§19. Unified Analytic Representation of Physical Sputtering Yields

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The existing analytic representations of physical sputtering yield Y(E) for ion incidence normal to the surface [1–3] (E is the incident ion energy) are all based on the Bohdansky formula [1] and contain two independent reduced energy parameters: E/E_{th} and E/E_{TF}, where E_{th} is the threshold energy and E_{TF} is the Thomas–Fermi energy. The parameter E/E_{th} is sufficient to describe the sputtering yield in a unified manner for all ion–surface collision pairs in the energy region not far from the threshold (i.e. for $E \ll E_m$, E_m being the energy where Y(E) has its maximum). Similarly, at large energies, $E \gg E_m$, the parameter E/E_{TF} is sufficient to describe Y(E) in a unified way for all collision pairs.

In the present work we derive a general reduced energy parameter $\eta=\eta(E, E_{th}, E_{TF})$ which reproduces the above limiting cases and provides a unified description of the sputtering yield at intermediate energies as well. We introduce the notation:

$$\varepsilon = E/E_{TF},\ \delta = E_{th}/E_{TF}, \tag{1}$$

and define the generalized reduced energy parameter as

$$\eta = A\left(\frac{\varepsilon}{\delta}-1\right)+B\left[\left(\frac{\varepsilon}{\delta}\right)^{C}-1\right]+1 \tag{2}$$

where

$$A=1.265\frac{\delta}{0.18+\delta^{2/3}},\ B=20.5\frac{\delta^{2/5}}{1+112\delta},$$

$$C=0.81\frac{5.1\times10^{-3}+\delta^{4/5}}{1.3\times10^{-2}+\delta^{3/5}}.$$

We further introduce the reduced sputtering yield $\tilde{Y}(\eta)$ by the equation

$$\tilde{Y}=\frac{Y(E)}{QG(\delta)} \tag{3}$$

where

$$G(\delta)=0.848+4.0\cdot\exp\left(-2.94\cdot\delta^{2/3}\right). \tag{4}$$

In Fig. 1 we present a large number of experimental and theoretical sputtering data [2,3] for various projectile–solid target combinations (including self–sputtering) in the Y–η representation. The projectile–to–target mass ratio and the value of the parameter δ for the selected collision pairs cover the entire possible ranges of variation of these parameters. The solid curve in Fig. 1 represents the least square fit of the data with an rms deviation of 32%. The experimental data in the $Y-\eta$ representation are distributed around the curve $\tilde{Y}(\eta)$ with a dispersion not larger than the dispersion of the original data. Thus, the function $\tilde{Y}(\eta)$ provides a single representation of all the experimental sputtering data and its equation is:

$$\tilde{Y}(\eta)=(1-\frac{1}{\eta})^{3}(0.436\frac{\ln\eta}{\eta}+\frac{0.212}{\eta^{2}}) \tag{5}$$

We note that $\tilde{Y}(\eta)$ has correct physical threshold and high–energy behavior. We further note that the function $\tilde{Y}(\eta)$ represents with the same level of accuracy also the TRIM data given in Ref. [2]. Therefore, the set of equations (2) – (5), together with the known theoretical and/or semiempirical expressions for the parameters E_{TF}, E_{th} and Q (see, e.g., [2]) provide a unique procedure to determine the sputtering yield Y(E) for a given projectile–solid target collision pair at normal ion incidence.

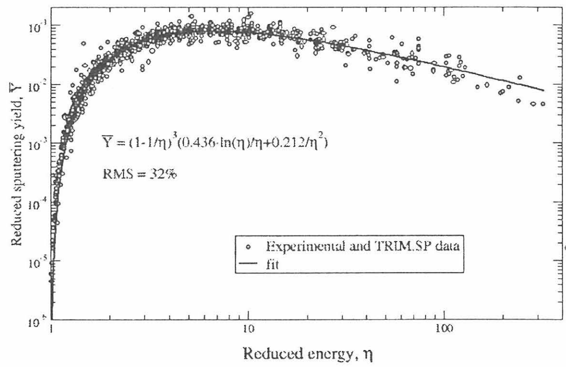

Fig. 1. Reduced sputtering yield for experimental and theoretical data from Ref. [2].

References

[1] Bohdansky, J., Nucl. Intr. Methods **B2**, 581 (1984).
[2] Ekstein, W., et al., "Sputtering Data", Report IPP–Garching 9/82 (1993).
[3] Thomas, E.W., et al., IAEA Report INDC (NDS)–287 (1993).