3.B Progress in Biased Magnetron Sputtering of ICF Target Pusher Layers

Hollow glass microballoons (GMB's) which are fractions of a millimeter in diameter are often used as fuel pellets in laser fusion experiments. Many designs require metal coatings whose thicknesses and densities vary by less than a few percent throughout the coating, and whose surface roughnesses are 50 nm or less. Applying these coatings to GMB's by means of sputtering or evaporation poses a unique set of challenges, not the least of which is the inherently oblique incidence of the coating flux. This typically leads to columnar growth defects, and a rough surface morphology.[1] Substrate bias has been studied extensively as a means of controlling the properties of sputtered coatings,[2] but we are unaware of any published work reporting the use of bias in coating GMB's.

The effect of substrate bias in the case of metal coatings on GMB's is interesting for several reasons. One method which has been proposed for coating unsupported GMB's is electrostatic levitation,[3] requiring a rather large charge on the substrate. It is important that the influence of this charge be understood. In addition, molecular beam levitation has been used for unsupported GMB coatings[4-6], and the effects of the self-bias acquired during sputtering are of interest. It has been suggested that this self-bias can lead to surface roughening.[6]

In an earlier report,[7] we described the effect of substrate bias on Ni coatings sputtered onto hollow glass microballoons. We have extended this work to examine bias-sputtered copper and aluminum on planar as well as spherical substrates. We have also studied the coating environment with Langmuir probes, and propose a model in which enhanced normal incidence of the coating flux is responsible for improved film microstructure.

The vacuum system and charging circuit have been described previously.[7] A total of 21 GMB's with diameters ranging from 190 μm to 570 μm have been coated in tests to date. Of these, 14 were done with bias and 7 without bias. For comparison, two planar substrates 2 cm x 2 cm were coated with Cu, one at 0-V bias and the other at $-$100-V bias. They were positioned at the same location as the microballoons with their planes normal to the source axis.

In order to determine the plasma characteristics at the location of the GMB's, a conducting cylinder 1.50 mm in diameter was used as a Langmuir probe. The current-voltage characteristics of the probe were measured for applied voltages from $-$10 V to $+$50 V while sputtering Cu at a current of 1.0 A and pressure of 1.3 Pa.

As reported earlier,[7] all of the GMB's coated without bias exhibited surface structure which is characteristic of columnar growth due to oblique incidence of the coating flux. Several representative samples were fractured, and the coating cross sections were viewed with an SEM. The coating thicknesses on unbiased GMB's were uniform within an uncertainty of 5%, as determined from measurements made at several points on each fractured unbiased GMB. Furthermore, the coating morphology was the same everywhere on any individual unbiased GMB.

Substrate bias produced a general overall improvement in coating microstructure and surface smoothness, and the results were qualitatively the same for all three metals. The structure of a typical biased coating depended on the position on the GMB surface. If we denote the point where the stalk joined the GMB as the south pole, and the diametrically opposite point the north pole, the coating microstructure and surface smoothness of biased GMB's were always best at the north pole. Figure 34a is a photomicrograph of an unbiased Ni coating, and Figs. 34b and 34c are respectively the north and south poles of a GMB coated with Ni using a bias of -100 V. The texture and surface smoothness have improved as a result of bias, with improvement at the north pole being considerably better than the south pole. The improvement due to bias was found to scale with the applied voltage.

Generally, the biased coatings were far more ductile than the unbiased coatings, causing them to pull apart rather than fracture. This made it difficult to measure accurately the film thicknesses for the biased coatings. In those cases where measurements of thickness could reasonably be made, however, the accumulation rate at the north pole

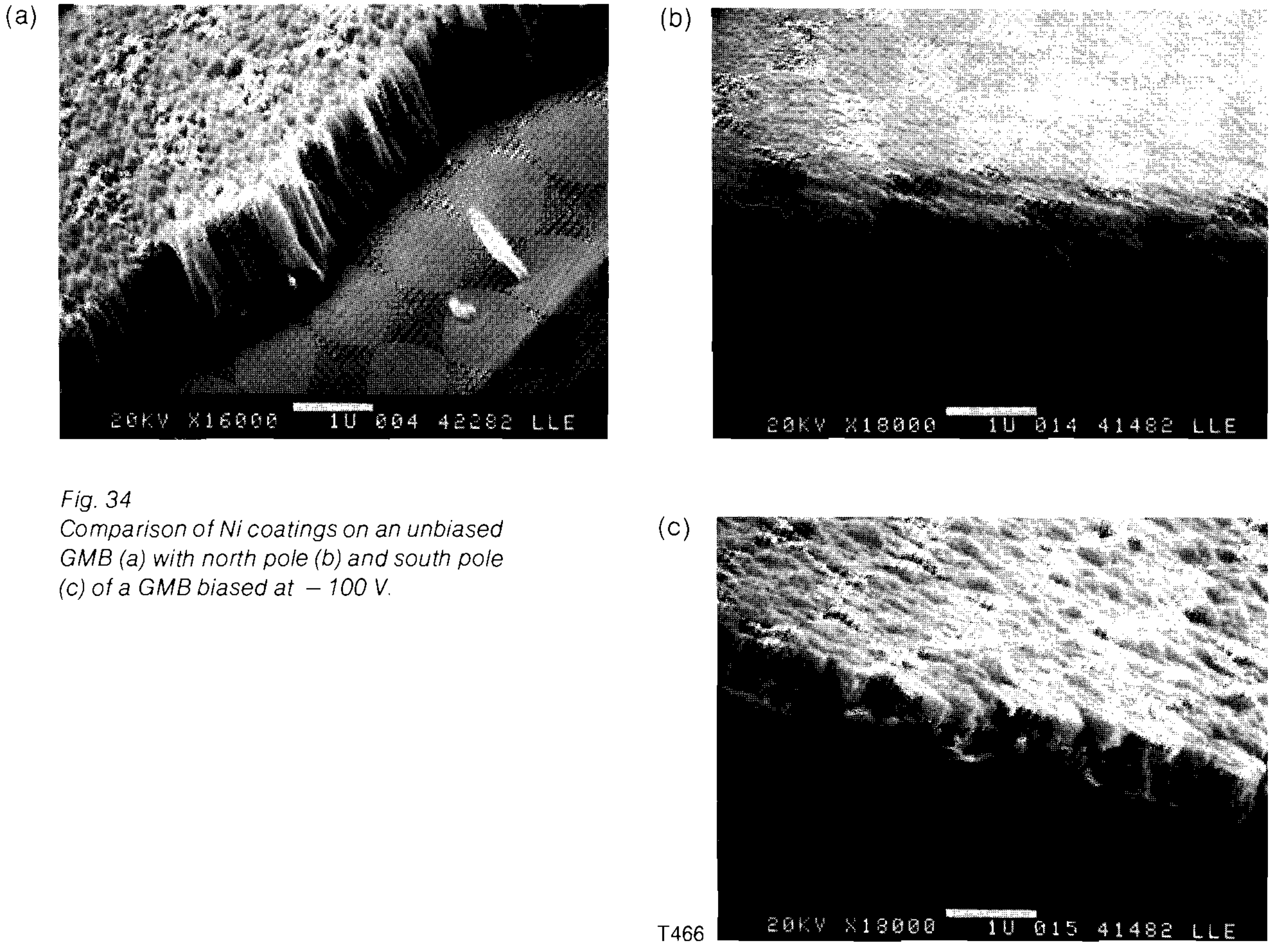


Fig. 34
Comparison of Ni coatings on an unbiased GMB (a) with north pole (b) and south pole (c) of a GMB biased at -100 V.

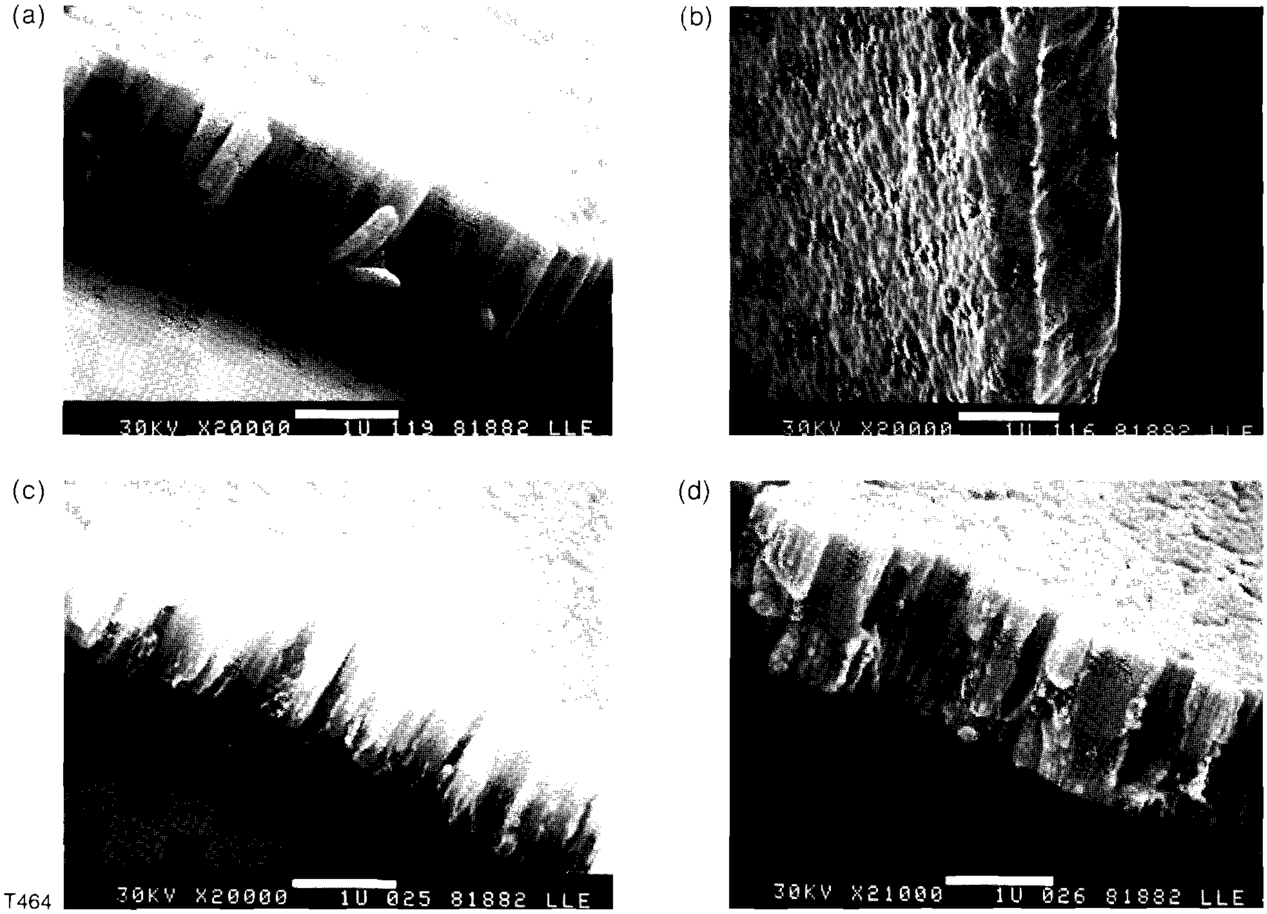
was greater than that at the south pole. This can be seen by comparing Figs. 34b and 34c. This variation in thickness was only observed in the case of biased GMB's.

The importance of substrate geometry is illustrated in Fig. 35. Figure 35a is a Cu coating applied to an unbiased GMB, while Fig. 35b is Cu which was coated on a GMB biased at − 100 V. A clear improvement is seen with bias. By contrast, Figs. 35c and 35d are Cu coatings applied under otherwise identical conditions to planar substrates which were unbiased and biased at − 100 V respectively. No clear improvement is evident as a result of bias for the planar substrates.

Based on the Langmuir probe measurements, the plasma density at the substrate was found to be approximately $5\times10^9/\text{cm}^3$. The electron energy distribution was non-Maxwellian, but an average temperature of 0.5 eV was calculated.[8,9]

Resputtering during film growth is the explanation often given for the results of biased sputtering, although this is a simple way of describing a very complex process.[2] The nature of the ion bombardment of the substrate in our case is determined by the sheath which surrounds the stalk/GMB. If we assume that ions enter the sheath with thermal velocities, ions of a particular species which arrive at a given location on the GMB will have a single velocity which is determined by the electric field sur-

Fig. 35
Comparison of the effect of bias on GMB's with the effect of bias on planar substrates. (a) and (b) are Cu coatings on GMB's biased at 0 V and − 100 V respectively, while (c) and (d) are Cu coatings on planar substrates biased at 0 V and − 100 V respectively.



rounding the GMB. By symmetry, at the north pole this velocity will be normal to the surface of the GMB, while at the south pole the stalk, with a diameter approximately 10% that of the microballoon, will produce a perturbation which results in non-normal ion incidence. It is possible that this non-normal incidence, which would be expected to lead to higher resputtering yields, may account for the generally lower rate of accumulation at the south pole. However, if resputtering were the only mechanism responsible for the improvement in coating quality, we would expect the thinner portion of the coating to be smoother and denser than the thicker portion, which is not the case.

It is possible that metal ions in the plasma may play an important role in our coatings. Even though they account for a small percentage of the metal vapor, the spherical geometry of our substrates will increase their significance. To illustrate, we will consider a GMB of radius r_G which is surrounded by a sheath of radius r_s. Since essentially all of the ions which enter the sheath will strike the substrate, the ratio of the effective area of the substrate for ions to that for neutrals is $(r_s/r_G)^2$. If a fraction γ of the metal vapor is ionized, then the ratio of the metal ion flux to the metal neutral flux is given by $\gamma(r_s/r_G)^2$. Consequently, for GMB's surrounded by sheaths several times their radii, the metal ion flux may play an important role in the coating process, even for small values of γ. This is particularly true when we consider that the metal ions will arrive at near normal incidence at the north pole, which may help explain the significant improvement at this location.

We can estimate the sheath radius in our experiments from the Langmuir probe data to be approximately 2 mm. The mean free path at our pressures is approximately 1 cm, making collisions in the sheath unlikely. This estimate is, of course, voltage dependent, and will certainly be different from stalk-mounted GMB's. Nevertheless, it indicates that for GMB's fractions of a millimeter in radius, the ion flux at the substrate could be enhanced by as much as two orders of magnitude.

The results of the experiments with planar substrates support the proposed explanation. In a planar geometry, a sheath whose thickness is small compared to the substrate dimensions will not alter the ratio of metal ions to metal neutrals striking the substrate, when compared to the unbiased case. Thus, we would expect little change as a result of bias other than that due to resputtering.

We therefore conclude that, in addition to resputtering, enhanced metal-ion bombardment as a result of bias contributes to the improvement in film structure which we have seen. This enhancement occurs because of the relatively large plasma sheath which surrounds the GMB's, producing a sizable number of metal ions arriving normal to the substrate. The reduced effect of bias in the case of planar substrates supports this conclusion. It is encouraging that large substrate biases appear to improve the quality of metal coatings sputtered onto GMB's. This provides an added bonus in the use of electrostatic and electrodynamic levitation schemes for unsupported GMB coatings.

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