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UCRL-51787

CYLINDRICAL LASER TARGETS

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June 5, 1975

Prepared for U.S. Energy Research & Development
Administration under contract No. W-7405-Eng-48

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Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy \$ *; Microfiche \$2.25

<u>*Pages</u>	<u>NTIS Selling Price</u>
1-50	\$4.00
51-150	\$5.45
151-325	\$7.60
326-500	\$10.60
501-1000	\$13.60

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Abstract

This report summarizes the work to date on cylindrical laser targets and describes the requirements, methods of preparation, and the results achieved on the initial prototypes.

Introduction

Cylindrical targets are one member of a series of acceleration targets that consist of thin sheets, cylinders, and spherical shells. Their purpose is to mock up the implosion characteristics of a thin bare shell of DT. All these targets have a radius-to-thickness ratio of approximately 30 to 1, and may be subject to Taylor instabilities. As a result the surface finish tolerances are extremely high and have been the controlling variable in determining the method of production of these cylindrical targets.

To achieve high surface finishes we have used a unique diamond turning machine available at LLL.* The process for making cylinders consists of machining cylindrical copper mandrel, vapor plating on a thin coat of aluminum or plastic, machining the outside surface, cutting the cylinders to length and dissolving out the copper.

*J. Bryan, R. Clouser, and E. Holland, Am. Machinist III (25) 149 (1967).

Cylinder Requirements

The overall requirements for the cylindrical laser targets are:

- Low Z to simulate DT.
- Transparent or reflecting to survive the long-term precursor.
- Surface finish tolerance – both inside and outside surfaces:

$$\text{for } \lambda \gg 2\pi d, \Delta(\rho d) < \frac{\rho d}{10}; \Delta d < \frac{d}{10}$$

$$\text{for } \lambda \ll 2\pi d, \Delta(\rho d) < 1\mu\text{g}/\text{cm}^2 \\ \Delta d < 10 \text{ nm}$$

where λ = wavelength; ρ = density and d = thickness.

- Dimensions:

length	500–1000 μm
radius	250– 500 μm
thickness	2– 15 μm
- Conformity to cylindrical shape $\pm 10\%$.

Fabrication

FABRICATION OF ALUMINUM CYLINDERS

This section describes a procedure for the construction of hollow cylinders of high-purity aluminum that are 500 μm in diameter and 500 μm in length, with a 25- μm wall thickness. The most restrictive requirement is that the cylinders have surface finishes on both the inside and outside surfaces of 10 nm or better. To meet this requirement, it was decided to machine a mandrel to tolerance and then vapor plate it with aluminum to replicate the mandrel surface on the inside of the aluminum cylinder. The outside surface of this aluminum-coated mandrel was then machined to size and to a high surface tolerance. The choice of suitable metals is limited by considerations of atomic number, the ability to be machined to a high surface finish, and the relative solubility-insolubility of any given pair of metals to a given solvent. Out of these constraints we chose OFHC copper for the mandrel metal and aluminum for the cylinder metal, the solvent being 70% nitric acid.

Figure 1 represents the copper mandrel after final machining and before vapor plating. Mandrels are 3.2 cm long and 6.3 mm in diameter over most of this length, tapering down on a 45° angle to a 500- μm -diam section 3 mm long. The 6-mm-diam section is used to hold the copper mandrel in the lathe and also serves as a reference surface for recentering the mandrel in the lathe after it has been vapor plated. The 500- μm -diam section is machined to a high surface finish as is a short length of the 6-mm section, for referencing. After the 500- μm -diam section has been vapor plated with aluminum the mandrel is put back into the lathe, recentered and the outside surface of the coated cylinder, now about 600 μm in diameter, is machined down to a final diameter of 550 μm . Using a tool with a 50° included angle, the 3-mm-long cylinder is grooved at 500- μm intervals through the aluminum layer and into the copper mandrel. Figure 2 is a photograph of one of these mandrels after the above steps, showing that four cylinders can be obtained from one of these mandrels. Several mandrels were produced in our initial run and the copper dissolved out in nitric acid to produce cylinders. The two finished cylinders with good surfaces are shown in Fig. 3.

Results from the copper dissolving step were mixed, with cylinders from one mandrel having a good surface finish and those from another showing definite areas

Fig. 1 Copper mandrel, 3.2 cm long.

Fig. 2 Aluminum-coated copper mandrel after machining.

of etching. In the first case, where a good surface was produced, pure 70% nitric acid completely dissolved the copper in 25 min. In this case, only the aluminum cylinders and part of the tapered section of the copper mandrel were dipped into the nitric acid. The copper dissolved out of the end cylinder first, and it fell off, followed in order by cylinders number 2, 3, and 4.

The conditions that produced the etched aluminum cylinders were different in two respects. First, the nitric acid was diluted to 60% to increase the rate of dissolution. Second, the entire copper pin was placed in the nitric acid solution. Whether these changes were the cause of the etching is unknown, but it is clear that more experimentation is required. However, we have demonstrated that aluminum cylinders with good surface finishes are possible, even if the exact conditions may not be fully known.

Fig. 3 Aluminum cylinders 500 μm long with high surface finish.

Another problem with the surface finish is the inside surface of the cylinder. One cylinder was cut in half and the inside surface of the aluminum examined under a microscope. We found that the aluminum surface had not replicated the copper mandrel, i.e. its surface structure had a grain size of 1-2 μm . There are several possible reasons for this failure to replicate, one of them being the geometry, and these are currently under investigation.

FABRICATION OF PLASTIC CYLINDERS

Plastic cylinders of parylene (poly-para-xylene) have been made using the same technique described above for the aluminum cylinders. Figure 4 shows one of these cylinders resting on a stage micrometer. The photo shows the high level of transparency of the plastic and also the high surface finish. Dimensions of the cylinders are 500 μm i.d. by 500 μm long with a wall thickness of about 70 μm .

Fig. 4 Parylene cylinder 500 μm long with high surface finish.

These cylinders were produced to determine the quality of surface finish obtainable on machined parylene cylinders. Because of this no attempt was made to achieve a thinner wall. We expect that wall thicknesses down to several micrometers should present no significant problems.

It would be desirable to eliminate the need to dissolve the mandrel in nitric acid, which reacts with

some plastics. This might be done by giving the mandrel a very thin vapor-deposited coat of sodium chloride to act as a release agent. The parylene or other plastic layer would be deposited from the vapor state or by a plasma deposition technique. After machining to a smooth outer surface the whole assembly would be soaked in water to dissolve the sodium chloride, freeing the plastic cylinders.

Surface Finish Data

Three separate methods have been used to evaluate the finish of the machined metal and plastic surfaces. These are direct contact, the transmission electron microscope (TEM) and a scanning electron microscope (SEM).

In our initial attempt at machining 500- μ m-diam copper mandrels to a high finish, we made a group of ten and measured the surface roughness by direct contact. The instrument, called a Taly-step, drags a 0.1-X-3- μ m foot over the surface and measures the displacements. Of the ten copper mandrels measured, one had a surface roughness of ± 10 nm over most of the area with the worst peaks being within ± 12.5 nm. Figure 5 shows part of the Taly-step trace for this mandrel. All nine of the other mandrels had surface roughness of less than ± 20 nm with a few spikes as high as ± 35 nm. Since this was the first attempt at matching these surfaces, it seems reasonable to expect surface roughness of ± 10 nm to be achieved on a production basis.

To check the Taly-step results we used the TEM in a somewhat unorthodox way. In this method, we cut the 500- μ m-diam section used in Fig. 5 off one of the copper mandrels so that it would fit on a normal TEM grid. Focusing the TEM on the waist of the cylinder produced a good shadow graph of the surface. Photographs taken in this way are shown in Fig. 6. The photograph at a magnification 10,000 X (10K) shows an area 6 μ m long. In this length, the surface roughness is within ± 10 nm. The other photographs at 40-80K show surface roughness of less than ± 15 nm, therefore verifying the Taly-step measurements. We do not expect a one-to-one correspondence of these measurements since different areas were measured. The photographs at 60 and at 80K show grooves with spacings of 0.2 - 0.4 μ m apart, i.e. the tool marks from the machining operation.

The scanning electron microscope was used to examine large surface areas in a qualitative way for

Fig. 5 Taly-step trace of copper mandrel surface.

Fig. 6 Shadowgraphs of 500- μ m-diam copper cylinder surface.

tool marks and gross surface imperfections. Figure 7 is a good example of what can be seen using the SEM. This photo shows an area at 5000X where there are three scratches that were seen at 100X using an optical microscope. Examination of Fig. 7 shows that these scratches are not the result of the machining, but are from some other source. The machine marks can be seen in the background and are spaced 0.2 - 0.4 μ m apart, as was shown in the TEM results in Fig. 6. The SEM photo gives a good measure of this spacing but not of their depth. This was better shown by the TEM shadow graphs.

The surface finish has been measured on three 500- μ m-i.d. parylene cylinders using the Taly-step. Surface finishes of ± 30 nm and ± 50 nm were achieved on

two cylinders machined on the same day and ± 125 nm peak-to-peak on another cylinder machined previously. All three were made on the same equipment used to produce the aluminum cylinders. Only the radius of the diamond bit was varied: a 25 μ m radius produced the best surface finishes.

The parylene cylinder with the best surface finish was examined using the SEM. Figure 8 shows two views of this cylinder at 100X and at 500X. These photos show that the surface is contaminated with small particles 1 - 10 μ m in size, which probably interfered with the surface-finish measurements. The areas between the particles, as may be seen in Fig. 8, appear very smooth.

Another plastic cylinder was produced but it cracked after machining and therefore no surface finish measurement was made. In this case the plastic, polystyrene, was applied by dipping the copper mandrel several times in a dilute solution of polystyrene in toluene and drying in an oven between coats. Microscopic examination of the polystyrene surface at 250X showed no surface features.

Fig. 7 Scanning electron microscope image of aluminum cylinder surface at 5000X.

Fig. 8 Scanning electron microscope image at 100X (top) and 500X of parylene cylinder after final machining and before dissolving away the copper mandrel.

Conclusions

We have demonstrated that aluminum cylinders 500 μm long and 500 μm in diameter can be produced with surface finishes of about ± 10 nm. Several of these cylinders, with slight imperfections, are available and could be used for alignment cylinders. We have also demonstrated two nondestructive methods of

examining the surfaces of these cylinders before each laser shot, the TEM and the Taly-step. In addition, we have produced clear plastic cylinders of high surface quality but more work needs to be done on characterizing these cylinders.

Acknowledgments

This project has drawn heavily from several groups here at LLL. I would especially thank J. Bryan and D. Clouser of Metrology for the diamond turning, the Taly-step measurements, and for suggesting the TEM

method. Also, L. Clevenger for the aluminum vapor plating, W. Steele for the SEM and S. Digiallonardo for the TEM work.