Useful Information and Facts about the Practice of Sputtering

Sputter Rates

Calculation:
The sputtering velocity or "sputter rate" z/t of a surface layer due to ion bombardment:

$z/t = M/(rN_Ae) \times S\ j_p$

M: molar weight of the target [kg/mol]
r: density of the material [kg/m^3]
N_A: 6.02×10^{26} 1/kmol; (Avogadro number)
e: 1.6×10^{-19} As (electron charge)
S: sputtering yield (atom/ion)
j_p: primary ion current density [A/m^2]

The target parameters M and r can be found in the literature.
Table 1 shows the sputtering yields S for some target materials for some of the standard primary ions at different energies.
If you need data for other materials please refer to the references given below.

Examples:
In the following we give calculation examples for the sputter velocity for the target elements W, Ag, and Fe:

Example 1:
Target: W; M=184 g/mol; r = 19.26 g/cm^3; Atomic Radius = 1.37 Å = 0.137 nm
Primary Ion: Ar+ ; Ion Energy = 1 keV; Sputter Yield S = 1
Ion Current Density: j_p = 1 mA/cm^2
Calculated Sputter Rate: z/t = 595 Å/min = 59.5 nm/min = 3.62 Monolayer/s
(1 Monolayer = 2 x Atomic Radius)

Example 2:
Target: Ag; M=108 g/mol; r = 10.49 g/cm^3; Atomic Radius = 1.45 Å
Primary Ion: Ar+ ; Ion Energy = 0.5 keV; Sputter Yield S = 3
Ion Current: j_p = 1mA/cm^2
Calculated Sputter Rate: z/t = 1924 Å/min = 192.4 nm/min = 11.06 Monolayer/s
(1 Monolayer = 2 x Atomic Radius)

Example 3:
Target: Fe; M=55.85 g/mol; ρ = 7.87 g/cm^3; Atomic Radius = 1.24 Å = 0.124 nm
Primary Ion: Ar+ ; Ion Energy = 0.5 keV; Sputter Yield S = 0.5
Ion Current: j_p = 1mA/cm^2
Calculated Sputter Rate: z/t = 221.03 Å/min = 22.1 nm/min = 1.27 Monolayer/s
(1 Monolayer = 2 x Atomic Radius)

The graphical illustration of the calculation examples 2 and 3 in figure 1 and 2 helps to find graphically a first and rough estimation of the corresponding sputtering velocity for a given sputter ion current.

Applications:
Sample Preparation:
If you use for example the SPECS Sputter Ion Source IQE 11/35 a typical Ion Current at 0.5 keV is 15 µA with a beam diameter of 7 mm. This gives with the help of figure 2 an average sputter velocity of 0.5 Monolayer/s for Ag and with help of figure 3 an average sputter velocity of 0.05 Monolayer/s for Fe. Please note that the given sputter velocity is an average value for the total ion beam and does not reflect the ion current distribution in the ion beam profile and hence sputter crater form.

Depth Profiling:
Another typical set of values for ion current, ion beam diameter and energy in case of use of the scanable Ion Source IQE 12/38 is 1 µA, 150 µm and 5 keV. This parameter combination is quite useful for XPS depth profiling. Using the graphical tool in figure 1 gives for Ag a sputter velocity of 20 Monolayer/s at 0.5 keV. For an ion energy of 5 keV the sputter yield increases from 3 to 8, which means an increase of the sputter velocity by a factor of 2.7, thus to about 50 Monolayer/s. If the beam is scanned over an area of 10 x 10 mm^2 then the resulting sputter velocity is reduced by a factor of about 10^4.

Experimental Data:
Besides the calculated values you find a list of measured sputter velocities in table 2. You can use this table also for estimating the sputter velocity for different ion energies using the listed values for the sputter yield in table 1. Multiply the value for sputter velocity at 0.5 keV with the sputter yield at the desired energy and divide by the sputter yield at 0.5 keV. As a rough estimation you can use a factor 3 to get the sputter velocity at 5 keV from the listed values in table 2 at 0.5 keV.
For further data on sputter yields please refer to the references given below. But please note that there are a lot of published data of sputter yields, but the reliability is sometimes not sufficient for precise calculations of sputter velocities. Sputter Yields generally depend also on incidence angle of the sputter ions and surface orientation.

Sputter rates for Ag Sample

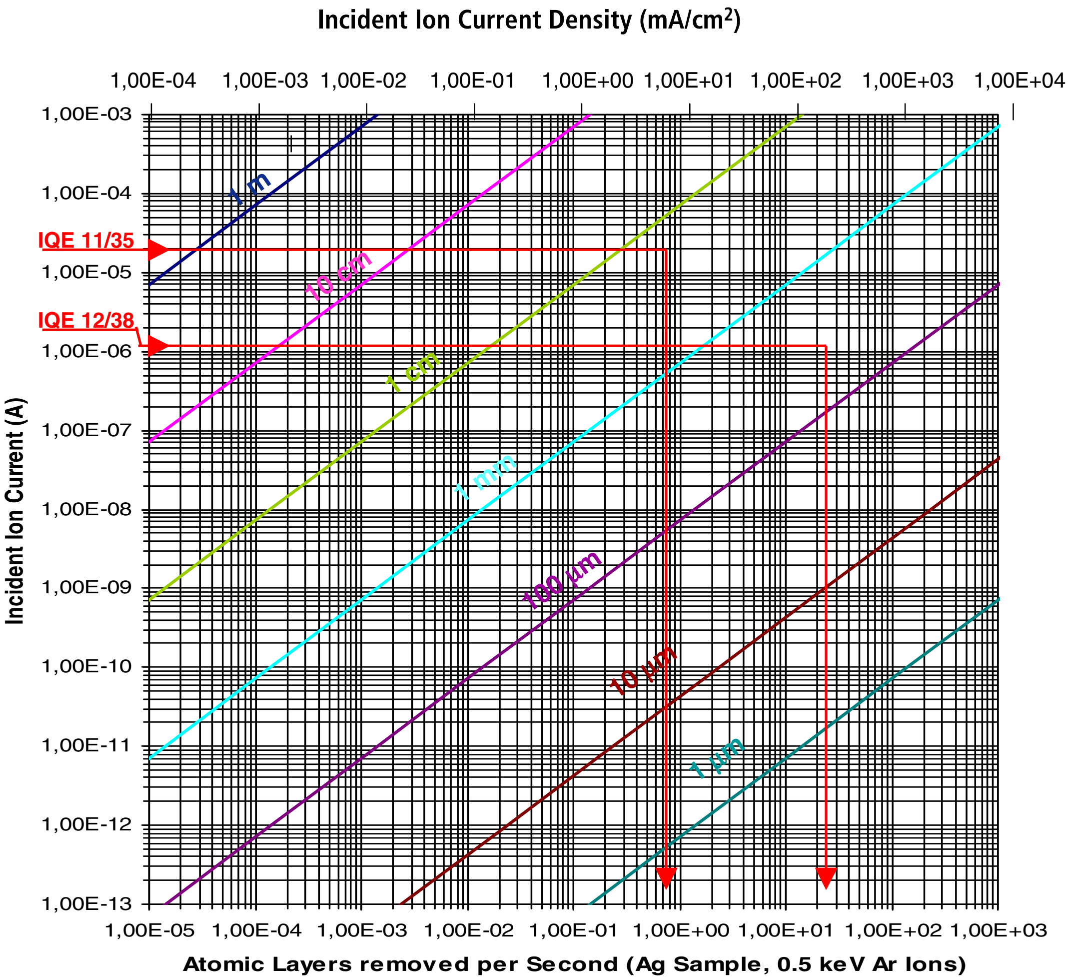

Figure 1: Correlation between Sputter Rate and incident Ion Current for different Ion Beam Diameters for Calculation Example 2 (Ag, Ar 0.5 keV, S=3)

Sputter rates for Fe Sample

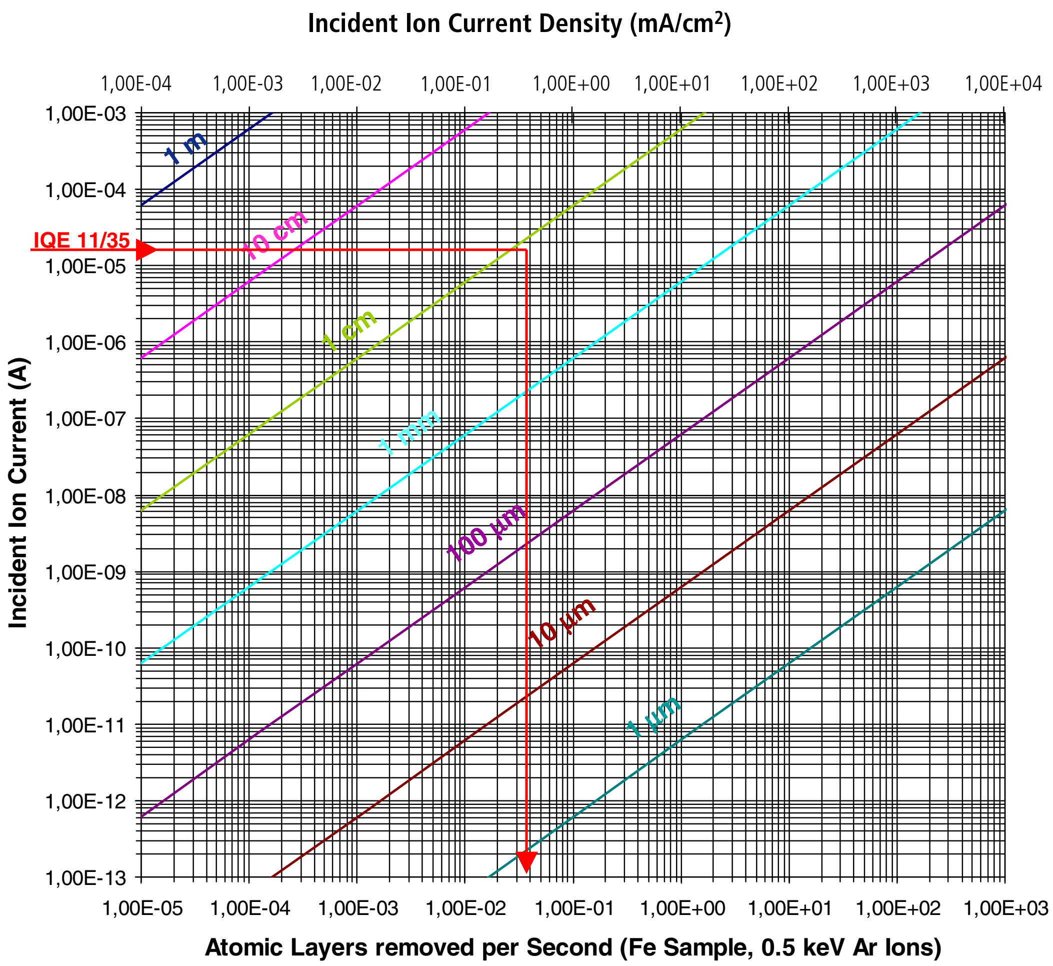

Figure 2: **Correlation between Sputter Rate and incident Ion Current for different Ion Beam Diameters for Calculation Example 3 (Fe, Ar 0.5 keV, S=0.5)**

		Target Material									
Ion	Energy [keV]	Al	Si	Ti	Fe	Ge	Nb	Ag	W	Au	
Ar+	0.2	0.33	0.18	0.15	0.20	0.5	0.20	1.0	0.10	0.70	
	0.5	0.95	0.55	0.55	0.50	1.0	0.50	3.0	0.6	2.0	
	1.0	1.8	0.90	1.0	1.0	1.4	1.2	5.0	1.0	3.5	
	2.0	2.5	1.2	1.3	2.5	2.0	2.0	6.5	1.5	5.5	
	5.0	3.1	1.4	1.5	3.0	2.6	2.2	8.0	2.0	7.5	
	10.0	3.7	1.5	1.8	3.5	3.2	2.4	10.0	2.5	8.5	
Xe+	0.2	0.23	0.12	0.12	0.22	0.30	0.18	1.0	0.20	0.90	
	0.5	0.85	0.50	0.45	0.80	0.90	0.60	3.0	0.70	2.2	
	1.0	0.18	0.90	1.0	1.9	2.0	2.0	5.0	1.2		
	2.0	0.25	1.5		3.0		3.0	7.0	2.5		
	5.0	4.0	2.0		4.0		4.0	10.0	4.0	15.0	
	10.0	6.0	2.5		5.0		5.0	15.0	5.0	20.0	

		Target Material									
Ion	Energy [keV]	Si	Ti	Fe	Ni	Cu	Nb	Ag	Pt	W	Au
Cs+	1.0		0.42	2.4							
	2.0		0.68	3.2		6.0	2.3				
	5.0		0.95	5.1		7.5	4.0				
	10.0		1.1	7.0		10.0	5.2				
O+	0.2				0.10				0.012		1.3
	0.5				0.21				0.022		1.6
	1.0		0.08		0.36				0.20		
	2.0		0.22		0.51				0.04	1.0	
	5.0	0.227	0.40	0.27	0.70			4.0			
	10.0			0.30							

Table 1: Experimental Sputter Yield at Perpendicular Ion Beam Incidence

from *Secondary Ion Mass Spectroscopy* 1987 Wiley & Sons

SPECS®

Target Material	Å / min	Target Material	Å / min
Be	159	Dy	1040
C	40	Er	881
Al	630	Hf	590
Si	310	Ta	380
Ti	336	W	340
V	337	Re	470
Cr	530	Os	440
Mn	874	Ir	540
Fe	429	Pt	792
Co	510	Au	1553
Ni	570	Pb	3073
Cu	818	Bi	8798
Ge	900	Th	740
Rb	4000	U	660
Y	837		
Zr	570	CdS	2100
Nb	390	GaAs (110)	1500
Mo	421	GaP (111)	1400
Ru	580	GaSb (111)	1700
Rh	650	InSb	1300
Pd	1150	LiNbO3 (y-cut)	400
Ag	1833	PbTe (111)	3300
Sn	1217	SiC	320
Sb	3238	SiO2	400
Sm	990	Al2O3	129
Gd	1027	Bi12GeO20	1290

Table 2: Measured Sputter Rates for E = 500 eV Argon Ions at 1 mA/cm^2

All sputter rates are for normal ion beam incidence.
Please note that you can use this table for a rough estimation also in case of E = 5 keV. The sputter rates increase then approximately by a factor of three. This is due to the dependence of the sputter velocity on the sputtering yield (ratio atom/ion, see table 1). But there are also deviations from the rule, for example the factor is 6 for Fe and 4 for Nb.

Literature:

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J. Geller and N. Veisfeld, Ion Sputtering Yield Measurements for Submicrometer Thin Films, JVST 6, 3, Part II, May/June 1988

G. Carter and J. S. Colligon, Ion Bombardment of Solids, Heinemann Educational Books Ltd.

Vince Smentkowski, Progress in Surf. Sci. 64 (2000) 1

Links:

www.srim.org
SRIM = The Stopping and Range of Ions in Matter

http://www.glow-discharge.com/sputtering_rate.htm
Web Site includes a program for calculating sputter rates for compounds

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