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ABSTRACT

Double-shell targets may be required for the next generation of inertial confinement fusion targets since the energy available for driving the implosion is limited with current drivers. The use of double-shell targets to provide a velocity multiplication driven implosion is an alternative to increased driver energy.

First generation hemishells, from which spherical shells are constructed, were fabricated by micromachining coated mandrels and by molding. The remachining of coated mandrels will be described in detail in this article.

Techniques were developed for coating the microsized mandrels with polymeric and metallic materials by methods including conformal coating, vapor deposition, plasma polymerization and thermoforming. Micropositioning equipment and bonding techniques have also been developed to assemble the hemishells about a fuel pellet maintaining a spherical concentricity of better than 2 µm and voids in the hemishell bonding line of a few hundred angstroms or less.

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MGW

INTRODUCTION

Theoretical laser fusion target designs have become quite sophisticated in specifying special combinations of materials aimed at enhancing the fusion process. For the majority of experiments done to date, a hollow glass microsphere (HGM) with a high pressure deuterium-tritium fill has been used. These fuel capsules may also have an additional low Z, low density ablator coating deposited directly on the outer surface of the HGM. However, the available energy for driving these implosively is limited, requiring that further design sophistication be used to enable targets to achieve the upcoming goals of the Inertial Confinement Fusion Program.

One type of target that may provide a more efficient use of the available energy is a multishell target with voids existing between some of the concentric shells. For instance a deuterium-tritium pressurized HGM may be surrounded by a void and the void enclosed in one or more concentric shells. These multishell targets attempt to use the principle of velocity multiplication to attain an enhanced efficiency. The outer shell(s) is imploded like an ordinary ablatively driven target, accelerating the massive outer shell(s) to a high velocity. When the outer shell(s) strikes the inner shell, the less massive inner shell recoils and implodes at an increased velocity.

In the initial version of this target a HGM is centered in the inner void of a hydrocarbon polymer shell (Figure 1). This double shell target design requires a HGM with inner shell to outer shell concentricity of two percent and a surface smoothness of less than 3000 A. The HGM must be centered in the outer shell with less than a two micrometer mismatch in their centers. The outer shell must be uniform in thickness to two percent and have a surface smoothness of less than 0.5 micrometers. There also must be neither voids nor density variations in the outer shell which would be equivalent to a 0.5 micrometer defect on the surface.

With the determination of this theoretical design, it is the task of target fabrication to translate the design into an experimental vehicle capable of testing the concepts and providing information for further refinements. To do this many new or improved techniques were developed to provide the initial target of this design. The techniques for producing the HGM have been available for some time.[1] However, the production of the second shell and the assembly techniques for placing the HGM in the outer shell were not available. After considering many techniques, we selected as the simplest, most expedient procedure the assembly of two independently fabricated hemispherical shells ("hemishells") around the inner HGM.

This approach then required the development of methods for producing the hemishell components and their subsequent assembly into a spherical shell. It also required developing a support mechanism for the inner HGM that did not detrimentally influence the desired implosion.

The production of the hemishells was a multistep process. A mandrel was machined to the desired inner slope of the hemishell. The mandrel was coated with a specified material and the outer surface machined to the required size. After the coating and remachining techniques were developed, isolation and cleaning techniques were needed. Once the hemishells were available, micropositioning and bonding of the various components were used to produce a completed target. Although most of the techniques used were similar to previously developed technology, it was the microscopic size (100 - 500 micrometers) and precision tolerances (± 1 micrometer) of the target components that required the extensive development efforts that are discussed in the following sections.

EXPERIMENTAL

Two types of lathes were used for the machining of the mandrels and coatings. Both machines were based on the use of an air spindle to hold and turn the mandrels. These air spindles provided a precise axis of rotation with out-of-roundness of less than 0.25 micrometers. They were both equipped with single point diamond cutting tools. Some of these tools were of the standard type with a 25 micrometer radius, but certain of the machining techniques required the use of a special diamond tool with a radius of 0.020 micrometer. Lathe number one has computer controlled stepping motor driven slides to generate the required shape. It is immersed in an oil shower to control temperatures to prevent thermal dimensional changes during the machining operation. This lathe was fitted with a massive fixture for holding the mandrels. This fixture, also made using the lathe, permitted the removal of the mandrel with repeatable replacement in the lathe to better than 0.1 micrometers. This lathe was designed to provide less than 0.1 micrometer finishes on large mirrors (up to 0.8 meters) but was adaptable to the required microscopic parts. Lathe number two used air slides driven by piezoelectric INCHWORMS and a radius turning attachment to generate the desired part size and shape.

Materials were required for two separate applications. Material selection for the mandrel was based on attainment of surface finish and ease of removal. An oxygen free high conductivity (OFHC) copper was selected for machining. It was either work hardened or for the best finish a layer of fine grained copper electroplated on the OFHC copper was used. For the coating materials to be used as hemishells, design parameters limited the selection to those materials containing only carbon and hydrogen such as polyethylene or polystyrene.

Coating procedures for the mandrels were determined by the lathe system being used. Since the fixture holding the mandrel could be removed from lathe number one, the hemishell material could be applied by dip coating. Prior to coating, the copper was cleaned by vapor degreasing. A band of fluoroacrylate polymer barrier coating was deposited just beyond the hemispherical section to prevent upward creep of the polymer coating. The hemispherical section was then lowered into the coating material and removed for subsequent drying. A number of these coating-drying cycles were completed to yield the desired thickness of coating. On those systems requiring a thermal cure cycle, the fixture with mandrel was placed in a low temperature oven.

On lathe number two the material was applied to the freshly machined copper mandrel while it remained in the lathe. The mandrel was first fitted with a heating device and the temperature raised to 210°C. A small bead of material was melted on another heat source and applied to the rotating machined end of the mandrel. When the material was satisfactorily centered on the mandrel, the heat sources were removed and the molten polymer resolidified.

The hemishell isolation procedure for both types of coated machined mandrels involved several steps. Their outer surfaces were cleaned and the tips of the mandrels with attached hemishells (Figure 3) were then immersed in a nitric acid solution and the copper mandrels dissolved. The hemishells were removed from the acid solution and further cleaned by ultrasonic agitation in filtered distilled water, aqueous surfactant, distilled water and a final ethanol wash and dried in a low temperature oven. The clean hemishells (Figure 4) were then fully characterized[2] and retained for subsequent assembly.

The assembly was performed by a highly skilled operator using hand-operated micromanipulators fitted with tiny glass vacuum chucks. The operator viewed the process with two high-power microscopes which provide perpendicular viewing angles. The inner sphere was placed at the center of a plastic support film which had been stretched over a wire loop and covered with a second support film on a smaller wire loop. The two films adhere on contact thus trapping the inner sphere. Severing the first film between the two concentric support rings left the sandwiched inner sphere supported by the smaller ring. We then applied hydrostatic pressure to force the two films to form about the HGM. As this sandwiching procedure controlled the centering of the fuel capsule in the polar direction, we next measured the distance from the film plane to the poles of the HGM. Those meeting the ± 2 micrometer deviation specification were held for further assembly. To complete the assembly one hemishell was held in position with a vacuum chuck. We extruded a minute bead of fast-curing adhesive onto the edge of the hemishell. Then we centered the sandwiched inner sphere over the hemisphere and pressed it onto the adhesive-coated rim. When the adhesive had cured, we repeated the process with the other hemisphere to produce a completed target. (Figure 5) Precise alignment had to be maintained, and each sequence had to be completed in the three to five minutes before the adhesive cured.

III. RESULTS AND DISCUSSION

With the use of the high precision air spindle lathe it is possible to machine surfaces to a few tenths of a micrometer. Since this is smaller than the grain structure of many materials, the selection of materials for the hemishell mandrels is crucial. In previous work we had demonstrated that oxygen free high conductivity copper could be machined to acceptable surface finish with diamond cutting tools. We found that further improvements could be made by electro-depositing fine grain copper onto the OFHC mandrel in the area where the surface was to be machined. This fine grain structure provides an even better substrate for precision machining, leading to a further improvement in the inner surface of a hemishell.

Many polymers were evaluated as the material for hemishells for this project. Among them were solutions of 1,2-polybutadiene in 30% vinyltoluene, polystyrene in dioxane, methylethyl ketone, carbon tetrachloride and styrene monomer, and a styrene-butadiene copolymer in toluene.

The 1,2-polybutadiene/30% vinyltoluene system gave the highest quality hemishells. An added advantage was that hardness could be adjusted to optimum machining requirements by changing initiator concentration or cure time. The polystyrene systems tended to be brittle and often cracked during or after machining. Mold releasing the copper tip, and/or annealing reduced such tendencies to some extent.

The molten deposition onto a mandrel provided some additional stresses and therefore some constraints on the materials chosen. Many of the hemishells made by this technique unexpectedly popped off the mandrel during machining, or were found to be cracked. The presence of thermally created stresses produced during cooling from the melt temperature (around 200°C) was suspected, and verified by examination under polarized light, and by further cracking when placed in isopropyl alcohol. Surprisingly, the stresses, while shown to be relatively small by study of compensator shifts in birefringence, could not be removed by annealing to 150°C.

To counter brittleness and stress formation, polystyrenes with higher elongation capability were used. Added stability was obtained by blending polystyrene with 15% of a styrene-butadiene copolymer.

It is apparent that the properties of a polymeric material are critical if hemishells of suitable quality are to be obtained. The proper balance of hardness, brittleness, elongation and strength must be obtained before the full capabilities of precision machining can be utilized. One of the most difficult problems is cutting a smooth, flat rim with sharp corners at the equator. Cutting tools tend to push the hydrocarbon polymer, often forming a "lip" of material on the inner edge of the hemishell. However, use of the recently introduced zero radius diamond tool (.02 micrometers) has greatly reduced this defect. This still remains as the most crucial machining area.

Another problem that arose was the change in the mandrel position during thermal excursions seen during the application and cure of the coating to the mandrel. Although this problem is not so serious as to cause a high failure rate, it is detrimental to the process and only partially understood. Solutions to this problem will be required for targets of the future.

There remain other areas of development for future targets. An area of concern to most designers is the seam created by the butt joint of the two assembled hemishells. We have begun two projects to improve in this area; a deposition method[3] whereby thin hemishells are coated with additional material in a molecular beam coater, and a second method involving the machining of mating stepped female and male hemishells (Figure 6).

The ability to position and hold the hemishells and the inner fuel capsule is sufficient for this initial target using micromanipulator held vacuum chucks viewed with high powered microscopes. However, as the tolerances become more stringent, other methods of determining the deviation during assembly are necessary. We presently have under development an assembly station using micrometer drives to position the inner fuel capsule in the outer shells. These positions are monitored by two micro-interferometers with a resolution of 0.1 micrometers. With development of this assembly system we should be capable of manufacturing the hemishell targets to the same tolerances as the machine defects in the hemishells.

IV. CONCLUSIONS

1. The development of micromaching techniques has successfully produced hemishells of target quality.

2. Careful control, selection, and application of polymeric materials are required for providing a substrate machineable to the required tolerances.

3. Coating techniques were developed for applying void free layers of polymeric materials on microscopic size mandrel substrates.

4. Specific cleaning and isolation procedures must be followed if a suitable hemishell is to be obtained.

5. Assembly procedures are available for suspending a HGM in two hemishells to produce a double shell fusion target.

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FIGURE CAPTIONS

1. Cutaway view of the 1st multishell target showing a hollow glass microsphere inner shell and a hydrocarbon polymer outershell.

2. Machined copper mandrel.

3. A polymer coated and remachined mandrel showing the surface and edge of a hemishell.

4. SEM photograph of a completed hemishell.

5. Fully assembled target.

6. Male and female stepped hemishells.

DISCLAIMER

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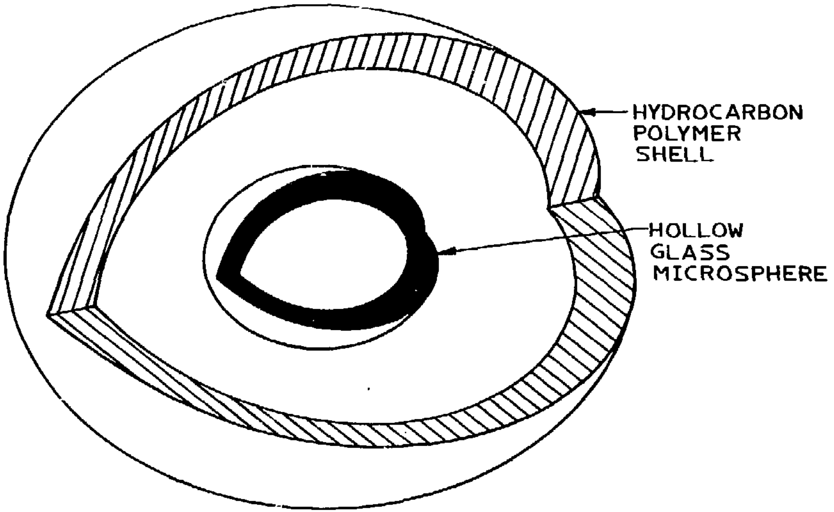

Fig. 1

Fig. 2

DIAMOND MACHINED HEMISPHERE ON MANDREL

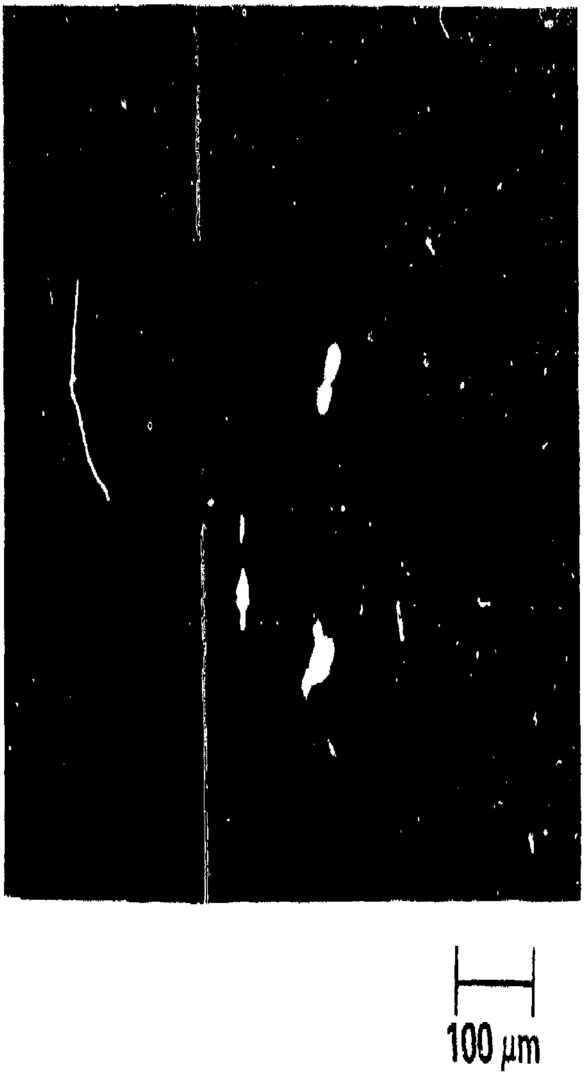

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Fig. 3

SINGLE-POINT DIAMOND MACHINED BUTADIENE HEMISPHERE

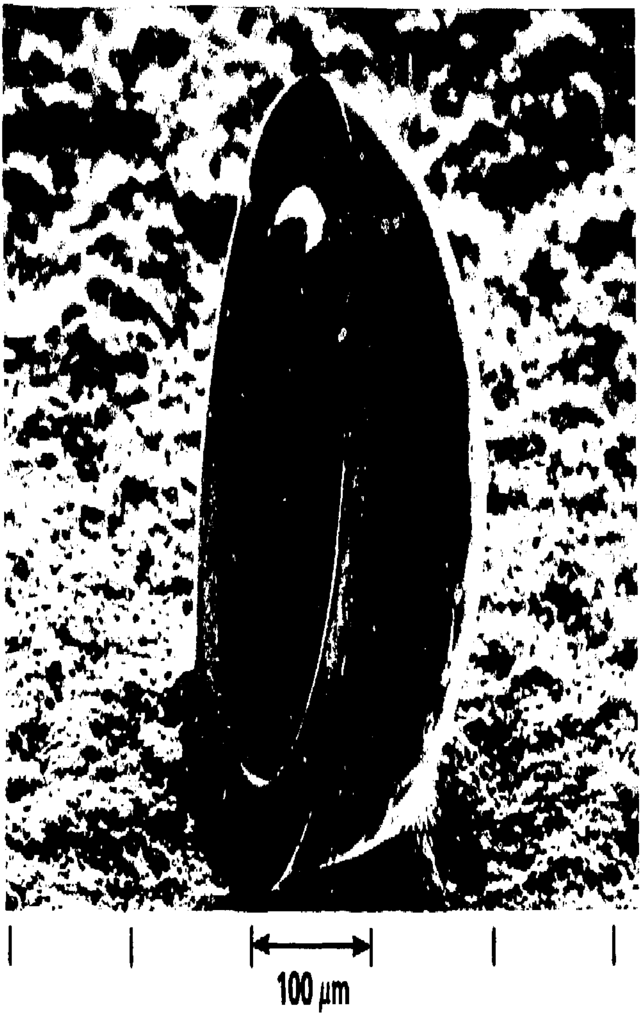

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Fig. 4

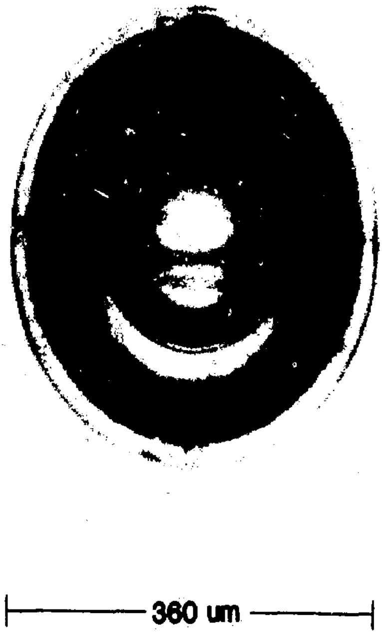

Fig. 5

MATING POLYSTYRENE HEMISPHERES

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Fig. 6