Ion-Assist Doses
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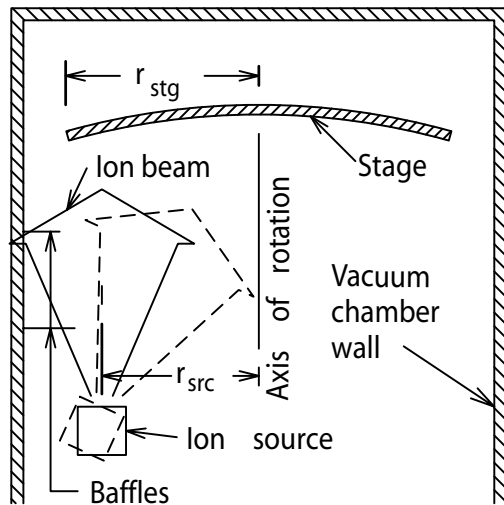

Fig. 1. Typical box-coater deposition system with end-Hall ion source. Source of vapor-deposited material not shown.

Fig. 2. Variation of ion-assist dose with melting temperature of deposited material. (Original from Ref. 2, with permission.)

INTRODUCTION

Ion assisted deposition has evolved from a collection of individual "recipes," to the use of ion energy per deposited atom as a measure of this dose,[1,2] to the variation of this dose with material melting temperature.[3] The energy range of interest for most applications has narrowed, focusing at present on the low-energy range from about 25 eV to about 100 eV.[3] Dense, low-defect films are believed to be generated in this range by lattice vibrations. Ion collision effects tend to be confined to the surface below ~25 eV, while damage is introduced into the film by the excessive penetration of ions above ~100 eV.

Ion-assist doses that have been used to deposit dense, low-defect films using a variety of deposition materials are presented herein. Also given are estimated doses for materials for which experimental data are not available. All of these doses are presented in a form that is convenient for starting the iteration to produce a useful thin-film product in a typical deposition system (Fig. 1).

ENERGY PER DEPOSITED ATOM

The variation of ion-assist dose (in eV per deposited atom) with material melting temperature that is used for estimates herein is shown in Fig. 2, which is from a recent review of ion-assist applications.[3] Linear extrapolations of the curve shown in Fig. 2 were used for melting temperatures above and below those shown by this curve.
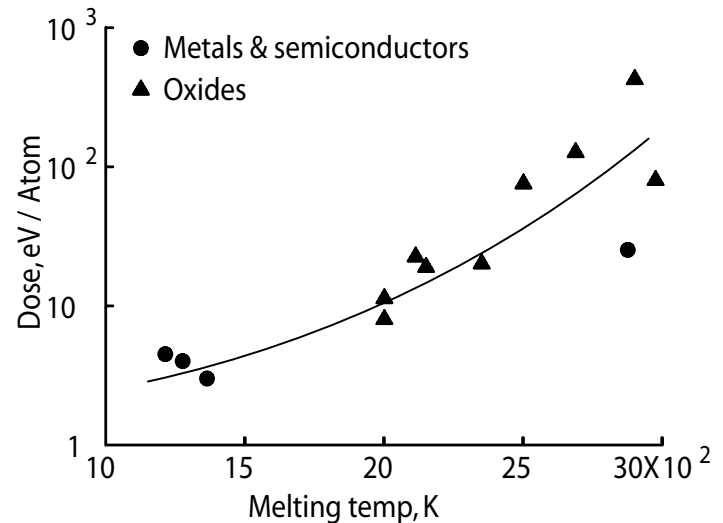
ION CURRENT DENSITIES

Ion current densities from experimental data for dense, low-defect films were obtained from a recent survey[3] and are given in Tables 1 and 2 for 100 eV ions and a deposition rate of 1.0 Å/s. These data are shown as numbers without parentheses. The curve in Fig. 2 was used to estimate current densities based on the melting temperatures. These values are shown in parentheses. An asterisk with an estimated value indicates uncertainty about the melting temperature.

The equations for the calculation of current density from eV/atom are given in Section 6 of Ref. 3. The doses are shown in units of μA-s/Å-cm^2, or $(\mu A/cm^2)/(Å/s)$. Thus, for silver (Ag), a deposition rate of 2 Å/s would require an average ion-assist current (100-eV ions) of 5.8 μA/cm^2. The assist ions should be O_2^+ for oxides, N_2^+ for nitrides, and Ar^+ for metals. For compounds that are neither oxides or nitrides (such as GaAs, MgF_2, and SiC, inert gas ions are often used. Depletion of a more volatile element (e.g., F in MgF_2) can be a problem in the latter compounds. This loss can be minimized by using the minimum effective dose and by using lower ion energies (<100 eV). The ion energy of 100 eV corresponds to a discharge of about 150 V in an end-Hall ion source. To provide the same energy per deposited atom for ion energies other than 100 eV, the ion current density should be varied inversely to the ion energy.

Table 1. Doses for elements, in μA-s/Å-cm^2.

Elem.	Dose	Elem.	Dose
Ag	(2.9)	Ni	(9.1)
Al	(2.2)	Pt	(12)
Au	(3.3)	Re	(1200)
Co	(9.8)	Si	(4.6)
Cr	(21)	Ti	(8.5)
Cu	4.0(4.9)	V	(18)
Fe	(9.9)	Ta	(500)
Ge	3.5(2.1)	W	(2600)
Nb	23(69)	Zr	(9.6)

Table 2. Doses for compounds, in μA-s/Å-cm^2.

Comp.	Dose	Comp.	Dose
Al_2O_3	37(44)	Si_3N_4	(26)
AlN	(51*)	SiO_2	8.7,12(11*)
BN	(960*)	SnO_2	(11)
Ce_2O_3	(9.8)	TaN	(1200)
CeO_2	520(140*)	Ta_2O_5	24(18)
Cr_2O_3	(67)	TiN	(670)
GaAs	(3.1)	Ti_2O_3	(42)
HfO_2	98(215)	TiO_2	32(19)
In_2O_3	(3.5*)	VO_2	(27)
MgF_2	(6.8)	V_2O_5	(2.9)
MgO	(520)	WSi_2	(3.3*)
Nb_2O_5	(8.0)	Y_2O_3	140(67)
SiC	(270*)	ZrO_2	110(220)

LOCATION OF ION SOURCE

For a single-rotation (nonplanetary) stage, good uniformity requires that the ion beam be directed near the outer edge of the stage - see the solid lines for the ion source and beam locations in Fig. 1. Contamination from the ion beam striking the vacuum chamber wall can result in either a compromise ion-source location closer to the axis of rotation or the use of optional baffles to shield the wall - see baffles in Fig. 1.[4] The location of the ion source is less important with a double-rotation (planetary) stage, due to the averaging effect of that motion. For such a stage, the ion beam can be directed more toward the center of the stage - see the dashed lines for ion source and beam in Fig. 1. With the more central direction of the ion beam, more than half the ion beam usually reaches the stage.

MAXIMUM DEPOSITION RATE

The maximum deposition rate of a given material can be calculated from the ion-assist dose (Table 1 or 2), the available ion-beam current, and the chamber geometry. This calculation can start with the ion-beam profile and be quite sophisticated. For this note, however, a shorter, more approximate approach will be used - assuming a given fraction of the ion beam will reach the stage. The fraction used here will be 50%, although it should probably be lower, perhaps 40%, for a single-rotation stage and higher, perhaps 60%, for a double-rotation stage. For the ion source, assume a KRI EH1000 with a rated discharge of 5.7 A at 150 V. The ion beam is about 25% of the discharge current, or 1.4 A. About 0.7 A (the assumed 50%) should reach the stage. For a stage with a radius of 35 cm, the stage area is $\pi 35^2 = 3800$ cm^2. Dividing the ion current (0.7 A) by this area, the ion current density is 180 μA/cm2. If SiO_2 is to be deposited, the required current density from Table 2 is about 10 μA/cm^2 for a deposition rate of 1 Å/s, giving maximum deposition rate for this calculation of about 18 Å/s. For a lower deposition rate, the discharge current should be reduced proportionately.

ACCURACY

There is considerable uncertainty in the recommended doses for ion assist, with much of this due to errors in the estimated ion-current density. The values given herein should therefore be considered *starting points* for experimental tests, not final values. As a further consideration, remember that an excess of assist ions is usually less harmful than a deficit.

REFERENCES

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2. H. R. Kaufman, J. M. E. Harper, "Ion Doses for Low-Energy Ion-Assist Applications," *J. of Vacuum Science and Technology*, A22 (1), pp. 221-224, Jan./Feb. 2004.
3. H. R. Kaufman, J. M. E. Harper, "Ion-Assist Applications of Broad-Beam Ion Sources," *Proceedings of SPIE, 5527*, pp. 50-68. Aug. 2004.
4. J. R. Kahn and H. R. Kaufman, "Low-Energy Ion-Beam Etching," *49th Annual Technical Conference Proceedings,* Washington, DC, Apr. 2006.