Laser Targets

The Next Phase

Two-millimeter, poly(alpha-methylstyrene) (PAMS) bead mandrels are rolled in a small, tilted, slowly rotating pan until evenly coated with plasma polymer. Heat treatment decomposes the PAMS and it diffuses through the plasma polymer coating, leaving behind smooth, spherical, thin-walled hollow shells that are the targets for laser fusion experiments.

IT will take a community of workers to bring the goals of the National Ignition Facility (NIF) to fruition. While national attention has been focused on the funding and construction of the 192-beam laser facility, scientists at Lawrence Livermore are working on myriad problems whose solutions are necessary to NIF's success. A group of materials scientists, for example, is developing techniques to produce round, hollow shells about 2 millimeters in diameter—smaller than BB-gun pellets. This work seems incongruous in a project dominated by a football-stadium-size facility. But when filled with deuterium or deuterium–tritium fuel, these shells become the targets for NIF's inertial confinement fusion (ICF) experiments. The goal of these experiments is to create fusion ignition—intense temperatures and pressures like those at the centers of stars for a small fraction of a second.

Steve Letts and Evelyn Fearon of the Laser Programs Directorate's Target Area Technology Program are among the materials scientists continuing Lawrence Livermore's more than 20 years of research and development on laser targets. Their focus now is on targets for NIF experiments. With 40 times more energy and 10 times more power than Nova (currently the world's largest operating laser), NIF will require targets about 2 millimeters in diameter, 4 times larger than those used previously, which are about half a millimeter in diameter.

The increased shell size must be achieved in tandem with making the shell very smooth and symmetrical. During an ICF experiment, extremely high laser energies are absorbed by the fuel capsule, causing the capsule wall to blow off with such tremendous force that the fuel inside is compressed to very high density. This compression, which must be as uniform as possible, is necessary for ignition. Any capsule surface or shape irregularities constitute perturbations that will grow in amplitude during implosion, because of hydrodynamic (Rayleigh–Taylor) instabilities (see *Energy & Technology Review*, April 1995, pp. 1–9). The perturbations cause the inner wall of the capsule to mix with the fuel, cooling it and thereby degrading efficiency.

The Progression of ICF Targets

Letts and Fearon's technique for making shells uses an entirely new approach. Previously, plastic shells were produced when droplets of polystyrene solution were dropped down a heated drop tower, where evaporation first caused a skin to form on the droplets and then further vaporization of the solvent inside the skin caused the droplets to expand into hollow shells.

Because the drop-tower technique produced shells of a limited size range, researchers tried micro-encapsulation techniques to increase shell sizes. They encapsulated droplets of water in a polymer solution suspended in an aqueous phase; the solvent containing the polymer would slowly dissipate into the aqueous phase, leaving behind a polymer shell. However, the resulting shells were uneven in thickness and had bubbles in their walls. Steve Letts explains that these techniques frequently "wouldn't produce round shells most of the time, so those that were round would have to be carefully picked out—not an easy task with such tiny things."

He came up with a new idea. While measuring mass loss in polymers when they were heated, he identified one polymer material that evolved into a gas when heated to about 300°C, disappearing cleanly without any trace or residue. He figured out a way to take advantage of the material's unique combination of characteristics.

That material was poly(alpha-methylstyrene), or PAMS. In Letts's new fabrication method, an amount of PAMS is shaped into a smooth sphere, or mandrel, which is overcoated with a thermally stable plasma polymer to a desired thickness. The overcoated mandrel is heated to about 300°C, at which temperature the PAMS depolymerizes (decomposes) into a gas, diffuses through the plasma polymer overcoat (which is thermally stable up to 400°C), and leaves behind a hollow plasma polymer shell (see the figure on p. 23).

Letts postulated that this method would be feasible for producing fuel capsules of the size needed for NIF if a suitable PAMS mandrel could be formed. In addition, because the shell is built outward from the PAMS mandrel, it might be feasible to incorporate various layers during the overcoating process, which would be useful for diagnosing shell performance. The method would be successful if good quality mandrels could be made, an even overcoat could be deposited on the mandrel, and pyrolysis (heat treatment) could be accomplished without distorting or collapsing the resulting shell.

Spherical, Smooth Mandrels

Evelyn Fearon coordinated PAMS mandrel production. She and the other fabricators ground commercial PAMS beads into smaller sizes, put them through a sieve, and suspended them in a water solution hot enough to soften them, thus taking advantage of surface tension to pull the bead into a sphere. Bead surfaces were smoothed further by exposing them to solvent vapor while dropping them down a heated column. During the drop, the bead's thin surface layer dissolved and dried, leaving a surface roughness of less than a billionth of a meter (as measured by an atomic-force microscope).

Smooth, spherical bead mandrels were fairly easy to make. However, they tended to distort from the heat generated during overcoating and become nonsymmetrical or coat unevenly. To overcome the heat effects, Fearon experimented with higher molecular weight PAMS and lowered the overcoating temperature, but the adjustments did not wholly overcome the distortion problem.

The Target Area group turned to hollow mandrels made by micro-encapsulation and supplied by General Atomics of San Diego, California, another DOE contractor. Hollow mandrels have two advantages. They contain less PAMS to depolymerize, and thus, less force is exerted on the overcoat during depolymerization. Second, higher molecular weight PAMS (96,000 versus 11,000 for beads) can be used to make them, because, unlike the beads, they do not need hot-water softening, which requires the lower molecular weight material. Because they are ultimately depolymerized, some wall unevenness and internal bubbles are tolerable, as long as the shells are spherical and their outer surface finishes are smooth. Compared with bead mandrels, the hollow mandrels have shown far less distortion during overcoating and pyrolysis.

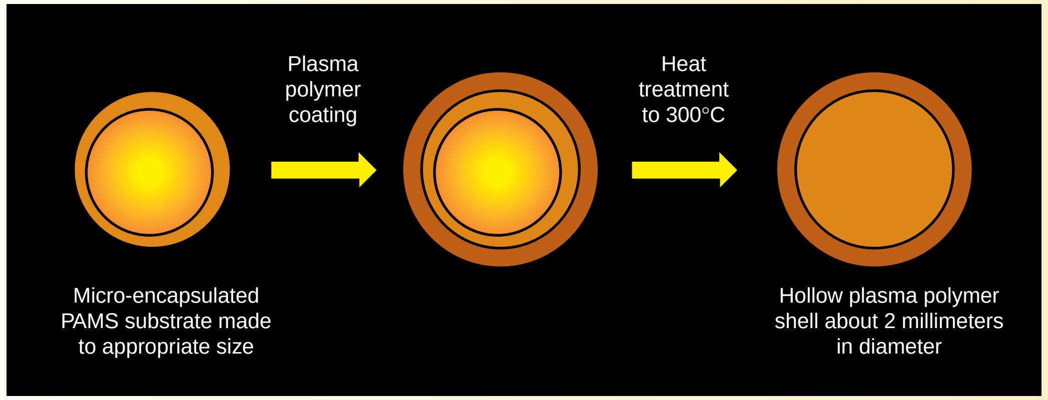
An Even Coat of Plasma Polymer

Plasma polymer is well suited to be fuel–shell material. It is transparent, which allows fusion experimenters to diagnose the contained fuel layer. It can be used to coat the mandrels because it can withstand PAMS pyrolysis temperatures and is permeable to the gaseous, depolymerizing PAMS.

In the coating technique used by the Target Area group, the mandrels are agitated in a bouncing pan in the plasma coating chamber or, in a variation, rolled in a tilted, slowly rotating pan until they are evenly coated (see the figure on p. 22). The crucial variables determining even coating are just the right amount of agitation and the correct (not-too-high) temperature.

Successful Pyrolysis

During pyrolysis, the shells can collapse, burst, deform, or shrink. While collapse is mainly caused by nonuniform coating, the other problems result from thermal effects. To avoid them, the researchers devised a temperature program that controls the rate of PAMS decomposition. It consists of raising the pyrolysis temperature by 10°C every minute until 200°C is reached, holding it there for 30 minutes to allow low-



Livermore scientists have developed a technique for producing hollow laser-target shells by starting with a hollow poly(alpha-methylstyrene) (PAMS) mandrel and then overcoating it with thermally more stable plasma polymer. The coated mandrel is heated to 300°C over 30 hours or more; the PAMS decomposes and passes through coating, leaving a spherical, hollow plasma polymer target shell.

temperature volatiles to escape, and then ramping it up by 0.2°C every minute up to 300°C, where it is held for 30 hours or more, depending on the size of the shell. The plasma polymer shrinks gradually and uniformly during pyrolysis, and thus sphericity is maintained. Experimenters observe and measure the shrinkage only to predict the size of a completed shell.

An optical microscope is used to measure the wall thickness and diameter of pyrolyzed shells, a scanning electron microscope is used to determine how smooth and free of particle defects shell surfaces are, and an atomic-force microscope is used to make detailed measurements of the sphericity and roughness of the shell.

Challenges Ahead

The techniques described here have now been adopted by General Atomics as the preferred method for making 0.5-millimeter-diameter capsule targets for Nova ICF experiments at Livermore and 0.9-millimeter-diameter capsules for ICF experiments at the Omega Laser facility at the University of Rochester. The success in moving this research proof of principle to actual target production is certainly encouraging. However, significant challenges still face Livermore's laser-target scientists.

Currently the development efforts at Lawrence Livermore are focused on adapting the technology developed by Letts and Fearon to the production of 2-millimeter-diameter capsules for NIF. This effort has two parts. The first, being led by Ken Hamilton, is to develop micro-encapsulation techniques to form PAMS microshells with the required outer surface sphericity and surface finish. To meet NIF specifications, these shells must be no more than 1 micrometer, or a millionth of a meter, out of round; that is, the radius to the outer surface can vary by no more than 1 micrometer (out of 1,000) as one moves across the surface. Solving this extremely difficult problem will require significant improvements in current micro-encapsulation technology. Once it is solved, the second part will be to maintain the sphericity of the shell through the coating and thermal treatment to remove the PAMS.

Members of the Laboratory's Target Area Technology Program will continue to refine laser target technology. Beyond making targets for current ICF experiments, they must focus on developing targets for the real NIF event—ignition. The PAMS technique is being investigated for that use.

—Gloria Wilt

Key Words: laser target, National Ignition Facility (NIF), inertial confinement fusion (ICF), fuel capsule, plasma polymer, polymer shell, micro-encapsulation, poly(alpha-methylstyrene) (PAMS), hydrodynamic instability.

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Patents and Awards

Each month in this space we report on the patents issued to and/or the awards received by Laboratory employees. Our goal is to showcase the distinguished scientific and technical achievements of our employees as well as to indicate the scale and scope of the work done at the Laboratory.

Patents

Patent issued to	Patent title, number, and date of issue	Summary of disclosure
John S. Toeppen	**Method for Optical and Mechanically Coupling Optical Fibers** U.S. Patent 5,560,760 October 1, 1996	An inexpensive technique to splice optical fibers that does not cause deformation of the host fibers, does not require repeated thermal cycling of the optical fibers, does not cause thermal and photonic degradation of the fibers even at high power applications, does not cause the fibers to prematurely deteriorate with age, and is suitable for use with optical fibers having a core diameter of as much as 1,000 micrometers or greater. A solder–glass frit having a melting point lower than the melting point of the optical fibers is used to splice the two optical fibers together.
Rex Booth	**Charge Line Quad Pulser** U.S. Patent 5,563,457 October 8, 1996	A quartet of parallel coupled planar triodes that is removably mounted in a quadrahedron-shaped PCB structure. Releasable brackets and flexible means attached to each triode socket make triode cathode and grid contact with respective conductive coatings on the PCB and with a detachable cylindrical conductive element enclosing and contacting the triode anodes.The configuration permits quick and easy replacement of faulty triodes. By such orientation, the quad pulser can convert a relatively low and broad pulse into a very high and narrow pulse. A maximum impedance mismatch within a quartet planar triode circuit of less than 10% is maintained.
Thomas E. McEwan	**Precision Digital Pulse Phase Generator** U.S. Patent 5,563,605 October 8, 1996	A timing generator comprising a crystal oscillator connected to provide an output reference pulse. A resistor–capacitor combination is connected to provide a variable-delay output pulse from an input connected to the crystal oscillator. A phase monitor is connected to provide duty-cycle representation of the reference and variable-delay output pulse phase. An operational amplifier drives a control voltage to the resistor–capacitor combination according to currents integrated from the phase monitor and injected into summing junctions. A digital-to-analog converter injects a control current into the summing junctions according to an input digital control code.
Kurt H. Weiner Thomas W. Sigmon	**Process for Forming Retrograde Profiles in Silicon** U.S. Patent 5,565,377 October 15, 1996	A process for the formation of retrograde profiles in silicon, either previously doped crystalline or polycrystalline silicon, or for introducing dopant into amorphous silicon so as to produce the retrograde profiles. This process involves the formation of higher dopant concentrations in the bulk than at the surface of the silicon. By this process, n- and p-well regions in CMOS (complementary metal oxide silicon) transistors can be formed by a simple, flexible, and inexpensive manner. This technique has particular application in the manufacture of silicon integrated circuits where retrograde profiles are desired for the n- and p-well regions of CMOS transistor technology and for buried collectors in bipolar transistors.
Daniel W. Shimer Arnold C. Lange	**E-Beam High Voltage Switching Power Supply** U.S. Patent 5,566,060 October 15, 1996	A circuit device for generating a ground-level voltage feedback signal for controlling the output voltage of one of a plurality of dc–dc converter modules having their outputs connected in series to form a supply output lead. Each module includes a switching device for producing a pulsating voltage of controlled duty cycle, an inductor mechanism for converting the pulsating voltage into a smooth direct current, and an inverter mechanism for producing from the direct current an alternating current through the primary of a transformer. The transformer has at least one secondary winding inductively coupled to the primary winding for producing an output voltage of the module.