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Report

SECONDARY ELECTRON EMISSION OF SAPPHIRE TUNGSTEN MOLYBDENUM AND TITANIUM FOR MAXWELLIAN INCIDENT ELECTRONS

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SECONDARY ELECTRON EMISSION OF SAPPHIRE TUNGSTEN MOLYBDENUM AND TITANIUM FOR MAXWELLIAN INCIDENT ELECTRONS

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ABSTRACT

The second electron emission coefficient of various materials, namely titanium, molybdenum, tungsten and sapphire, has been calculated for a Maxwellian energy distribution from data for a normally incident monoenergetic beam of primary electrons. The most significant difference from the monoenergetic case occurs at low energies. In addition the influence of the incident angle of the electrons is discussed.

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INTRODUCTION

To study plasma wall interaction in fusion reactors it is necessary to know the yield of secondary electrons released by the impact of the plasma electrons on the surface. These incident electrons, in the case of a hot plasma, usually have a Maxwellian distribution even when they have passed through a boundary sheath. Unfortunately, most data in the literature are for mono-energetic incident beams. Hence, the purpose of this work is to consider several materials which are representative of those used in high temperature experiments, namely titanium, tungsten, molybdenum and sapphire, and to evaluate the difference between their secondary electron yields due to mono-energetic incident electrons at energy E, and their average Maxwellian yield at temperature T, given as $\sigma(E)$ and $\sigma_M(T)$ respectively. In general, the secondary electron yield $\sigma(E)$ increases from a low threshold of a few eV to a maximum at a few hundred eV, above which it decreases. For Maxwellian incident electrons at a low temperature T, the emission will be dominated by the high energy tail of the distribution function and so the yield should be higher than that due to monoenergetic electrons at energy E = kT and the appearance potential will be smeared out. At higher temperatures ($T \gtrsim 300$ eV), $\sigma_M(T)$ should be smaller than $\sigma(E)$ but the proportional difference will not be as great as at low energy.

The Maxwellian emission coefficient was computed as follows:

$$\sigma_M(T) = \int_{E=0}^{E=30\ kT} \left(\frac{E}{kT}\right) \sigma(E) \exp\left(\frac{-E}{kT}\right) d\left(\frac{E}{kT}\right)$$

For practical reasons a finite upper limit of integration was chosen for the energy E. In this case, it is 30 kT. The error in $\sigma_M(T)$ due to taking a finite limit was negligible in comparison to other errors.

In the present paper, σ is defined as the ratio of the "total" secondary emission electron flux to the incident electron flux. This coefficient includes the "true" secondary electron emission coefficient, δ, and the "back-scattered" electron coefficient, η, through the relationship, $\sigma = \delta + \eta$. In our data, wherever possible, we used δ instead of σ. However, there were no available data for Ti. To show the influence of η we have plotted both δ and σ for Mo, noting that these two coefficients, δ_M and σ_M, have been calculated from values of $\delta(E)$ and $\sigma(E)$ measured by different authors. This comparison confirms that the coefficient η is important both for slow primary electrons (up to 10 eV) and is also apparent for fast primary electrons (several keV).

The results described here were used by Harbour and Harrison[1] to calculate

the effective electron emission coefficient from a tokamak divertor target with the plasma separated from the target by an electrostatic sheath.

RESULTS AND DISCUSSION

In Figures 1-3, the broken line represents the coefficient $\delta(E)$ plotted against energy, E, for sapphire, tungsten and molybdenum respectively[2-4]. The full line represents the coefficient for Maxwellian electrons, $\delta_M(T)$, plotted against kT. The coefficient σ is plotted against energy for molybdenum[5] (Fig.4) and titanium[6] (Fig.5). Again the broken line represents the coefficient $\sigma(E)$ for monoenergetic electrons of energy E while the full line represents $\sigma_M(T)$ plotted against kT.

For most of the materials under discussion σ or δ are known only up to a certain energy, E_1. In order to calculate σ_M or δ_M it was necessary to extrapolate $\sigma(E)$ or $\delta(E)$ in the range $E > E_1$. By examining the tungsten data for which $\delta(E)$ is given at energies up to 200 keV, it was concluded that the extrapolation $\delta(E) \alpha E^{-1}$ was reasonable for calculating δ_M at temperatures up to $kT = E_1$ and the associated error reached a maximum of about 10% for typical values of E_1. For titanium, apparently no data are available for $\sigma(E)$ at energies greater than 580 eV and, from this energy, the extrapolation $\sigma(E) \alpha E^{-1}$ appears inappropriate. In fact for many materials $- d\sigma/dE$ is approximately constant in the range 500 eV < E < 2 keV so for titanium it was assumed to be equal to the value of $- d\sigma/dE$ at 580 eV in the range 580 eV < E < 2 keV, above which the same high energy extrapolation $\sigma(E) \alpha E^{-1}$ was used. These errors associated with extrapolation are no greater than typical experimental errors in the monoenergetic data which appear to range from ± 5 to 12%.

Figures 1 to 5 show that the Maxwellian peak occurs at an energy a few hundred eV lower than the peak of $\sigma(E)$ or $\delta(E)$; also, at the peak, the Maxwellian yield is 10 to 15% smaller. At higher energies the Maxwellian coefficients are 20 to 30% lower than the monoenergetic coefficients and this difference falls to less than 10% at around 10 keV but the curves do not appear to cross. However, the most significant difference comes at low energies where δ_M exceeds $\delta(E)$ by 30 to 60% in the range 30 to 100 eV. The difference is not so great between σ_M and $\sigma(E)$ at low energies for σ_M varies more slowly with energy because of the contribution of the elastically back-scattered electrons.

The experimental data were obtained for normally incident monoenergetic electrons. For a plasma, the direction of electron incidence on the wall often follows a cosine distribution. As a result, the secondary electron emission is enhanced[7]. Bronshtein and Segal[8] measured the variation of σ with

angle of incidence in the energy range $0 < E < 3600$ eV. We have integrated their results for monoenergetic electrons incident on tungsten over a cosine distribution and in Figure 6 the cosine averaged coefficient, $\overline{\sigma_\theta}$, is compared with the coefficient for normal incidence, $\sigma_\perp$, as a function of impact energy, E. Thus it is seen that in addition to the corrections to secondary emission coefficients due to Maxwellian velocity distributions, a correction of about + 17% at low energy and + 27% at 3600 eV is required to allow for the variation in angle of incidence. A correction of approximately the same magnitude is required for δ.

Finally, it should be noted that the secondary emission coefficients under discussion were generally measured for clean materials. In a hot plasma the walls of the containing vessel would contain a substantial quantity of gas, both in the bulk of the material and on the surface. Under these conditions the secondary emission coefficients would be expected to be higher than for clean surfaces. Nevertheless, corrections of the type described in this paper would have to be made.

Acknowledgment

We would like to thank Dr E S Hotston for his invaluable contribution in computing the results.

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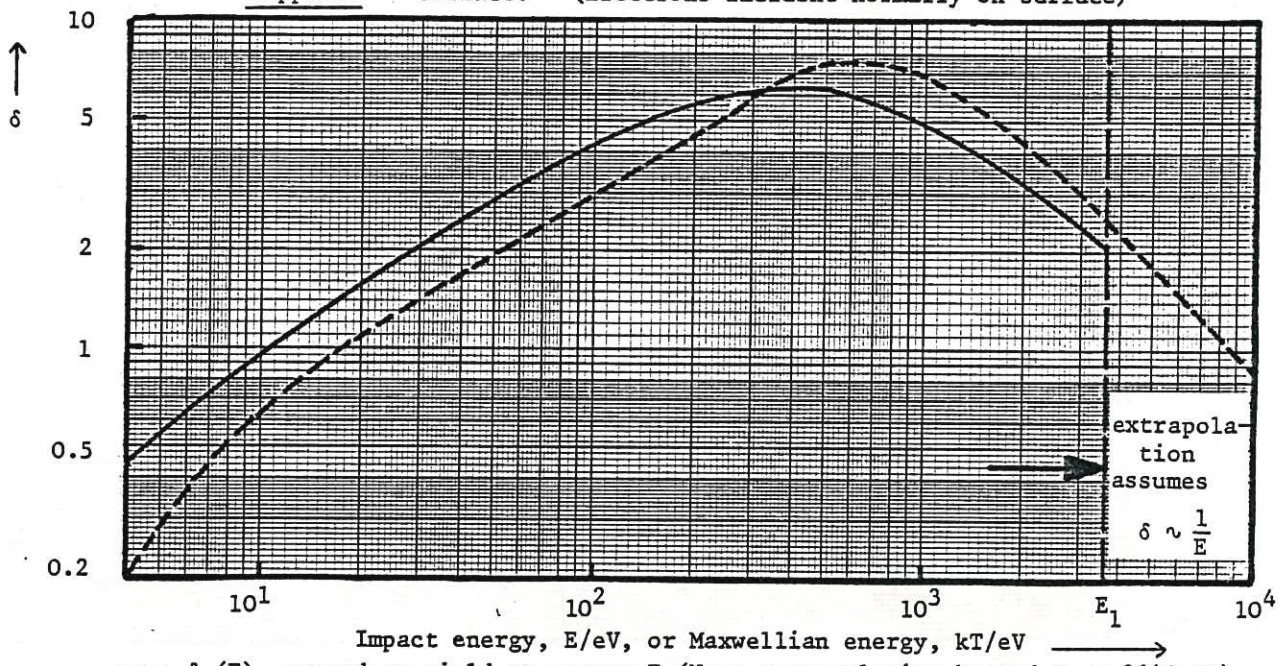
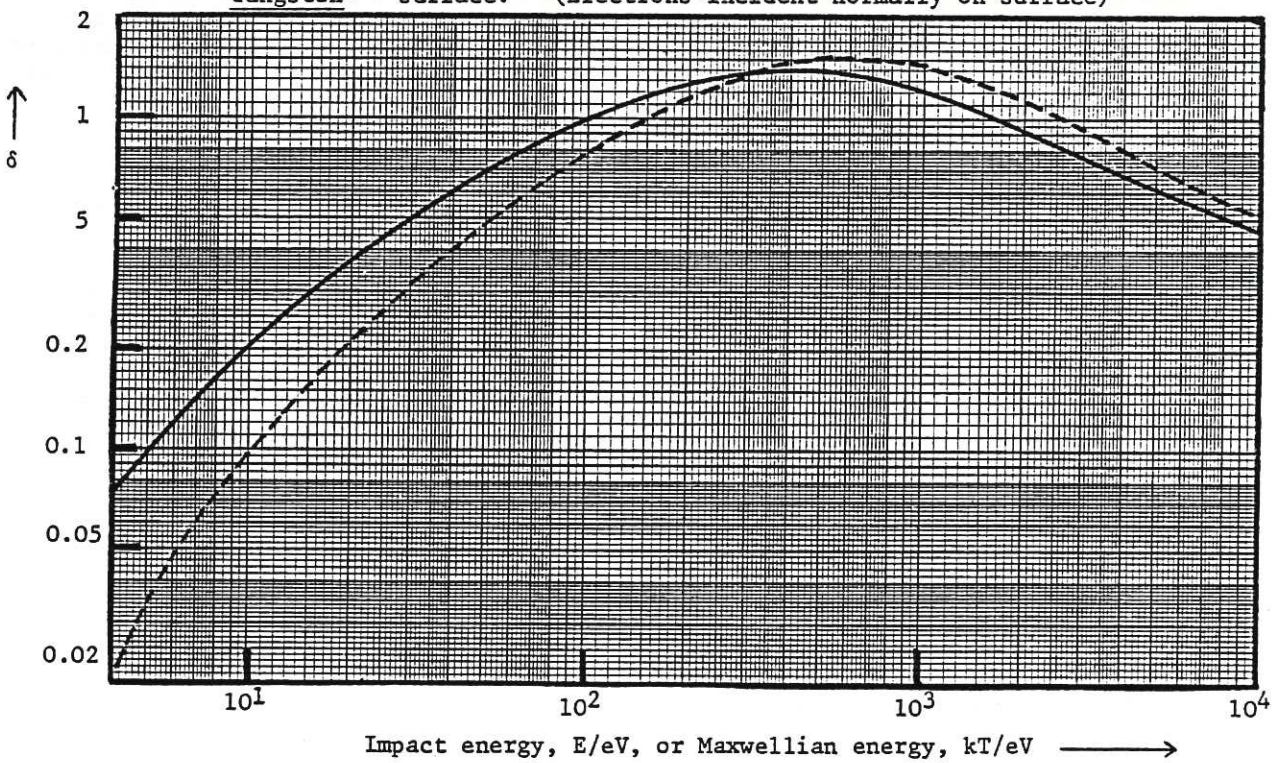
Fig.1: "True" secondary electron yield by electron impact on a highly polished sapphire[2] surface. (Electrons incident normally on surface)



---: δ (E), secondary yield at energy E (Note extrapolation beyond E_1 = 3640 eV)

——: $\delta_M(T)$, average Maxwellian yield at temperature T.

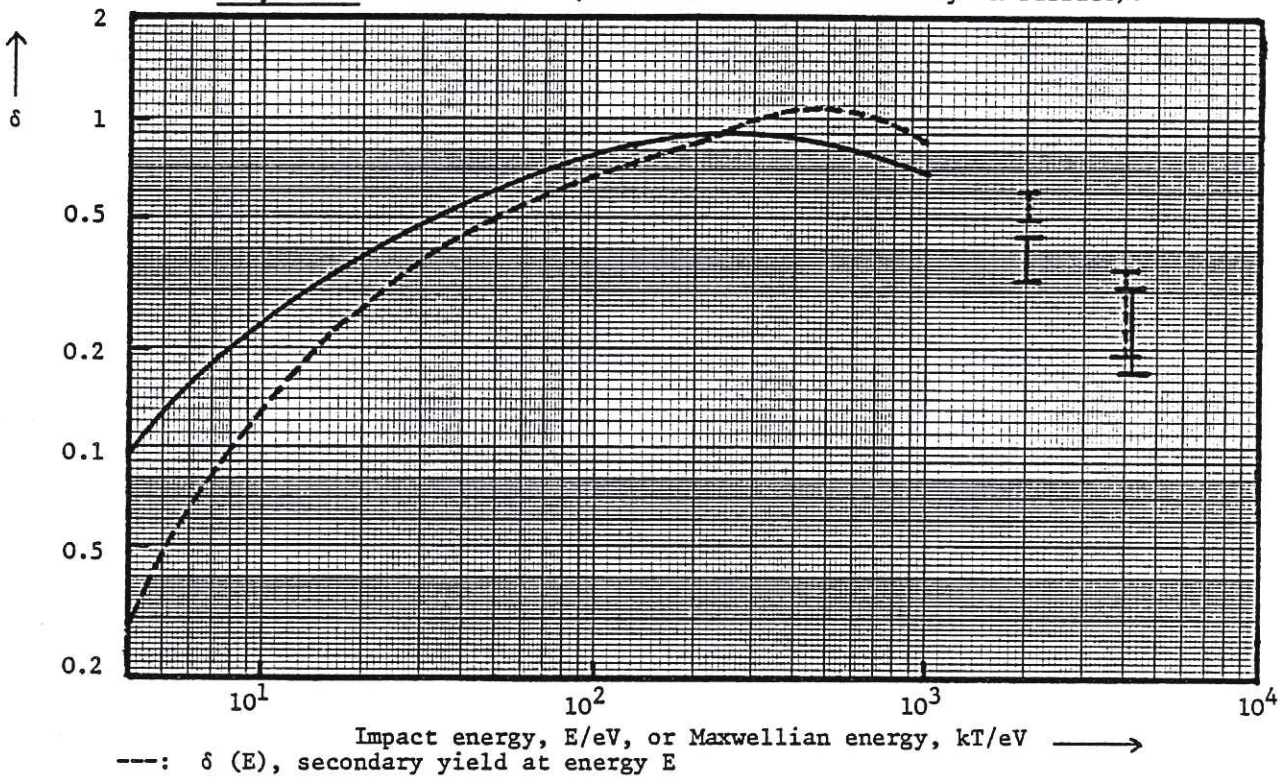
Fig.2: "True" secondary electron yield by electron impact on a polycrystalline tungsten[3] surface. (Electrons incident normally on surface)



---: δ (E), secondary yield at energy E

——: $\delta_M(T)$, average Maxwellian yield at temperature T.

Fig.3: "True" secondary electron yield by electron impact on a polycrystalline molybdenum[4] surface.* (Electrons incident normally on surface).

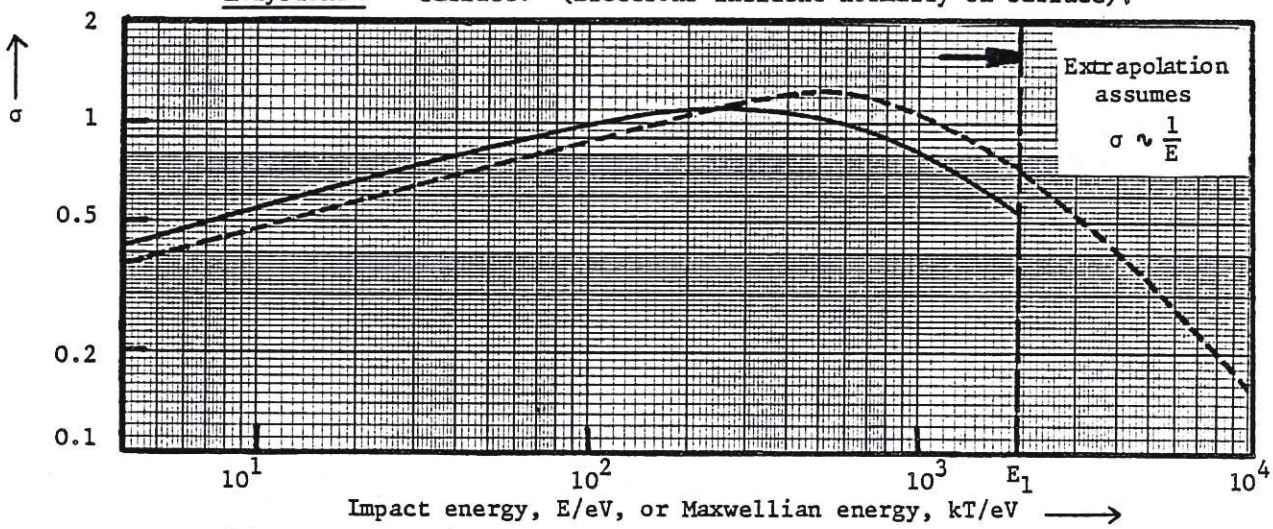


---: δ (E), secondary yield at energy E

——: $\delta_M(T)$, average Maxwellian yield at temperature T.

*The data in Reference 4 were misplotted in the range 200 ≤ E ≤ 1 keV. Also, above 200 eV, δ was obtained by subtraction of η from σ. However, at high energies the results are inconsistent, so above 1 keV an extrapolation was estimated by comparison with data for tungsten. This estimate is shown at 2 keV and 4 keV and the error bar is derived from reasonable limits for extrapolation.

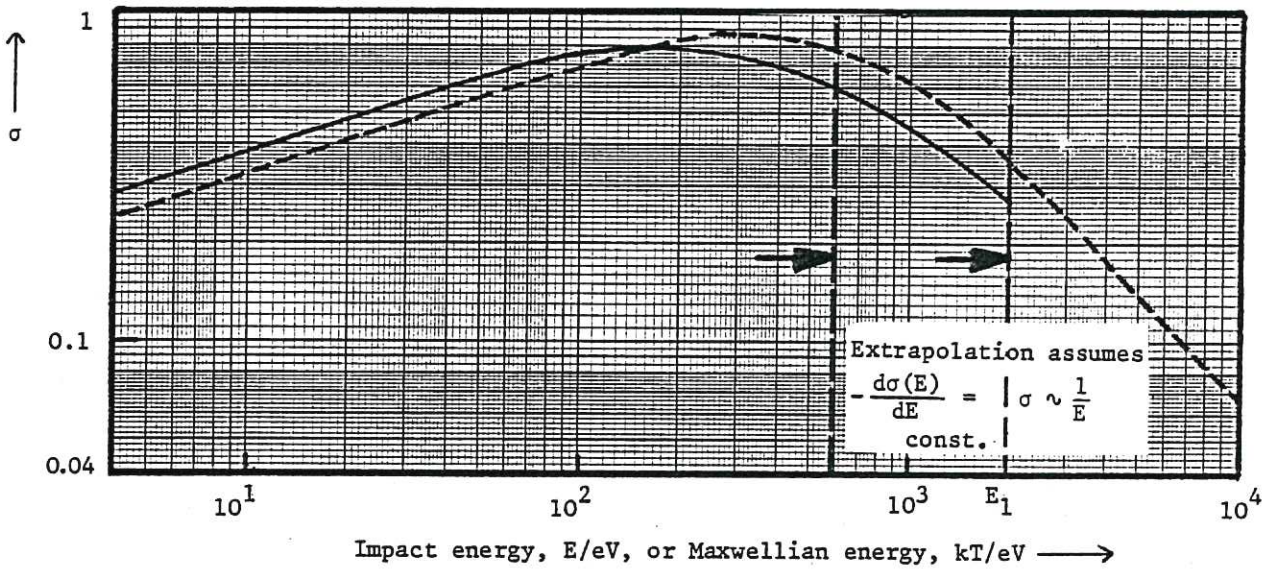
Fig.4: "Total" secondary electron yield by electron impact on a polycrystalline molybdenum[5] surface. (Electrons incident normally on surface).



---: σ (E), secondary yield at energy E. (Note extrapolation beyond E_1 = 2 keV)

——: $\sigma_M(T)$, average Maxwellian yield at temperature T.

Fig.5: "Total" secondary electron yield by electron impact on a polycrystalline titanium[6] surface. (Electrons incident normally on surface)

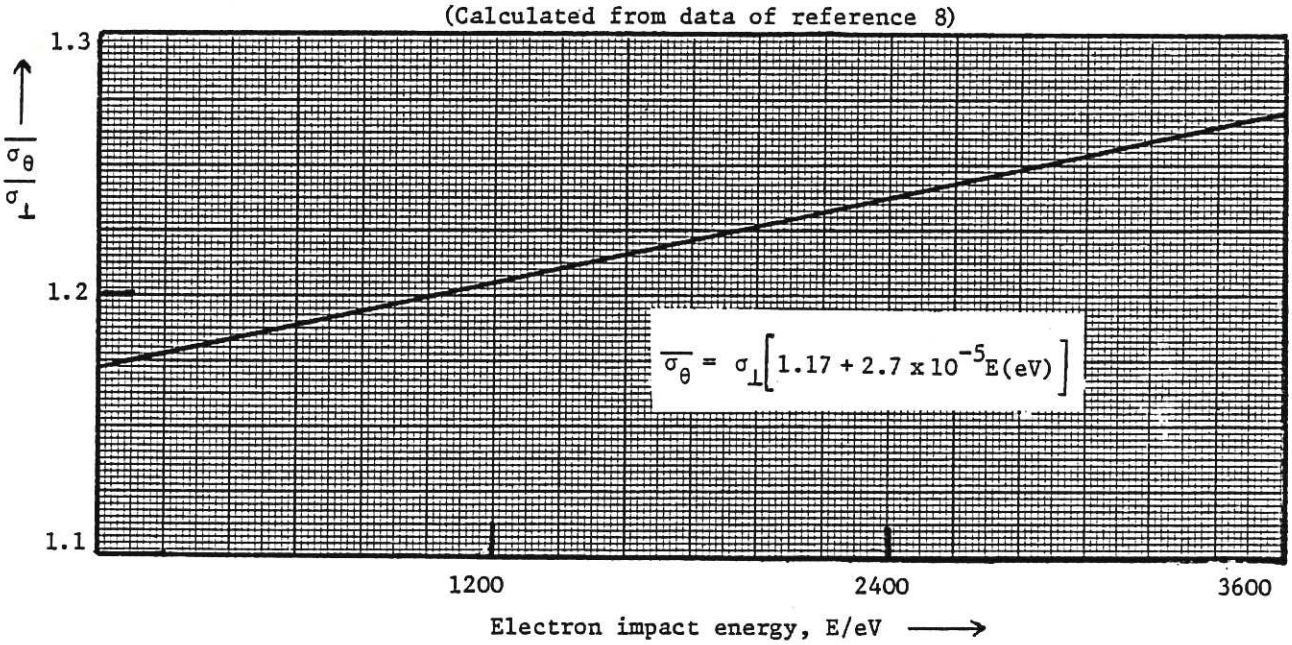


—·—: σ (E), secondary yield at energy E. (Note extrapolation beyond 580 V but E_1 = 2000 eV)

——: $\sigma_M(T)$, average Maxwellian yield at temperature T.

Fig.6: The ratio $\frac{\overline{\sigma_\theta}}{\sigma_\perp}$ as a function of monoenergetic impact energy on a tungsten surface.

(Calculated from data of reference 8)



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