Fusion with the Megajoule Laser

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Abstract. Achieving fusion with LMJ requires a coordinated program associating the facility itself, and associated targets. New results obtained since the last IFSA conference are presented, starting from the facility itself (including operations), moving to cryogenic targets, on to plasma diagnostics. We identified high yield fusion capsules that require no more than 1.4 MJ of laser energy, offering new opportunities for operating LMJ. The corresponding experimental path to fusion is described and commented.

1. LMJ/fusion target system design

The LMJ facility is a key part of the French « Simulation Program ». The LMJ is devoted to laboratory experiments on the behavior of materials under very high temperature and pressure conditions. It is a key facility for training physicists engaged in the French deterrent. It also has applications in the field of astrophysics, Inertial Fusion Energy (IFE) and fundamental physics [1]. In order to cover those different applications, the facility is designed with maximum flexibility in terms of pulse duration (from 200 ps to 25 ns) and power. Plasma diagnostics will be easily interchanged depending on the type of experiments, using special diagnostic inserters and positioners.

The LMJ most stringent specifications are dictated by fusion experiments. Specifications for the laser were obtained with an optimization of the laser itself together with the fusion target (figure 1). A fusion target is composed of a 1 cm long, usually gold, cylindrical hohlraum, used to convert laser light to X-rays. X-rays smoothly irradiate a 2 mm diameter capsule, composed of a polymer ablator and DT. The laser beams are distributed in three cones that enter the hohlraum through two apertures, one on each side of the hohlraum. The laser beams illuminate the hohlraum as quadruplets. The beams are distributed in three cones that enter the hohlraum through two apertures, one on each side of the hohlraum. The laser beams illuminate the hohlraum as quadruplets. The laser light spots locations are chosen in such a way that the converted X-rays provide a very uniform irradiation of the capsule. In order to further enhance the efficiency of the implosion, the DT contained in the capsule is solid for the most part.
The fusion capsule is composed of the ablator, a layer of solid DT, and a central gaseous DT core. The target assembly is maintained at about 18 K with an elaborate cryogenic system. Figure 1 shows the high purity aluminum target holder that refrigerates the target through thermal conduction [2]. To determine LMJ and target specifications, we used numerical simulation to optimize 1D capsules imploding under shaped laser pulses. This gave the required energy and laser power. 2D integrated simulations were then performed to optimize beams position and energy balance. Such calculations accounted for laser plasma interaction within the target’s hohlraum, as well as symmetry requirements. Margins were added to the reference design in order to take into account the two main remaining uncertainties, that is the effect of laser parametric instabilities (LPI) and hydrodynamic instabilities (figure 2). With current laser specifications, 2D integrated simulations show that our point design targets deliver more than ten times as much energy as the laser energy itself. The next step is to design and optimize our fusion target, which is been done using our suite of 1D/2D/3D target implosion codes. These codes have a rich physics package, necessary for simulating the implosion of a fusion target. They include laser-matter interaction (a raytracing package), multifluid approximations for both ions and electrons, coupling to radiation transport, as well as coupling to fast electrons, neutrons and alpha particle transport [3].

2. System optimization

2.1 Fusion target optimization

The optimization strategy is as follows. We first identify a robust capsule, with respect to perturbations induced by laser/matter interaction and departures from sphericity coming from both the laser and the target. Our model shows there is a threshold for the capsule’s gain as a function of the invested laser energy. The gain then grows to flatten and reach a plateau. Our initial point design was chosen to be on the flat part of the curve.

Ten years in the Simulation program, we now have a series of new modelling tools, implosion models and simulation codes. Based on those, we could identify new fusion capsule, with yields of about 10, but functioning at lower laser energy, and showing a still robust implosion. The figure shows our first base design, demonstrating now a gain 14 with 1.8MJ laser energy. Our new optimized design shows a gain 11, with a 1.4MJ laser energy. Other fusion capsules were also identified that function with a still lower laser energy, but they are less robust. These results were conforted by our 2D simulations [4].
We then optimize the hohlraum shape and material, and insure the symmetry of the implosion, relying on energy balance in the laser cones. Our point design is a “cocktail” hohlraum, composed of a mixture of uranium and other heavy materials, to optimize laser energy conversion into X-ray energy.

Margins are added to take into account backscattered light, as well as 2D/3D defects due to the target and the laser itself. We also optimized the fusion capsule’s roughness specifications.

Most specifications were demonstrated on the Ligne d’Integration Laser, our technological prototype [5]. As for symmetry, we checked that they could be reached in experiments on the U. of Rochester OMEGA laser, using a 40 beam configuration.

2.2- Target fabrication
The feasibility of all the different phases of fusion targets fabrication is now demonstrated: capsule fabrication, target assembly, cryogenic DT conformation, equipments for filling, cooling, and transporting fusion target from production location clear on to target holder.

Figure 2: target energy gain as a function of laser energy

Figure 3: Target assembly
Capsules fabrication procedure and apparatus is under operation and a high enough fraction of the already produced capsules are within specifications. In particular, a gradient dopant technique was demonstrated in 2005-2006, insuring even more robust capsules, with respect to hydrodynamic instabilities.

Figure 4: The red curve shows that current capsules are within LMJ’s specifications (in green)

As for DT conforming as an homogeneous, low roughness solid layer, a new technique was proposed. It allows to dramatically decrease the capsule’s cooling time, from several tens of hours down to a few hours. This technique consists in ending the cooling procedure with a rapid freezing of the DT. First estimates show that the final temperature is obtained within a few seconds. The solid DT surface roughness is not altered [6].

3. Conclusion
LMJ’s ignition program is well underway. First experiments will be carried out at the end of 2012. Besides the facility’s itself, most critical technologies have been demonstrated, plasma diagnostics, cryogeny, target design and fabrication. During the course of the next few years, additional optimization is expected in the field of target design fusion capsules.

References
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