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SECONDARY ELECTRON EMISSION FACTORS FROM METALS BOMBARDED WITH HIGHLY-CHARGED, LASER-PRODUCED TANTALUM IONS

Y. Amdidouche, M. Bourgeois, J.L. Collier, T.R. Sherwood

Abstract

Copper-Beryllium and stainless steel surfaces were bombarded with highly charged tantalum ions with charge states ranging from 7+ to 20+. The electrons emitted from these surfaces were collected, and the secondary emission factor, γ, was determined in the energy range 20-150 keV for the incident ions. The projectile Ta ions were produced using the CO_2 laser of the CERN Laser Ion Source facility. The dependence of γ on the projectile ion charge states, ζ, and energy is given. The experimental results are compared with existing theoretical predictions.

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Secondary Electron Emission Factors from Metals Bombarded with Highly-Charged, Laser-Produced Tantalum Ions.

Y.AMDIDOUCHE, M.BOURGEOIS,J.L.COLLIER, T.R.SHERWOOD

European Organization for Nuclear Research (CERN), CH 1211 Geneva 23, Switzerland

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1. Introduction

The emission of particles from solids and particularly Ion Induced Electron Emission (IIEE) phenomena are of great importance in such fields as materials science, study of beam losses in accelerator vacuum chambers, charge collectors and particle multiplier design and calibration.

Ejection of electrons from metals under ion bombardment has been studied intensively, both theoretically and experimentally. An extensive survey of the subject is given in [1,2,3].

The present work concerns the measurements of γ from chemically cleaned Copper-Beryllium (CuBe) and stainless steel bombarded under normal incidence. Experimental values of the electron yield for heavy ions such as Ta, with few keV/ζ are needed, especially when using secondary electron multipliers (SEM) with CuBe dynodes for measuring ion beam currents, ζ is the incident ion charge state. The determination of γ for stainless steel surfaces may also help the study of interactions between ion beams and vacuum chambers. A Secondary Electron Detector (SED) was built for this purpose. Only results for Copper-Beryllium surfaces are presented.

The ζ- dependence and the projectile kinetic energy dependence on γ were investigated. The results are compared with the potential emission and kinetic electron emission theories.

2. Experimental arrangement and method

2-1 Experimental arrangement

Figure 1 shows a scheme of the experimental layout. The laser ion source (LIS) and the characteristics of the 50J per pulse CO_2 laser are described in [4]. In comparison with the nearly mono-energetic beams obtained with other types of ion source, the ions produced by an LIS have an energy spread of a few keV/ζ. The ions with different ζ can be distinguished by time of flight (TOF) after passing through the 77^0 magnetic analyzer. For a given magnetic induction (B) setting, only the laser-created ions with a narrow range for the ratio momentum per charge, P/ζ, are selected and reach the detector. The range is adjusted by varying the slit widths.

2-2 Apparatus and method.

Figure 2 shows the secondary electron detector and its associated equivalent electronics. The detector is located in a cylindrical vacuum chamber placed at the 77^0 exit port of the magnet analyzer. Two 1.5 mm thick 48mm diameter targets are used, CuBe (with 10 % beryllium) and stainless steel 316 L. The electron collector is a 70x10mm copper plate. In order to avoid secondary electrons which can be emitted from the magnet slit edges from reaching the collector, an electrode with a 30x 80 mm aperture is placed in front of the slits at the magnet exit slits. The surrounding chamber is grounded.

The ion beam passing the electron collector electrode induces a current in it, and distorts the secondary electron pulse shape. This phenomenon is geometry dependent. The first attempt to collect the electrons was with a cylindrical tube, as in [5,6]. However, the use of a plate, instead of a cylinder for collecting the secondary electrons was found to be preferable, because it reduces the induced current.

The electron collector plate voltage was fixed at V_c=300V. The front electrode was biased at V_{fe}= - 350V and target was earthed. Two identical amplifiers, each with a gain of 10^5 V/μ A and a rise time of 50ns were used. For each selected laser shot, the amplified signals from the target and electron collector were recorded on a Tektronix digital oscilloscope, and sent to a computer for storage and data treatment.

Figure 3 shows typical oscilloscope traces for CuBe TOF spectra. The peaks on the lower traces peaks are for Ta ions of different charge impinging on the target. In figure 3, times of flight for ions with charge state ζ=22+ and ζ=12+ are 8.1 μs and 14.8 μs respectively. For a magnet analyzer, if τ_ζ is the TOF for an ion of charge state ζ, the ratio $\frac{\zeta}{P}$ is constant, or for $\tau_\zeta = \frac{l}{v}$, where τ is the flight time and l is the flight path. Then the product $\zeta \cdot \tau_\zeta$ is constant

$$\zeta \cdot \tau = K \qquad (1)$$

For a given $\tau_\zeta = t_\zeta - t_0$, where t_ζ is the measured time on the oscilloscope trace, and t_0 a constant dependent on the laser triggering, equation (1) leads to $t_i = a + (b \cdot 1/\zeta)$ (2)

where a and b are constants.

A least squares fit based on a χ^2 minimization method was performed in order to assign a charge state value ζ to each ion peak in the TOF spectra.

The design of the SED is based on the method used in [5,6]. Currents due to the projectile ions and the ejected electrons were measured on the target and collector plate, and later integrated to obtain the charge.

The value of γ is given by $\gamma = \zeta \cdot \frac{|Q_c|}{Q_t - |Q_c|}$ (3)

and the number of ions N_i is given by: $N_i = \frac{Q_t - |Q_c|}{\zeta \cdot e}$ (4)

were Q_c and Q_t are the total charges resulting from currents emitted from the electron collector and the target respectively, and e the electronic charge. During all the experiments, the pressure inside the detector vacuum chamber was maintained at $\cong 10^{-7}$ torr.

3. Results and discussion

The dependence of γ on the ion velocity is represented on figures 4-a and 4-b, for different ion charge states, ranging from ζ=9+ to ζ=16+. The energy range covered is 20 keV to 120 keV per ion. For these measurements, the magnetic induction was varied between 0.09 to 0.15T, and a series of laser shots was taken for each magnetic induction setting. From the obtained TOF spectra, it was possible to reconstruct the variation of γ with the ion velocity for different charge states. Each experimental point is averaged over a number of laser shots varying between 2 to 20. A weighted least squares fit was applied to the experimental points in order to get an estimate of γ for a given charge and at a given velocity. For charge states higher than 17+, the number of experimental points was less than 5 and therefore the results less accurate.

For all ζ in figures 4, γ increases with the ion velocity. It is then necessary to see if a correlation exists between the secondary electron emission factor and ζ at a given velocity. Figure 5 shows the representation of γ with the Ta ion charge state, obtained from figures 4-a and 4-b, by recording γ values at three different velocities, 2.3 10^5, 2.52 10^5 and 2.72 10^5 m/s, corresponding respectively to 50, 60, and 70 keV for Tantalum. A fit based on a χ^2 minimization method was applied to the data.

The state of the target surfaces influences the secondary electron emission. For surfaces which have not been cleaned, γ may be a factor 3 to 4 higher than for pure metallic surfaces. In our experiment, at least a factor two is present in the γ values between a gas covered and a chemically cleaned CuBe target.

Two theoretical models exist for explaining the mechanism of ejection of electrons by metals: Potential Emission (PE) and Kinetic Emission (KE). These are discussed respectively in [2] and [3].

Basically, below a velocity range of 0.6 to 1.0 10^5 m/s, IIEE is primarly due to the PE mechanisms, providing the ionization potential of a singly charged ion exceeds twice the work function of the metal target. This condition is always fulfilled with highly-charged ions. The potential emission is a Coulomb force based process. Some of the target electrons are attracted by the electric field induced at the metal surface by the incident ions. Therefore, γ should depend on the ion charge. For ion velocities greater than 1.0 10^5 m/s , the KE mechanism will be superimposed on the potential emission. At higher velocities, the kinetic emission may become the dominant process. A part of the kinetic energy of the incident ion is transferred to the target electrons, of which a fraction can leave the target. Therefore, the resulting γ should depend on the kinetic energy of the incident ion, and γ should be similar for all ion charges.

In the energy range of 2 10^5 m/s to 2 10^6 m/s, the secondary electron factor is proportional to the ion velocity and thus varies as the square root of the kinetic energy. This comes from the dependence of γ on the inelastic stopping power of the incident ion in the metal as predicted and observed in [8]. Taking the proportionality of γ on the ion velocity as an assumption, experimental data of figure 4 were fitted to a straight line. The values of velocities in figure 5 are just within that range. On can observe that for $v_i = 2.3\ 10^5$ m/s an increase of γ, both with ion velocity and with ion charge state. For $v_i = 2.72\ 10^5$ m/s, γ increases with the Ta ion velocities, but tends to be independent of ζ. Therefore, below $v_i = 2.72\ 10^5$ m/s, both kinetic and potential emission contribute to the secondary electron emission. While above this velocity, the electron ejection starts to be dominated by the KE process.

Conclusion

The IIEE for Copper-Beryllium bombarded with highly-charged Ta ions under normal incidence was studied in order to determine the dependence of γ on the incident ion charge state and kinetic energy. The secondary electron emissi factor, γ, was measured for Ta^{8+} to Ta^{17+} in a kinetic energy range from 20 to 120 keV. The variation of the electron emission factor with the ion velocity was deduced from the experimental results and will help to get values of γ for high charge state Ta ions in this energy range. The results have shown that for ion velocities below 2.7 10^5 m/s, the ejection of electrons by highly-charged Ta ions may be due to both PE and KE mechanisms. An extension of the velocity range to higher velocities could be made by accelerating the laser-produced ion beam. The determination of the energy distribution of the ejected electrons would help to obtain a better understanding of the mechanism involved in the ejection of electrons by heavy ion bombardment.

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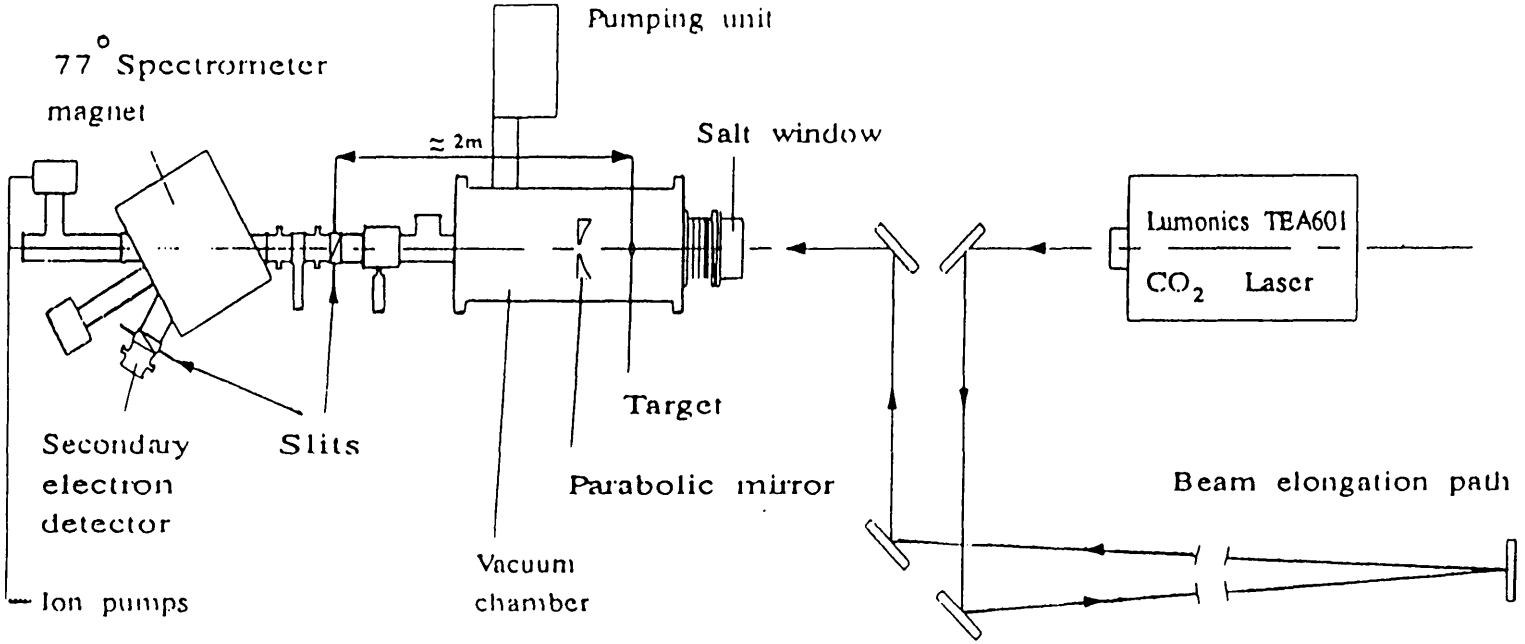

Figure 1: Schematic representation of the Laser Ion Source experimental arrangement.

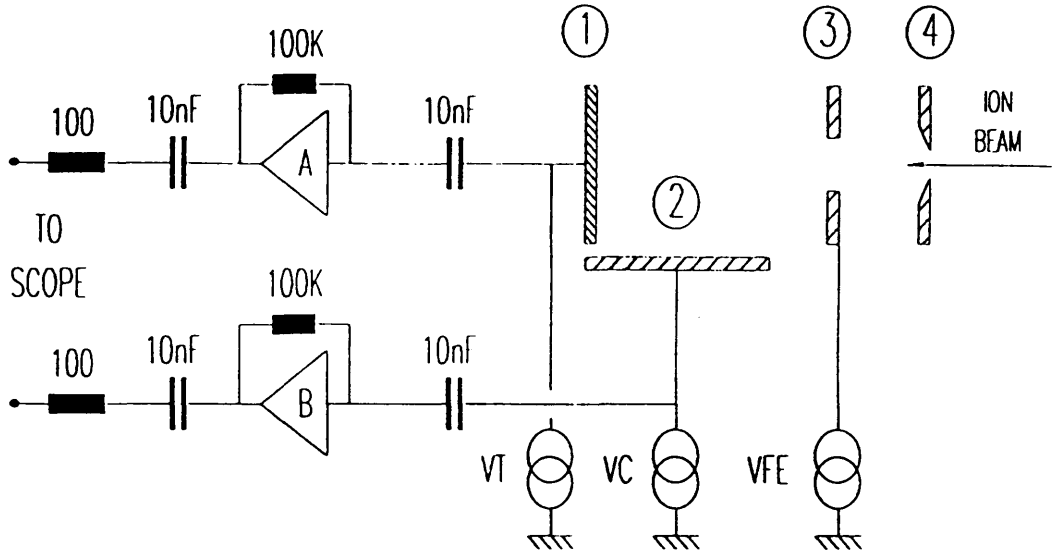

Figure. 2: Secondary Electron Detector scheme.
1: target 2: electron collector electrode 3: front electrode 4: magnet slits . Equivalent circuits: target (A) and electron collector (B) amplifiers.

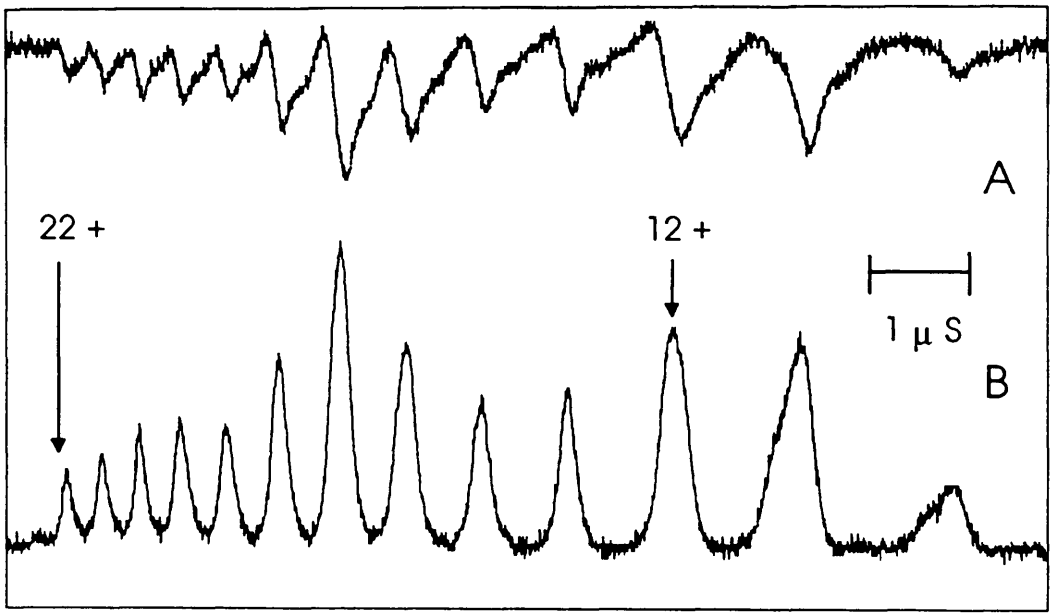

Figure 3 : Electron collector (A) and CuBe target (B) signals for a magnetic induction of 0.11T.

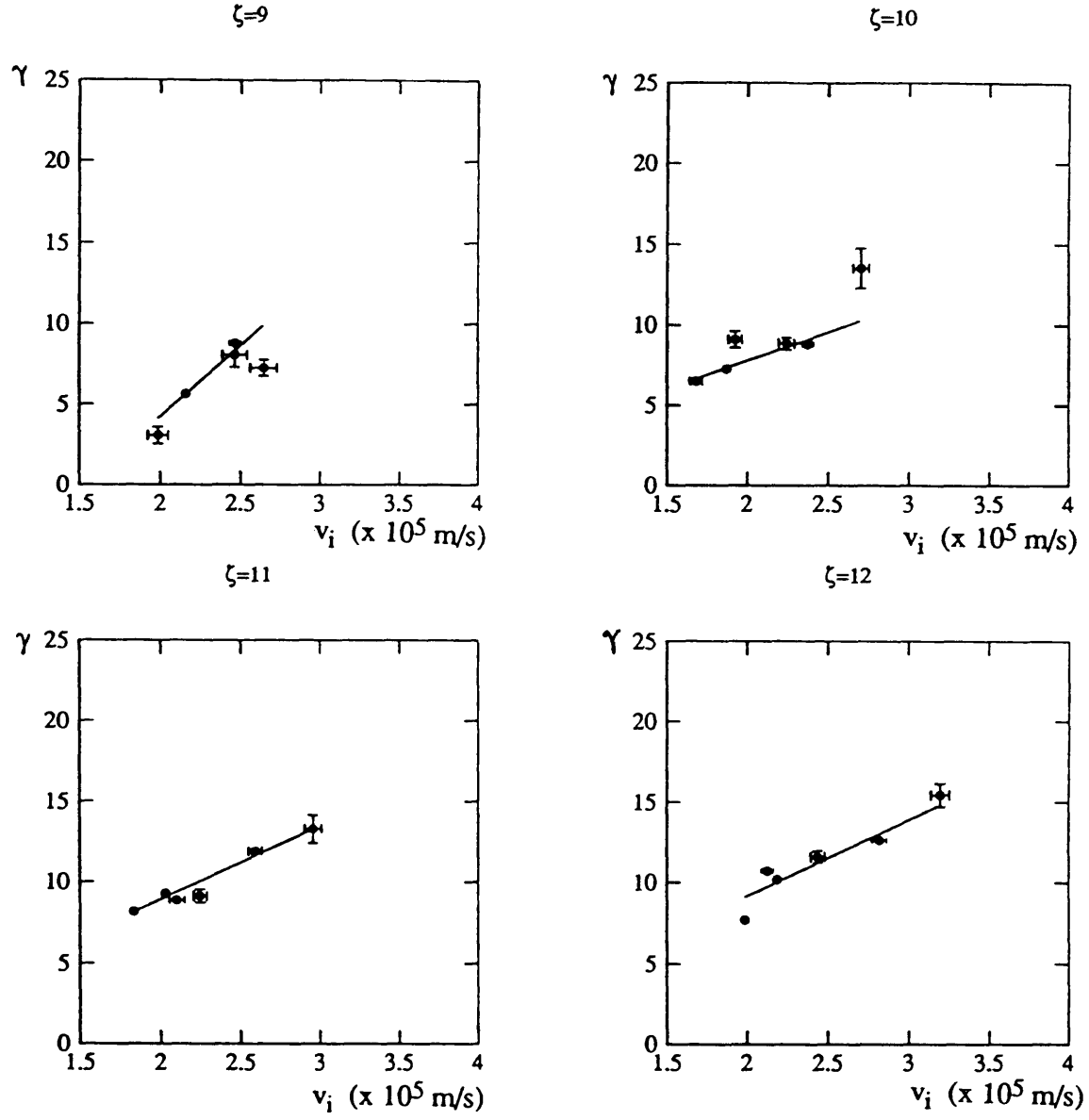

Figure 4-a: Secondary electron factor γ against Ta ions velocity, v_i (x 10^5 m/s), for ion charge states 9+ to 12+. The ion energy is ranging between 25 keV and 95 keV. The CuBe surface is chemically cleaned.

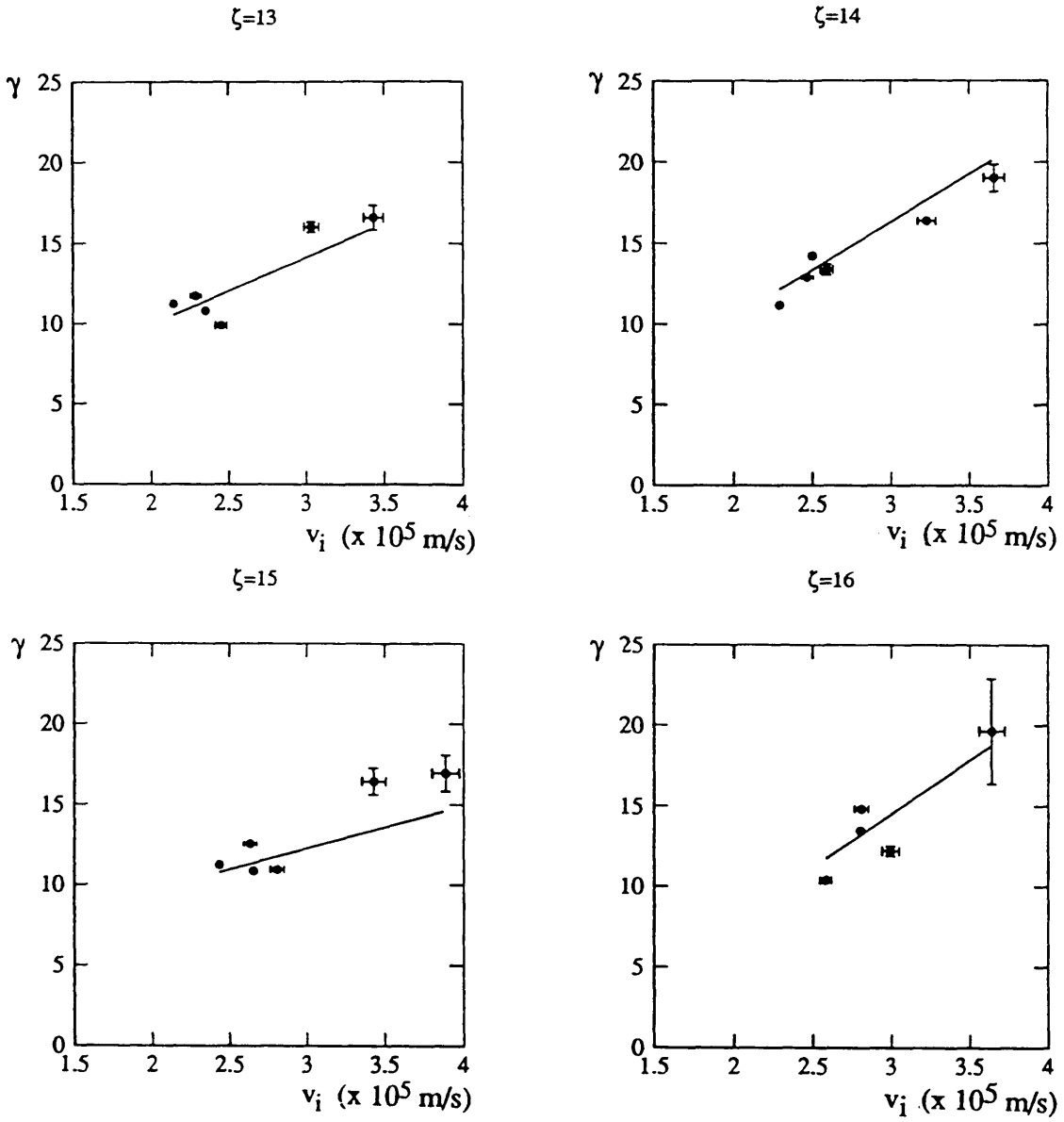

Figure 4-b: Secondary electron factor γ against Ta ions velocity, v_i (x 10^5 m/s), for ion charge states 13+ to 16+ impinging on the same CuBe surface as in 4-a. The corresponding ion energy range is 40 to 120 keV.

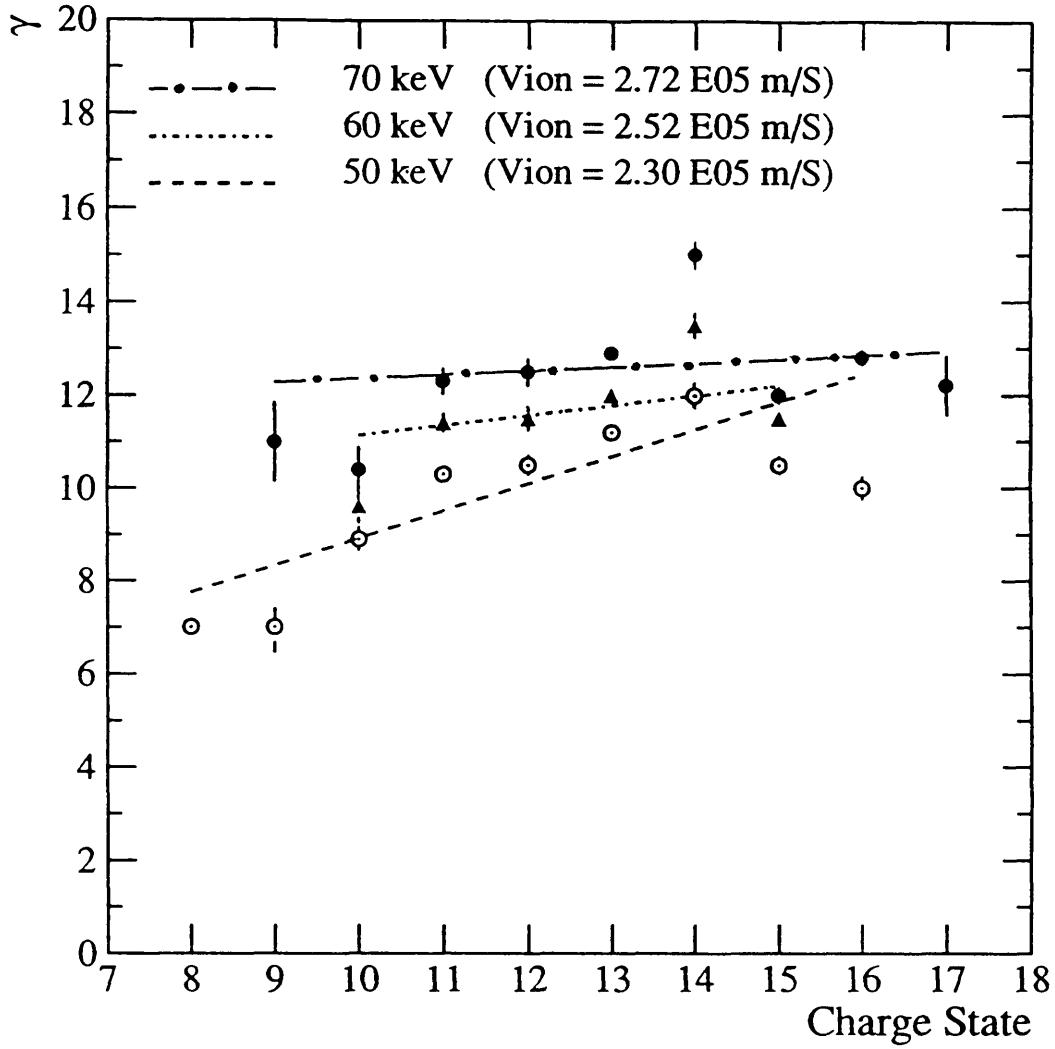

Figure 5 : Secondary electron factor, γ, against Ta ion charge state for three different ion velocities corresponding to 50 keV, 60 keV and 70 keV. The CuBe surface is chemically cleaned.