FORMATION AND CHARACTERIZATION OF POLYIMIDE TENTS FOR NIF-TARGET CAPSULES

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Tents meeting current thickness and uniformity/roughness specifications are needed to position ICF target-capsules inside hohlraum assemblies. We have developed a vacuum-forming technique to mold less than 100nm-thick polyimide films into partially-conforming capsule-tents. Characterization of the tents has been performed by an in-house metrology system designed to measure their roughness- and thickness-distributions. This paper will review the results of our tent-forming technique and the characterization of these tents surrounding capsules in hohlraum assemblies.

I. MOTIVATION

The tenting material is required to be sufficiently stiff and strong in tension to the minimize spatial-oscillations and withstand accelerations resulting from motion during target-insertion.[1] The roughness-spectrum of the tenting material is required to meet the NIF standard for ablator roughness. Finally, the material needs to be transparent to the x-ray energy being emitted from the hohlraum wall.

Luxel Corporation specializes in the production and assembly of ultra-thin (approximately 10nm) polyimide (PI) films. It is expected that polyimide will meet all of the material-requirements for NIF target-capsule tents.

II. VACUUM-FORMED POLYIMIDE TENTS

A machined mold is used to vacuum-form thin-film polyimide into a conical shape with an apex having a radius-of-curvature comparable to that of a NIF target-capsule. This design is used to control where the film separates tangentially from the capsule.

Partial elastic recovery (~20%) is accounted for in the mold design to produce a sufficient pre-load on a capsule when top- and bottom-tents are placed about a capsule. This enables positioning of the capsule, laterally, relative to the hohlraum wall. Vertical positioning is controlled by a differential pre-load between the top- and bottom-tent.

Figure 1 shows a tent (pre-formed thickness of 400nm) produced from a conical, female mold. It starts as a planar, spun-cast PI film that is adhered to a stiff ring. This is then placed over the mold and evacuated to deform it into the mold cavity. Upon return to ambient pressure, the apex recovers to approximately 80% of its maximum displacement under vacuum.

Figure 1. Vacuum formed polyimide tent.

III. METROLOGY SYSTEM

A custom measurement system has been assembled to characterize film-tents prior to assembly and after they are assembled in the hohlraum bodies. Characterization includes topography to quantify geometry and film-thickness over formed tents. Figure 2 shows the system, which is comprised of three major tools: a six-axis positioner, a topography sensor, and a film-thickness sensor. The positioner is a six-legged parallel kinematic manipulator or hexapod. It has a approximately 50nm repeatability within a 15mm^3 working-volume. The hexapod is used to raster-scan samples under the topography and thickness sensors. An additional requirement of the hexapod is the assembly operation for the capsule, tents, and holhraum body halves. The required spatial uncertainty of the capsule relative to the holhraum body is 8 microns or less. At present, the assembly plan has yet to be finalized, however several scenarios have been proposed for both radially and axially positioning the capsule using our current equipment and custom fixturing.

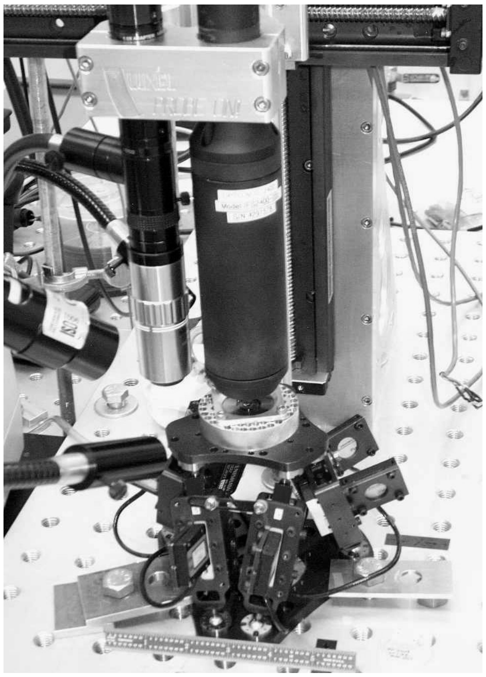

Figure 2. Hexapod mounted on test bench with topography and film thickness sensors mounted above.

The topography sensor is a non-contact, surface-displacement sensor. It is based on calibrated chromatic deviation of white light. A specific distance is assigned to each wavelength by a factory calibration. The wavelength that is maximally focused on a surface is used to obtain a given displacement measure. This reflected light is passed to a spectrometer-detector via a confocal aperture where the detectable surface-area is from a 10-micron spot-size. This sensor resolves sub-micron displacements on tilted, specular surfaces up to 25° from horizontal and has a range of 350-microns.

The thickness sensor is also non-contact and is based on visible spectroscopic reflectometry. The sensor is calibrated by measuring the reflectance of a specular surface with a known optical constant spectrum. Visible light from a 10-micron spot-size is then reflected at normal incidence from a film surface of unknown thickness. This light is passed to a spectrometer and a model is fit to the reflectance versus wavelength data. Fit parameters include the film-thickness. Figure 3 shows a reflectance spectrum from an approximately 70nm-thick polyimide film with a model-fit.

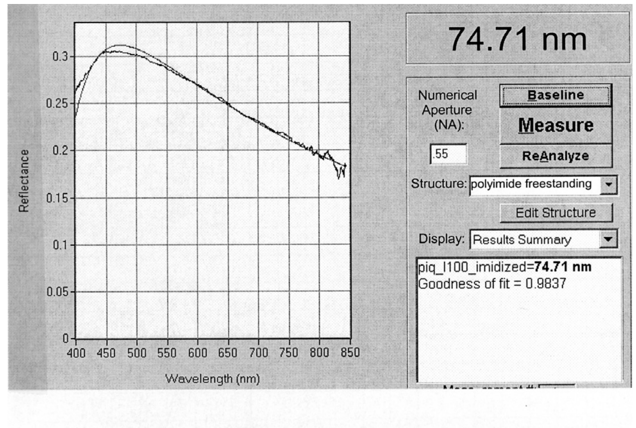

Figure 3. Graphical output for a film thickness measurement.

Reflectometry requires knowledge of all the optical-interfaces present to obtain an accurate thickness-measure of a film. For polyimide on a CH NIF target-capsule, two interface-models are required: (1) air-polyimide-air and (2) air-polyimide-CH. The former model applies to those areas of the thin-film tent that are not in contact with the CH capsule, while the later applies to those areas contacting the capsule. If Be-capsules are used, the CH in model (2) is replaced with Be. Figure 4 depicts the optical-constant data[2,3] used in these models. Reflectance spectra based on these models are shown in Figure 5.

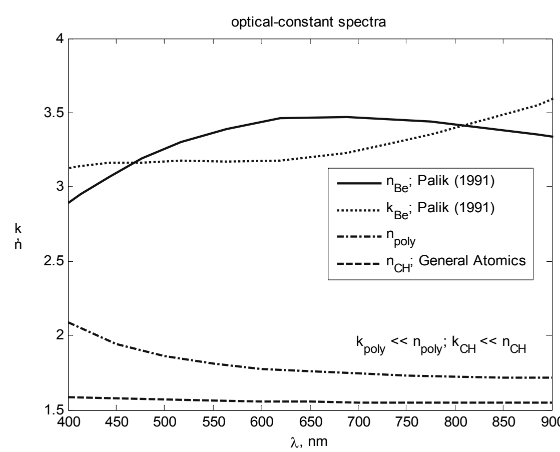

Figure 4. Optical-constant data for thickness measurements that are used for beryllium, polyimide, and 'CH' capsule constructions.

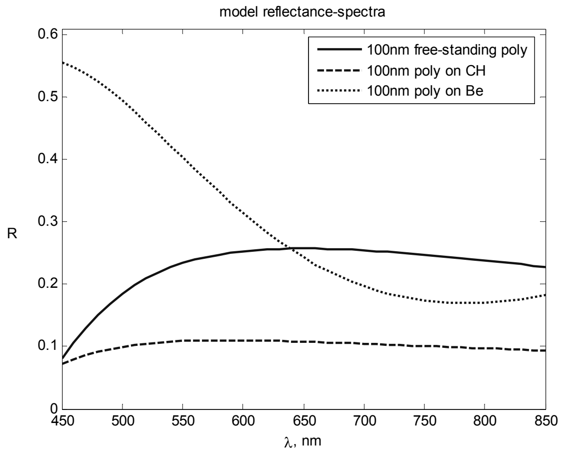

Figure 5. Modeled reflectance spectra for typical capsule/tent interface.

IV. METROLOGY RESULTS

Measurement maps for surface geometry and film thickness have been initiated using machined molds, CH capsules, and formed polyimide tents. Results are presented in the following sections.

IV.A. Topography Mapping

Initial topographic-scans were conducted on a tent-mold. This was done to verify the as-machined mold geometry. The image shown in Figure 6 verifies the conical form of the mold with a designed-depth of one-millimeter. The image shown has been inverted for clarity.

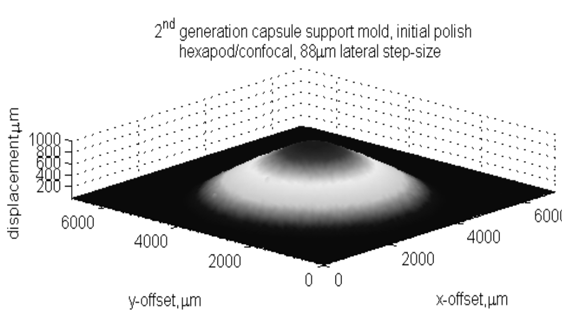

Figure 6. Inverted scan of a tent mold.

Additional scans were done on an approximately 2.2mm diameter CH capsule supplied by LLNL. This was done with a 25-micron step size over 1-millimeter square area covering the top of the capsule. A spherical-cap equation was fit to the scan-data. The fitted capsule-diameter is 2163±23 micron, which is within 2% of the LLNL measurement. The raw scan-data and the spherical-fit data are shown in Figure 7.

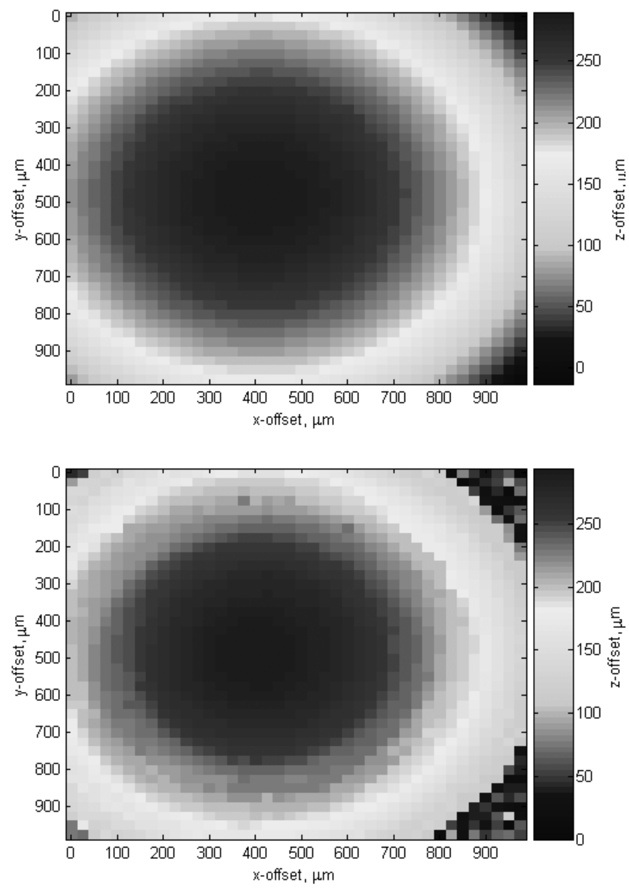

Figure 7. Surface topography scan of bare NIF capsule and spherical-fit to the raw data.

IV.B. Thickness Mapping

Figure 8 is an example of a thickness map of a flat-film over a mold prior to being vacuum-formed. This map indicates the film-thickness non-uniformity across the 5-millimeter diameter mold opening is less than 2%.

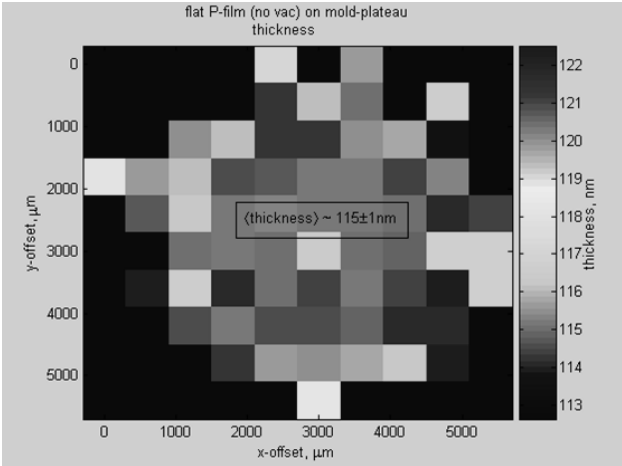

Figure 8. Thickness map.

Results indicate that for films less than 100nm-thick, the accuracy of the measured thickness is significantly reduced as the angle between the incident light-beam and the surface decreases from normal, i.e. 90°. For example, when an 80nm-thick film is tilted to approximately 25° from normal-incidence, the goodness of the model-fit decreases from greater than 90 percent to nearly zero.

A solution to this problem will use the hexapod's ability to rotate about an arbitrary point within its working-volume. Using topography data exemplified in section IV.A., the normal-surface-vector of a given point may be estimated. This will be used to rotate about the given point such that the local-surface is maximally-normal to the incident light-beam.

V. DISCUSSION

How a film thins during deformation in a mold or around a target-capsule needs to be understood / quantified if films less than 100nm-thick are to be used as robust target-supports. It is observed that the strain-limit of a film with thickness less than 1 micron depends on its thickness. For example, the 1-dimensional strain ($\Delta l/l_0$) of a film that is perfectly conforming to a hemisphere of a target may be shown to be $(\pi/2)-1 \approx 0.6$. This assumes the diameter of the initially flat-film equals the capsule's diameter. For a Kapton-like polyimide film (PMDA-ODA) with a thickness of 0.5 micron, its observed strain-limit is approximately 0.3, indicating it will not fully conform. As this initial thickness is reduced further to 100nm, its observed strain-limit is found to be less than 10%. This indicates the dependence of strain on thickness. To benefit from those properties of polyimide that make it attractive as a tenting-material, these results indicate that other polyimide chemistries and their deformation processes will need to be further considered.

Film-strain resulting in a film by conforming to a capsule may be reduced by increasing the initial-diameter (l_0) of the flat-film. It can be shown that the 1-D strain of a film perfectly-conforming to a hemisphere of a capsule is given by:

$$\varepsilon = \Delta l/l_0 = (\pi - 2)r/l_0 \ , \tag{1}$$

where r is the radius of the capsule.

If $l_0 = 2r$, the above-mentioned strain-limit is recovered. If the strain-limit of a film is known to be less than 0.1, Eq. (1) indicates the starting diameter of the film needs to be greater than $20r$. For a one-millimeter radius capsule, this implies l_0>2cm. It is noted that this assumes a film strains uniformly, which, as shown below from thinning-data, is not accurate. However, it does suggest that increasing the initial area results in a mean-reduction in strain-growth as a film is deformed.

The conical-mold used here is an attempt to deform thin-film polyimide within its strain-limit. This design results in a partially conforming film that contacts a NIF-target over an angle of ±24° degrees and then separates tangentially, following a straight-line path to the hohlraum wall—see Figure 9.

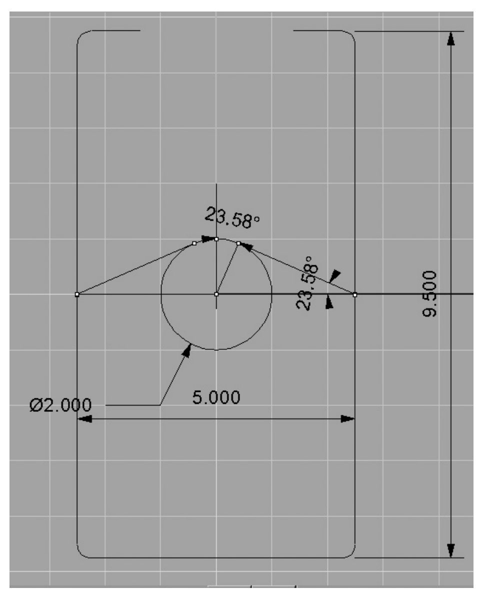

Figure 9. Tented NIF-target within a hohlraum; units = mm.

Film strain for this design (assuming an initially flat-film) are calculated to be approximately 0.10. Given the strain-limit for films less than 100nm-thick is less than ten percent, this design will need to be modified to safely accommodate these films. Current target designers[4,5] indicate film-tents may need greater conformation than this initial design to avoid contacting a low-density foam filling the hohlraum. The foam may be approximately 100µm away-from the target. Greater conformation means film-tents will be required to maintain higher strain-limits for a given initial flat-film diameter.

Figures 10 and 11 are an example of a formed tent that is compatible with foam-filled hohlraums. It conforms to ±55° of a capsule's perimeter. Instead of pre-forming thin-film polyimide in a separate mold, films are vacuum-molded directly about a capsule.

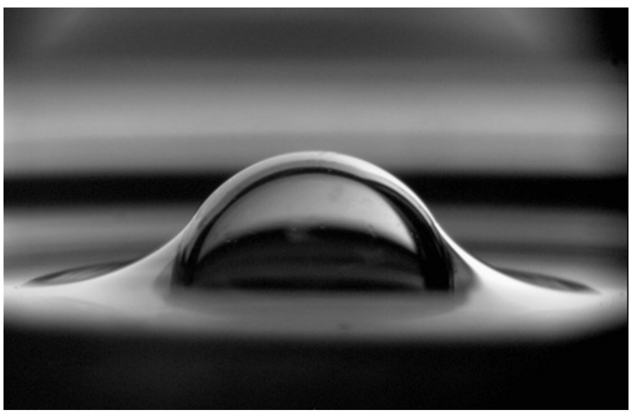

Figure 10. Film-tent vacuum-formed around NIF target; side-view.

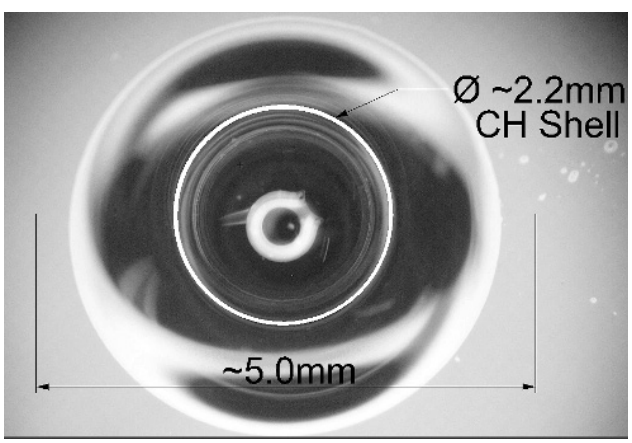

Figure 11. Film-tent vacuum-formed around NIF target; top down view.

Figure 12 is Figure 10 with a "measuring-guide" over-laid for the following analysis. The film is conforming to ±55° (about the apex) of the capsule's upper-hemisphere surface. In Figures 10 and Figure 11, no wrinkles in the film are detectable on, at the film-capsule tangent, or away from the capsule. Reflection from the apex of the shell is a florescent microscope bulb.

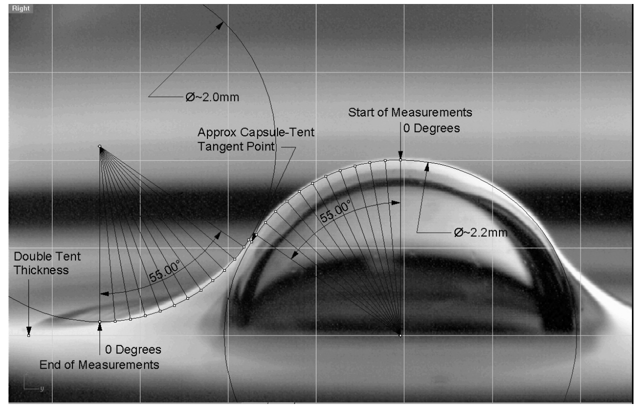

Figure 12. Film-tent vacuum-formed around NIF target; measuring-guide.

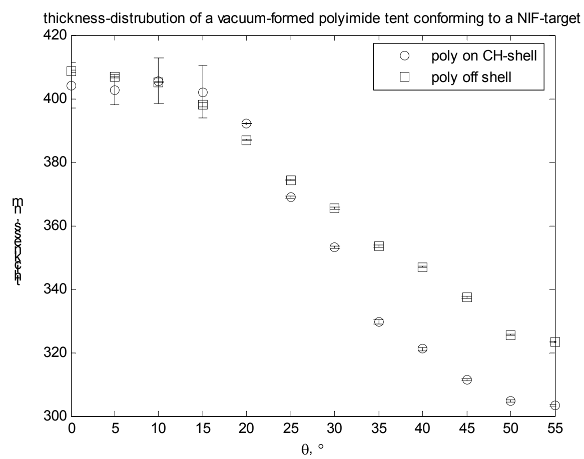

Figure 13. Thickness profiles.

Figure 13 is a plot of film thickness on and off the capsule. Measurements are taken at five-degree intervals as shown in Figure 12. They start at the apex of the capsule, move toward the film-capsule tangent, and end on the flat-film surface where the upper- and lower-films have converged. At the apex, thickness is found to be statistically-equal to the thickness of the converged flat-films. This indicates that once a film contacts a capsule-surface, it is not able to move or stretch laterally. The minimum thickness is observed to occur at the film-capsule tangent, which corresponds to 15% film-thinning. The measured approximate 20nm difference between the film-thickness off the capsule and on the capsule, about the tangent is not yet understood.

VI. CONCLUSIONS

Luxel Corporation has fabricated a custom metrology system capable of mapping both surface topography and film thickness for capsule tents in support of NIF. The process includes the forming and assembly of the PI tents meeting near-NIF specifications.

A vacuum-formed film directly about a capsule has shown an initial thickness-profile of less than 15% thinning. Maximum thinning is found to occur in the region where the film and capsule separate. Results indicate films less than 100nm have lower strain-limits than originally anticipated. This will require modifying the forming process as proposed above and/or using different polyimide chemistries allowing for greater strain-limits. Significant progress in refining this design is expected in the next year.

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