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An Overview of the Target Fabrication Operations at Lawrence Livermore National Laboratory

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AN OVERVIEW OF THE TARGET FABRICATION OPERATIONS AT LAWRENCE LIVERMORE NATIONAL LABORATORY

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1.0 Introduction

The Target Engineering team at Lawrence Livermore National Laboratory (LLNL) builds precision laser targets for the National Ignition Facility (NIF) and the Omega Laser in Rochester, NY, and other experimental facilities. The physics requirements demand precision in these targets, which creates a constant need for innovative manufacturing processes. As experimental diagnostics improve, there is greater demand for precision in fabrication, assembly, metrology, and documentation of as-built targets. The team specializes in meso-scale fabrication with core competencies in diamond turning, assembly, and metrology. Figure 1 shows a typical diamond turning center.

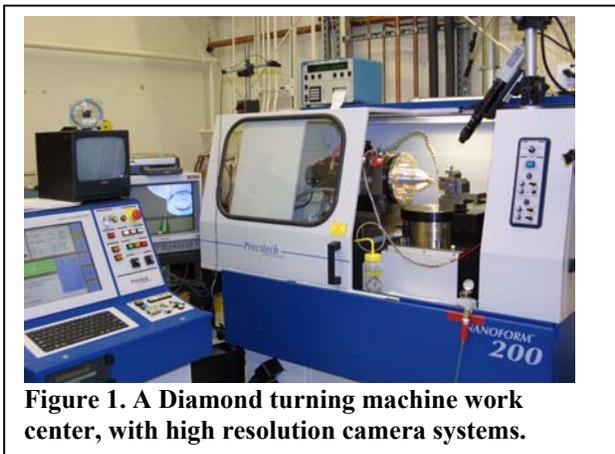


Figure 1. A Diamond turning machine work center, with high resolution camera systems.

The team builds over 200 laser targets per year in batches of five to fifteen targets. Thus, all are small-lot custom builds, and most are novel designs requiring engineering and process development. Component materials are metals, polymers and low density aerogel foams. Custom fixturing is used to locate parts on the Diamond Turning Machines (DTM) and assembly stations. This ensures parts can be repeatably located during manufacturing operations. Most target builds involve a series of fabricating one surface with features and then relocating the components on another fixture to finish the opposite side of the component. These components are then assembled to complete multiple-component targets. These targets are typically built one at a time. Cost and efficiency are issues with production of targets, and the team is developing batch

processing techniques to meet precision target specifications and cost goals.

Three example target builds will highlight some of the fabrication and material issues faced at LLNL. A low temperature Rayleigh Taylor target shows how multiple precision targets can be fabricated out of a single large disk. The ignition double shell targets highlight the required manufacturing complexity. A low density aerogel target highlights some material handling and assembly issues. The metrology requirements for these targets typically include absolute size, thickness and feature location, which is very challenging. Our team is always looking to other fields for similar operations where we can learn and apply new techniques to fabricating targets

2.0 Batch processing of thin foil targets

Some experimental campaigns require up to 15 targets per day. Thus, there are technical and economic reasons to

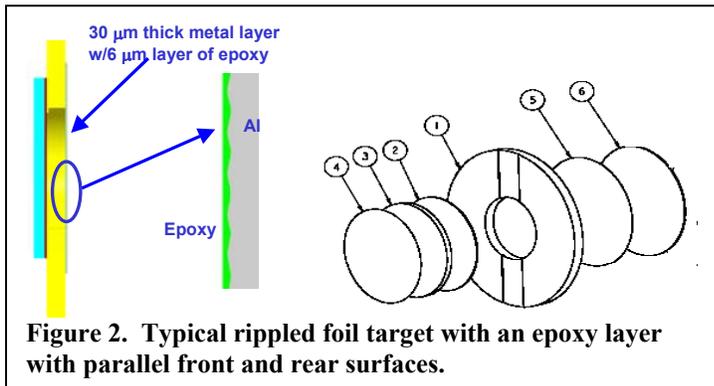


Figure 2. Typical rippled foil target with an epoxy layer with parallel front and rear surfaces.

fabricate targets in a more cost effective manner; batch processing is a way to achieve both performance and cost goals. Another challenge faced with material strength targets is a requirement to have the front and rear surfaces parallel to each other. Figure 2 shows the typical target design. The target designs are rippled aluminum foils, 30 μm thick, coated with a 6 μm thick plastic layer. The foils (item 5 and 6) 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). The metal foil and epoxy layer are the precision portion of the target. These components were manufactured with two different batch processing techniques: direct machining and replication. The replication method is discussed in a separate reference [1]. In the direct machining process a large, 90 mm diameter aluminum disk was machined to a thickness of 30 μm and a sine wave of 3.4 μm peak-to-valley amplitude, and a wavelength of 40 μm was machined into the surface. This thin section was coated with an epoxy layer.

The vacuum chuck design entails a compromise between wanting to fully support the surface so it cannot deform and providing enough area for the vacuum force to hold the work piece. There are two reasons for minimizing the area where the work piece is supported. One is that wide grooves leave more area for dirt and dust to fall into and not distort the part mounting. Two, narrow lands minimize the surface area where dirt can be trapped. In general, the chuck designs use large annular vacuum grooves where that work piece material is left thick. The radial vacuum

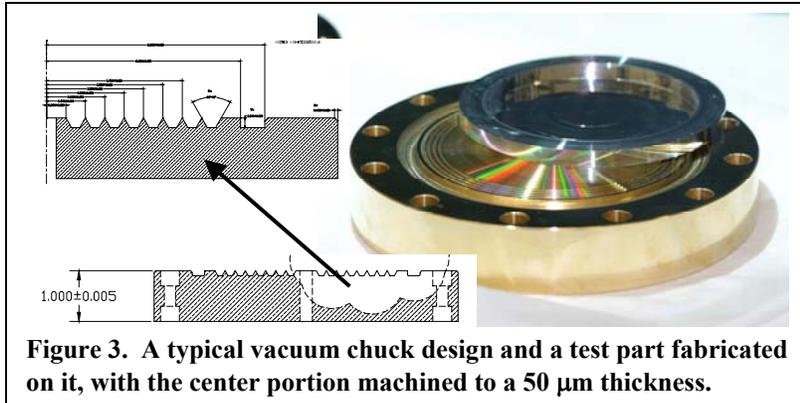
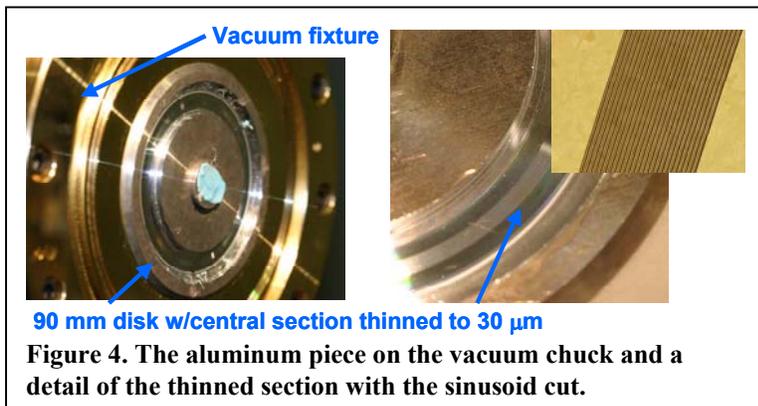


Figure 3. A typical vacuum chuck design and a test part fabricated on it, with the center portion machined to a 50 μm thickness.

grooves are spaced every 90 or 45 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. 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 30 μm thick foil is a few nm, and this was deemed a good balance for the design. The land width in this case was 5 μm . Figure 3 shows a typical

vacuum chuck design and a test part fabricated on it.

In the 90 mm diameter disk, a tapered trench 8 mm wide was machined to the 30 μm thickness, as shown in Figure 4. 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 4. 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. The epoxy was then spread over the machined sine wave. Since the part was in a vertical orientation, the diamond



90 mm disk w/central section thinned to 30 μm
Figure 4. The aluminum piece on the vacuum chuck and a detail of the thinned section with the sinusoid cut.

turning machine 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.

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, where the plastic layers were coated after completion of the targets. With a coating process, the plastic conforms to the shape of the substrate

surface and the target requirements are not met. Figure 5 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, which is an argon fluoride laser with a 193 nm wavelength, and a programmable x-y stage with a positioning capability of 2 μm . Figure 5 shows the end results of the laser machining. A total of 32 disks were cut

out of the large disk. 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. The laser cutting process left burrs around the edges that were approximately 15 μm high and extend into the top and bottom surface areas up to 50 μm around the perimeter. This excess



Figure 5. The masked area for metrology and the 32-4mm diameter disks cut out of the larger disk.

material was evenly distributed around the perimeter, and the added height from the burrs was accounted for by adjusting the thickness of the spacer.

The metrology for these targets consisted of measuring the surface roughness of the aluminum and epoxy

faces, $R_a = 75 \text{ nm}$ 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 6, shows a 4 mm diameter disk and some of the metrology results.

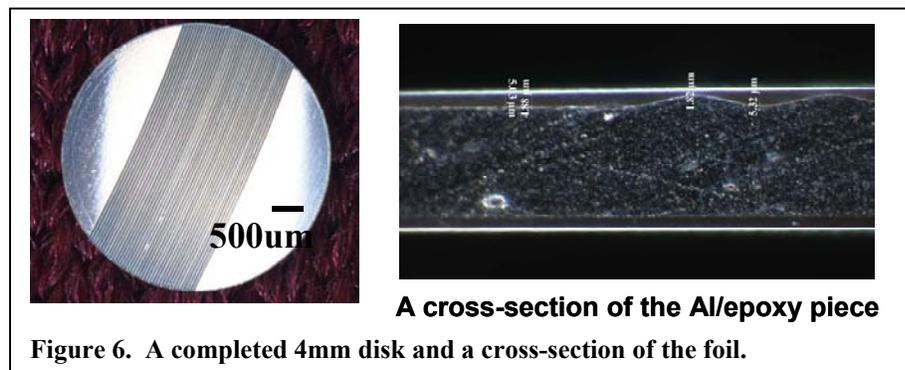


Figure 6. A completed 4mm disk and a cross-section of the foil.

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.

3.0 Fabrication of double shell targets

Historically, double shell capsules have been investigated because they reach ignition conditions at lower velocities than single shells. The suite of double shell ignition designs for the NIF, [2], consists of a low-Z outer shell that absorbs laser generated x-rays, implodes, and then collides with a smaller high-Z inner shell containing the high-

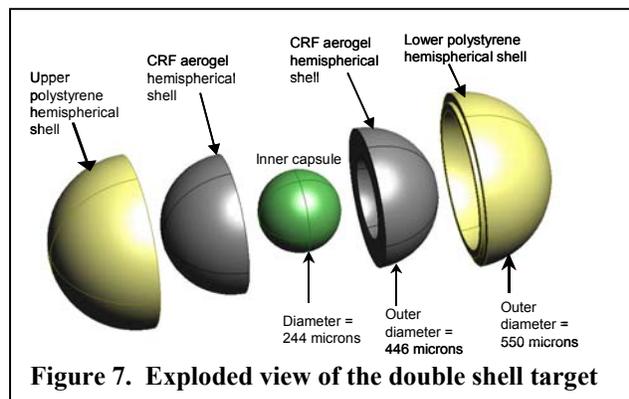


Figure 7. Exploded view of the double shell target

pressure deuterium-tritium fuel. Because the ignition tolerance to interface instabilities is rather low, the manufacturing requirements for smooth surface finishes and shell concentricity are particularly strict. As a prelude to fabricating and fielding ignition double shell targets on the NIF, an effort is underway on the Omega laser facility to build and field scaled ignition-like double shells. The fabrication of two versions of these targets is fully described in references [3 and 4], an overview of the target design is presented here.

An exploded view of the double shell target appears in Figure 7. The design consists of an inner plastic capsule with an outer diameter (OD) of 244 μm and a wall thickness of 15 μm . The inner capsule is

suspended in two hemispherical shells (hemis) of low density CRF aerogel with a thickness of 101 μm . The outer

ablator hemis have an outer diameter of 550 μm and are 52 μm thick. They are made of bromine-doped polystyrene. A bonded joint secures the two ablator hemis together and is designed to bond only in the outer half of the step joint, where a 2 μm gap has been intentionally left for the adhesive to fill, as shown in Figure 8.

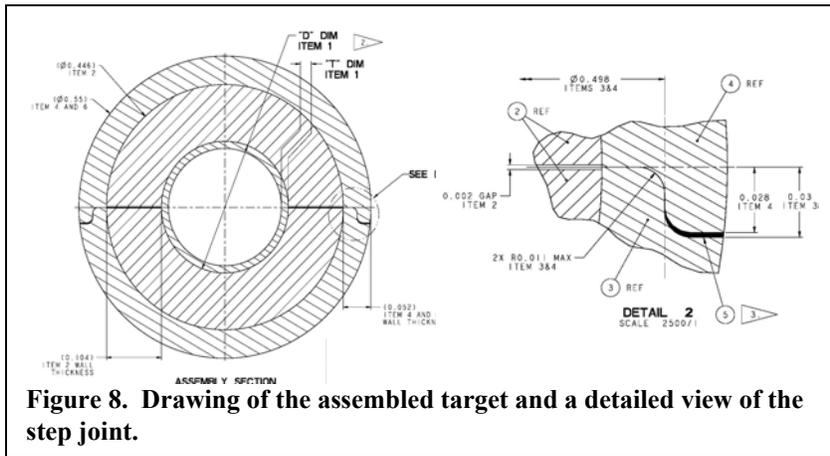


Figure 8. Drawing of the assembled target and a detailed view of the step joint.

The following capsule parameters are particularly important to these implosion experiments: concentricity of the two shells, thickness uniformity of the inner and outer shells, roughness of the various spherical surfaces, void volume fraction of the cyanoacrylate adhesive in the outer shell bond joint, and the cell size of the aerogel. All of these non-ideal effects can potentially degrade the performance of the target by causing hydrodynamic instabilities, so they require accurate pre-shot characterization. The overall

requirements are to maintain the dimensional tolerance of each component to $\pm 1 \mu\text{m}$ and all internal flaws to less than $\pm 0.5 \mu\text{m}$. Surface roughness requirements for the polystyrene surfaces are $0.01 \mu\text{m}$ RMS for Legendre mode numbers ten and greater. The inner capsule and outer shell are required to be concentric to within $5 \mu\text{m}$.

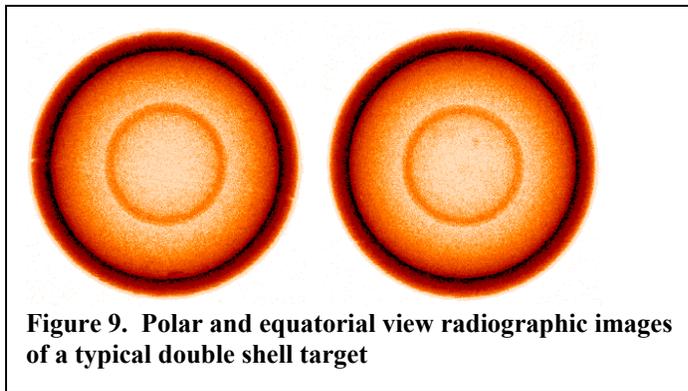


Figure 9. Polar and equatorial view radiographic images of a typical double shell target

The design and fabrication of these targets met the target requirements. To verify the as-built conditions, contact radiographs, with an estimated resolution of approximately $1 \mu\text{m}$ were taken. Two orthogonal radiographs were taken of each target. Example radiographs for one of the targets appear in Figure 9. For each target, two different fitting routines were used to calculate the concentricity errors in the plane of the joint and in the pole-to-pole direction. The six targets had concentricity errors of 1, 3, 4, 4, 5, and $5 \mu\text{m}$, which represent a $\Delta r/r$ of between 0.4% and 2%.

4.0 Fabrication of an aerogel target

A series of low density aerogel targets made out of 250 mg/cc tantala (Ta_2O_5) and 110 mg/cc silica (SiO_2) have been

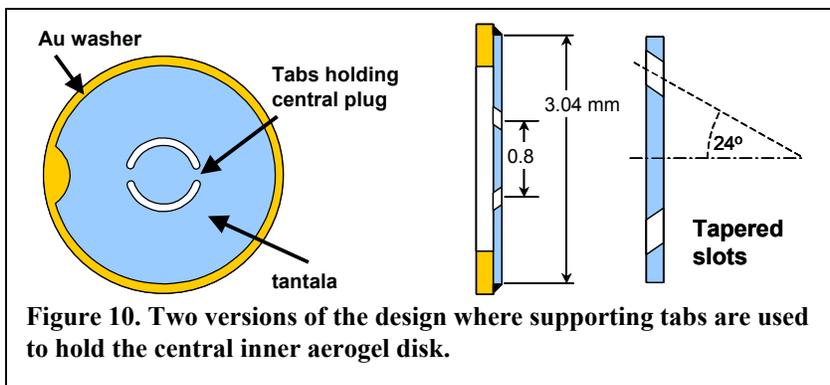


Figure 10. Two versions of the design where supporting tabs are used to hold the central inner aerogel disk.

made over the years with increasing complexity. Two simple versions of this target are shown in Figure 10, where a single layer of the tantala material is fabricated with different types of grooves in the aerogel. The desired goal is to have no support tabs holding the inner disk of aerogel. The third design, shown in Figure 11, achieved this goal by supporting the centerpiece on a lower density silica disk. The silica and tantala disks are $125 \mu\text{m}$ thick, the OD of

the part is 3.2 mm and the OD of the center plug is 1.0 mm. The manufacturing plan and fabrication of this target design highlight the intricate part handling and machining operations necessary to make this aerogel target.

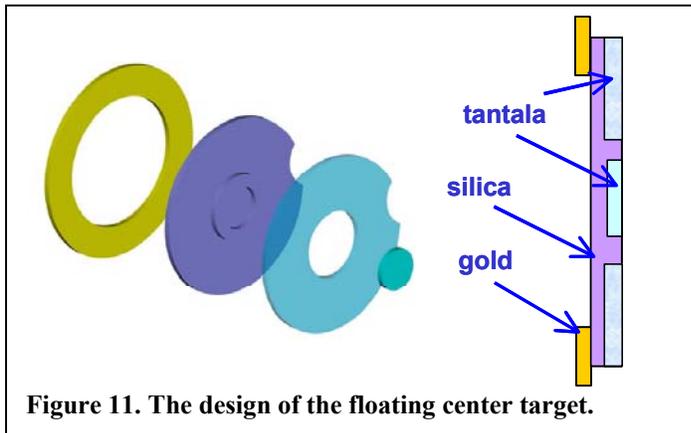


Figure 11. The design of the floating center target.

The fabrication process for this type of target is based on building up layers of material and mating them together. All of this is predicated on having repeatable fixturing to be able to locate parts on the DTM and assembly stations accurately. Because these materials are so fragile, the handling, fit, part tolerancing, and how the parts were mated and pressed together is critical. Any interference or miss alignment in assembly would cause the material to fail. The first stages of fabricating the silica base and the gold support ring are shown in Figure 12. All of these components were built up on standard fixtures that can be repeatably located on the DTM to 0.25 μm .

In the first operation, a silica piece was mounted on a standard fixture and an outside diameter and face were finish machined, as shown in Figure 12 (a). The part was also partially parted off during this operation. The fixturing and mounting of the gold support ring is shown in Figure 12(b). In this operation, a stepped chuck was made and the gold ring bonded on the exterior perimeter. Then the entire top surface was faced to ensure all surfaces are co-planar.

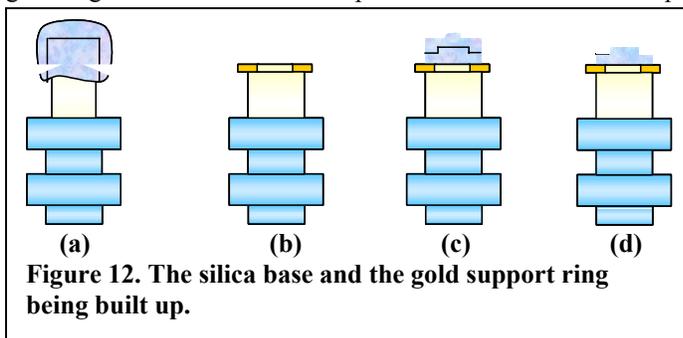


Figure 12. The silica base and the gold support ring being built up.

This was necessary to ensure when mating and bonding low density foam pieces; against this surface the material was loaded uniformly and would not fracture. Figures 12(c and d) show the partially parted off silica piece mated to the gold support ring and bonded around the perimeter, with the last piece broken off. The part was then remounted on the DTM and finish machined with a 1.25 mm diameter boss on it. The lower lands were then machined to a 125 μm final thickness.

Similarly, the outer portion of the tantala piece was roughed out, and the annular ring was cut, deeper than necessary, as shown in Figure 13(a and b).

At the same time, the inner plug of tantala was prepared, as shown in Figure 13(c). The tantala exterior piece was then mated and bonded in a manner similar to the silica part attachment to the gold washer, as shown in Figure 14(a). This piece had a 1 μm clearance fit and was assembled on a separate assembly station with two high resolution vision systems viewing the component alignment in orthogonal directions. This piece was then broken off manually and faced within 25 μm of the final thickness, as shown in Figure 14(b). The next step was to bore the inner diameter hole, with a 5 μm radius diamond tool, as shown in Figure 14(c). This bore was sized to have a 2 μm interference fit with the tantala plug.

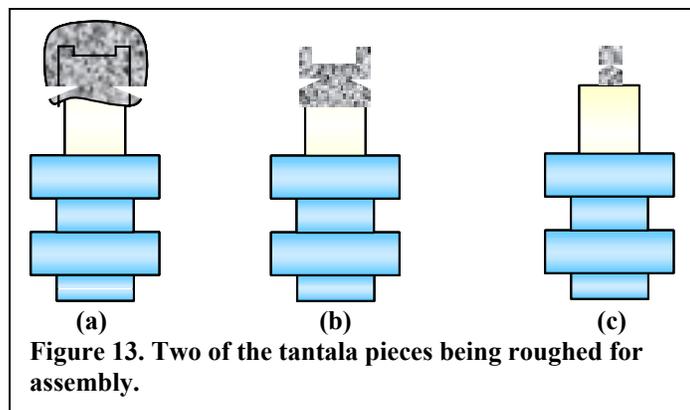


Figure 13. Two of the tantala pieces being roughed for assembly.

The final operations were to press the tantala plug into the hole in the silica, as shown in Figure 14(d), and to face the surface to final thickness. The depth of the seating of this was controlled by measuring the force applied in the z direction, and when a few gram change in the force built up quickly it was assumed the part was bottomed out. The

final step in the process was to machine the target to a 250 μm thickness. This was done with the inner plug held in place by friction only. A completed target is shown in Figure 15.

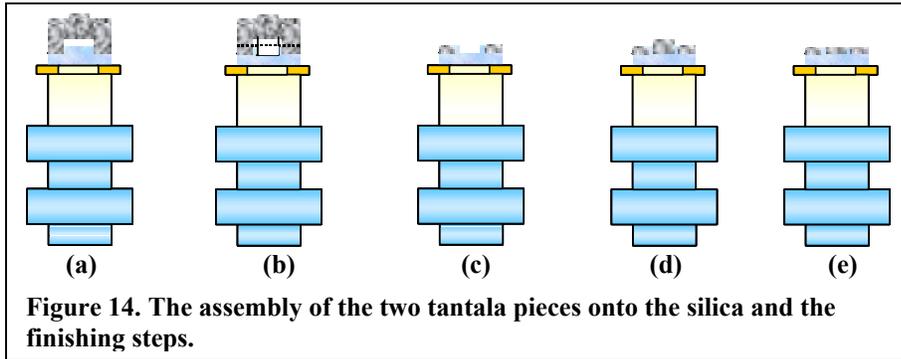


Figure 14. The assembly of the two tantalum pieces onto the silica and the finishing steps.

This target design shows the intricate part handling and how one surface was fabricated and then transferred to another part so a mating surface could be fabricated. This target required great care in handling, assembly, and machining fragile low density aerogels. These techniques are used in many

of the targets we build. This effort required that many different processes and sequences of operation be developed before we could successfully make these targets.

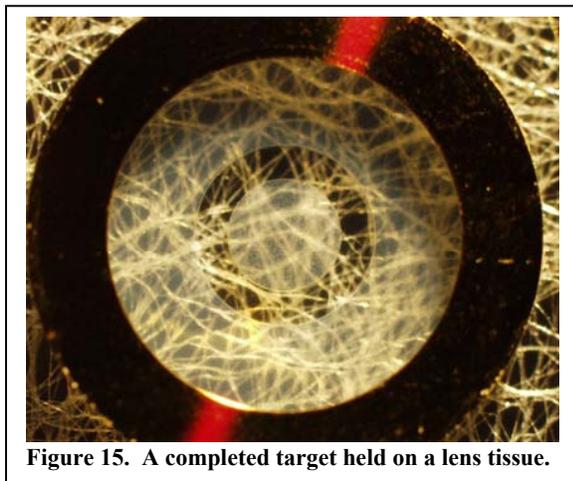


Figure 15. A completed target held on a lens tissue.

5.0 Discussion

The targets presented here highlight typical challenges faced in target fabrication at LLNL. The fabrication goal is to develop detailed manufacturing processes and plans that are deterministic and repeatable. The business is development-oriented and requires manufacturing techniques that are invented during a production run. The tools available to build these targets are extensive and state-of-the-art, but because of the exotic designs and materials, we are dependent on a team of highly skilled engineers, material scientists and machinists to build these targets. In some cases, we still are dependent on operator skill and ingenuity, rather than a perfectly deterministic process. Metrology of components this size continues to be a challenge that is not solved in all cases. The need for knowledge about the

absolute thickness of components increases the difficulty of verifying components meeting the requirements. We are always looking to other fields to find similar operations where we can learn new techniques that can be applied to our manufacturing problems, and likewise, others could learn from the manufacturing at LLNL.

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