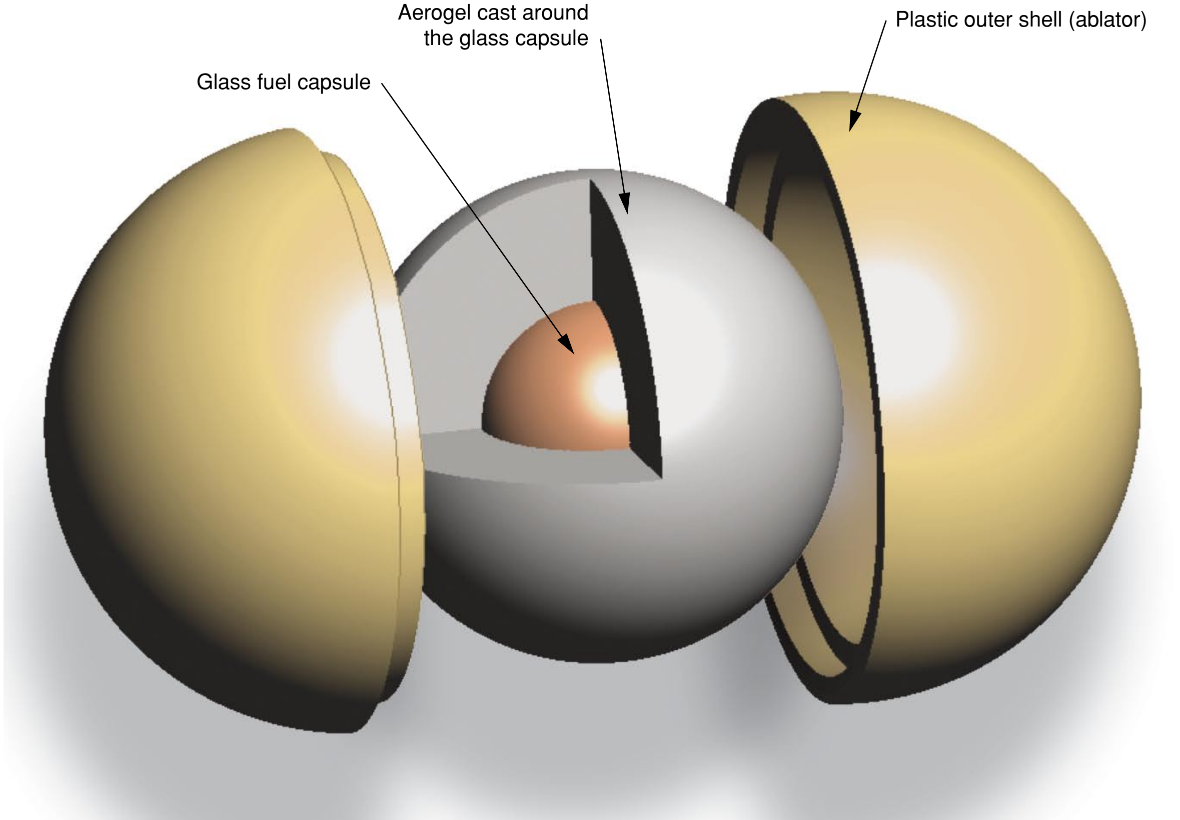
Fusion Targets on the Double



A double-shell target designed for fusion experiments consists of an inner capsule of fuel supported in aerogel and surrounded by a plastic outer shell (ablator).

IMAGINE manufacturing an object that ends up being the size of a dust mite. Nearly invisible to the naked eye when complete, it must be carefully machined and assembled and then precisely measured and inspected. Engineering experts at Lawrence Livermore have developed new tools and imaging methods that can do just that, meeting all fabrication requirements.

The dust-mite-size objects are spherical, double-shell targets that in August were blasted by x rays created on the OMEGA Laser at the University of Rochester's Laboratory for Laser Energetics. These and future experiments are designed to test how perfectly the targets implode. In 2010, such targets will face the enormous energy density of the National Ignition Facility's (NIF's) 192 beams. Achieving controlled thermonuclear ignition is one of the goals for NIF, and these targets are a critical aspect of successfully reaching that goal.

When x rays generated by a laser hit a double-shell target, the outer shell (ablator) absorbs the x rays, implodes, and collides with a smaller inner shell that contains a fuel of deuterium and tritium, isotopes of hydrogen. When conditions are just right, the deuterium and tritium atoms fuse into helium and release high-energy neutrons. Laser scientists have been investigating double-shell targets for fusion experiments since the 1980s. Calculations and models show that these targets can reach ignition conditions—tens of millions of degrees and a billion atmospheres of pressure—more easily than single-shell targets.

New Tools for High Precision

Double-shell targets for fusion experiments have a plastic ablator shell made of polystyrene doped with bromine. Inside that shell is a layer of silica dioxide aerogel, one of the lowest density materials in the world. The aerogel envelopes a tiny glass fuel capsule at the center. The fuel capsule must be precisely centered in the target—that is, the target must be concentric—and the shells must be as smooth as possible. When the ablator shell implodes, stability is crucial. Hydrodynamic instabilities near the fuel will reduce its ability to achieve ignition conditions.

Physicists who design laser experiments have known for some time what they want double-shell targets to look like.

"The challenge has been to successfully fabricate them," says mechanical engineer Matthew Bono, leader of the Livermore manufacturing effort, which is part of the Target Technology Team. Bono's team has developed tools that allow an entirely new method of fabricating double-shell targets to eliminate defects. With this method, the team can achieve a higher level of concentricity and precision than was possible with past techniques.

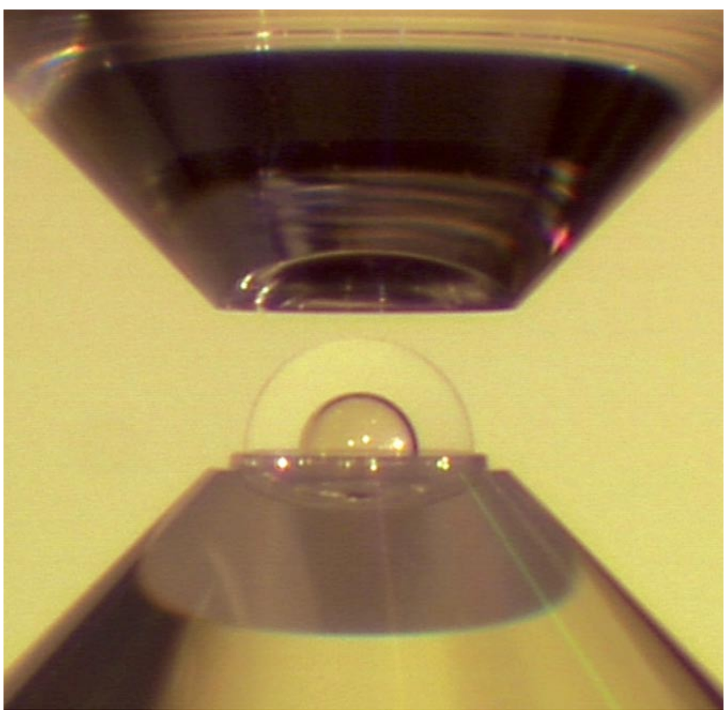
Previously, a double-shell target was fabricated by placing a glass capsule of fuel between two hemispherical shells of aerogel. The fuel capsule was properly concentric within the aerogel, but x-ray images revealed a void along the seam between the two aerogel hemispheres.

Now, aerogel is cast around the fuel capsule, using a process developed by the Livermore aerogel group, led by Joe Satcher. Chemist John Poco devised a method in which the aerogel sol is poured into a cubic mold until half full. When the sol begins to gel, the glass capsule is placed in the center, and more sol is added. Finally, all solvent is removed using a fast, supercritical extraction process that is much like taking water out of Jello. The result is a seamless cube about 1 centimeter square.

The cube of aerogel must then be made spherical and concentric around the fuel capsule, with a finished thickness of just over 100 micrometers—the width of a human hair. As in similar manufacturing processes, the material is machined. But how does one machine a material that is almost as light as air? Very, very carefully.

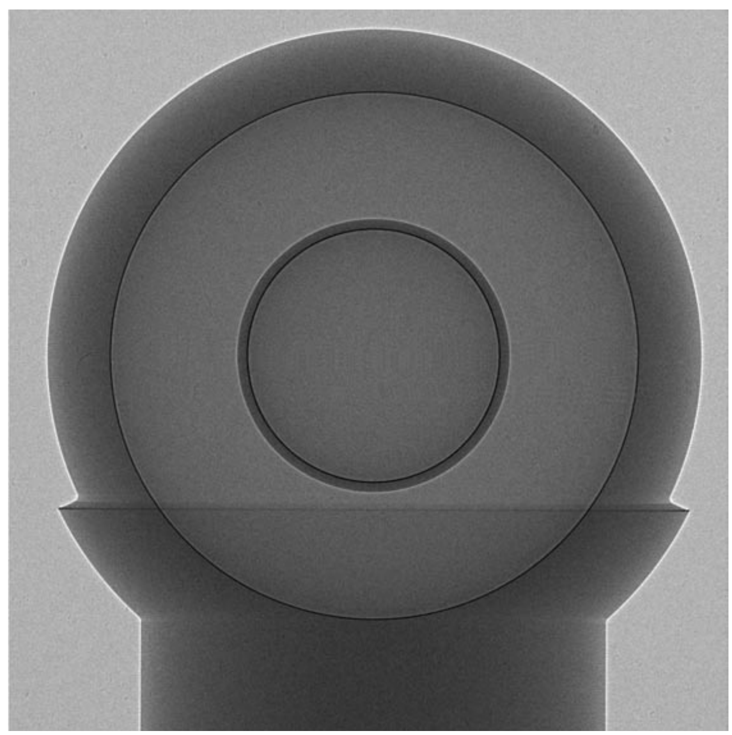
The first challenge is to mount the cube on the center of a diamond-turning machine's spindle, precisely symmetrical to the spindle's axis. Once the cube is properly mounted, it is rough-machined to dispose of the excess outer portions of aerogel. Fine adjustments are made prior to final machining, so that the aerogel and embedded capsule are concentric to a tolerance of less than 2 micrometers.

In most manufacturing settings, engineers use probes and other metrology tools to ensure that the finished product meets the required specifications. The products' dimensions, materials, and other properties are measured at various stages of the manufacturing process. The same is done for most millimeter-size laser targets made at Livermore. However, for these double-shell targets, existing metrology tools were not adequate, so new ones had to be invented.



~440 micrometers

During target assembly, the aerogel sphere is placed between the two halves of the ablator. Then the outer surface of the ablator is machined.



Radiograph of a double-shell target in fabrication reveals no flaws and shows that it meets or exceeds all specifications. The lower portion of the outer target shell has yet to be completely machined.

The final thickness of the ablator shell is 53 micrometers. The total tolerance during machining is just 0.5 micrometer, or 500 nanometers. "That's just 250 nanometers of tolerance for each half of the ablator shell," notes Bono. "In a manufacturing environment, those tolerances are extremely difficult to achieve."

Bono's team developed a tool holder that can precisely position the diamond-cutting tool on the machining table. The cutting edge is centered to within 100 nanometers of the rotary table's axis of rotation—1/1,000th of a human hair's width. The team also designed an imaging system that acts as a measuring microscope. The system's camera is moved with respect to the aerogel workpiece, measuring the workpiece to ensure the radial and axial dimensions are always the same.

After the aerogel sphere is machined, the team starts work on the plastic ablator shell, which is fabricated in two halves. The inner surfaces of the two hemispheres are machined, including a step joint with a gap of 0.1 to 0.2 micrometer around the outer edge, where adhesive will later be applied. Bono's team uses a method of machining ablator components that compensates for the submicrometer thermal drift of the machine tool.

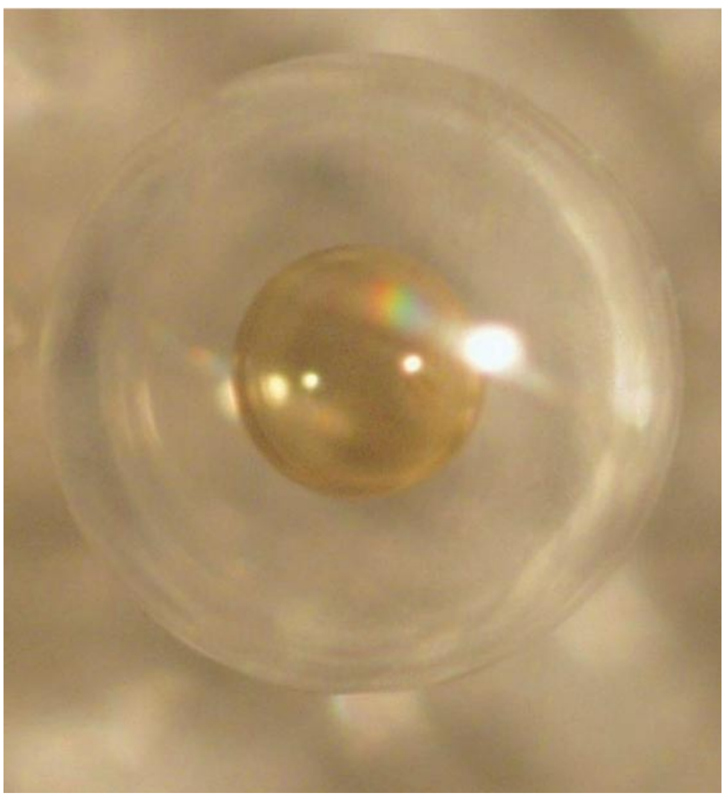
The aerogel sphere is encased within the two halves of the ablator. Then the tiniest drop of adhesive is applied with a hair to a spot on the joint. The glue wicks around the seam, filling the gap completely and sealing the target.

Perfect Scores in the Final Exam

But the target is still not finished. A detailed examination is essential to ensure that it meets specifications. The target is examined using several x-ray imaging systems, each with a different resolution and field of view. Radiographs show that after assembly, the uniformity of the ablator, specified to be within 1 micrometer, meets this specification. The shells, which are specified to be concentric to less than 3 micrometers, are concentric to less than 1.4 micrometers with no visible voids.

Finally, the outer surface of the ablator is diamond-turned to form a sphere. The entire process—from the creation of the aerogel cube to the finished target—takes several weeks of painstaking work. The result is a miniscule fusion target that is as symmetrical as can be manufactured today.

—Katie Walter



A finished double-shell target is just 0.5 millimeter in diameter.

Key Words: ablator, aerogel, concentric tolerance, diamond turning, double-shell target, fusion experiment, submicrometer machining.

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