Summary of US/Japan Workshop on Target Fabrication and Injection
February 3-4, 2003

The Second US/Japan Workshop on Target Fabrication, Injection and Tracking was held at General Atomics in San Diego, California on February 3-4, 2003. The purpose of this workshop was to allow specialists in the areas of IFE target fabrication, injection, and tracking to exchange detailed technical information specific to their work. The objectives of the workshop were to disseminate detailed technical information, obtain knowledgeable peer review of results, and facilitate a sound scientific understanding of target issues. These objectives were achieved in this very worthwhile workshop.

The following future invitations and actions were planned at the meeting.
1. The US is invited to ILE Osaka for the next workshop on targets in September of 2004
2. Abbas Nikroo (Head of the Center for Polymer and Coatings Development at GA) will visit ILE target labs in April, 2003.
3. Japan will send Dr. Yoshida to the USA for an extended stay in March of 2004 to work on tracking with our injection demonstration system
4. We will explore doing an injection demonstration with a Japanese fast ignition target on the US injection tracking system.

The first day of the meeting emphasized target fabrication and the second day target injection and tracking. A brief summary of the presentations made (most of which are included in these proceedings) follows.

Mike Campbell (GA) welcomed the participants. His presentation emphasized advantages and special challenges of fast ignition for IFE. He presented fast ignition concepts for all drivers and gave recent experimental results from both the US and Japan. Potential advantages of fast ignition include, higher gain, reduced fabrication tolerances, and use of longer wavelength drivers which have higher efficiency and smaller aperture requirements. Special challenges include innovative cryogenic layering and 3-D geometry with cones and shells.

Takayoshi Norimatsu (ILE) gave a broad overview presentation on target fabrication and injection activities leading to a laser fusion reactor with a wet wall. This includes work by many researchers on the reactor system, lasers, plasma, and fueling. He described the roadmap (long term research plan), requirements for injection and tracking for both central hot spot and fast ignition, and this year's research activities. FIREX-I is a short pulsed laser experiment that has been approved and is being designed. The follow-on FIREX-II experiment is expected to demonstrate fast ignition and burn. They also have plans to demonstrate repetitive laser illumination of targets in the next few years. A simulation experiment on the contamination of final optics in a reactor with wet wall has also started. A preliminary experiment indicated that deposition of metal vapor on the final optics can be prevented by filling low-pressure hydrogen gas in the beam duct.

Dan Goodin (GA) described the viability of an economical target supply for IFE. He described proposed target mass production processes and noted that target cost reductions of 4 orders of magnitude are predicted. He noted that the most difficult issue for direct drive targets is target survival during injection. For indirect drive targets the most difficult issue appears to be target fabrication. Foam shells with seal coatings are being developed by Schafer Corp. High-Z coatings are being experimentally developed at GA. DT layer smoothness is being measured and DT response to rapid heating will be measured at LANL. GA is investigating layering in fluidized bed and other mechanical motion systems. GA has built an experimental target injector in the newly refurbished building 22. GA and UCSD are calculating the effect of the high temperature chamber on target survival.

Keiji Nagai (ILE) described the manipulation of the microstructure of ultra-low-density TPX foams using coagulant alcohol. Poly (4-methyl-pentene) cyclohexane solution is mixed with boiled alcohol solution, gelled and dried with supercritical CO_2. Depending on which alcohol is used, foams down to 2 mg/cc are produced this way.

Diana Schroen (Schafer) described fabrication of divinyl benzene foam shells for laser fusion. Schafer has begun producing prototype targets for an NRL IFE reactor. These targets are made from a CH polymer (divinyl benzene), are 4 mm in diameter with a 0.3 mm wall and are overcoated with an interfacial polymerization technique. The most difficult target specifications will be those of sphericity and nonconcentricity. She showed the results to date and expected approaches they will take to improve the quality.

Chuck Gibson (Luxel) described the use of polyimide ($C_{22}H_{10}N_20_4$) in IFE target components. Polyimide is commercially available in films and bulk. It has much higher strength than most plastics, is used in applications from 1.8 K to 400°C and has high radiation resistance. Polyimide shells are fabricated by vapor or solution deposition on mandrels or directly by blowing bubbles. Polyimide is used for hohlraum entrance holes, gas-bag targets, and may be used for hohlraum anti-convection baffles.

Don Czechowicz (GA) described foam shell fabrication research at GA. The goal is to produce 100-250 mg/cc, ~1 mm diameter, 30-100 micron wall shells with a 1-3 micron seal barrier for University of Rochester (LLE). Resorcinol formaldehyde chemistry is used with an oil/water/oil triple orifice generator to produce transparent shells. Solutions to many challenges were discussed. Shell stability during curing is improved by proper density matching of the fluids. Polyvinyl phenol (PVP) coated shells have greater strength and higher percentage seal coat effectiveness than Glow Discharge Polymer (GDP) coated shells. PVP coated shells have larger high-mode roughness than GDP, but this can be corrected with a final GDP overcoat.

Haibo Huang (GA) described research on fluidized beds for fabrication of IFE shells and factors that affect surface smoothness and scale-up potential. High coating rates in the range of 1 to 2 microns per hour were demonstrated on small batches of 30 shells where good surface smoothness is achieved. (Specifically, 50μm GDP with Ra=26nm and 4μm GDP with Ra=6nm were deposited on PAMS mandrel with a baseline surface roughness of Ra=3nm. The NIF requirement is Ra=2nm.) Very thick GDP coating up to 300 μm were also made that are visually transparent, without void and stress-fracture. Gas-phase precipitation and high-impact collisions were identified as the main surface roughening mechanisms. The former produces dense cauliflower-like surface patterns which can be prevented by adjusting gas flow rates and flow ratio. The later produces isolated dome-like surface defects which can be reduced, but not eliminated, by introducing concerted motion between the shells and by changing tube geometry. By converting the vertical reactor into a horizontal configuration, fully transparent GDP coatings were obtained on 350 shells, which serves as proof-of-principle for a horizontal coater with either pulsed gas flow, tube tilting or tube rotation to provide minimum fluidization.

Brian Vermillion (GA) described his micro-encapsulation studies for mass-production of direct drive and indirect drive IFE targets. Gas agitation is being tried to replace rotary contactors for agitation during curing. Gas agitation has the potential to scale to larger sizes and we are trying alternate washing solutions to minimize foam production. Pulsed droplet generation will be tried for higher capsule production rates and potentially less debris formation.

John Sheliak (GA/LANL) described recent results of cryogenic DT layering studies. They found that a foam layer substantially reduced DT surface roughness in a platinum torus. Foam has the potential disadvantage of trapping small voids that occur when DT contracts on freezing. Cooling from 19.25 K to 16 K increased RMS surface roughness from 0.9 to 1.4 microns. 1.4 micron roughness is better than previous results without foam even before cooling.

Dale Hill (GA) described fabrication of fast ignition targets. Methods of machining gold cones and fabricating doped and machined shells that allow these two parts to be joined with precise position were presented. These methods are very labor intensive and new methods will be required for mass production.

Rich Stephens (GA) described concepts for fast ignition target design. He noted that fast ignition targets present new concerns not present for central hot spot ignition targets. These include the need for a robust joint between the cone and shell, uniform layers probably cannot be achieved by beta layering with cone present, contamination from cone is possible, and need to minimize energy wasted in central hot spot. To address these concerns, Rich suggested a molded ice layer, inner and outer cone sections and a hole in the inner cone to vent contamination from the cone and hot spot gases.

James Maxwell (LANL) described fabrication of HIF hohlraums by Laser Chemical Vapor Deposition (LCVD). Photographs showed coils of material grown by this method. Typical chemical reactions involved in the process were shown and temperatures required to catalyze the reactions were presented. A unique concept for fabricating the hohlraums from the inside out was introduced.

Jill Dahlburg (GA) described the future of fusion energy programs in the US using the preliminary report from the fusion development path panel. The goal is to begin operation of a demonstration power plant in about 35 years. Both MFE and IFE research are to be pursued. The fusion development path is defined by a set of overlapping scientific and technical challenges. These include configuration optimization, burning plasma, materials testing, component testing, and demonstration with underlying scientific and technology development programs. Within IFE, the heavy ion beam program needs to begin design of a next-step proof-of-principle experiment. The z-pinch approach to IFE and fast ignition research need to be pursued more aggressively. The high-average-power laser program is of critical importance to the laser IFE development path, and needs to be supported on a continuing basis.

S. Uchida (Institute of Laser Technology, Osaka) described the use of optical phase conjugation for laser irradiation on laser fusion fuel pellets. Optical phase conjugation removes wavefront distortions that may be caused by turbulence in the reaction chamber. This is expected to enable more accurate target position measurements.

Sergei Krasheninnikov (UCSD) described IFE chamber ionization and its effect on target heating. Sergei explains that it is not possible to pump down the chamber to less than about 10^{13} molecules/cm^3. At this density, radiation can lower the temperature only to about 1 eV. There will be significant plasma densities remaining between shots at this temperature. There is not enough time for conduction to lower the gas temperature very much except near the chamber walls. Convection could possibly bring cooler gas from the walls into the target path, large convective eddies could be set up.

Rene Raffray (UCSD) described analyses of target heating during injection. He noted that previous thermal analyses have shown very low heat flux limits (~0.6 W/cm^2) for direct-drive target survival based on maintaining DT below it's triple point. Heat loads include radiation from the chamber wall and heat exchange from gas and plasma in the chamber. Highly reflective target surfaces are needed to minimize radiation absorbed from the chamber wall. We are investigating design modifications (such as outer foam insulation) for more thermally robust targets and the possibility of relaxing the DT phase change constraint. If there is a high-quality bond between the shell and DT, a temperature change to >26 K may be possible without vapor formation in the liquid DT. Results of calculations of gas evolution assuming this bond does not exist were also given.

Ron Petzoldt (GA) described the status of experimental target injection/tracking system. The system includes a gas gun with an 8 m gun barrel and 17 m free flight distance. Targets are protected in the barrel by sabots that use spring force for axial separation after the target leaves the gun barrel. A sabot deflector removes the sabot and the target proceeds to target detectors that use laser beams and line scan cameras to measure the targets position. From preliminary target position measurements, target downstream timing and trajectory are predicted in real time. All major equipment for single shot operation is now at GA and is being installed. A tour of the injector was also provided.

Ilya Agurok (Physical Optics Corp) described interferometric in-chamber tracking for IFE. Optics are positioned to achieve two closely spaced point sources from a single laser beam. An interference pattern is thereby set up in the reaction chamber. As the target passes through this interference pattern, it reflects the light and dark fringes. Knowing the approximate initial position of the target as it enters the chamber, precise continuous target position measurements are anticipated. Experimental system design will be completed in May and should be fabricated by the end of 2003.

T. Endo (Nagoya University) described a preliminary conceptual design of target injector for fast-ignition laser fusion and a small experimental accelerator. A gas gun with a sabot that holds the capsule and cone is planned. Magnetic deflection is used to separate the sabot. A small gas gun using room air propellant was built. Target trajectory was recorded using LED's and a digital camera. Excessive target tumble was observed and rifling is recommended.

Hiroki Yoshida (Gifu University) discussed target-tracking work at Gifu University. Direct imaging on CCD arrays, they have achieved 10 micron position measurement accuracy on stationary targets. Matched filters are being considered to reduce noise that may be due to aerosols in the reaction chamber.

R. Tsuji (Ibaraki University) described the flying metal pipe for target protection in an IFE reactor. A very cold metal pipe precedes the target into the reactor at a speed much slower than the target injection speed. Heavy gas molecules condense on the tube and are no longer present in the target path to affect target trajectory or heat the target. The target passes out of the pipe a short distance before reaching the chamber center. The pipe then passes into a pool at the bottom of the chamber or out a hole on the opposite side of the chamber from where it entered.

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