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*University of California-San Diego, La Jolla, California.

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FABRICATION AND CHARACTERIZATION OF BERYLLIUM RAYLEIGH-TAYLOR TARGETS FOR OMEGA EXPERIMENTS

K.A. Moreno, H.W. Xu, A. Nikroo, H. Huang, J. Fong,[1] J.E. Knipping, J.L. Kaae, and E.M. Giraldez

General Atomics, P.O. Box 85608, San Diego, California 92186-5608
[1]University of California, San Diego, 9500 Gilman Drive, La Jolla, California 92093
moreno@fusion.gat.com

Rayleigh-Taylor experiments have been designed for the OMEGA laser facility at the Laboratory for Laser Energetics (LLE) of the University of Rochester to explore perturbations during implosion of this ablator. For the experiment to be relevant, the beryllium copper flat used as the target must be similar in chemical makeup and morphology to the NIF ignition target. To visualize the perturbation growth, the flats were fabricated with sinusoidal perturbations on one side of a wavelength of 50 μm and amplitude of 0.25 μm. The flats were doped with more copper than required in the NIF ablator specification to increase the x-ray optical depth during burn through. These flats were successfully fabricated using a mold technique. This technique, as well as the characterization techniques used to verify the chemical makeup and thicknesses, will be described in this paper.

I. INTRODUCTION

Copper-doped beryllium is one of the preferred ablators for ignition on the National Ignition Facility (Fig. 1).[1,2] Beryllium poses many advantages for inertial confinement fusion such as, low x-ray opacity, high thermal conductivity, and high density. The lower x-ray opacity of beryllium is more attractive (than plastic) because it allows the x-rays to penetrate deeper into the beryllium shell. Beryllium is doped with copper to effectively absorb the hohlraum x-ray energies, thus limiting the premature heating of the fuel. The higher thermal conductivity is important because it allows for more variations in the temperature uniformity in the hohlraum.[3] In addition, the density of beryllium is a better match to the ice layer, which helps to reduce Rayleigh Taylor growth during implosion.[3]

Although Cu-doped Be is one of the ablators of choice for the reasons listed above, it does have some disadvantages. One of the greatest disadvantages of beryllium is that it is opaque to visible light, which makes the determination of the thickness of a shell impossible when using measurement techniques such as white-light interferometry.[4] Another concern is the grain structure of the sputtered Cu-doped Be, because of the potential for defects in the material could contribute to the seeding of instability in the implosion.[5]

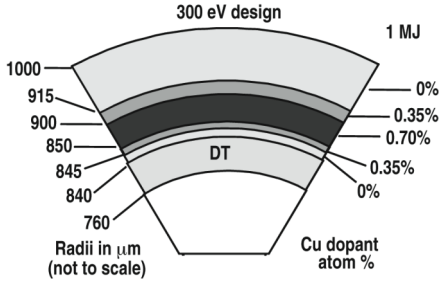

Figure 1. The NIF specification of the graded copper doped beryllium capsule. The shell has an outer diameter of 2 mm and a total wall thickness of 160 μm. The chemical composition of the layers is shown above.[1]

A rippled flat with a mixture of beryllium and copper is used as a diagnostic tool to measure Rayleigh-Taylor instability in inertial confinement fusion experiments. A flat is used because it is easier to characterize the perturbations without having to equate the geometry of a sphere during ablation. The specifications of the flats are shown in Table I. As shown Table I, the atomic percentage of copper is almost three times that of the NIF specification (Fig. 1). This was done to increase the x-ray opacity as well as to increase the contrast of the perturbation growth during ablation.

II. FABRICATION OF THE FLATS

The initial experimental approach was to directly machine the sputtered copper doped beryllium. During test runs, however, the sputtered material chipped off causing uneven machining or in some cases no machining at all. Additionally, carbide formation due to heat generation caused the diamond tool to break. After these initial tests it was evident that a different approach was needed.

Table I. Specifications and Characterization Techniques of the Beryllium Rayleigh-Taylor Flats

	Characteristic	Specification	Characterization Technique
A	Thickness	A: 40±5 μm, flat to ≤1 μm B: 50±5 μm, flat to ≤1 μm	Interferometic microscopy
B	Morphology	Similar to Be shells	Scanning electron microscopy of cross section
C	Wavelength	50±1 μm	Interferometic microscopy
D	Amplitude	0.25±0.03 μm	Interferometic microscopy
E	No ripples side, surface finish	<200 nm RMS	Interferometic microscopy
F	Chemical composition	Be doped with 2–3 Cu at. % measured to 10%	X-ray fluorescence and contact radiography
G	Density	Known to within <3%	Correlation of Cu at. % with known samples, floating

The mold technique[11] utilizes a substrate of aluminum or copper machined with features having the required wavelength and amplitude as shown in Fig. 2. After machining these features, trenches were milled to produce circles of 1 mm diameter, to produce a path to the substrate during the etching step. The trenches were milled before coating so that the mill would not be contaminated with beryllium, as well as to prevent a similar result that was seen when direct machining of the beryllium was tried. These trenches define the outer diameter of the flat, which are required to be >0.8 mm, as seen in Fig. 3. While developing the process, it became clear that aluminum would be the more reliable substrate. It was observed that because of the elevated temperatures during coating, the beryllium delaminated from the copper substrate due to the difference in the coefficient of thermal expansion (CTE) between beryllium (11.3) and copper (16.5).[6] This delamination due to the CTE mismatch made it impossible to polish uniformly or get an accurate starting thickness. Also, the nitric acid, which is used to etch the copper substrate, posed a threat to the copper in the Be-RT flat.

The sputter deposition was done in a high vacuum chamber with 2-in. magnetron sputter sources. There were three beryllium sources and one copper source. The beryllium sputter sources were 8.75 cm away from the substrate, and the copper sputter source was adjusted to 23.8 cm away from the substrate. Sputter coating in this manner has been described previously.[6,7] The copper source was moved closer than it is typically positioned

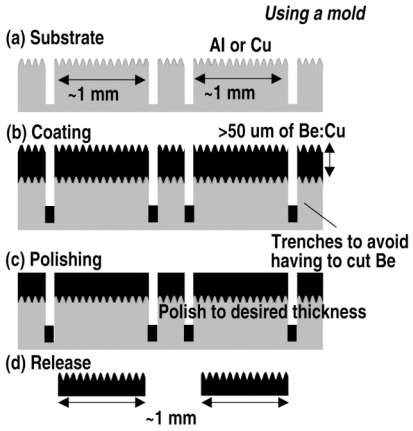

Figure 2. "Mold technique" (a) begin with a substrate machined with the required ripples, (b) overcoat with Be and Cu, (c) polish to required thickness, (d) release Be:Cu flats by etching away substrate. (*Not to scale*)

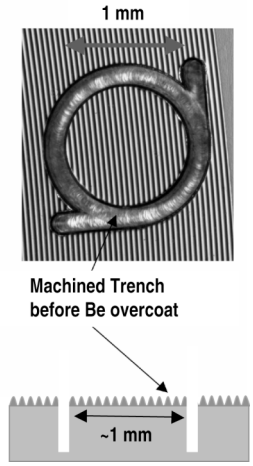

Figure 3. Milled trench to allow access to substrate after over coat.

when fabricating the NIF specification capsules to obtain the higher Cu atomic percent that was required for this experiment. A calibration run was performed to check that the chemical composition was correct, and was measured by x-ray fluorescence. The final distance and power settings for the beryllium and copper magnetron sputter sources were adjusted using the results of the calibration run. The substrate was then sputtered with 60–70 μm of beryllium with ~2 at. % of copper. This 2 at. % of copper is close to the solubility limit for copper in beryllium, but because sputter coating is not an equilibrium process, solubility was not an issue. Part of the substrate was physically masked in order to create a step, the height of which was measured by interferometry, giving an accurate starting point for the thickness of the material before it was polished.

The substrate with 60–70 μm of Be:Cu was polished down to the required thicknesses. An automated "MetPrep 3-in. polisher by Allied High Tech was used. The polishing was monitored by using the masked area as height, set initially to 0 μm, and then measuring the height of the beryllium by interferometric microscopy. When the thicker of the two required thicknesses, 50 μm, was reached, the substrate with coating was removed from the polisher and half of the flats were released by etching the aluminum substrate with sodium hydroxide. After releasing the first half of the flats the other half were polished down another 10 μm to reach the second required thickness of 40 μm, and then released in the same fashion.

The freestanding beryllium rippled flats were then characterized to verify that the specifications outlined in Table I were met.

III. CHARACTERIZATION OF THE FLATS

III.A. Thickness

White light interferometry was used to accurately (±0.2 μm) measure the thickness of each Be rippled flat. The high opacity of the Be flat obviates optical transmission diagnostics. The Be flat was placed on a tripod of plastic above a flat glass slide. This tripod was fabricated by putting three spots of UV glue of similar size on a glass slide. The distance from both the top and bottom of the Be flat to the glass slide was measured. The bottom of the flats was inferred from careful characterization of the UV glue spots. A simple subtraction gave the overall thickness of the Be copper flats. The three spots of the tripod allowed for three separate measurements. This technique, although with a slight variation in approach, was fully examined by Steinman et al.[4]

III.B. Morphology

For the Raleigh-Taylor experiment to be relevant, the grain structure of the flat needed to be similar to that in a NIF-specified shell. In a NIF-specified capsule, a columnar grain structure is observed by scanning electron microscopy (SEM).[5] The samples were prepared by physically breaking a shell and a surrogate flat to expose a cross section. The cross sections were than viewed using an SEM. A very similar grain structure was seen in the SEM image of the beryllium rippled flat and the NIF spec shell. SEM images are shown for comparison in Fig. 4.

III.C. Wavelength/Amplitude and Non-Rippled Side Surface Finish

A WYKO "NT3300" surface profiler was used to measure the wavelength and amplitude of the ripple pattern in the surface of the freestanding flat. The wavelength measured on the rippled side is the required 50±0.2 μm, as shown in Fig. 5. The amplitude measured was 0.4±0.2 μm, which did not meet the specification but could be fixed by careful machining. The experimental requirement for the smoothness of the non-rippled surface called for an RMS roughness of less 200 nm. The surface roughness of this side was measured to be between 140-180 nm, well within this specification.

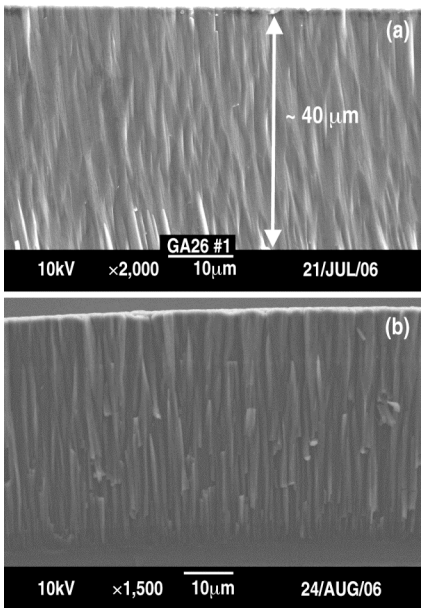

Figure 4. (a) An SEM image of the cross section of beryllium rippled flat after breaking. (b) An SEM image of a cross section of a NIF spec shell after breaking.

III.D. Copper Atomic Percent

Each individual flat was analyzed using x-ray fluorescence (XRF) and quantitative contact radiography,[8–9] both of which were done to determine the concentration of copper. According to XRF and contact radiography measurements, the copper atom percent ranged from 1.5–3.0 Cu at. %. The two methods agreed to within 10%, which met the specification for the accuracy of the copper atomic percent. This variation in the copper atomic percent is believed to be due to the positioning of the substrate during coating. More investigation needs to be done to confirm this hypothesis.

III.E. Density of Sample

The densities of different beryllium copper alloys has not been widely studied, so little published information exists. In order to determine the densities of our samples, a comparison was made with beryllium copper standards.[10] J. Cooley of Los Alamos National Laboratory

made many different standards by arc melting different mass percentages of beryllium and copper. The density of these standards was measured by adjusting a mixture of dibromopropane and carbon tetrachloride to equilibrate the flat. The densities of the standard and the solutions were matched by varying the concentrations of the two solvents. Once the proper mixture was found, the solutions were analyzed with a densitometer to determine the densities. By knowing the different mass percentages and their measured densities by floating, it is then possible to determine the density of other samples when the concentration of copper was known. The variations in the microstructure of the sputtered flats and the arc-melted standards were checked by ultra small angle x-ray scattering. The result was that there were as many voids in the Rayleigh-Taylor flats as there were in the arc-melted standards indicating that their densities could be compared. We used the copper atom percent measured by XRF to compare our samples with the standards to determine the densities. These densities were verified by floating surrogate flats in the same manner as the standards. The samples that were floated agreed with the standard curve to within 5%, as shown in Fig. 6.

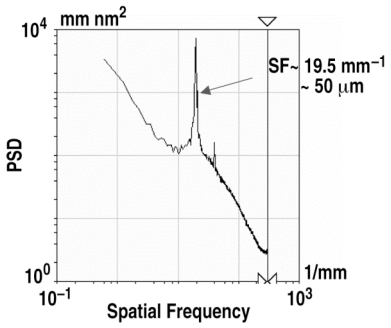

Figure 5. Spatial frequency of a typical wavelength (50 μm) seen in a beryllium Rayleigh Taylor flat measured by interferometry.

IV. CONCLUSION

Rippled copper-doped beryllium flats were successfully fabricated and characterized for Rayleigh-Taylor experiments on the OMEGA laser. A mold was used to form the required ripple on one side and to produce the proper sized free-standing flat. Beryllium and copper were co-sputtered to obtain the required chemical composition. This sputtered material was then polished down to the appropriate thickness and released by etching away the mold. The freestanding flats were than characterized to verify that they met the specifications required by the Rayleigh-Taylor experiment. All of the specifications were met except for the amplitude of the rippled side, which could have been adjusted by the machining of the mold.

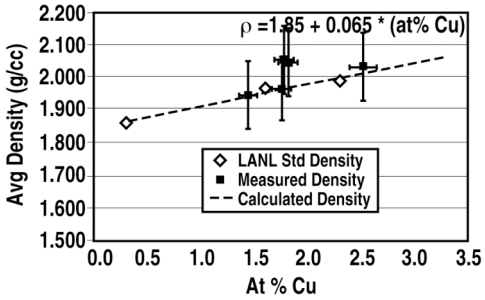

Figure 6. A comparison between the standard Be Cu alloys and surrogate beryllium Rayleigh-Taylor flats.

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