Fabrication of thin cylindrical targets for x-ray laser experiments

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(Received 26 September 1985; accepted 15 November 1985)

For a laser-produced plasma to be most useful in current x-ray laser experiments, it should have a cylindrical shape and a uniform plasma density and temperature to provide high x-ray gain along the axis. One approach to producing such a plasma is the uniform compression of hollow cylindrical targets with multiple, line-focused laser beams. These targets are typically ultrathin (< 3000 Å) cylindrical shells of materials such as Al. These cylinders have diameters $\simeq 100\ \mu$m and lengths $\simeq 2$ mm. To fabricate such targets, solid polystyrene cylinders are coated with a metal and/or parylene layer of the appropriate thickness. The coated cylinder is then cut to the desired length and the polystyrene is leached out by immersing the system in a solvent.

I. INTRODUCTION

There is considerable interest in x-ray laser schemes which incorporate collisional or recombinational pumping. Gains on selected transitions of Se and Y neon-like ions have recently been reported for a collisionally pumped system utilizing ultrathin (750 Å) foils supported on thin Formvar substrates.[1] In addition, gain on the 182 Å transition of C VI has been reported in recombination laser schemes from solid wires,[2] and thin foil targets.[3]

An optimum laser medium for collisional scheme is a uniform, high aspect ratio plasma of electron density 10^{20}–10^{21} cm^{-3} and temperatures in excess of 500 eV. X-ray refractory losses from the medium will be minimized with a low transverse electron density gradient in the plasma, and laser output will increase, the longer these conditions are maintained. In a theoretical and experimental study at the Laboratory for Laser Energetics (LLE), University of Rochester, selected target geometries have been investigated to optimize these parameters. One target geometry which appears to have some advantages over planar foil targets is a thin-walled cylindrical target. When irradiated with orthogonally oriented, line focused laser beams, as can be provided by the OMEGA facility at LLE, the wall of the target uniformly compresses, before being imploded to form a hot dense linear plasma.[4] Subsequent to the cylinder implosion, the lateral plasma density profile becomes flat-topped and broad; this leads to reduced refraction losses of the x-ray laser even with a relatively long lasing medium. Prior to peak implosion, the lateral density profile has a minimum on axis; x-ray laser refraction now can be beneficial in that it causes collimation. Figure 1 illustrates such an experimental geometry.

This paper describes the fabrication technique for these ultrathin metallic cylindrical shells.

II. FABRICATION OF CYLINDRICAL TARGETS

The cylindrical target to be fabricated is schematically illustrated in Fig. 2. The method of fabrication is similar to that[5] which we have developed for fabricating high-aspect-ratio, plastic-coated, metal-shell inertial fusion targets. The fabrication steps are illustrated in Fig. 3. The sequence begins with the selection of a polystyrene fiber of proper diameter. Coiled (or otherwise not straight) fibers are straightened by drawing them in a water bath at its boiling temperature. The fibers are cut to about 1.5 cm and perpendicularly bonded to a glass stalk at their midpoints. The fiber is next coated with aluminum using magnetron sputtering.[6] In magnetron sputtering, we have utilized a pulsed nitrogen process[7] to obtain an excellent surface finish. This metal sputter coating should be performed at temperatures below the glass-transition temperature of polystyrene, 90 °C, to prevent deformation of the polystyrene mandrel. The aluminum coating is then followed by a parylene coating. After coating, the fibers are cut to a 2 mm length using a specimen grid trimmer made by E. F. Fullam, Inc. Fracture of the coated film at the point of shear was small (~ 5-μm chips) by this process. The coated fibers are placed in toluene at room temperature for 24 h during which the polystyrene cylinder is dissolved and leached out through both ends of the tubule. The resulting hollow cylinders are removed using an eye dropper and allowed to dry on a microscope slide. The targets are then mounted on drawn glass capillaries using UV curing epoxy.

The polystyrene was Dow Styron 685-n-26W which has a weight-average-molecular weight of 50 000. The polystyrene resin was extruded through a $\frac{3}{4}$-in. Brabender extruder

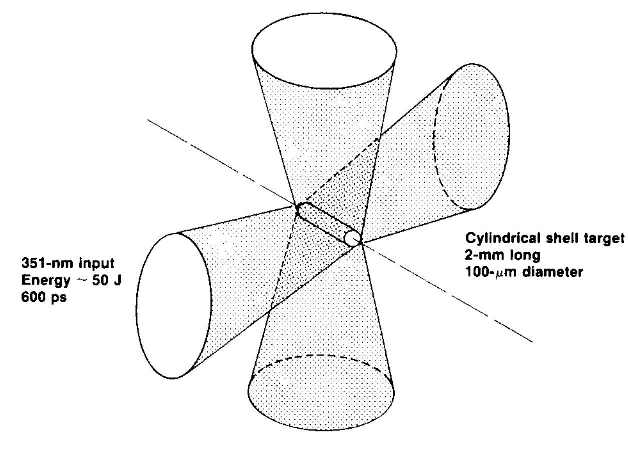

FIG. 1. Schematics of four beam compression of cylindrical targets with four orthogonal, line-focused beams of OMEGA laser system at LLE.

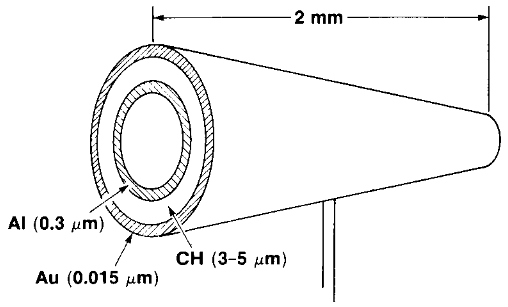

FIG. 2. Structure of cylindrical shell targets for x-ray laser experiments.

which had a temperature profile of 190 and 260 °C zones. The melted polystrene was then extruded through a 1.25-mm spinneret hole and melt stretched with a 15:1 ratio to form a 100-μm fiber.[8] In bonding the polystyrene fiber to a glass stalk, UV-cured epoxy proved to be a more suitable adhesive than RTV. Due to the the thermosetting nature of the UV-cured epoxy, the volume expansion of the epoxy upon being dissolved by the solvent is minimal and this contributes to the stability of the bonding even if it is immersed in a solvent during the leaching procedure.

The Al layer was coated on the polystyrene fiber by magnetron sputtering. Deformation of the fiber by the plasma heat can be avoided by positioning the fiber 10 cm from the sputter target. The optimum power density not to deform the polystyrene mandrel was 2–3 W/cm^2. Nitrogen gas pulsing during the sputter coating produced a very smooth surface finish.[7,9] The flow rate of Ar sputter gas was 3.0 sccm and the flow rate of N_2 was also 3.0 sccm during the nitrogen pulsing period. The pulsing rate was 25 s in 3-min intervals. Without N_2 pulsing, the oblique incident of the flux of sputtered aluminum atoms causes self-shadowing, surface roughness, and voids, thus forming brittle coatings. Furthermore, columnar growth, a characteristic crystal-growth habit during thin-film depositions, also contributes substantially to the poor surface finish and inferior mechanical properties. When nitrogen ions, which can be considered defect forming impurities, are periodically injected onto growing crystallographic planes, they poison the growth. Therefore, ordinary dendritic crystallization cannot proceed. Deposit of nitrogen ions may become new heterogeneous nucleation sites. Under such conditions, either grain refinement occurs or an amorphous structure forms. It has been shown that the structure obtained by nitrogen pulsing is essentially amorphous and the improved surface finish is due to the amorphous nature of the coating.[7] The Al coating was then followed by a parylene coating.[10] The coating process was closely monitored using optical reflectometry, which enables us to control the coating thickness to 500 Å.[11] In the parylene coating, only nonsubstituted 2, 2-paracyclopane was used, resulting in a relatively rough surface finish.[12] However, no complications are expected in using ethyl-substituted 2, 2-paracyclopane to obtain a smoother surface.[10]

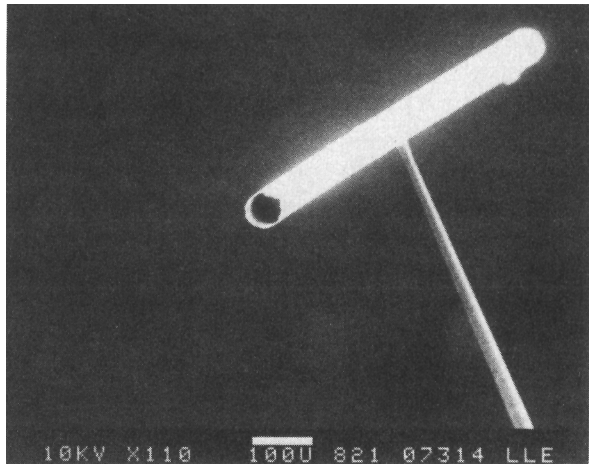

FIG. 4. Scanning electron micrograph of a thin-walled cylindrical aluminum shell.

III. DISCUSSION

The hollow cylindrical targets used for x-ray laser experiments which were fabricated by the above described procedure were characterized by scanning electron microscopy. For some experiments which utilized aluminum cylindrical shells, the parylene coating process was omitted. Figure 4 shows an SEM photo of such a target. As mentioned previously, the aluminum shell was fabricated by sputter coating of aluminum using a N_2 pulsing process.[7] The nitrogen gas pulsing incorporates a minute quantity of nitrogen atoms into the Al layer. Though the injection of nitrogen gas is by periodic pulsing, it is not an abrupt "on" and "off" switching

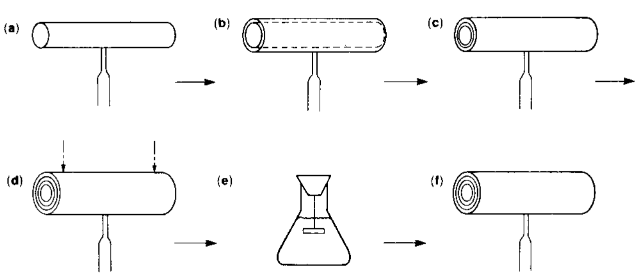

FIG. 3. Sequence for fabricating thin-walled large-aspect-ratio cylindrical targets. (a) Stalk-mount polystyrene fiber, (b) coat polystyrene fiber with metal layer in magnetron sputter, (c) coat polystyrene fiber with parylene, (d) cut to a desired length with a razor blade, (e) immerse in toluene to dissolve polystyrene, (f) remove tubule after 24 h. Target is fabricated.

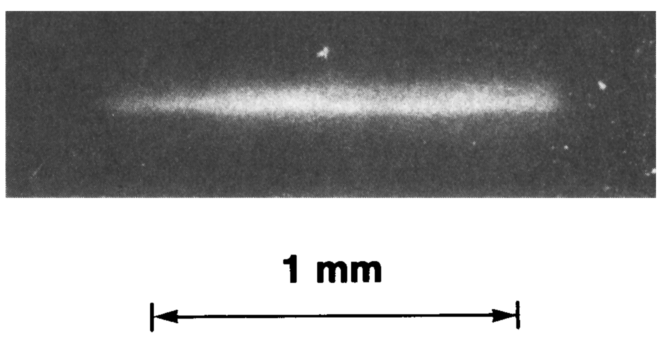

FIG. 5. X-ray photograph of a 3000 Å thin aluminum shell of 70 μm diameter irradiated by four orthogonal beams of the OMEGA laser system.

but resembles a sinusoidal shape. The net result is that nitrogen incorporation is more or less continuous. The uniform distribution of the nitrogen in the aluminum layer poisons the crystal growth in the layer and the film becomes amorphous. The chemical composition of the Al layer obtained by N_2 pulsing was studied by an energy dispersive x-ray analysis method and the content of nitrogen incorporation is estimated to be less than 5 at. %.

The cylindrical aluminum shell targets have been utilized in a recent experiment designed to produce linear plasmas suitable for x-ray laser media. The implosion of 3000 Å-thick Al shells 70 μm in diameter has generated x-ray emission (0.8–1.2 keV) which is uniform and collinear with the original cylinder axis, and whose radial extent ($\sim 25\ \mu$m diameter) is in reasonable agreement with hydrocode calculation. An x-ray photograph of the implosion is shown in Fig. 5. Detailed discussion of the experiment is described elsewhere.[4]

ACKNOWLEDGMENTS

Assistance by Dr. P. Park of Mobil Chemical Company, Macedon, New York is gratefully acknowledged for fabricating polystyrene fibers for this experiment. This work was supported by the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics which has the following sponsors: Empire State Electric Energy Research Corporation, General Electric Company, New York State Energy Research and Development Authority, Northeast Utilities Service Company, Ontario Hydro, Southern California Edison Company, The Standard Oil Company, and the University of Rochester. Such support does not imply endorsement of the content by any of the above parties.

[1]D. L. Matthews, P. L. Hagelstein, M. D. Rosen, M. J. Eckart, N. M. Ceglio, A. U. Hazi, H. Medecki, B. J. MacGowan, J. E. Trebes, B. L. Whitten, E. M. Campbell, C. W. Hatcher, A. M. Hawryluk, R. L. Kauffmann, L. D. Pleasance, G. Rambach, J. H. Scofield, G. Stone, and T. A. Weaver, Phys. Rev. Lett. **54**, 110 (1985).
[2]D. Jacoby, G. J. Pert, S. A. Ramsden, L. D. Shorrock, and G. J. Tallents, Opt. Commun. **37**, 193 (1981).
[3]J. M. Seeley, C. M. Brown, U. Feldman, M. C. Richardson, B. Yaakobi, and W. E. Behring, Opt. Commun. **54**, 289 (1985).
[4]M. C. Richardson, R. Epstein, O. Barnouin, P. A. Jaanimagi, R. Keck, H. Kim, R. S. Majoribanks, S. Noyes, J. M. Soures, and B. Yaakobi, Phys. Rev. A **33**, 1246 (1986).
[5]H. Kim, T. F. Powers, and J. F. Mason, J. Vac. Sci. Technol. A **2**, 649 (1984).
[6]D. Glocker, J. Vac. Sci. Technol. A **1**, 877 (1983).
[7]S. G. Noyes and H. Kim, J. Vac. Sci. Technol. A **3**, 1201 (1985).
[8]Polystyrene fibers were fabricated by P. Park, Mobil Chemical Co., Macedon, NY.
[9]R. W. Springer and C. D. Hosford, J. Vac. Sci. Technol. **20**, 462 (1982); R. W. Springer and D. S. Catlett, Thin Solid Films **54**, 197 (1978); R. W. Springer, B. L. Barthell, and D. Rohr, J. Vac. Sci. Technol. **17**, 437 (1980).
[10]D. G. Peiffer, T. J. Corley, G. M. Halpern, and B. A. Binker, Polymer **22**, 450 (1981).
[11]H. Kim, T. Powers, and J. Mason, J. Vac. Sci. Technol. **21**, 900 (1982).
[12]LLE Review, University of Rochester, Vol. 9, 21 (1981).