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GAS-FILLED HOHLRAUM FABRICATION

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ABSTRACT

Los Alamos National Laboratory (LANL) researchers have fabricated and fielded gas-filled hohlraums at the Lawrence Livermore National Laboratory (LLNL) Nova laser. Fill pressures of 1 - 5 atmospheres have been typical. We describe the production of the parts, their assembly and fielding. Emphasis is placed on the production of gas-tight polyimide windows and the fielding apparatus and procedure.

INTRODUCTION

Current indirect drive inertial confinement fusion (ICF) target designs for the proposed National Ignition Facility (NIF) use an unlined gold hohlraum filled with gas. The purpose of the gas is to limit the expansion of the gold ablating from the hohlraum wall, thus allowing the laser beams to penetrate the hohlraum interior and maintain the drive symmetry needed for ignition. Recent experiments testing this concept have used hohlraums containing 1 - 5 atmospheres of gas. The gas compositions have been varied from hydrogen/helium mixtures to hydrocarbons (e.g., methane, propane and pentane) to xenon. The hohlraums have been of two basic designs - toroidal hohlraums for laser-plasma instability (LPI) experiments and cylindrical hohlraums for implosion symmetry

experiments. The former are 3.2 mm in diameter with a 1.6 mm light entrance holes (LEHs) and only 1.6 mm in length, while the latter are 1.6 mm in diameter with 1.2 mm LEHs and range from 2 to 2.5 mm in length.

THIN WINDOWS

Windows are placed over the LEHs so the gas can be contained at a known density within the hohlraum. A low window mass is crucial to minimize the laser energy expended in burning through the window. The first windows we used were silicon nitride, formed by partially nitriding a silicon wafer and then removing the base silicon with a chemical etch. Selective masking of the silicon during the etching process results in windows with an areal density of 85-90 $\mu\text{g}/\text{cm}^2$ (thickness of 0.25 μm and density of 3.4 g/cm^3) over a 1.8 mm circular area supported by a frame of 50 μm thick silicon.¹

The silicon nitride windows have a high inherent tensile strength. In fact we measured some ultimate bi-axial tensile strengths at over 400 ksi. Moreover, its high stiffness results in a relatively small deflection when pressurized.

However, the silicon nitride windows have not proven to be ideal for these experiments. Their high stiffness, which yields the low deflection, also results in a high tensile stress at relatively low pressures. This becomes apparent

from the expression for pressurized thin spherical shells, namely $S=Pr/2t$, where S is the bi-axial stress, P the pressure, r the radius of curvature and t is the thickness.² Hence a small deflection means a large radius of curvature and a high bi-axial stress. (Note that a perfectly flat window has an infinite radius of curvature.) Moreover, the silicon nitride material exhibits high inherent stresses. This is demonstrated by the windows' propensity to spontaneously rupture, even when no differential pressure is imposed on the window. Some will even rupture after being pressure tested and surviving, when no obvious external stresses are being imposed.

The erratic behavior exhibited by the silicon nitride windows led us to polymeric windows. Though even the strongest polyimides have bi-axial tensile strengths 4 - 5 times lower than the silicon nitride, their compliant nature allows them to deflect and relieve stresses - both the intentional stresses imposed by the gas pressure and any unintentional stresses induced during fabrication and assembly.

For our polymer windows we chose to use a polyimide (PIQ-L100, Hitachi Chemical Company America Ltd.). This material is purchased as an amide-acid solution. Films produced from this material have a density of 1.47 g/cm^3 . The amide-acid solution is diluted with 1 part dimethylformamide to 5.7 parts amide-acid by weight, filtered to $0.2 \mu\text{m}$ and then centrifuged to remove entrained air. The resultant solution is spun onto silicon wafers and subsequently cured with one hour each at 150°C , 250°C and 350°C . By varying the spin speed from 3000 to 10,000 rpm, film from $0.95 \mu\text{m}$ to $0.35 \mu\text{m}$ (140 to $50 \mu\text{g/cm}^2$), respectively, can be produced from the same solution. Film thicknesses are determined using a stylus profilometer. The film is scored to the appropriate dimensions (typically 2-3 mm diameter) after curing and then allowed to soak in hot water for up to 24 hours. Then the individual pieces are teased loose from the silicon, floated free and

picked up onto a strip of $\sim 50 \mu\text{m}$ plastic sheet. After drying the polyimide piece can then be transferred to the hohlraum and epoxied in place using the thicker plastic strip. Attempts were made to use parting agents to accelerate the removal process. Generally the removal was much faster, but the films thus produced were troubled with a high density of pinholes. So use of the parting agents was abandoned.

The strength of the polyimide films thus produced has proven to be substantial. To compare films of differing diameters and thicknesses we use the rupture coefficient as defined by Chen³, namely $R = PD/t$, where R is the rupture coefficient (J/mg), P is the pressure (Pa), D is the diameter (cm) of the pressurized area and t is the areal density (mg/cm^2). With this choice of units we can compare directly with recent data on polyimide films produced by Eykens et al.⁴ Eykens reports rupture coefficients of 0.2 to 0.3 J/mg for polyimide films from 30 to 120 mg/cm^2 with test diameters of 20 mm. Our films have demonstrated rupture coefficients of 0.5 - 0.7 J/mg in the 50 - 140 mg/cm^2 range and test diameters of 1.2 - 1.6 mm.

This difference in measured strengths between the current work and that of Eykens deserves some discussion. First the specific polyimide is different in the two cases. We used the commercial amide-acid while Eykens began with the reagents to synthesize a different amide-acid. The other obvious difference is the diameter of the test samples. In principle any diameter differences are removed as the rupture coefficient is defined. But larger samples are more apt to include a point defect caused by dust or bubbles. The other factor affecting strength is moisture. In fact Eykens reports using a dry box to attain higher rupture coefficients. We do not use a dry box, but fortunately the dry climate of northern New Mexico where our films are produced allows us to operate in the ambient.

TARGET ASSEMBLY

The gold hohlraums used in these targets are fabricated by electroforming - electroplating gold onto sacrificial copper mandrels and subsequently removing the copper with nitric acid. The details of this process are discussed elsewhere.⁵

For a simple toroidal hohlraum target a small 150 μm hole is drilled to serve as a gas passage. Hypodermic tubing is epoxy bonded to the gold over this hole to complete the connection. The silicon nitride windows used on this target are also epoxy bonded over the LEHs, but in two steps. First a thixotropic epoxy (Hardman Adhesives #04008) is used to attach the window in place while minimizing flow or "squeeze-out" into the clear LEH opening. The window is subsequently sealed with the application of a non-thixotropic epoxy (Hardman #04001) which flows into voids and completes the seal. After 12-24 hours curing at room temperature, the targets are tested to 15 psi - the normal fill pressure for these targets.

Cylindrical hohlraums are used to conduct implosion symmetry experiments. These targets typically include deuterium-filled plastic shells (440 μm inside diameter, 20-50 μm wall) which are held within two 0.08 μm Formvar films at the center of the hohlraum. These targets also use 0.35 μm polyimide windows in place of the silicon nitride. They are bonded in place using the non-thixotropic epoxy alone. Another difference is the existence of diagnostic openings that must be covered and sealed with 7 μm titanium patches. The application of the polyimide windows and the titanium patches all occur after the plastic shell is mounted inside. This whole process requires 4-8 hours, during which time the deuterium gas is diffusing out of the shell. (Half-life for the deuterium fill at room temperature is about 30 hours.) Consequently while the epoxy is curing the entire target is pressurized with deuterium, typically at 50 atmospheres.

This pressure is maintained inside and outside the hohlraum, so there is no pressure differential across the windows, but the plastic shell is boosted back towards its original deuterium pressure. After 12-24 hours the target is removed from the deuterium boost system and tested at the working pressure of 15 psi. Once the integrity of the target is established, it may be stored in the deuterium boost system until it is used in an experiment.

The third major variety of target is the high-pressure (75 psi) target. These targets have been toroidal, but have used relatively thick (0.9 μm , 130 $\mu\text{g}/\text{cm}^2$) polyimide windows. This thickness of polyimide has proven to be strong enough to seal against the 75 psi fills over a 1.6 mm circular LEH. (Some have held to 130 psi.) However it was necessary to add reinforcement at the edge of the LEH to prevent peeling of the film. This peeling action is independent of the film thickness or strength but is instead dependent on the bond strength between the epoxy and the film or gold. The reinforcement was added in the form of a 50 μm thick stainless steel washer with a 1.8 mm opening. The stiffness of the washer bonded over the outer edge of the polyimide film essentially distributes the force of the peeling action uniformly over the area of the washer to a very acceptable tensile stress in the epoxy.

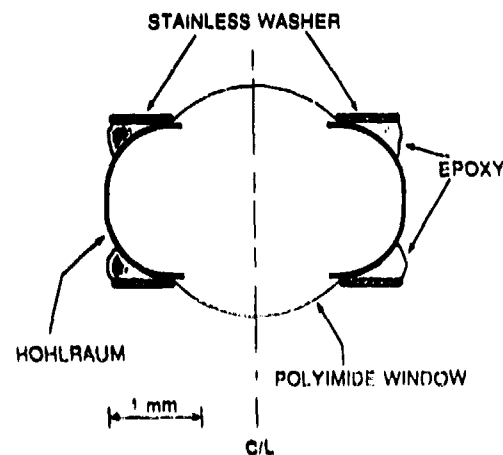


Figure 1. A high pressure gas-filled hohlraum.

This simple addition has prevented any peeling failures in these targets. It is necessary that the inside edge of the washers be rounded and free from any burrs to prevent tearing of the window.

TARGET FIELDING

There have been two means of fielding these targets. We separate the targets into those with 1 atmosphere fills, and those without.

One Atmosphere Targets - Targets that require a 1 atmosphere fill enjoy a level of simplicity. For such targets a small (7 cc) reservoir is attached directly to the target, with no intervening valves. A single manual valve accesses the target and reservoir for evacuation and filling, while a pressure transducer also in direct connection with the target shows the absolute fill at any time.

To begin a filling operation the target (with its reservoir and transducer) is placed inside a small vacuum vessel. The vessel is first evacuated, then the target itself is evacuated. This procedure is necessary for targets with silicon nitride windows, since experience has shown that these windows cannot support a "negative pressure", but has been adopted for the filling of all 1 atmosphere targets. Then the hohlraum fill gas is introduced into the target to the 1 atmosphere pressure. Only then is the vacuum surrounding the hohlraum released until the laser is ready for the target.

Targets thus filled may be required to wait a few hours before being inserted in the Nova target chamber. But during this period there is no net force on the windows. Moreover, any minor leak that may be present will have a negligible effect. Diffusion through any such leak would result in some slight change in the composition of the gas, but this has not proven to be significant.

When the target is finally inserted into the Nova target chamber, the windows become stressed as the pressure exterior to the target is reduced. Connections to the pressure transducer

allow constant monitoring of the pressure within the hohlraum right up to shot time.

Non - One Atmosphere Targets - Any target with a gas fill other than one atmosphere requires a different fill system and procedure. For all these targets the hohlraum is isolated from a reservoir until a few seconds before shot time. This serves a couple of functions. First higher pressure targets are not subjected to stress until just before the shot. If the system used for one atmosphere shots were used the windows would be under stress for as much as 2-3 hours prior to insertion in the Nova chamber, and any small leaks could become significant. For targets using sub-one atmosphere fills the one atmosphere system would place a "negative pressure" on the window, and any small leak would result in air being pushed into the hohlraum during the waiting period.

This more complicated fill system consists of a manual valve for filling the reservoir, an electrically operated valve between the reservoir and the target and a second electrically operated valve between the target and ambient. There are also pressure transducers monitoring both the reservoir and the target.

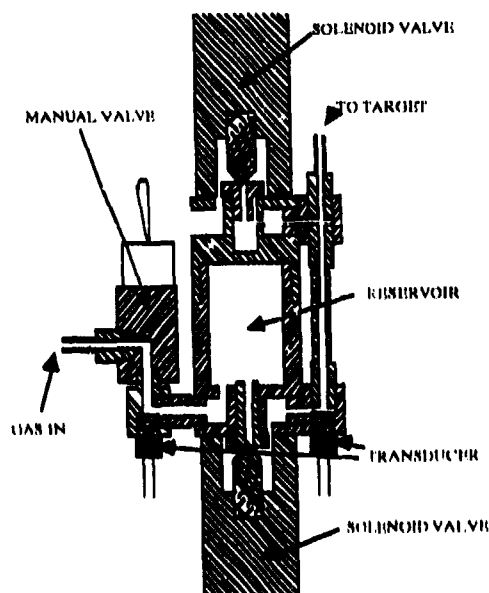


Figure 2. Dynamic fill system used for high pressure targets.

A fielding operation starts with filling of the reservoir. The target with its reservoir, valves and transducers then enters the target chamber with the manual valve closed, the valve between the target and reservoir closed and the valve between the target and ambient open. This guarantees the target will be evacuated upon entering the target chamber. Less than a minute before the shot, the valve to ambient is closed. A few seconds later the valve between the reservoir and target is opened. Then about 5 seconds before the shot this valve is again closed. This last step again isolates the target and reservoir, so that at shot time only the gas within the target escapes into the target chamber. The larger quantity of gas within the reservoir remains in place. Throughout the process pressures within the reservoir and target are monitored. Thus far targets up to 75 psi have been fielded.

CONCLUSION

The targets discussed have demonstrated that thin, gas tight windows can be fabricated, assembled to hohlraums without significant leaks and then fielded at the Nova laser system. This has been done with a variety of hohlraum designs and at pressures as high as 75 psi.

Experimenters have now requested targets with gas densities 2-3 times higher than these. In principle this could be accomplished by extending the current techniques and using thicker windows, but since laser energy is required to burn through the windows, there is a desire to keep the windows thicknesses to a minimum. Higher densities can be attained using cryogenics. Targets are now planned to be cooled to LN₂ (77 K) temperatures. This should allow the same gas density to be obtained at one-quarter the pressure (for non-condensable gases).

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