2.9 Energy distributions in sputtering processes

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The determination of the ejection energies of the atomic particles sputtered from a solid under ion bombardment is not only important for an enlarged understanding of the sputtering process, but also for the attainment of useful information concerning the applications of sputtering. In addition to the various mechanical spectrometer devices and time-of-flight techniques used for the investigation of the energy distribution of the sputtered particles, a different method was developed, which is connected with the application of low-pressure, electrodeless, high-frequency discharges of high purity in sputtering experiments. A short outline of this method was given in a previous letter[1].

The energy distributions $N(E)\mathrm{d}E$ of the neutral particles emitted in a direction normal to the bombarded surface have been detetmined for polycrystalline targets of Ag, Al, Cu, Ni and Ti under the bombardment of normally incident Ar^+ ions of 900 eV. The resulting distribution curves, having been normalized to their maximum value $N(E_w)$ at the most probable ejection energy E_w, are plotted in Fig. 1. They always show the same characteristic behaviour — a pronounced maximum at ejection energies about some eV and a drop off with increasing E. This behaviour is in good agreement with the results of Stuart, Wehner, and Anderson[2] whose experiments were conducted under nearly the same conditions with 1200 eV Kr^+ ions.

To get information on the energy distribution of the recoil atoms within the solid, lifted from their lattice sites in consequence of the ion bombardment, it is necessary to consider the emission process in some detail. A simple model which refers to the particles sputtered into a small solid angle about the normal to the surface and which is in agreement with corresponding considerations in Thompson's work[3] leads to an energy-dependent factor, by which $N(E)\mathrm{d}E$ can be converted to the energy spectrum $N_t(E_t)\,\mathrm{d}E_t$ of the recoils within the target. The energy of a recoil particle inside the solid is related to its energy E after ejection by $E_t = E + S$, where S is the surface binding energy. It can be shown that recoils emitted into a cone of half-angle Δ given by the experimental arrangement must reach the boundary of the solid with angles Θ_t such that $\Theta_t < \Theta_t^{\max} < \Delta$. $\Theta_t^{\max}$ becomes smaller with decreasing E_t and zero when $E_t \to S$. This means that for ejection close to the normal of the target suface, $N(E) \to 0$ when $E \to 0$. The experimental results tend to confirm this behaviour.

When the peaked $N(E)/N(E_w)$ curves shown in Fig. 1 are converted as mentioned above, the resulting $N_t(E_t)/N(E_w)$ curves referring to the inside distributions $N_t(E_t)\; dE_t$ are found to decrease monotonically as E_t^{-2}.

If the individual $N_t(E_t)/N(E_w)$ curves for the different target materials are plotted versus a reduced energy E_t/S, they are found to lie within the hatched region shown in Fig. 2 and so tend to converge to a single curve. The spread of the results within the hatched region is primarily due to experimental error, but may also be influenced by differences between the available tabulated values of the sublimation energies, taken for S in this work, and the values of the surface binding energies which are valid for surfaces under ion bombardment.

The result that $N_t(E_t)$ decreases as E_t^{-2} is in agreement with the measurements of Thompson[3)] who found the same behaviour at higher ejection energies for those particles emitted in the 45° direction from polycrystalline and monocrystalline Au and Cu under high energy ion bombardment. Taking into account the different direction under observation compared with that in the present work, it can be concluded that by the bombardment of a polycrystalline solid with ions at energies ranging upwards from approximately 1 keV, a random collision cascade is produced with an isotropic spectral flux density $N_t(E_t)$, which decreases in a wide range as E_t^{-2}.

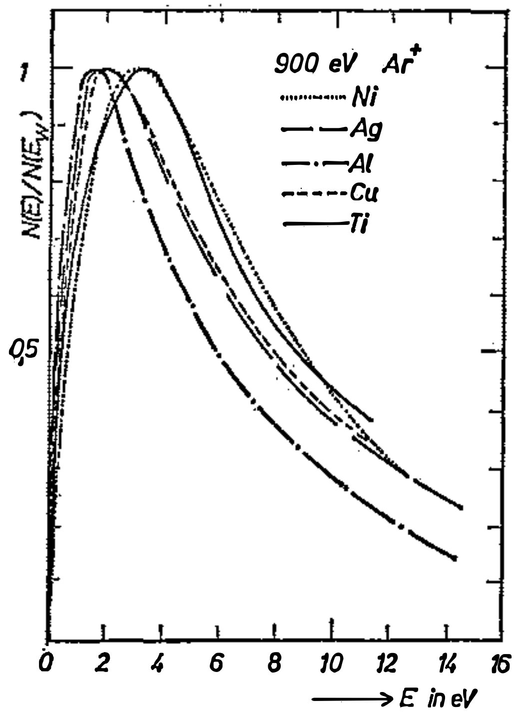

Fig. 1 Normalized energy distribution functions $N(E)/N(E_w)$ of the neutral particles sputtered from polycrystalline metals in a direction normal to the bombarded surface by normally incident A_r^+ ions of 900 eV.

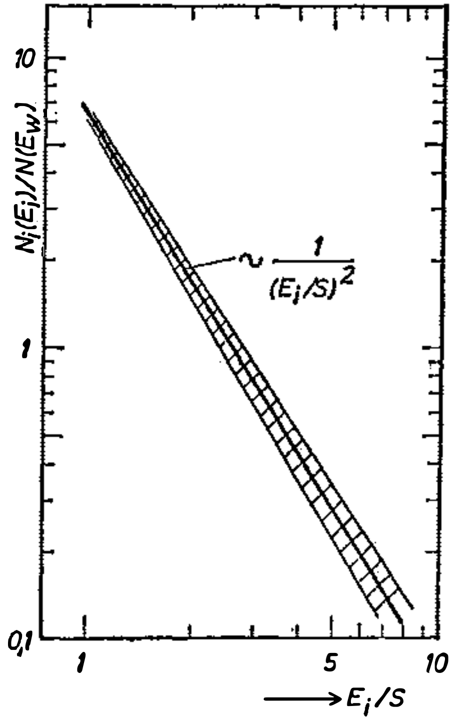

Fig. 2 Normalized energy distribution functions of the recoil atoms within the bombarded solid versus reduced energy E_t/S. The $N_t(E_t)/N(E_w)$ curves for the different target elements appear in the hatched region and are compared with the $(E_t/S)^{-2}$ curve.

The uniform behaviour of the $N_t(E_t)/N(E_w)$ versus E_t/S curves, shown in Fig. 2, suggests that the normalized energy distributions $N(E)/N(E_w)$ outside the target should be discussed in terms of a reduced ejection energy $E' = E/S$. If a distribution function $N^*(E')$ is introduced with $N^*(E'_w) = 1$, which corresponds to the kind of normalization chosen in Fig. 1, it is found that the various normalized distribution curves in Fig. 1 are described within a certain limit of error by a uniform relation

$$N^*(E') = \frac{27}{4}\frac{E'}{(E'+1)^3}.$$

References

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2.10 Determination of sputtering yields for thin film targets

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In spite of the numerous investigations of different aspects of ion bombardment of solid targets, there are very few data on the fundamental parameters for sputtering of thin films. At low energies some studies were made in a glow discharge[1], and for some investigations the thin film target was placed in the ion source of a mass spectrometer[2]. More research has been done on defects induced in thin films by low energy ion bombardment[3,4].

Results given in this contribution show the determination of sputtering yields for thin film targets. The method used was the change in electrical resistance of thin films induced by low energy ion bombardment. It has already been shown by the authors that the change in electrical resistance of gold, silver, titanium and tungsten thin films is a function of the ion dose[5,6]. From the third part of the curve, where the resistance starts to increse to infinity as a result of sputtering of the thin film (pure ion erosion), the sputtering yield can be determinend. The experimental apparatus and techniques have been described elsewhere[7]. For bombardment A^+ ions with energies from 250 to 5000 eV were used. Ion current densities were up to 0.2 mA/cm^2. Thin films were evaporated in a vacuum of 10^{-7} torr onto heated pyrex glass slides. Fig. 1 shows a typical diagram for electrical resistance changes induced in a thin gold film by different A^+ ion doses with an energy of 1500 eV. The geometry of the experiment is shown in Fig. 2 ($l \times d$ is thin film area, $z \times d$ is ion beam profile, x is depth of ion erosion, R_m is sector resistance of the bombarded area and t is thickness of thin film).

The initial resistance is given by $R_t = R_T\, p/l + R_T\, z/l$ if R_T is the total resistance measured during ion bombardment. The resistance change induced by ion bombardment R is then $R = R_T\, z/t\ (1-t)/(t-x)$. Since the depth of erosion x is proportional to the product of ion dose and sputtering yield for a thin film ($x = DS_{TF}$), we can determine this suttering yield S_{TF} if we draw the conductivity of the bombarded area as a function of $1/D$. In the large dose region, where all the resistance changes are induced by ion erosion (thinning of the thin film), this dependence is linear and the slope gives the sputtering yield for the bombarded thin film. Table I shows the results of such a sputtering yield calculation for titanium, gold, silver and tungsten thin films. For comparison, sputtering yields for solid targets are also given[8]. All values for sputtering yields of thin films are larger than for solid targets. The difference is larger for higher energies (30—40 %), while for energies smaller than 500 eV the