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A PROCEDURE FOR THE RAPID EVALUATION OF CARBON STRIPPER FOILS

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The motivation for trying to use very low energy ion beams for testing carbon foils is obvious. First of all, it is considerably faster and, secondly, the hardware is much simpler and generally more available for such studies than large accelerators. An ideal source for such beams is a sputtering apparatus, which can provide a variety of ions at energies on the order of 20 keV. The question then arises as to whether or not the results obtained under these conditions can be related to the much higher energies encountered in large electrostatic accelerators.

To answer this question, we have made the basic assumption that foil lifetimes under ion bombardment are limited by structural changes induced by radiation damage. We believe this is the case since the lifetimes do not appear to be limited by more fundamental processes such as sputtering. This is an important point since it leaves open the possibility for further improvement in foil lifetimes through control of the microstructure of the foil. The rate at which radiation damage occurs is determined by the damage energy, E_d, given by

$$E_d = \int_{T_d}^{E_{max}} E_R \frac{d\sigma}{dE_R} \nu(E_R)\, dE_R \qquad 1)$$

where $d\sigma/dE_R$ is the cross section for the production of a primary knockon atom (pka) with energy E_R and $\nu(E_R)$ is the fraction of E_R which is ultimately deposited in the material in the form of displaced atoms. The integration is over all pka energies from the threshold energy, T_d, required to displace an atom from its crystal lattice, to E_{max}, which, for elastic scattering, is given by

$$E_{max} = \frac{4 M_1 M_2 E_o}{(M_1 + M_2)^2} \qquad 2)$$

where M_1, M_2 are the masses of the incident and target atoms, respectively, and E_o is the energy of the incident beam.

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For low energy heavy ions, the reaction cross section can be replaced by the Rutherford scattering cross section,

$$\frac{d\sigma}{dE_R} = 6.51 \times 10^{-18} \frac{(Z_1 Z_2)^2}{E_o} \frac{M_1}{M_2} \frac{1}{E_R^2} \ (m^2 eV^{-1}). \qquad 3)$$

The damage efficiency can be calculated using the accepted[1] expression which, for carbon, is

$$\nu(E_R) = \left[1+0.4336\left(\frac{E_R}{5687}\right)^{1/6} + 0.0513\left(\frac{E_R}{5687}\right)^{3/4} + \frac{E_R}{5687}\right]^{-1}. \qquad 4)$$

Using these expressions, we have calculated the damage energies for several different incident ions. We found that most of the damage is produced by pka energies less than 10 keV, and have used this fact to derive an easy to use expression to estimate the damage energy. In addition, the damage efficiency varies slowly over the energy range from 40 eV, which is the value of T_d assumed in this study, to 10 keV, and can be approximated rather well by a linear function of E_R. With these approximations, the damage energy for carbon becomes

$$E_d = 8.64 \times 10^{-17} \frac{Z_I^2 M_1}{E_o} \ (m^2 eV). \qquad 5)$$

Carbon foil lifetimes can, therefore, be estimated easily from

$$T_{foil} \propto \frac{1}{E_d} = k_{foil} \frac{E_o(ev)}{Z_I^2 M_1} \ (p\mu A \cdot min \cdot mm^{-2}) \qquad 6)$$

The proportionality factor, k_{foil}, will depend on the detailed microstructure of the foils and will, therefore, be different for foils made by different techniques. The empirically determined constants are found to be $k_{foil} = 0.0018$ for vapor deposited foils, and $k_{foil} = 0.0073\ t - 0.010$ for glow discharge foils of thickness $t(\mu g \cdot cm^{-2})$. The latter is for foils made using ethylene plus 10% argon and 2 -2.5 kV bias. Measured lifetimes are found to be in remarkably good agreement with estimates from eqn. 6 as shown in tables 1 and 2. Measurements at much higher energies have been reported[2] for vapor-deposited foils and the agreement is much poorer, measured values being up to ten times the estimates from eqn. 6. Further studies at higher energies should, therefore, be made to determine the energy range over which these estimates can be applied.

These results suggest that lifetime measurements made with very low energy ion beams can be readily related to energies and ions used in large accelerators. We have, therefore, used this technique to test glow discharge foils made with different hydrocarbon gases. The results, shown in table 3, have been disappointing thus far. Foils made using

welding grade acetylene and with MAPP gas have given lifetimes which are essentially the same as those made with ethylene + argon. Thus, it appears at present that further improvements will have to find their origins in other areas, such as annealing or the use of refractory compounds having more isotropic properties than graphite.

References

1) D. G. Doran, J. R. Beeler, Jr., N. D. Dudey and M. J. Fluss, USAEC Report HEDL-TME-75-76 (1973).

2) G. Frick, V. Chaki, B. Heusch, Ch. Ricaud, P. Wagner, and E. Baron, Revue de Physique Appliquée 12, 1525 (1977).

TABLE 1. LIFETIMES FOR VAPOR DEPOSITED CARBON FOILS

Incident Ion	Energy (MeV)	Lifetime ($\mu A \cdot min \cdot mm^{-2}$)	$\frac{k_{foil} E_o}{Z_1^2 M_1}$
^{35}Cl	20	3.4[a]	3.6
^{35}Cl	10	1.8[a]	1.8
^{127}I	10	0.066[b]	0.051
^{127}I	4.5	0.030[b]	0.024
^{40}Ar	1.2	0.33[c]	0.17
^{40}Ar	4.8	1.0[c]	0.67
^{14}N	0.020	0.021[a]	0.053[d]

TABLE 2. LIFETIMES FOR GLOW-DISCHARGE CARBON FOILS

Incident Ion	Energy (MeV)	Lifetime ($\mu A \cdot min \cdot mm^{-2}$)	Thickness ($\mu g \cdot cm^{-2}$)	$\frac{k_{foil} E_o}{Z_1^2 M_1}$
^{35}Cl	10	33[a]	6	33
^{127}I	10	1.2[b]	≈10	1.8
^{40}Ar	1.2	3.0[c]	5-10	4.1
^{40}Ar	4.8	>28[c]	15	37
^{14}N	0.020	0.64[a]	≈6	0.98[d]

a) Oak Ridge National Laboratory
b) Chalk River Nuclear Laboratories
c) Daresbury Laboratory
d) Uncorrected for energy loss in foil

TABLE 3. LIFETIMES OF CARBON FOILS IRRADIATED WITH 20 keV NITROGEN IONS

Vapor Deposited Foils ($\approx 5 \mu g/cm^2$)

$T = 0.021 \pm 0.010$ $\mu A \cdot min \cdot mm^{-2}$

Glow Discharge Foils

Ethylene	$T = 0.64 \pm 0.07$ $\mu A \cdot min \cdot mm^{-2}$	($5-7 \mu g/cm^2$)
	$T = 0.15 \pm 0.10$ $\mu A \cdot min \cdot mm^{-2}$	($3-5 \mu g/cm^2$)
Acetylene	$T = 0.29 \pm 0.11$ $\mu A \cdot min \cdot mm^{-2}$	($4-7 \mu g/cm^2$)
Mapp Gas*	$T = 0.37 \pm 0.14$ $\mu A \cdot min \cdot mm^{-2}$	($3-7 \mu g/cm^2$)

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