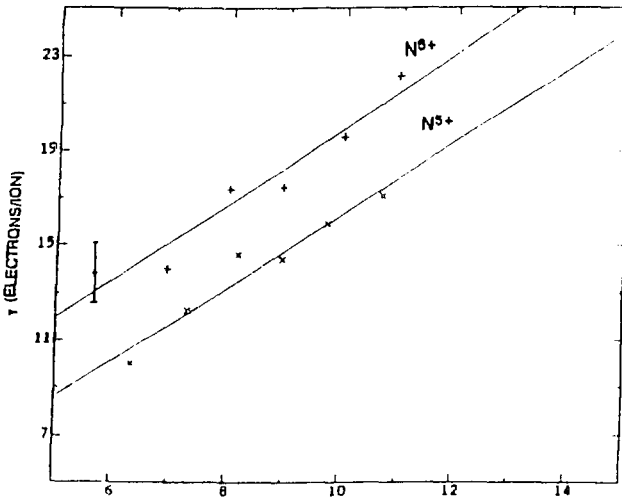

Fig 1. Total yield versus velocity.

In Fig 2a we present our measurements of the total electron yield as a function of the crystal azimuthal angle for 30 keV N^{2+}, N^{5+} and N^{6+} ions at 20^0 incidence. The total electron yield can be seen to exhibit characteristic azimuthal variations. Furthermore the amplitude of these variations is found to be independent of the incident ion charge state. We can obtain the contribution to the total electron yield due to the initial ion charge state by subtracting the spectra for N^{6+} and N^{5+}, and N^{5+} and N^{2+} incident ions respectively. These

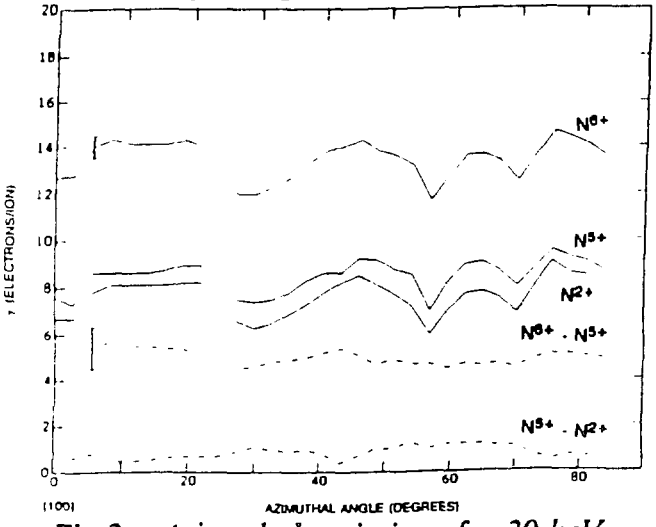

Fig 2a. Azimuthal variations for 30 keV N^{5+} and N^{6+} ions.

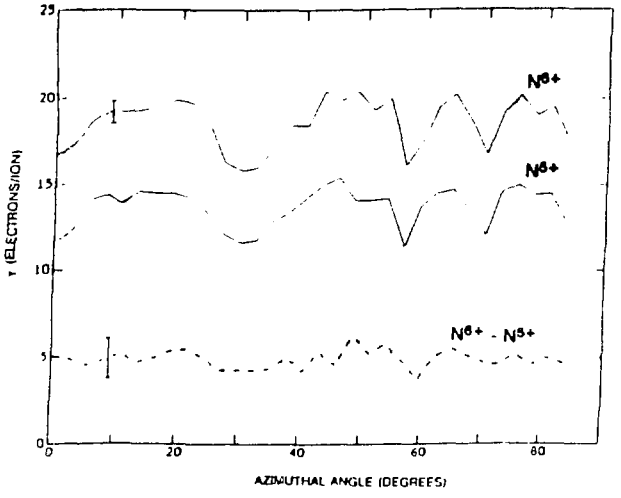

Fig2b. Azimuthal variations for 80 keV N^{5+} and N^{6+} ions.

charge state dependent contributions are also shown in Fig 2a and can be seen to be essentially azimuthally invariant. Similar measurements of the azimuthal variations in the total electron yield for 80 keV N^{5+} and N^{6+} are shown in Fig 2b for the same incidence conditions. It can be seen that the amplitude of the variations has increased. This is consistent with KEE being responsible for this component. The contribution due to the initial ion charge state can again be obtained by subtracting the N^{6+} and N^{5+} spectra. This component is found to have the same magnitude as for 30 keV incident ions.

DISCUSSION.

The azimuthal variations in the total electron yield seen in Fig 2a and 2b are suggestive of electron emission from the bulk of the target crystal. Such variations have been observed previously for singly charged ions and interpreted using simple geometrical models of the opacity of the single crystal planes[4]. The increase in the amplitude of the variations with incident ion kinetic energy indicates kinetic electron emission is responsible for this component.

The component of the electron emission arising due to the initial ion charge state is seen in Fig 2a and 2b to be essentially azimuthally invariant. This azimuthal invariance suggests that the electrons comprising this component originate either above the target surface or within a short distance below the vacuum/surface interface. It is possible that these electrons are due to either Auger emission from the fast neutralisation of the incident ion (PEE), or from an enhancement to KEE due to the survival of the initial ion charge state in the topmost layers of the target. The apparent invariance of this component with incident ion velocity suggests PEE is responsible.

Consider first KEE. The linear increase in the total electron yield with incident ion velocity shown in Fig 1 has been observed previously by Alonso et al.[5] for singly charged ions incident on a range of clean metal surfaces. For singly charged ions the total electron yield is comprised essentially entirely of KEE. The two principal theories of KEE, that of Sternglass[6] on one hand and of Parilis and Kishinevskii[7] on the other, propose different mechanisms for the primary production of excited electrons within the solid. The theory of Sternglass assumes that electrons are produced by two processes; (1) by distant or large impact parameter collisions between the incident projectile ion and target surface atoms which give rise to a large number of low energy electrons, and (2) by close or small impact parameter collisions which result in a small number of energetic electrons which may produce further electrons by cascade processes. The theory of Parilis and Kishinevskii assumes that, rather than direct excitation of electrons from the valence band into vacuum, KEE results from a two step process. In the first step, as a result of a close collision, a core electron of the target atom is excited to just above the Fermi level. The second step is the filling of this inner shell vacancy via an Auger transition with the emission of an electron from the conduction band. We have used the MARLOWE Monte Carlo simulation code[8] to calculate the energy loss of N ions within a Au target. The details of this calculation will be presented elsewhere. Fig 3 shows the local inelastic energy loss averaged over 5000 incident ion trajectories for 30 keV N ions incident at 20^0 on a Au(011) single crystal as a function of crystal azimuthal orientation on traversing a slab of thickness 40Å. It can be seen that the local inelastic energy loss exhibits azimuthal variations similar to those observed experimentally in the total electron yield. The nonlocal inelastic energy loss was also calculated but does not show the observed variations. It appears therefore that within the present energy range, KEE arises from an apsis dependent local energy loss mechanism.

Nonlocal energy loss mechanisms such as the excitation of nonlocalised valence electrons, do not appear to play a significant role. Now consider the time scale required for the completion of PEE. Two aspects of the present measurements suggest that extremely rapid neutralization is occurring. Firstly, the constant amplitude of the azimuthal variations, seen in Fig 2a and 2b, show that the contribution of the initial ion charge state to KEE is small. This conclusion is in agreement with previous measurements by Schram et al.[9] and Pedrix et al.[10] If the initial ion charge state were to survive far below the target surface, an enhancement of KEE would be expected. That no such enhancement is observed suggests rapid projectile neutralization within the first few layers of the target surface. Secondly, the independence of PEE from the incident ion velocity within our energy range, as shown by the equal slopes of the curves for N^{5+} and N^{6+} in Fig 1 and by the independence of the intensity of the azimuthally invariant component in Fig 2a and 2b, also indicates rapid projectile neutralization. Since PEE is projectile related emission, the emitted electron intensity would be expected to decrease as the ion penetrates further into the target material where inelastic electron scattering becomes important. That PEE is observed to be constant in the present energy regime, suggests that PEE is complete within one electron inelastic mean free path of the surface. Assuming straight line trajectories, this indicates neutralization times of the order of 10^{-15} secs, which is consistent with previous measurements in this laboratory[2].

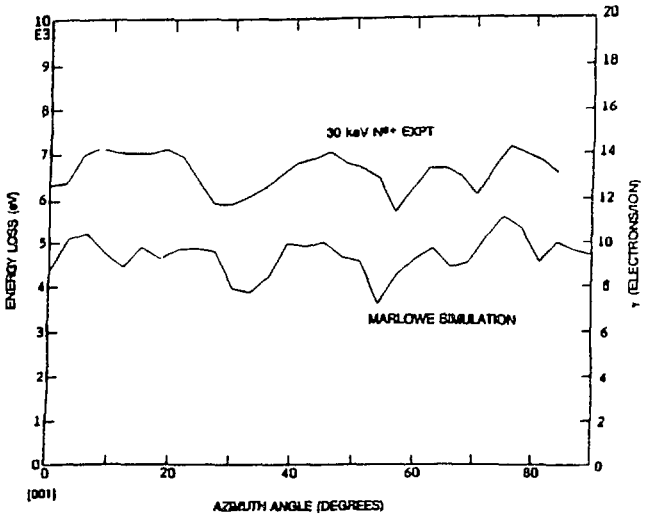

Fig 3 MARLOWE energy loss calculation.

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