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SHOCK ELECTRONS FROM ION-SOLID PENETRATION[1]

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Résumé

Les distributions angulaires des électrons lents (E_e<20 eV) émergeant d'une cible solide lorsque elle est bombardée avec des ions rapides montrent des structures importantes qui peuvent être expliquées à l'aide de la prédiction théorique de l'émission des électrons directionels induite par des ondes de choc dans le plasma d'électrons à l'intérieur du solide. L'émission de ces électrons directionels dépend fortement de l'état de la surface de la cible.

Abstract

Angular distributions of low energy electrons (E_e<20 eV) from ion-solid-penetration show prominent peak structures which agree in each studied detail with the predicted directed electron emission from shock waves in the electron plasma of the solid. The emission of shock electrons is strongly influenced by surface contamination and structure.

Penetrating a solid foil, a fast ion (ion velocity $v_P \geq v_B$, v_B=Bohr velocity) causes a collective response of the electron plasma, which manifests as an electron density fluctuation with axial symmetry, the dynamical polarization wake /1/.
Experimental studies show an influence of the wake on such signals as e.g. the energy-angle distribution of fragments of coulomb-exploding molecular ions /2,3/, on ion induced secondary electron emission /4,5/, on the stopping power of molecular ions /6/ and on the substate population of heavy hydrogenlike ions produced by electron capture in solids /7/.
The ion induced electron density fluctuations show the characteristic behaviour of Mach shock waves propagating in cones through the solid with the group velocity v_s. This has been predicted to lead to the emission of "shock electrons" in a direction perpendicular to the shock wave front /8/. The preferential emission angle Θ_{em} is given by the Mach relation $\cos \Theta_{em} = v_s / v_P$ as a function of the projectile

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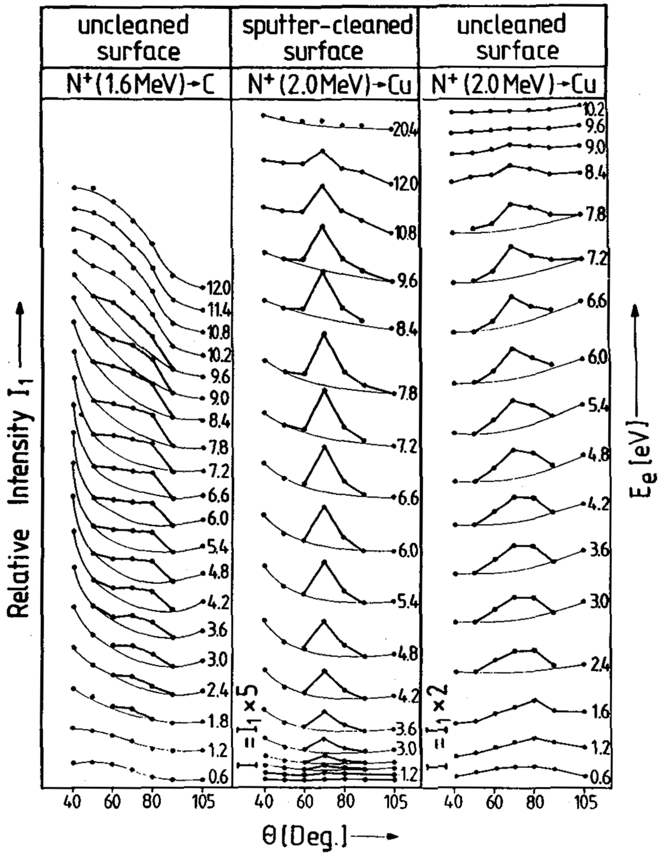

Fig.1: Angular distributions ($40^o \le \Theta \le 105^o$) of low energy secondary electrons at different electron energies 0.6 eV$\le E_e \le$20.4 eV from a C-foil (d=1000Å;left) and an uncleaned resp. sputter-cleaned Cu-foil (d=1000Å;centre and right) bombarded with N^+ (see text). Note the different intensity scales!

velocity v_p /8,9/. It has been proposed to detect shock electrons as peak structures in angular distributions of low energy secondary electrons emitted from thin solid foils in the forward half cone with regard to the beam direction /8/. Recently, first evidence for the emission of shock electrons has been found /10/. Angular distributions of low energy electrons show prominent structures at electron energies E_e<20 eV. The mean emission angle Θ_{em} of electrons from these peak structures depends on the projectile velocity v_p according to the Mach relation and the target electron density n_e in agreement with the theoretical predictions /8,10/.

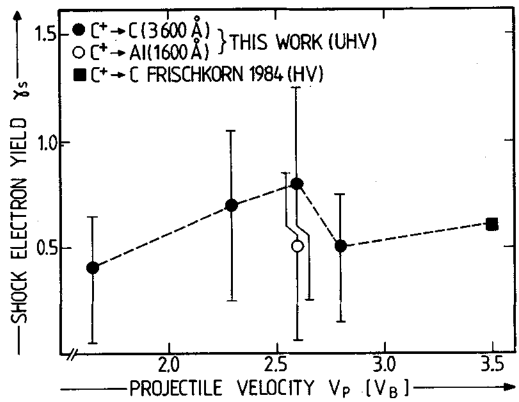

Fig.2: Number of shock electrons per incoming projectile γ_s as a function of the projectile velocity v_p.

Fig.1 gives an example of angular distributions ($40^o \le \Theta \le 105^o$) of low energy secondary electrons at different electron energies 0.6 eV$\le E_e \le$20.4 eV from the collision systems N^+ (E_p=1.6 MeV) on C-foil (d=1000Å) and N^+ (E_p=2.0 MeV) on Cu-foil (d=1000Å). The distributions have been measured under ultrahigh vacuum conditions ($p \approx 10^{-7}$ Pa) from uncleaned and sputter cleaned solid surfaces with an electrostatic electron energy analyser /11/. The surface condition of the solid foil targets has been controlled by Auger- and secondary electron spectroscopy and Rutherford forward scattering /12/. Static magnetic fields of the environment were compensated to less than 10 mGauss. In every angular distribution, a v_p-dependent peak appears at electron energies E_e<20 eV superimposed on the continuous secondary electron background. For electron energies E_e>20 eV, the secondary electron intensity shows only a weak monotonic dependence on the observation angle Θ .

The surface structure and composition of a solid strongly influences both the total secondary electron yield /13/ and the shape of secondary electron energy distributions /13,14/, especially in the case of low energy electrons E_e<20 eV. Electron emission from the single electron deexcitation of plasmons, a collective effect related to wake phenomena, is strongly dependent on surface properties,too /15/. The transmission of electrons through the surface, their energy loss and reflection at the surface strongly depend on both the surface potential barrier and the surface structure, influenced by adsorbed substances and oxides /14/. The important influence of these surface properties on shock electron emission is demonstrated in fig.1. In the case of a sputter cleaned (8 nAmin Kr^+-ions of 24 keV/u specific energy) copper target, the shock electron intensity is enhanced by a factor of 3 and shows a sharper maximum at $\Theta_{em} \approx 70^o$ over a broader range of electron energies 1 eV $\le E_e \le$ 20 eV compared to an uncleaned copper target, where the shock electrons appear at lower energies E_e<12 eV. In the case of an uncleaned copper surface, which is covered mainly by carbon /12,14/, the angular distribution and the shape of the shock electron structure resemble the angular distributions from carbon targets (fig.1).

Surface diffraction and reflection phenomena, caused by the surface potential barrier and geometrical inhomogeneities leading to a broadening of the shock electron peak, are not included in recent theories /8,9/. Surface absorption and reflection effects can also be the reason for the deviation of the theoretically calculated number of shock electrons per projectile produced inside the solid ($\gamma_s \approx 1000$) from the measured number of shock electrons ejected from the surface ($\gamma_s \approx 0.7$). The shock electron yield γ_s is shown in fig.2 as a function of the projectile velocity v_p for the collision systems $C^+ \Rightarrow C$ and $C^+ \Rightarrow Al$. The γ_s-values are only a rough estimation based on the following assumptions: 1. The secondary electron yield in forward direction for the quoted collision systems is $\gamma_f \approx 25$, 2. the transmission of the spectrometer is $T(E_e)=1$, 3. the secondary electron intensity shows only a weak, cosine-like dependence on the observation angle Θ and 4. 85% of all emitted electrons have energies less than 20 eV. This calculation leads to a surprisingly good agreement with an estimate of γ_s given by Frischkorn /16/ (see fig.2).

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