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Beryllium Materials for National Ignition Facility Targets LDRD Final Report

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The National Ignition Facility (NIF) will require spherical ignition capsules approximately 2 mm in diameter with a 120- to 150-μm-thick ablator. Beryllium-based alloys are promising candidates for an ablator material due to their combination of low opacity and relatively high density (compared to polymer coatings). For optimum performance, the Be-coated capsules require a smooth surface finish, uniform thickness, microscopic homogeneity, and preferably high strength. The coatings must contain on the order of 1 at.% of a high-Z dopant (such as Cu) and permit the capsule to be filled with fuel, which will be a mixture of hydrogen isotopes. These demanding requirements can be met through a synthesis method with a focus on the control of microstructure. In our experiments, the sputter deposition process has been manipulated so as to decrease the grain size, thereby reducing roughness and improving homogeneity.

The material properties of sputter-deposited coatings are sensitive to their microstructure and growth morphology. To meet the requirements for Be coated capsules, the goal of this project was to optimize the microstructure and growth morphology through the control of deposition process parameters.

Prior experimental studies of evaporation and sputter deposition revealed that the grain size of 99.8 at.% pure Be can be reduced by adding insoluble metal impurities such as Fe or Ti. These higher atomic weight elements can replace the requirement of adding 1 at.% Cu to the Be. Grain size can also be reduced by using additives that are metallic-glass formers, such as boron. Finally, the microstructure can be modified by changing the energy or angular distribution of the depositing flux.

Our initial experiments focused on the development of Be-B-X alloys, where X is Fe and/or Cu. This work was successful in reducing the grain size of coatings deposited on planar substrates from microns to at least nanometers. TEM cross sections of these films showed no discernible grain structure, so for the purposes of this project the material was a glass. Deposition of a few μm of this alloy onto stationary capsules produced extremely smooth films: rms roughnesses of about 1 nm were observed using atomic force microscopy. As the coating thickness was increased, however, intrinsic stress in the film became a serious problem. Buckling and delamination were the typical symptoms of this phenomenon. Although there are techniques for mitigating stress build-up in deposited films, we concluded it would pose a formidable problem for the very thick coatings required for NIF capsules. For this reason, we shifted our efforts away from glassy alloys and concentrated on modifying the energy and angular distribution of the depositing Cu-doped beryllium flux.

Application of a negative substrate bias draws positive ions from the ambient sputter gas, inducing bombardment of the growing film. The ion-assisted deposition process results in dense columnar growth and reduced grain size. The effect on mechanical strength is also favorable: introduction of ion bombardment increases the fracture stress of Cu-doped Be capsules from less than 40 MPa to greater than 200 MPa. The roughness of 10-μm-thick coatings has been reduced from ~150 nm to ~30 nm rms. In support of these experiments, we developed a technique for producing a variable-intensity glow discharge above the substrate. This provides a means for adjusting the bombardment current at a fixed energy. We have routinely obtained films on planar substrates with roughly 10 nm rms surfaces. The other process modification we studied was to restrict the angular distribution of the depositing atoms. When atoms land on a growing film from all directions (isotropic deposition), surface roughness tends to be amplified by the process of self-shadowing. By using an aperture to restrict the flux to near-normal incidence, coatings were produced with a grain size of roughly 60 nm and a roughness of 5 nm rms. These results were encouraging, but they mostly served as a proof of prinicple. The technique suffers from an extremely slow deposition rate: to produce a NIF-thickness capsule would require many weeks of coating.

Although this LDRD ended before detailed studies of bias-deposited capsules could be completed, our results point to this as a promising approach to producing fine-grained, smooth Cu-doped beryllium capsules. Not only can the capsules be mass produced, but other dopants can be incorporated in place of copper with relatively minor modifications.

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