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Progress on Indirect-Drive Target Design for the Laser MégaJoule Facility.

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Introduction

The Laser Mégajoule (LMJ) facility is under construction near Bordeaux [1] and will deliver up to 2 MJ of 0.35 μm light. On the indirect-drive scheme, the laser energy is converted into x-rays inside a hohlraum, which implode the spherical capsule containing the deuterium-tritium (DT) fuel [2]. In this paper, we will summarize our recent progress concerning the effects of low and high mode deformations and the first results in green light ignition target design.

LMJ baseline design

Our nominal design is the result of a global optimization [3] including laser plasma instabilities (LPI), irradiation symmetry, hydrodynamic instabilities and ignition margin. Except for a few changes on the ablator, the target design has kept the same prevailing features for several years [4]. The first ablator layer was a uniformly doped Br-CH (0.25% atm), then we optimized a uniform CH-Ge 0.4% for technological reasons, and this year we have begun the study of a plastic ablator with graded Ge dopant as S. Haan did [5]. For each configuration, the ablator thickness and the drive are optimized to obtain the same 1D performances. Major device choices are a DT filling by permeation through the plastic, a cryogenic temperature of 18.2 K, and a gold hohlraum filled with HHe at 0.8 mg/cc in order to minimize plasma blow-off. 2D integrated simulations give 25 MJ yield with 1.4 MJ absorbed laser energy (0.4 MJ on inner cones and 1.0 MJ on other cones) and 440 TW peak power.

Low mode deformation ($l \leq 10$) of the outer DT shell at maximum velocity

The three main causes of low mode deformation are capsule roughness, technological defects, and intrinsic x-rays non-uniformity. These distorsions remain small enough to validate a linear analysis approach. The nominal integrated FCI2 simulation gives intrinsic deformation. Roughness growth factors are obtained with 2D linear computations. The great number (197) of laser and target 3D-defects leads us to develop a computation line based on a 3D view factor code [6] and an implosion rocket model [7]. The time shape of power errors is obtained with a Frantz-Nodvik equation-like [8]. We have taken into account the technological dispersions by estimating the final deformation probability distribution with each error sampling according to the specification [9].

For the inner ice surface roughness, we have considered the best power spectrum for the D_2 ice layer achieved at Rochester last year [10] with a mode 1 amplitude of 1 µm rms, and a total rms for modes 1 to 10 of 1.36 µm. As first LMJ capsule characterizations of outer ablator roughness are very close to NIF specification, we used the following NIF spherical harmonics formula for modes 2-10:

$$|R_{l,m}| \text{ (nm)} = 9353/l^{3.5}+10/l^{1.5}+0.08 / [(l/60)^{0.7}+(l/1200)^{4.0}] \qquad \text{(eq. 1)}$$

Mode one is a concentricity error we set at $R_{1,m}$ = 2 µm, m=0,±1.

Finally, the rms deformation (modes 1 to 10) is 7.7±1.8 µm at 2σ, which is too high compared to the tolerable rms of about 10 µm given by 2D simulations where high mode roughness and 1D defects are not taken into account. At least, modes 1 and 2 for CH roughness must be smaller than those given by (eq. 1).

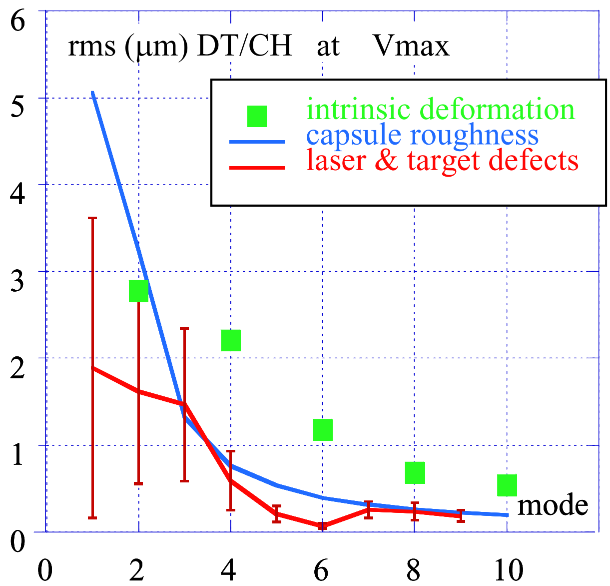

Figure 1: Contributions of the 3 main causes of low mode deformation to the outer DT rms spectrum at maximum velocity for the uniformly doped Br capsule.

First LMJ design with graded doped ablator

The ablator is composed of 4 layers, which are respectively, starting from the outer interface: 115 µm of undoped CH, 10 µm of CH+0.4%Ge, 45 µm of CH+0.75%Ge and 10 µm of CH. The role of the undoped outer layer is to reduce instability in the ablation front at early time, because of a larger density gradient scale length. The role of the undoped inner layer is to reduce instability at DT/CH interface by increasing the final internal ablator density [5]. FCI2 simulations were performed with modes 12 to 120 perturbations at outer ablator interface given by (eq. 1). There is not a clear difference on the growth factors at the ablation front between graded and uniformly doped capsules, but graded Ge drastically lowers the growth factors at DT/CH interface and at the hot spot location. It follows that the graded doped design may support an outer ablator roughness close to 300nm rms(12-120), that means 45 times the NIF spectrum given by (eq. 1), compared to ~70nm tolerable with an uniform 0.4%Ge dopant (Figure 2).

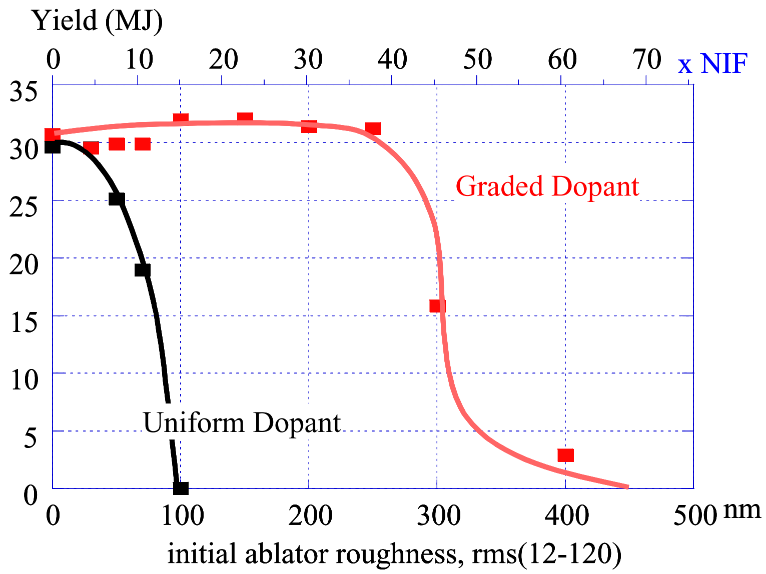

Figure 2: Thermonuclear energy versus rms(12-120) for uniformly (0.4%) and graded doped GeCH capsules. Multimode simulations are run with outer CH roughness proportionnal to (eq. 1).

Capability of green light ignition designs

Although laser plasma instabilities are more developed with a green light laser, L. Suter had shown [11] that it is possible to design 2ω-targets with a filamentation figure of merit (FFOM) less than the threshold of about 0.5 to 1. 10^{13}:

$$\mathrm{FFOM} = I\,[\mathrm{W/cm^2}]\,\lambda^2\,[\mu\mathrm{m}^2]\,ne / nc\,(3 / Te)\,[\mathrm{keV}]\,(f / 8)^2\,.$$

Our 3ω-baseline design has a FFOM of 0.9 10^{13} with a maximal outer focal spot of 660*2000 µm. FCI2 integrated simulations with the same laser intensity have shown that FFOM(2ω) ≈ 3.5 FFOM(3ω) and $T_R(2\omega) \approx 0.985\, T_R(3\omega)$ for a wide range of targets. We have modified our global optimization [4] in that way to find 2ω-ignition targets with the three security factors (1D margin, shell break-up and FFOM) at least as good as 3ω-baseline design ones. In a first step, we have studied baseline scaled targets, with scaled laser entrance holes. For each scale, the laser focal spot is the maximal possible one [12]. The possible ignition region on the laser {Energy, Power} domain is plotted in Figure 3.

For a FFOM of 0.5 10^{13} (black circle in Figure 3) we obtained 2.5 MJ and 530 TW. The peak drive temperature is 265 eV (1.45 scaled) and maximum laser intensity is 2.5 10^{14} W/cm^2. As we need about a 20% margin for backscattering and other contingencies, LMJ should deliver about 3 MJ at 2ω to drive this design.

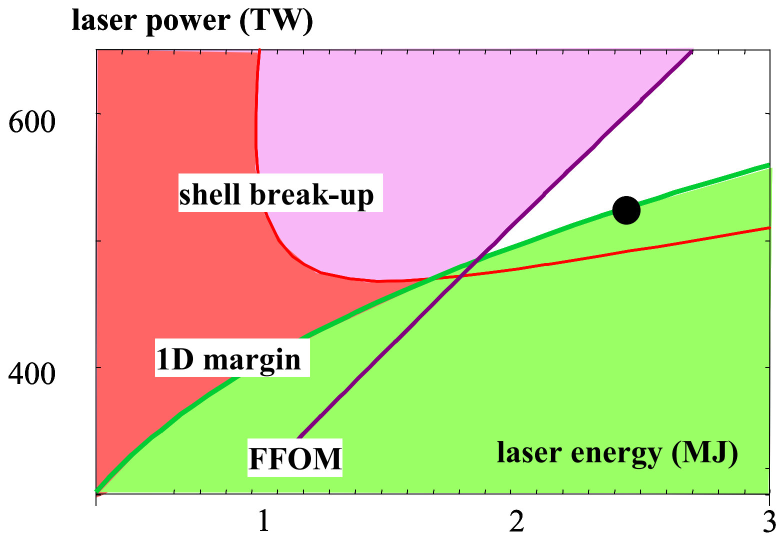

Figure 3: Operative domain for green light and baseline scaled targets. For each scale, we set the maximum laser focal spot passing through laser entrance holes.

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