Sputter Deposited Beryllium Fuel Capsules for NIF

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Doped beryllium is a material of considerable interest to the ICF, as well as finding application in specialized industrial settings (e.g., x-ray windows). Some of these uses require conformal coating of thin films on (possibly) irregularly-shaped surfaces. Physical vapor deposition (PVD) is often used to accomplish this, and sputtering is often the technique of choice. Among its advantages are the fact that the depositing atoms are relatively energetic, leading to more compact films. Also, by simply applying a voltage bias to the substrate, ambient noble gas ions will bombard the growing film, which can cause further densification and other modifications to the microstructure. Sputtering is also well-suited to the introduction of dopants, even those that are insoluble. Most applications of these novel materials will require fundamental knowledge of their properties. Because so many can be devised, such information is generally unavailable.

Requirements for ICF targets will include the fabrication of spherical shell targets about 2 mm in diameter with a 120 to 150-μm beryllium or beryllium-boron ablator (Fig.A). The Beryllium or boron capsules have to meet demanding requirements with respect to surface finish, microstructure and strength. Surface roughness specifications indicate 10 nm or better with very fine grain or no grain at all. Also the capsule must withstand DT pressures up to 350 atmospheres.

The objective of our effort is to systematically study the properties of films produced under different conditions, with an emphasis on improving surface morphology and microstructure while studying permeability and capsule strength. We have made extensive use of atomic force and electron microscopy to determine the microstructure of the films, along with composition probes (mainly x-ray fluorescence) to quantify the chemical structure.

The beryllium, beryllium-boron films were prepared in a vacuum coating chamber inside a chemical fume hood with a HEPA filtered exhaust (Fig.B). The chamber was evacuated using a CTI cryopump to a pressure of 2.6 x 10⁻⁶ Pa. Three small magnetron sputtering sources in a triangular array were vertically positioned approximately 6.3 cm above the substrate pan (Fig.C). The dish shaped pan could be configured for coating either flat substrates or microspherical mandrels. A piezoelectric crystal isolating the
Our studies can be roughly divided into three categories. First, there are those in which the effects of substrate biasing have been investigated. This includes varying the substrate voltage from 0 to 120 V and applying an intermittent bias. Next, there are studies of Be combined with boron, a non-soluble dopant. Because of its low Z this dopant is of particular interest for x-ray related applications. Finally, there are experiments in which pulses of nitrogen are admitted to the vacuum chamber during deposition. The layers of nitride formed tended to disrupt the growth of Be grains, leading to a more fine-grained microstructure. For all these studies, we have most often used hollow plastic spheres for our substrate material. However, there have been some samples deposited on glass spheres or silicon flats.

The application of a voltage bias to the substrate had a significant effect on the morphology of the Be films. For 8- to 10-μm-thick films deposited on plastic spheres, the rms. roughness decreased from ~150 nm with no bias (Fig.1) to ~40 nm with a 120 V bias (Fig.2). At the same time, the grain size was reduced, and the film density increased (reflecting the elimination of voids). X-ray fluorescence measurements detected the presence of implanted argon in 120 V bias films, but not at 80 V bias or below. This observation would be relevant for applications sensitive to the x-ray transparency of the film.

Two experiments were conducted using intermittent biasing: 1 min at 100 V/10 min at 0 V and 1 min at 200 V/10 min at 0 V. In both cases, the biasing appeared to have no significant effect.

The studies involving boron doping have just begun, so there are few results. We have observed that films with about 3 atom % boron display a distinctly different morphology. Figure 3. shows an outer surface and cross section of a 1 mm diameter microsphere with no boron doping while Figure 4. shows the same sized microsphere with finer grain structure and reduced surface roughness doped with 3 atom % boron. We have also noted that films deposited with 18 atom % boron are quite smooth with ~1 nanometer surface roughness. We hope to perform x-ray diffraction measurements on such films to determine how the crystal structure differs from pure beryllium.

Exposing the films to pulses of nitrogen gas during deposition also had a significant effect. In these experiments, a 0.8 second pulse of N2 was
released in the vacuum chamber every 5 min. The resulting films were smoother, with roughnesses of 60 to 70 nm rms. as compared to films produced with no N2, with roughnesses measurements of ~150 nm rms. (Fig.5). These N2 doped films were also highly stressed and quite brittle. Some of samples fractured spontaneously. For most applications, these characteristics would be highly undesirable, so at present we have chosen not to pursue these experiments.

Characterization of these films for strength and permeability is still in its early stages. By pressurizing a Be-coated sphere using a fill tube, we have determined that films deposited without bias possess at least half the tensile strength of bulk-processed material. Also by applying high pressure (60 atmospheres) to Be-coated spheres we have found these films to be impermeable to Deuterium up to 150 °C.

The experiments done to date have demonstrated that doped Be capsules similar to NIF designs can be fabricated using sputter deposition. Although many questions remain to be resolved as to strength, surface finish, and permeability of these films, promising results have been obtained with only modest modifications in process parameters.
Fig. A. Left. Current NOVA capsule. Right. Proposed NIF design capsule.
Fig.B. Deposition vacuum chamber with viewport and microsphere viewing camera.
Fig. C. Magnetron sputter sources positioned above the piezo driven random bounce pan.
Fig. 1. 6 μm Be on CH microsphere. No bias, rms roughness ~150 nm.

Fig. 2. 9 μm Be on CH microsphere. 120V bias, rms roughness ~40 nm.

Fig. 3. Top. 6 μm Be on the outer surface of a CH microsphere, no boron. Bottom. Fracture cross section.

Fig. 4. Top. 9 μm Be/3 at.% Boron on the outer surface of a CH microsphere. Bottom. Fracture cross section.
Fig. 5. Left. 6µm Be on CH microshell, no N2, rms roughness ~150 nm.
Right. 8 µm Be on CH microshell, 800 msec N2 exposure every 5 min, rms roughness ~65 nm.