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**Fabrication and Testing of Gas Filled Targets for
Large Scale Plasma Experiments on Nova***

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An experimental campaign on the Nova laser was started in July 1993 to study one set of target conditions for the point design of the National Ignition Facility (NIF). The targets were specified to investigate the current NIF target conditions - a plasma of ~3 keV electron temperature and an electron density of $\sim 1.0 \text{ E}+21 \text{ cm}^{-3}$. A gas cell target design was chosen to confine a gas of $\sim 0.01 \text{ cm}^3$ in volume at ~ 1 atmosphere. This paper will describe the major steps and processes necessary in the fabrication, testing and delivery of these targets for shots on the Nova Laser at LLNL.

Major Steps for Gas Cell Target Fabrication

- Target Specification**
- Target design and drawing production**
- Target material selection and window fabrication**
- Target component micro-machining**
- Gas specification**
- Gas mixing system design and fabrication**
- Gas mixing and analysis**
- Pressure transducer specification**
- Target manifold design and assembly**
- Target pressure / vacuum testing hardware**
- Target fabrication and final assembly**
- Target vacuum testing**
- Target filling hardware and filling procedures**
- Target documentation and reporting**

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1. Target Specification

These targets were specified by the Nova experimental shot physicists in conjunction with the X-Division theoretical modeling section staff to produce a plasma of ~3 keV electron temperature and an electron density of $\sim 1.0 \text{ E}+21\text{-cm}^{-3}$. The gas cell targets were defined as either open or closed geometry. This referred to the access or visibility of the target from diagnostics on the Nova target chamber. A range of gas mixtures to vary the target conditions and diagnose the plasma were specified. Seed gasses with ionic species permitting temperature measurements were added as well. Metal coated diagnostic fibers and foils were also inserted into the target to monitor temperature.

2. Target design and drawing production

The fabrication of these targets required integration of a gas manifold with a pressure transducer, the target and gas fill lines, gas mixing, testing and filling systems and the Nova Target Positioner. Scaled CAD drawings of target and associated components were produced to look at fit and interference with the existing target handling hardware.

The open geometry targets were formed by bonding CH windows on a specially fabricated support ring. Fill lines were drilled through the side walls of the support ring. The fill lines were connected to a gas system and over pressured to form the nearly spherical gas cells. The previous non-gas hohlraum targets shot on Nova were modified to allow gas fill lines and CH windows over diagnostic and laser entrance holes.

For the closed geometry targets, a series of drawings were required to allow precise the placement of shields, fibers, foils and other target components. Alignment tolerances for the closed geometry targets were $\pm 25 \text{ }\mu\text{m}$ and $\leq 2^\circ$ in 3-dimensions. The production of CAD drawings allowed the shot physicist to check for diagnostic line-of-sight and beam placement conflicts before target components were machined and fabricated.

For the open geometry targets, a nearly spherical volume of gas with sufficient gas integrity to hold pressure for 1 - 3 hours was needed. The target skin needed to be strong enough to withstand >1 atmospheric pressure over an area of $\sim 20 \text{ mm}^2$, surrounded by a vacuum of $<10^{-5}$ Torr. The target skin also needed to be ductile enough to form a nearly spherical bubble from two flat sheets. A thin ($\leq 1 \mu\text{m}$) sheet of polyimide was glued across both sides of a thin ($\sim 400 \mu\text{m}$) Al washer. Two small diameter ($\sim 250 \mu\text{m}$) stainless steel fill tubes were passed through the sidewall into the inner diameter of the washer and glued in place. The gas fill lines were then over pressured by >20 PSIA. This allowed the films to distend, forming a nearly spherical bubble. These targets were identified as GASBAG targets. The ID of the washer was 2.75 mm and the bag width typically 2.4 - 2.5 mm.

Figure 2. Photo of GASBAG target with x-ray imaging slit.

For the closed geometry targets, the target was based on the electroplated gold hohlraum design used at Nova. Diagnostic views into the interior of the targets required a hole or slot to be milled in the side of the target mandrel prior to the copper core being leached chemically. Fill tube holes were also drilled into the side of the hohlraum mandrel to allow gas filling. The Laser Entrance Holes (LEH) and any diagnostic windows were then covered with thin ($0.2 - 1.0 \mu\text{m}$) polyimide.

One of the requirements for the closed geometry targets was to reduce the window distortion and more closely control the total gas volume. A different polyimide and process cure cycle was used for these polyimide films. Some distortion of the films was tolerated in these films - typically 0.1 - 0.4 mm beyond the edge of the target.

Figure 3. Photo of GASBIG target showing diagnostic view window.

5. Target component micro-machining,

The GASLAG targets were fabricated by starting with a 400 μm wide support washer. The washers were made from brass, Lucite and aluminum. Stock aluminum rod was standardized as the material of choice for the washers. Two 270 μm holes for the fill tubes were drilled through the side walls of the washer. The washers were micro bead-blasted to increase the surface area and improve the polyimide adhesion.

The bodies for the closed geometry targets were produced by machining into the gold plated copper mandrel fill tube holes, slots and other openings in the targets. After the mandrels were machined and inspected for accuracy, the outer surface was micro-bead-blasted to produce a roughened finish. The mandrels were then leached in a nitric acid solution ($\text{HNO}_3 \sim 0.5\text{N}$ solution) at 60 degrees C. The etching process would take from 1 - 3 hours.

6. Gas specification

The gas mixture and pressure was specified by the shot physicist to mock-up the experimental conditions for the point design of the NIF targets. The main gas for this series was selected as neopentane (C_5H_{12}). To aid in measuring the ion temperature, spectroscopic seed gasses were added to the mixtures. The spectroscopic gasses were Ar and Freon - 13 ($CClF_3$) and varied from 0.25 to 10 atom percent in concentration. The nominal standard target gas for the early experiments was 98 % neopentane (C_5H_{12}) + 1 % Ar + 1 % Freon - 13 ($CClF_3$) at a nominal pressure of 1 atmosphere. To achieve lower target densities CO_2 , C_3H_8 , and CH_4 were used as the base gasses.

Jeff Colvin of LANL suggested obtaining a deuterated gas C_5D_{12} , to possibly use the fusion neutron yield to diagnose the experiment. Samples were obtained and used in doped and undoped forms. At one point it was suggested that a tritiated gas sample would allow other neutron diagnostic development, but no vendor could be found to produce the mixture.

7. Gas mixing manifold and gas analysis

A manifold was designed to permit gasses to be mixed into a sample bottle for later use in filling the targets. As the main gas C_5H_{12} condensed at ~1300 Torr, an upper limit on the system was placed at 1000 Torr. The components for the manifold were bellows style valves and VCR style metal gasket fittings. The inner connecting pieces and the tubing for this system was fabricated from 316 type stainless steel fittings. The original gas mixing manifold was used to both mix the gas and fill the targets. A flow through filling method was initially employed. As the cost and complexity of gas mixtures increased, separate systems for filling were fabricated. An evacuation/backfill method used by the LANL Target Fabrication group was adopted and will be described below.

The gas cylinders were fitted with a pressure regulator, a pressure relief valve and a small flow control/shutoff valve. The pressure relief valve was set to vent at 10 PSIG or 10 PSI above ambient atmospheric pressure. As the operation of the gas mixing manifold and sample bottles involved flammable gasses, the system was moved to an exhaust hood to meet LLNL safety requirements.

Figure 4. Photo of gas mixing system on optical bread board table.

The gas mixture was specified by the shot physicist in atomic percentage for the individual components. A diaphragm style pressure manometer was used to measure the pressure in the manifold lines and bottles. The gas bottle was connected to the mixing manifold and evacuated for 60 minutes. After the system had reached the ultimate vacuum (typically <0.2 Torr), the pump and sample bottle were valved close. Each gas was purged 3 - 4 times before a mixing session, with the exception of neopentane (C_5H_{12}) and deuterated neopentane (C_5D_{12}). The neopentane bottles were directly connected to the manifold with a small pre-chamber and a valve. This permitted us to maintain a small positive gas pressure in those regulators and lines.

Once the gasses were purged, the manifold was pumped back down to the base vacuum. Starting with the lowest percentage gas, the pressure in the system was allowed to increase until it reached the partial pressure for the Ar - 10 Torr. The $CClF_3$ was added until the partial pressure reached 20 Torr and the balance was filled with C_5H_{12} up to the 1000 Torr level.

In order to interpret the target results, it was necessary to know the gas ratios to <0.1 atom percent. The gas mixtures were analyzed using a mass spectrometer with a resolution down to $Z = 1$ (hydrogen) and a discrimination down to 0.01 atom percent. In addition to the measured values, the analysis would also provide the standard deviation of the measurements. To improve the accuracy of the analysis, pure samples of each gas were drawn off into small (<75 cc) sample cylinders and given to Chemistry as "reference" standards for the process. This was done for all the starting gasses and also when primary gas source bottles were changed.

11. Pressure transducer specification

A strain-gage style, absolute pressure transducer was used to monitor gas pressure. The transducer selected was a amplified type producing an output signal of 0 - 5 VDC that was linear with pressure. A major concern for these transducers was their ability to operate not only at atmosphere on the bench, but also in vacuum of the Nova target chamber. A test unit was field tested on a Nova laser shot using a Zener diode chain to protect the electronics in the transducer. When the target is shot on Nova, a plasma is produced that has a designed electron temperature of 3 kV. To electrically protect the transducers, a 5 watt / 47 VDC zener diode was added to each connector line on the transducer cable to strip off voltage spikes > 50 VDC. The unit was calibrated before and after the laser shot to measure the voltage drift at vacuum and to check for any signs of virtual leaks. The transducer voltage values were within ± 0.001 VDC of the values before the shot.

13. Target manifold design and assembly

A manifold to support the transducer, gas flow valves and target fill lines was fabricated out of brass. The valves were chosen due to the space available within the Nova target insertor and on the size of available valves. The valves were not designed for vacuum sealing but rather for liquid/gas flow metering. In order to obtain a good vacuum seal it was necessary to over tighten the stainless steel metering needle into the brass body of the valves. It was necessary to change the valves after 6 - 10 shots. The valves were one of the main sources of leaks on assembled targets.

The early gas cell targets used a flow-through method to fill the targets with gas and two valves were utilized on the manifold. One port on the target manifold was

connected to the gas sample bottle and the plastic line on the other port inserted into a beaker of water. The gas was allowed to flow until it was estimated that all of the air had been displaced with the sample gas. The current system of evacuated back-fill of targets retained the two valves to safeguard against one of the fill lines being blocked at the target.

A pair of 1 mm OD stainless steel fill lines were attached to the top of the manifold. Plastic tubing was used to connect the manifold to the target. The stainless steel fill lines on the target were $\sim 250\ \mu\text{m}$ OD and smaller plastic tubes were slipped over the ends. These smaller diameter tubes were then inserted into the 1 mm ID plastic lines from the manifold. All threads for parts connected to the manifolds were coated with a liquid thread sealing compound before attachment. After all the components had been attached to the manifold, the interior of the manifold was attached to a vacuum system and pumped on for 24 hours. This ensured that all the solvents in the thread sealer had dried and would not interact with the gas.

LNL '0 Beam Gas manifold: Filename: FBTRANSDUCER.MANIFOLD

Figure 5. CAD drawing of manifold with transducer, valves and gas fill lines.

15. Target pressure testing hardware

The original design and fabrication of the evacuation test chamber system and the evacuation backfill method was the work of Mike Salazar and the LANL Target Fabrication staff. A single unit was initially used for both the testing and filling of LANL gas filled targets. As the number of shots per day increased to as many as 6 targets a day, it was necessary to be able to test targets and fill at the same time. The other major improvement of this evacuation/back fill system was the reduction in the total gas used per targets. The deuterated neopentane procurement cost was ~\$1000 per liter. In addition to using large quantities of gas, the flow through system did not ensure that only test gas remained inside the target and manifold.

Figure 6. Photo of testing system for two target manifolds.

The target testing procedure was divided into three steps. The target manifold was tested as a stand-alone unit. The target body was tested by either the on-site staff or the off-site fabricator and certified gas tight. The assembled target attached to manifold was tested as an integrated system before filling. As the targets were shot, the manifolds and transducers were returned to the Target Assembly area, repaired, re-tested and returned to service.

17. Target fabrication and assembly

The fabrication of these targets was complicated by the requirement to hold gas behind thin CH windows. The same basic assembly procedures used for non-gas targets were employed on the gas cell target series. Target fabrication was generally performed with the aid of an optical microscope, with micro-manipulators holding target parts held in place with vacuum chucks. Fast curing or UV/visible cured cements are employed to fix target components in place.

The gas cell targets were returned by either the off-site vendor or the in-house group as certified gas tight assemblies. For the open geometry targets, the final assembly would consist of mounting the target on a Nova magnetic base at the desired 3-space orientation (X , Y , Z , Φ , and Θ). The closed geometry targets would have the further alignment restrictions placed upon them by alignment fibers and flags, backlighter patches, diagnostic holes and slots. The target components are required to be placed within $\pm 25 \mu\text{m}$ and $\leq 2^\circ$, relative to the Nova target base.

After the target had been positioned on the base, additional components such as shields and alignment fibers were added to the targets. The target was then metrologized by the assemblers for internal record keeping (QA/QC) and later by the shot physicist. The second metrology was used by the shot physicist to aid in positioning beams and aligning target diagnostics. After the final metrology, the small diameter ($250 \mu\text{m}$) plastic fill lines were attached and the target delivered to the testing area. To complete assembly of a gas target, the plastic tube loop on the manifold was cut and the smaller $250 \mu\text{m}$ OD fill lines on the target were glued inside the manifold fill lines. The target assembly was then vacuum tested to ensure it remained gas tight.

19. Target filling hardware and procedures

The gas filling hardware developed by the LANL Target Fabrication Section was initially used for both target testing and gas filling. The target filling manifold had an absolutely calibrated pressure transducer attached to monitor internal target pressure. A mechanical manometer was also placed in-line with the chamber to monitor the external target pressure in the 1 - 200 Torr range. A small valving manifold was attached to the test chamber to control gas flow and chamber evacuation. It was equipped with valves to control the independent pumping of the interior and exterior of the target as well as filling the target.

Figure 7. Photo of gas filling system.

The target was placed on the filling system and the transducer cable attached. A nitrogen purge line at $\sim 0.25 - 0.5$ PSIG was attached to the fill manifold to verify the fill lines to the target were not blocked. The main vacuum valve on the pump was then SLOWLY opened to pump out the air around the target. After the bell jar pressure reached ~ 5 mm Hg, the next step was to SLOWLY pump out the interior of the target. Due to the low conductance of the $100\ \mu\text{m}$ ID fill tubes, the system was allowed to pump for 15 minutes to fully remove the air from the target interior.

After the interior of the target had been evacuated for 15 minutes, the target was slowly filled. Once the aim pressure was reached, the valves to the gas fill bottle and manifold were closed. The chamber was then slowly vented to atmosphere. The target transducer reading was observed for drift. If the target pressure was stable, the fill line was disconnected and the target carefully placed in the target transport box.

A calibration sticker was prepared and attached to the target. It contained the transducer number, voltage and pressure readings for atmosphere and vacuum, the target number and the target name used at Nova, and the fill date. This data was duplicated in a transducer logbook. A tag for the top of the shipping box with the target name and fill gas was also prepared.

Conclusions

Targets to test the National Ignition Facility proposed point design were developed and fabricated for use on the Nova Laser at LLNL. Sub-micron thickness CH windows capable of holding >1 atmosphere were adapted to standard Nova hohlraums and nearly spherical targets with $>20 \text{ mm}^2$ surface areas. A system to pressure test targets prior to delivery to Nova and verify gas integrity was fabricated in conjunction with the Target Fabrication Section of LANL. A gas mixing system was developed that permitted mixture ratios as low as 0.25 atomic percent for individual gasses up to 1000 Torr total pressure. A system to measure gas pressure inside the target was developed and integrated into the Nova Target positioner. In support of the ICF programs at LANL and LLNL, more than 350 gas cell targets were successfully fielded on Nova.