BATCH-PROCESSED COMPOSITE FOILS TARGETS WITH PARALLEL SURFACES

R. L. Hibbard, M. J. Bono, S. R. Strodtbeck, R. J. Vargas, C. Castro
Lawrence Livermore National Laboratory, LLNL[1]

1. 0 Introduction

The Target Technology team at LLNL fabricates targets for high energy density experiments. The experiments are conducted at the National Ignition Facility located at LLNL and at the Omega facility located at the University of Rochester. Material strength experiments feature targets composed of 30 µm thick aluminum and vanadium foils with sinusoidal rippled surfaces. The rippled surfaces of the foils are coated with a 6 µm plastic layer, and the front and back surfaces of these targets must be parallel to each other within +/-1 µm, Figure 1. Each material strength shot series typically requires up to 15 targets. Therefore, there is an opportunity to achieve a significant cost savings by designing a process to manufacture a large batch of targets simultaneously, rather than pursuing a standard method of fabricating each target individually [1]. The batch processing method designed for these targets achieves both performance and cost goals. The team developed two fabrication approaches for two different target designs. In one case, a 100 mm diameter aluminum disk was directly machined to the 30 µm thickness on a vacuum chuck. This operation required a carefully designed vacuum chuck and special part fixturing methods. The plastic layer was applied and machined without removing the aluminum component from the vacuum chuck, thereby assuring that the parallelism tolerance was met. Over 30 targets were then laser cut from the disk.

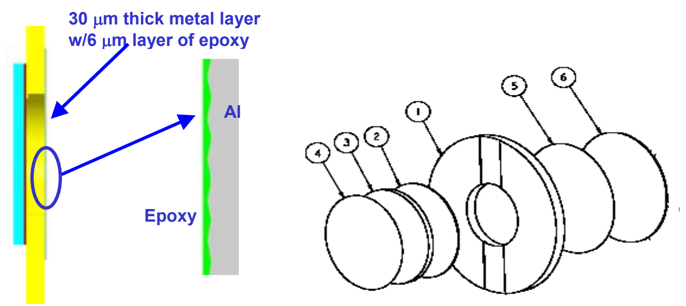


Figure 1. Typical rippled foil target with an epoxy layer with parallel front and rear surfaces.

The second set of targets was made of vanadium. These targets required a surface roughness of better than 100 nm, which is difficult to obtain when machining vanadium. Therefore, a replication approach was used to make the targets. A 30 mm diameter copper disk was machined to create a mandrel with the sinusoid pattern for a deposition process. Several 4 mm diameter disks of vanadium were deposited onto the mandrel, through a shadow mask, and then polished to the specified thickness. Once freed from the mandrel, the freestanding vanadium foils curled up to 200 µm per mm, from residual stress, and had to be flattened and mounted on special fixtures prior to the application of the epoxy. Because of the curvature of the vanadium disks, even after flattening them as well as possible on the special fixture, the thickness of the epoxy layers varied by approximately +/-1 µm within each target. These techniques could also be used to economically fabricate other thin foils.

2.0 Batch processing of thin foil targets – direct machining

These targets were also required to have the front and rear surfaces parallel to each other. Figure 1 shows the aluminum target design, 30 µm thick 1100 aluminum foils, coated with a 6 µm thick plastic layer. The foils (item 5 and 6) are the precision portion of the target and are supported on a polystyrene ring (item 1). On the input side of the target is a laminated heat shield (items 2 and 3) composed of plastic layers with a thin metal coating (item 4). In this design a sine wave of 3.4 µm peak-to-valley amplitude, and a wavelength of 40 µm was required.

The vacuum chuck design requires sufficient groove area to provide the needed holding force. Narrow lands are used because there is less area for dirt to be trapped and distort the part mounting, [2]. Wide grooves also allow more area for dirt to fall into. Typically a maximum ratio of 1 to 5 is used for the part thickness-to-groove area. With foil thickness of 30 µm and groove width of 75 µm the deformation of the foil is a few nm, and this was deemed a good balance for the design. The land width in this case was 5 µm. The radial vacuum grooves are spaced every 90 degrees to minimize the groove path length in the narrow land area and ensure adequate flow. A local deformation is tolerable over these radial grooves. Figure 2 shows a typical vacuum chuck design and a test part fabricated on it.

---

[1] This work was performed under the auspices of the U.S. DOE, by the UC, LLNL, under contract W-7405-ENG-48

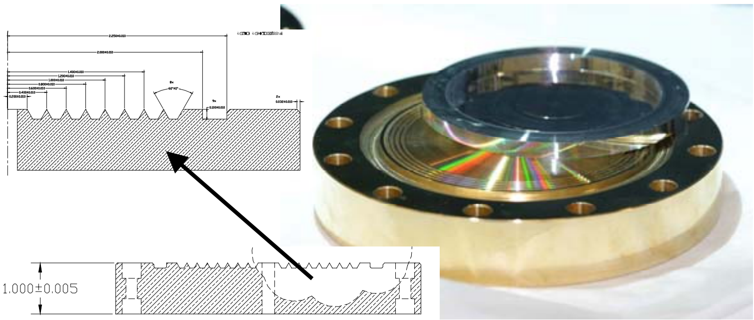


Figure 2. A typical vacuum chuck design and a test part fabricated on it, with the center portion machined to a 50 µm thickness.

In the 100 mm diameter disk, a tapered trench 8 mm wide was machined to the 30 µm thickness, as shown in Figure 3. The perimeter of the disk was left to provide structural support for handling. The inner portion of the disk was left 6 mm thick to decrease the amount of machining time and minimize the thin foil surface area where there is an increased risk of the foil distorting and losing vacuum. While the part was still on the machine, a layer of epoxy was manually applied around the thin foil section of the disk, as shown in Figure 3. A Hardman Green Epoxy with a two hour working time was mixed and pumped down slowly in a vacuum chamber to evacuate all trapped air. Since the part was in a vertical orientation, the diamond turning machine, DTM, was then left running at 5 rpm while the epoxy cured, so it would not flow. The epoxy was then machined to the 6 µm thickness.

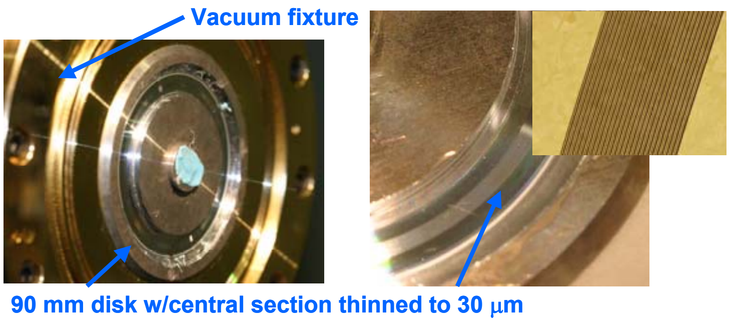


Figure 3. The aluminum piece on the vacuum chuck and a detail of the thinned section with the sinusoid cut.

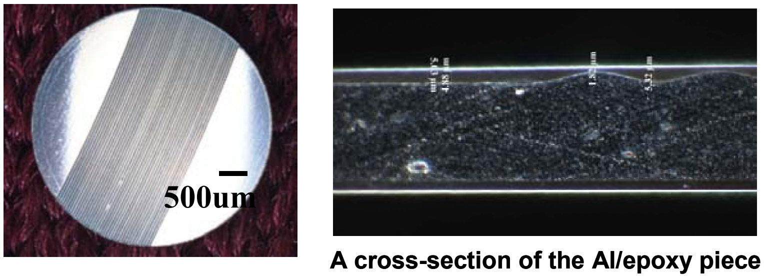
The parallelism of the front and rear faces of the laminated layer was ensured because the part was never removed from the precision vacuum chuck. This is in contrast to previous manufacturing methods, [3] where a plastic coating is applied and conforms to the shape of the substrate surface, replicating the sinusoid, and the target requirements are not met. Figure 4 shows where three areas were masked off when the epoxy was applied to allow for post process step height measurements. Once the epoxy was machined to thickness, the part could then be removed from the DTM because the precision processes have been completed.

The final manufacturing step was laser cutting 4 mm diameter disks out of the larger part. This was done with an Excimer laser, with a programmable x-y stage and a positioning capability of 2 µm. A total of 32 disks were cut out of the large disk, Figure 4. Residual stress in the parts either from the laser cutting or the machining caused the parts to curl slightly. Up to 15 µm of "bowling" occurred over the 4 mm diameter. This distortion was also removed in the final assembly process when the thin foil was flattened and mounted to the spacer. Once mounted, the flatness was 1-3 µm over the central 2.5 mm area.

Figure4. The masked area for metrology and the 32-4mm diameter disks cut out of the larger disk.

The metrology for these targets consisted of measuring the surface roughness of the aluminum and epoxy faces, R_a = 75 nm and 15 nm respectively. The thickness of the epoxy layer and the thickness of the aluminum foil were also measured. A representative target was also destructively cross-sectioned to allow evaluation of the part geometry.

Figure 5, shows a 4 mm diameter disk and some of the metrology results. After the fact the thickness of the aluminum and epoxy were measured on a two-probe thickness measuring gage developed at LLNL, [4]. The manufacturing principles of the vacuum chuck design, machining thin foils, and application of laminated layers on the DTM were successfully demonstrated. These can lower the cost per component. The techniques used for this can be applied to many similar planar targets.



A cross-section of the Al/epoxy piece

Figure 5. A completed 4mm disk and a cross-section of the foil.

3.0 Batch processing of thin foil targets – replication

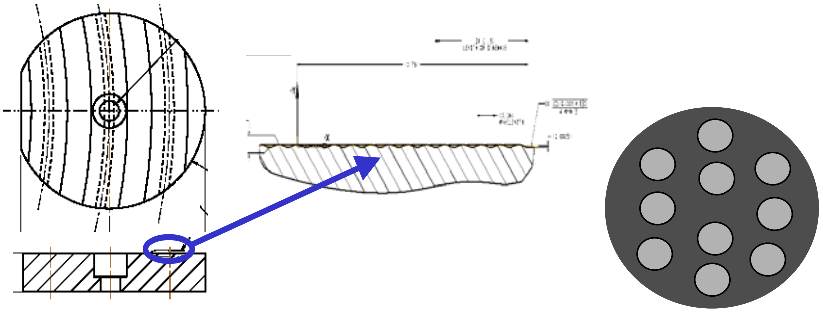
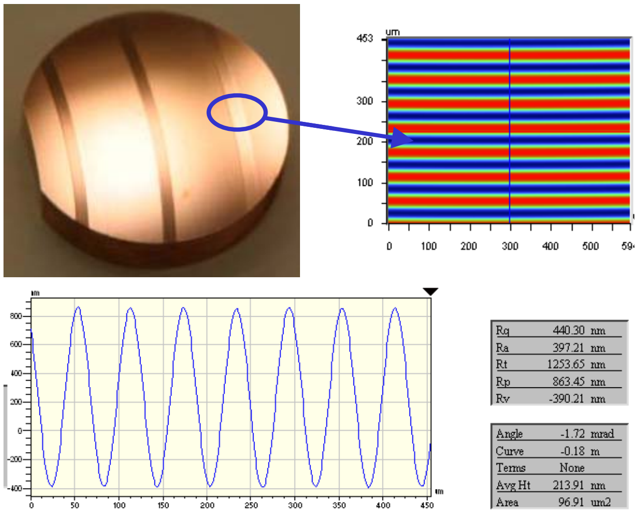


Figure 6. The design of the copper mandrel and mask for replication.

This target design was vanadium and a replication/deposition process was used. In this method a 30 mm diameter precision copper disk is manufactured for use as a mandrel for deposition, the design of this mandrel and a shadow mask to produce the 4 mm disks are shown in Figure 6. The targets have a 1.25 µm PV sinusoid with a period of 60 µm. The 6 µm thick epoxy layer and the parallel front and rear faces were also required, similar to the design shown in Figure 1.



Rq	440.30	nm
Ra	397.21	nm
Rt	1253.65	nm
Rp	863.45	nm
Rv	-390.21	nm

Angle	-1.72	mrad
Curve	-0.18	m
Terms	None	
Avg Ht	213.91	nm
Area	96.91	um2

Figure 7. The finished Cu mandrel and inspection

The mandrel was designed with reference surfaces so the height of the back surface of the vanadium could be measured during a polishing process to bring it to the correct thickness. The completed mandrels were inspected on an interferometer Figure 7, the period is 60.0 µm, the amplitude 2.5 µm and the surface roughness is R_a=4 nm. 35 µm of vanadium was deposited, because the process does not deliver a uniform thickness, so a post deposition polishing process is used. During this process the step height (or thickness) measurement is made periodically to calculate the thickness of the vanadium and it progressively polished to the final thickness. The electron beam vapor deposition process was also done at approximately 400 degrees Celsius and there are residual stresses introduced in the cooling process. When the mandrel was etched away to release the vanadium disks the residual stresses caused the thick foils to curl cylindrically up to 1 mm over the 4 mm diameter. To resolve this issue they were stress relieved and this allowed many to have only 80-200 µm of curl in the foils, which was dealt with in the epoxy application.

To apply the epoxy layer the single pieces of vanadium now had to be fixtured for machining, this was done with the typical fixtured used in diamond turning components. The repeatability in our ability to locate them on the DTM is 0.25 µm, [1]. The process for this is laid out in Figure 8, the first step is to establish a reference height on the

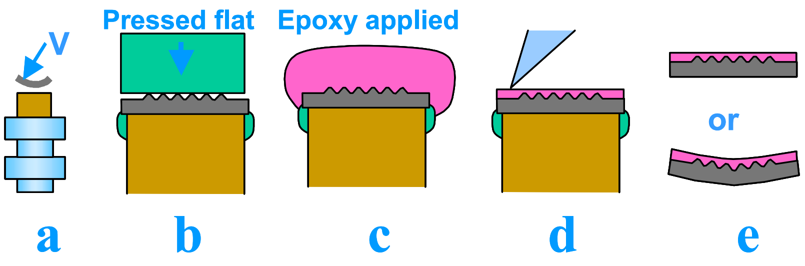
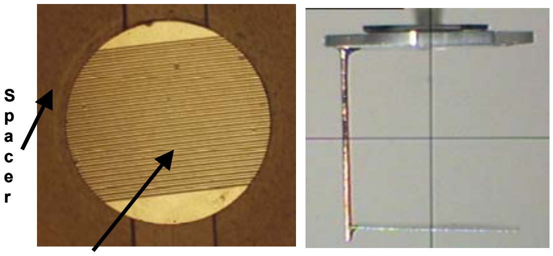


Figure 8. The manufacturing steps for applying the epoxy to the vanadium in a piece by piece process.

fixture, Figure 8a. The vanadium piece is then mounted on the fixtured, pressed flat and bonded around the perimeter of the fixture, Figure 8b. The part is then measured on an interferometer to see the flatness of the top surface, in all cases it is not perfectly flat, there is a loss of precision due to the stress in the vanadium foils. In most cases the foil has a bowl shape to it and within a central 1.25 mm diameter area the flatness was maintained within a specification of 1 μm, so the parallelism required could be met over a limited area. The epoxy is the applied, and machined to thickness, Figure 8c and d, by touching off on a reference surface on the fixture and knowing the thickness of the vanadium foil the machine can be positioned in the Z-axis such that a thickness accurate to 0.5 μm can be machined. The thickness of the epoxy is then verified with a measuring microscope. The pieces are then released from the fixture and they do curl up a few microns, Figure 8e, but the precision in the epoxy thickness was done in a constrained condition to ensure it meets specifications.



Epoxy over vanadium foil

Completed v/epoxy target

Figure 9. A completed target, and one mounted on a stalk with back lighters and fiducials.

A finished vanadium disk mounted on the spacer with the reservoir and a completed target are shown in Figure 9. When the vanadium foil with epoxy is mounted to the spacer it is pressed flat again and most of the free standing curl is removed from the specimen. The completed target is viewed through the spacer opening looking at the embedded sinusoid in the vanadium. The replicated surface roughness is R_a= 90 nm, and the polished back side R_a=75nm.

4.0 Discussion

A contrast in the ability to maintain precision is shown in these two different methods. In the first the part is prepared and fixtured on the DTM and it is never removed from the machine until the aluminum and epoxy are completed, thereby ensuring the parallelism and thicknesses of the layers. There is a single part setup and reference and the part is never removed from a fixture until completed. The parts did deform some during the laser cutting process, but this is if no consequence. In the second method because there is a transfer of the vanadium part from one fixture to another and in this process the stressed vanadium foil cannot be relocated in a perfectly constrained condition the precision cannot be maintained at a very high level. The vanadium foil thickness may be uniform but the thickness in the epoxy and the parallelism of the front and back surfaces suffer a loss of precision. The advantage of the direct machining is never losing control of the component while the precision is manufactured into the part. We are continuing to develop the batch processing techniques and are direct machining components out of 25 μm diameter parts to produce 10 – 15 parts. Other deposition processes are being investigated such as vacuum sputtering done at 100 degrees Celsius. This is a much slower process and only can apply approximately 1 μm on material per hour, but has shown to produce nearly stress free components.

References

1. Hibbard, R. L., Bono M. J., Amendt. P. A., Bennett, D. W., Castro, C., “ Precision Manufacturing of Inertial Confinement Fusion Double Shell Laser Targets for OMEGA”, J. Fusion Technol., Vol. 45, No. 2, pp. 117-123, 2004
2. Bono, M. J., Hibbard, R. L., Castro, C., “Fabrication of Planar Laser Targets with Sub-Micrometer Thickness Uniformity”, Accepted for publication in ASPE Annual Meeting, October 2005.
3. Hibbard, R. L., Bono, M. J., “Two methods of batch processing of thin foil targets With Features”, Target Fabrication Specialist Meeting May 2005, Internal viewgraph presentation.
4. Nederbragt, W. W., Hibbard, R. L., Kroll, J., Kelly, D., “Design and Use of a High-Accuracy Non-Contact Absolute Thickness Measurement Machine”, Accepted for publication in ASPE Annual Meeting, October 2005.