Target developments program to prepare LMJ campaigns

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Abstract. To carry out laser plasma experiments on CEA laser facilities, a R&D program was set up and is still under way to deliver complex targets. For a decade, specific developments are also dedicated to “Ligne d’Intégration Laser” (LIL) in France and Omega facilities (USA). To prepare the targets intended for the first experiments on the Laser “Mégajoule” (LMJ) facility, new developments are required, such as cocktail hohlraum fabrication, gas barrier coating and foam shells developments. For fusion experiments on LMJ, an important program is also under way to elaborate the Cryogenic Target Assembly (CTA), to fill and transport the CTA and to study the conformation process of the deuterium-tritium (DT) layer.

1. Introduction
Target developments started in France with first laser facilities four decades ago. The targets complexity has increased to meet ever more demanding experimental requirements. To achieve the production of these specific targets, materials and micro technologies research programs have started. Since 1999, this program involves CEA scientists, engineers and technicians to realize specific targets, used to carry out laser plasma experiments mainly on LIL and Omega facilities. This article presents an illustration of these micro technology fabrications through some complex laser targets.

The current know-how is not sufficient for some steps of the experimental program planned on the LMJ [1], [2]. New target developments are required such as cocktail hohlraums, DT gas shells and foam shells.

Among the LMJ targets, one of the most complex targets is the CTA [3]. An important program is dedicated to its manufacture, its filling (cryogenic targets filling station or IRCC) and its transportation (moving cryostat or VTCC) at cryogenic temperature. The CTA has to meet severe specifications and involves a lot of challenging tasks for its manufacture. To fill CTAs by permeation with DT, the IRCC needs to meet strict thermal, mechanical and dimensional specifications. Today, many parts of the installation have been successfully prototyped, such as the permeation cell, the cryogenic gripper, the DT purification process, and the cryogenic DT pressure process. After DT filling, to obtain a good combustion yield, a very homogenous DT ice layer with a low roughness at 1.5 K below the DT triple point, are also required. The conformation of the ice is studied in two specific cryostats: the integrating sphere and the study filling station (SFS).

2. Target developments for LIL and Omega plasma experiments
Various techniques are fully operational to fabricate target elements: Chemical Vapor Deposition (CVD), Physical Vapor Deposition (PVD), Glow Discharge Polymer (GDP), precision machining,
laser machining [4], and electrochemical deposition. Characterization means are also needed for each step of target element manufacturing and after the assembling. The following paragraphs describe two complex targets delivered to LIL and Omega facilities.

2.1. Equation of state targets
Recent targets were realized to study the Equation of State (EOS) of boron on LIL facility [5]. These targets were composed of a gold spherical hohlraum, with two steps at 90°: one was the studied material i.e. boron, and the other was aluminum as a reference. Machining of these materials needed very specific fabrication processes to obtain thin films of 50 µm with 20 nm roughness. Gold cones were also added to shield diagnostic measurement from laser light.

2.2. Multilayers GDP shells
New designs have been developed to reduce hydrodynamic instabilities propagation during target implosion [6]. In this field, multilayer germanium doped and undoped CH\textsubscript{x} coating were developed with GDP techniques. These films are realized by controlling the germanium flow in the GDP coater in order to realize many 1 µm thick layers as shown on picture 1. A specific Labview™ software was developed to pilot the mass flow controllers that allow us to obtain these multilayers.

![Figure 1](image.png)

**Figure 1.** Picture of the cross section of a 60 µm thick coating with 1 µm thick germanium doped and undoped layers. The red curve shows the germanium concentration and the blue one, the oxygen concentration (Energy Dispersion Spectroscopy).

3. New target developments for LMJ
Before reaching the ignition on LMJ, different types of plasma experiments will have to be carried out. Several of these will need new kinds of targets which have not been required up till now. This part of the paper describes three key developments realized.

3.1. Cocktail hohlraums
In order to decrease the wall absorption of hohlraums during laser matter interaction, a thick layer of depleted uranium with gold (DU alloy), can be deposited on the inner surface of the hohlraums. In order to achieve such a coating, sputtering of massive targets of DU and gold directly in the hohlraums is used, the vacuum chamber being placed in a box gloves under nitrogen atmosphere.

Two major technological problems have to be solved to produce such pieces. First, the composition has to be controlled through sputtering parameters as pressure, power of sputtering and target – substrate distance. Gold – molybdenum (Mo) alloys have been synthesised on LMJ hohlraum with a thickness homogeneity better than 5%. The second problem is the rapid delamination of DU alloy in contact with water, air or hydrogen. To protect the DU alloy, a thin coating of dense gold is sputtered on DU alloy. The studies on the effective protection of gold on praseodymium (Pr) deposits have demonstrated that a layer of 0.2 µm of gold is sufficient to prevent Pr from any degradation. The first deposition of DU is to be fabricated to begin the studies of DU alloy aging in aggressive atmosphere (DT).
3.2. Gas barriers for DT gas shells
Gas hohlraum at room temperature with a DT filled CH$_x$ shell would be needed on LMJ before cryogenic shots. The D$_2$ gas retention in CH$_x$ shells is around 7 min (half life time - T$_{1/2}$). After including thin layers (100 – 300 nm) of metal oxides (such as TiO$_x$, SiO$_2$), the current D$_2$ gas retention reached for Omega targets is 1 month (T$_{1/2}$), which is currently experienced on Omega facility, but not sufficient with DT. Work is going on to control the deposition parameters to increase gas retention up to 3 months to be compatible with LMJ experiments.

3.3. Foam shells to study implosion
The specification required for 2 mm diameter “CH” foam shells are tight: sphericity > 99%, concentricity > 99.9%, porosity of the foam < 1 µm. Two densities are also required: 0.1 and 0.25 with metallic atoms as dopants such as ytterbium and titanium. The process uses two main steps: triple injection (followed by final polymerization and solvent exchanges) and drying by CO$_2$ supercritical dryer. The results obtained meet the main requirements (doping of Yb and Ti including). For sphericity and concentricity, good results (99.6% and 96% respectively) are obtained (15 experiments, hundreds of microballoons) and work is under way to reach the final goal on concentricity.

4. CTAs, filling station and conformation for ignition on LMJ
The CTA has to meet many requirements [7], among them the Contact Thermal Resistance (CTR) at cryogenic temperature when CTA is connected to a cryogripper. Satisfactory CTR results have been obtained by removing the “Beilby layer” [8] using electrolytic polishing (CTR < 1 K/W).

The developments of graded germanium doped CH$_x$ shells is another priority [9]. The last developments focus on bumps characterization at the outer surface of CH$_x$ shells by Digital Holography Microscope (DHM). The DHM allows the 3D mapping of the shell outer surface (pictures scale is 250 x 250 µm$^2$). The surface is mapped by recording images along equators using two rotation axis (72 pictures by equator and 12 equators to map a shell of 2100 µm diameter). Pictures are then stitched to rebuild pictures of entire equators and datas are reconstructed in 3D to identify bumps redundancy. The dimensions of each bump are determined by mathematical functions (wavelet or spherical function). At the end of the process, many results are available: number of bumps, bumps dimensional characteristics, rate covering surface, and rate redundancy surface [10].

The research program for operational filling facilities which will deliver CTAs filled by permeation in DT to LMJ has been already described [11]. Glove boxes have been received for most of them.

4.1. Layering studies
Layering studies are focused on crystal growing and thermal quenching in spherical integrating sphere. Experiments in a complete CTA have started in the Study Filling Station (SFS).

4.1.1. Spherical integrating sphere. Experiments on layering of solid deuterium in integrating sphere help to learn about the solid crystallization behaviour. Easier to handle since it is not radioactive, deuterium needs the use of a volumetric heating by an infrared laser. To growth a perfect crystal, a thermal stable environment is required at the triple point. It starts from a small crystal seed. The crystal growth speed has to be dominated by the latent heat of fusion. For these experiments the laser power fluctuations have to be at a sufficiently low level since they act directly on the shell temperature, and so the crystal growth.

Following the layering, nominal temperature is obtained by a rapid cooling. The basis of this concept, originally developed at CEA [12], is to cool down the solid faster that the roughness increases. A range of temperature speed drop has been explored. We determined that the minimal slope is 2 K/min. Roughness is keeping its initial value as far as the temperature is going down. It has been possible to keep a smooth layer at 2.5 K below the triple point. When temperature is stabilized (1.5 K under triple point), roughness stays in the requirements during about 5 seconds (figure 2).
4.1.2. SFS. The whole permeation filling system for the LMJ cryotarget is now fully operational [13]. First experiments have been successfully done with deuterium in a 70 µm thick CH capsule. Preliminary layerings have been done. Work is now focussed on optimizing the infra-red laser injection in order to reach a uniform volumetric heating in this cylindrical geometry.

5. Conclusion
The CEA covers since a long time all the fields of research and development in targets for laser plasma experiments. This know-how allows delivering targets for current laser facilities such as LIL and Omega. New fields of developments are required for some parts of the LMJ experimental program, and are well under way, one of the most important among them being a significant program on the cryogenic target assembly. The most part of the tritium workshop is now under completion.

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