Sputtering Yields

W. Eckstein
Max-Planck-Institut für Plasmaphysik, D-85748 Garching, Germany, wolfgang.eckstein@ipp.mpg.de

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Abstract

This paper gives a short summary of a new survey about experimental and calculated sputtering yields. A comparison of both datasets show a reasonable agreement in most cases.

1 Introduction

Sputtering, the removal of target atoms by energetic incident ions is characterized by the sputtering yield, the number of atoms removed per incident ion (or neutral). The sputtering yield has been measured for many ion-target combinations since many years and the results have been compiled by Andersen and Bay in 1981 [1]. The insight that the process is caused by atomic collisions allowed a theoretical description [2] and later the application of computer simulation [3]. Several books about the sputtering process and its effects have been published [4, 5, 6]. Now a new book is published which discusses new aspects of sputtering and gives a new survey of the sputtering yield [7].

2 Yield comparisons for elemental targets

The new chapter on the sputtering yield [8] undertakes the task to compare experimental data with values calculated by computer simulation. This is done by fitting the calculated values with an empirical formula proposed a few years ago [9], which describes the energy dependence of the sputtering yield at normal incidence.

$$Y(E_0) = q\ s_n^{KrC}(\varepsilon_L) \frac{\left(\frac{E_0}{E_{th}} - 1\right)^\mu}{\lambda / w(\varepsilon_L) + \left(\frac{E_0}{E_{th}} - 1\right)^\mu} \quad . \tag{1}$$

with the nuclear stopping power for the WHB (KrC) potential.

$$s_n^{KrC}(\varepsilon_L) = \frac{0.5 \ln(1 + 1.2288\varepsilon_L)}{w(\varepsilon_L)} \quad \text{with} \quad w(\varepsilon_L) = \varepsilon_L + 0.1728\sqrt{\varepsilon_L} + 0.008\varepsilon_L^{0.1504} \tag{2}$$

and with the Lindhard reduced energy

$$\varepsilon_L = E_0 \frac{M_2}{M_1 + M_2} \frac{a_L}{Z_1 Z_2 e^2} = E_0/\varepsilon \quad . \tag{3}$$

It should be mentioned, that the function $w(\varepsilon_L)$ in eq. (1) is missing in [8, 9]. Z_1 and Z_2 are the atomic numbers, and M_1 and M_2 the masses of the projectile and the target atom, respectively. The Lindhard screening length, a_L, is given by

$$a_L = \left(\frac{9\pi^2}{128}\right)^{1/3} a_B \left(Z_1^{2/3} + Z_2^{2/3}\right)^{-1/2} \tag{4}$$

where a_B is the Bohr radius. E_{th} is the threshold energy for sputtering, and E_0 is the incident energy of the projectile. Q, E_{th}, μ and λ are used as parameters. The yield values at normal incidence for the fitting procedure have been taken from Yamamura [10] and Eckstein [11, 12], who provided the most extensive sets of calculated yields. It should be mentioned that only the interaction potential and an inelastic energy loss model, usually the LS-model or an equipartition of the LS [13] and OR [14] models, are used as input in the calculations besides element-specific values from data tables. The chapter presents 376 fit curves for the energy dependence of the yield for different ion-target combinations and 280 comparisons with experimental data. The fitting parameters, which iclude the threshold energy of the sputtering yield (at normal incidence), are provided in tables. As an example the yields for Ni bombarded with different incident ions at normal incidence are provided in Figs. 1 and 2. The book chapter [8] shows 60 such figures.

Analoguously, the angular dependence of the sputtering yield is handled in a similar way. The calculated yield values at a fixed incident energy [11, 12]are fitted by another formula [9]

$$Y(E_0,\alpha) = Y(E_0,0)\left\{\cos\left[\left(\frac{\alpha}{\alpha_0}\frac{\pi}{2}\right)^c\right]\right\}^{-f}\exp\left\{b\left(1-1\Big/\cos\left[\left(\frac{\alpha}{\alpha_0}\frac{\pi}{2}\right)^c\right]\right)\right\} \tag{5}$$

This formula is similar to the original Yamamura formula, but introduces additional physical information, namely, that incident atoms (projectiles) may experience a binding energy E_{sp}, which creates an acceleration and a refraction towards the surface normal [3], so that an incidence angle of 90° is never reached. The new value α_0 takes care of that and is given by

$$\alpha_0 = \pi - \arccos\sqrt{\frac{1}{1+E_0/E_{sp}}} \quad \geq \quad \frac{\pi}{2} \tag{6}$$

The parameter η in the Yamamura formula is not used anymore, but a new parameter c is chosen. The fitting curves are compared with experimental values. 500 fit curves and 179 comparisons with experimental data are presented. The parameters for the fit curves are provided in tables. A set of 6 comparisons for Ti and Fe are shown in Fig.3 as an example out of 21 such figures in [8].

Generally, the agreement of experimental data and the fit curves of calculated values is reasonable. Deviations can be explained by uncertainties in the data as well as in the calculations. The main uncertainties in the experiment are: the surface roughness (deviations in the experiments up to a factor of 5 at oblique incidence [15]), implantation of gaseous species (errors up to 30%), and adsorption of species at the target surface. Surface roughness has the tendency to increase the yield at normal incidence and to decrease the yiels at oblique incidence (larger than about 45° compared to flat surfaces. The main uncertainties in the calculations are the interaction potential and the inelastic energy loss. Larger yields for noble gas ion bombardment of Cu, Ag and Au can be explained by electronic contributions as discussed in the chapter by Assmann et al. [16]. The statistical errors of the calculated yields are smaller than 3% in nearly all cases. Sputtering yields of single crystal targets have not been included in these comparisons due to channeling effects, but the corresonding literature is provided in a table.

3 Multicomponent targets

In multicomponent systems as in compounds or elemental targets bombarded with non-volatile species the sputtering yield becomes fluence dependent so that each system has to investigated separately. This is, in principle, also true for noble gas ion bombardment, but the error is small in most cases. Surprising effects as oscillations can occur for the bombardment of targets consisting of light elements with heavy atoms [17]. Isotope sputtering also belongs to this section. Comparisons of calculated values with experimental data have to done carefully because of possible diffusion and/or segregation effects, which depend on temperature.

Two regimes can be distinguished: an erosion and a deposition regime. If the sum of the particle reflection coefficient and the partial yields is larger than unity, then the system is in an erosion regime and a steady state composition profile will occur. In the other case the bombarding (non-volatile) species will cover the original target and the target will become thicker with increasing fluence.

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4 Figure captions

Fig.1 Energy dependence of sputtering yields of Ni for bombardment at normal incidence with H, D, ^{4}He, Ne, Ar and Ni (Fig.25 of [8])

Fig.2 Energy dependence of sputtering yields of Ni for bombardment at normal incidence with Kr, Xe, N, O and T, ^{3}He (Fig.26 of [8])

Fig.3 Angular dependence of sputtering yields of Ti for bombardment with He and Ar, and of Fe with H at different incident energies (Fig.68 of [8])

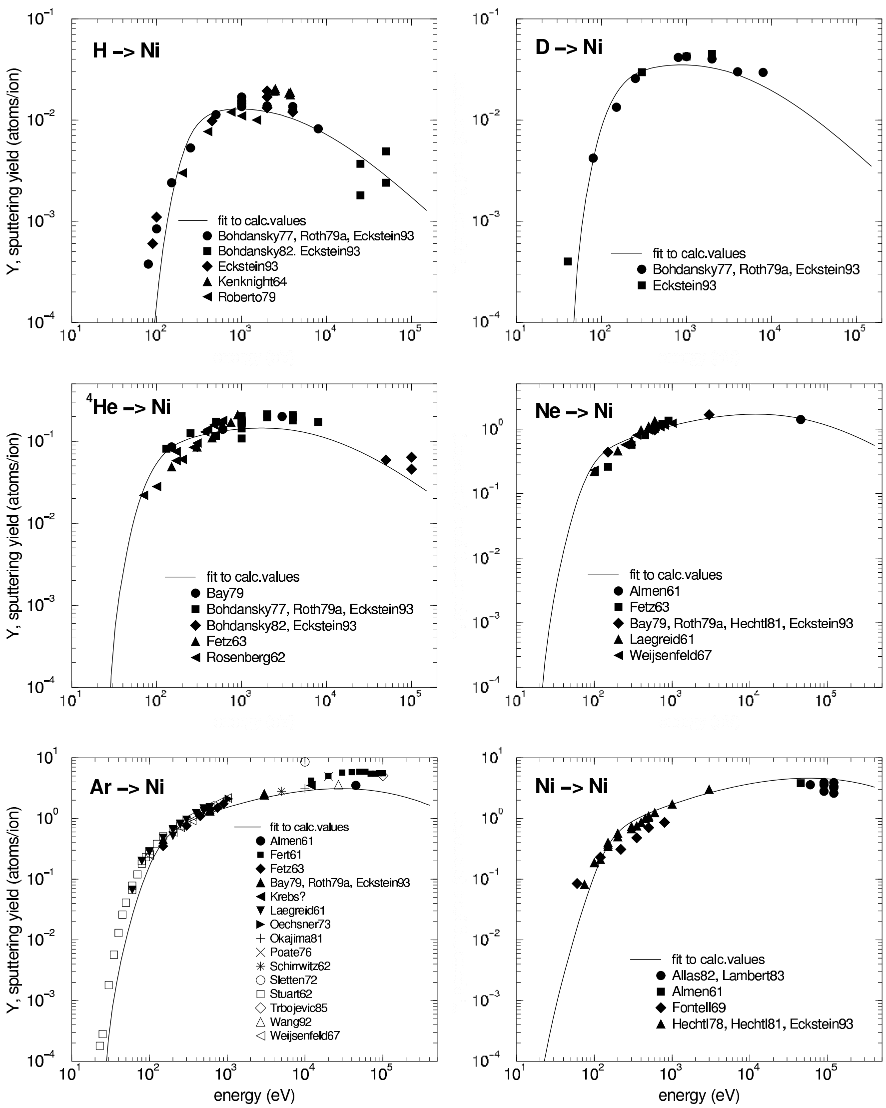

Figure 1: Energy dependence of sputtering yields of Ni for bombardment at normal incidence with H, D, ^{4}He, Ne, Ar and Ni (Fig.25 of [8])

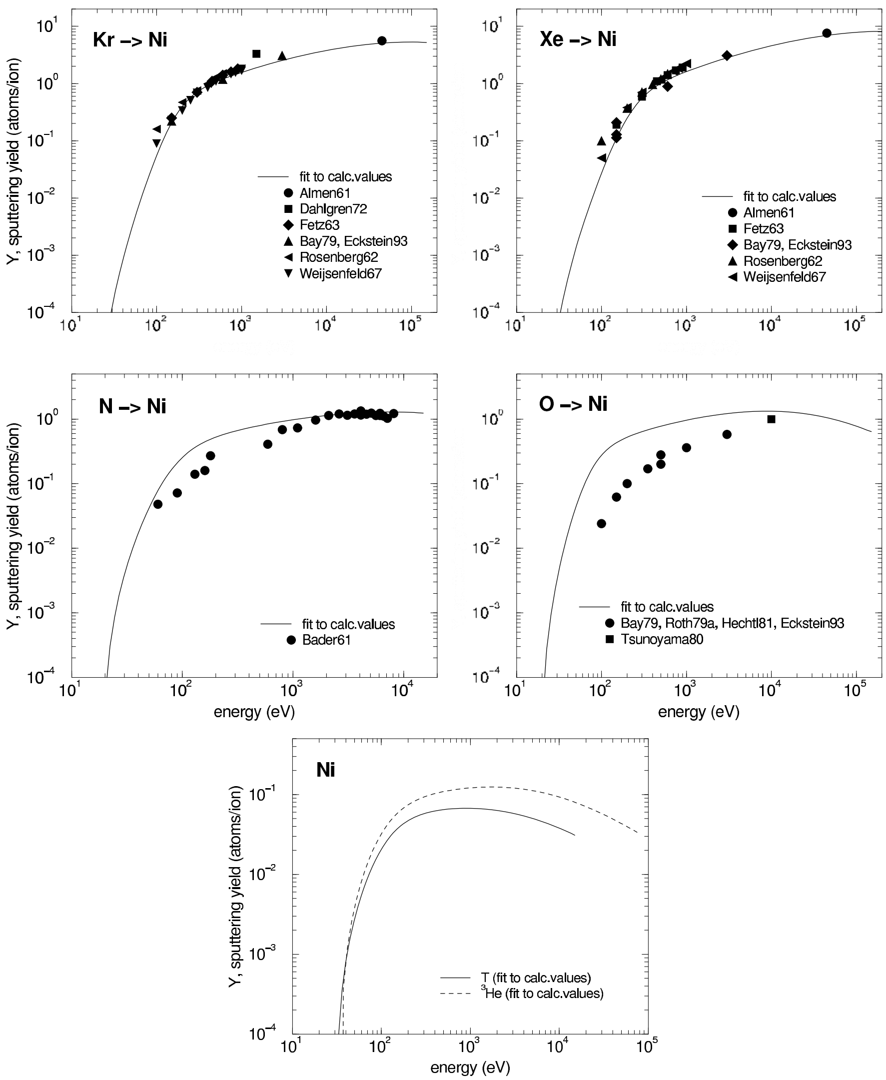

Figure 2: Energy dependence of sputtering yields of Ni for bombardment at normal incidence with Kr, Xe, N, O and T, ^{3}He (Fig.26 of [8])

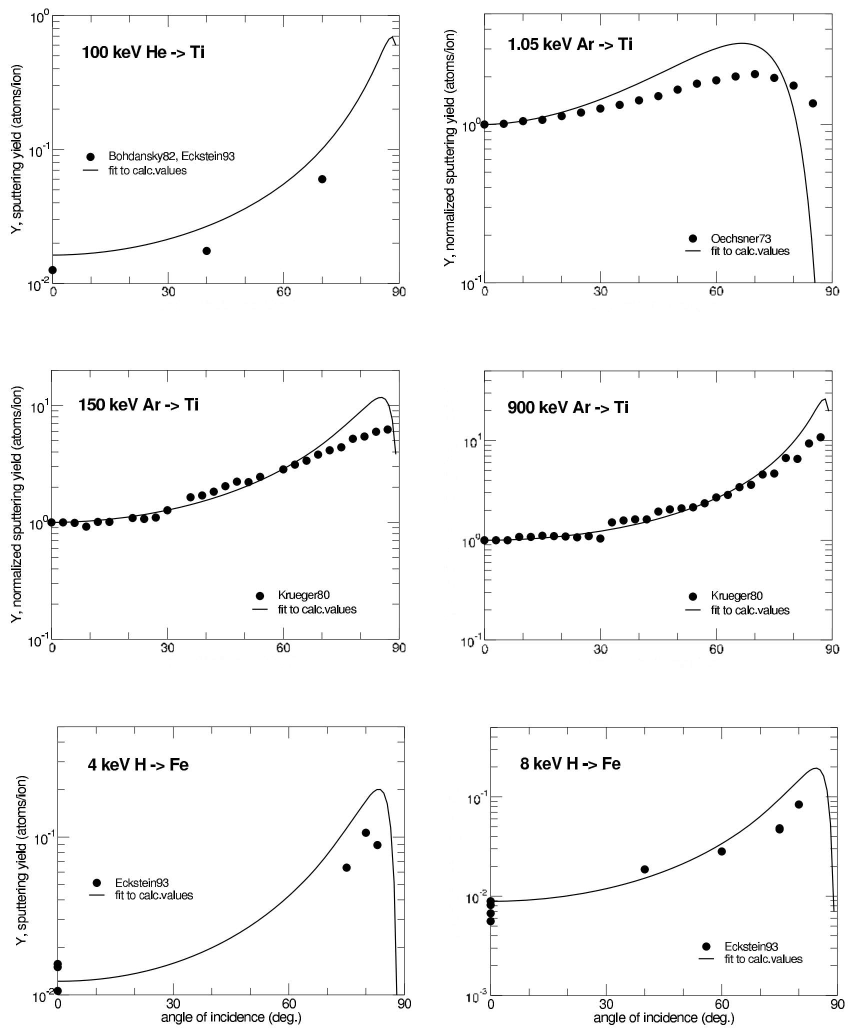

Figure 3: Angular dependence of sputtering yields of Ti for bombardment with He and Ar, and of Fe with H at different incident energies (Fig.68 of [8])