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Active mirror amplifiers for HiPER kiloJoule beamlines

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Abstract. A major challenge the HiPER [1] project is facing is to derive laser architectures satisfying simultaneously all HiPER requirements; among them, high wall-plug efficiency (15 to 20%) and repetition rate (around 10 Hz) are the most challenging constraints. Several groups over the world are actively pursuing research in the field of High average power Diode Pumped Solid State Lasers (DPSSL) [2]. We propose a comprehensive solution for a 1 kJ DPSSL beamline as the unit brick of a 12 beams bundle.

1. INTRODUCTION

HiPER (High Power laser Energy Research) [1, 3, 4] in Europe, LIFE (Laser Inertial Fusion Engine) [5] in the United States of America and GENBU (Generation of ENergetic Beam Ultimate) [6] in Japan are scientific programs dedicated to demonstrate the feasibility of laser driven fusion [1] as a future energy source.

The Centre National de la Recherche Scientifique (CNRS) Laboratoire pour l'Utilisation des Lasers Intenses (LULI) at Ecole Polytechnique, Palaiseau, France is working on a HiPER scheme relying on Yb^{3+}:YAG cryo-cooled active mirror amplifiers. Six amplifiers in a double pass configuration will be required to reach the 1 kJ unit beam (called "Beamlet") requirement for HiPER. Considering the state of the art coating maximum Laser Induced Damage Threshold ($\sim$ 30 to 40 J/cm^2 for 1030 nm, ns regime), the component lifetime requirements (10^9 shots) and a reasonable damage safety factor, it seems safe to target maximum extraction fluence around 10 J/cm^2. Therefore, about $\sim$1 kJ per beam leads to an aperture of about 100 cm^2.

A single beamline (see arrangement of 12 beamlets on figure 1) will be based on 9 beamlets to be incoherently combined for compression pulses. And, considering the requirements in terms of spot size, the 3 remaining beamlets will be coherently combined for shock ignition pulses. The laser requirements are summarized in the table of figure 1.

2. OPTICAL LAYOUT

Figure 2 displays a schematic of the proposed 2-pass amplifying chain for HiPER. The laser beam passes through the amplifier system twice after reflection on a deformable mirror (left): it travels through each disk four times. Six of these amplifiers will be used in series in order to reach the requested energy level.

Figure 4 shows an alternative triangular configuration where the footprint would be approximately 12×12 m^2.

	Total energy (kJ)	Spots	Energy per spot (kJ)	Beam per bundle	Energy per beam (kJ)
Compression	500	48	10,42	9	1,16
Shock Ignition	130	48	2,71	3	0,90
Total	630	48	13,125	12	-

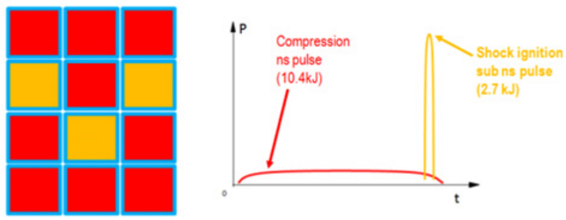

Figure 1. HiPER shock ignition scheme relies on 48 spots on the target. The 630 kJ total energy will therefore have to be delivered through 48 bundles of twelve 0.9 to 1.16 kJ beams.

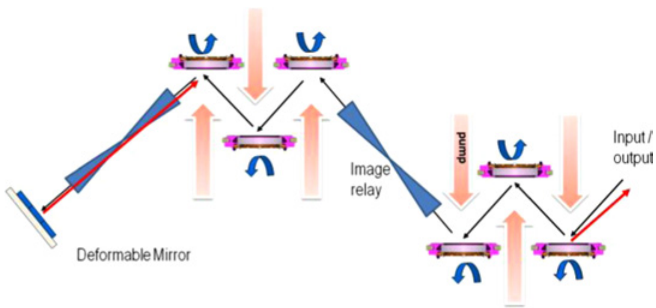

Figure 2. Schematic of a six disk Yb:YAG amplifying chain, where the laser beam passes through the amplifier system twice and through each disk four times.

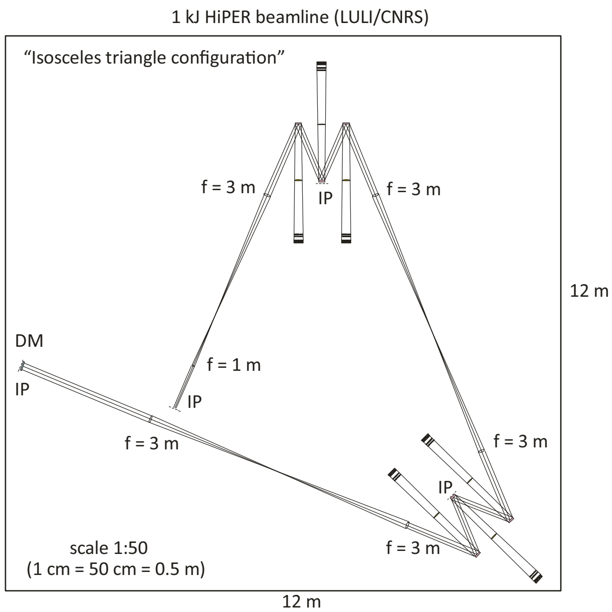

Figure 3. Triangular configuration for 1 kJ HiPER beamlet.

Table 1. Parameters used in the parametric study.

λ_p	940 nm	Pump wavelength
λ_s	1030 nm	Laser wavelength
σ_{ems_L}	$5.7\ 10^{-20}$ cm^2	Laser emission cross section
σ_{abs_L}	$5.8\ 10^{-22}$ cm^2	Laser absorption cross section
σ_{ems_p}	$9.75\ 10^{-22}$ cm^2	Pump emission cross section
σ_{abs_p}	$1.3\ 10^{-20}$ cm^2	Pump absorption cross section
τ_f	1 ms	Fluorescence time
I	4 to 8 kW/cm^2	Pump intensity
τ_p	0.7 ms	Pump duration
L	1 to 2.5 cm	Crystal thickness
D	11 cm	Rectangular aperture smaller size
θ	0 to 40°	Extraction angle
d	0.1 to 0.2 at%	Doping level

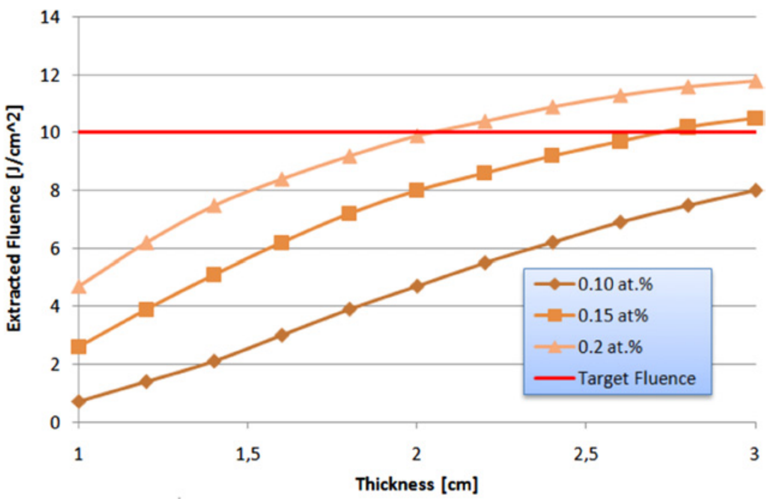

Figure 4. Extracted fluence (in J/cm^2) versus the thickness for three doping concentrations (0.1at%, 0.15at%, and 0.2at%) and the thickness of the thin disk for $I_P = 6$ kW/cm^2.

3. EXTRACTED FLUENCE

We have explored the influence of different pump and disk parameters. Having fixed the aperture (∼ 100 cm^2) and the extraction fluence (∼ 10 J/cm^2), we have performed a parametric study with parameters and limits given in table 1 and resulting optimum point of operation in section 4.

Thermal management [7] and Amplified Spontaneous Emission management [8] solutions proposed within the LULI Lucia program framework helped us deriving an optimum point of operation. Figure 4 displays the resulting extracted fluence for $I_P = 6$ kW/cm^2.

4. CONCLUSION

For doping concentration of 0.15 at%, thickness about 2.6 cm, and incident angle of 22° we are able to mitigate ASE parasitic oscillations. The corresponding extracted energy is close to 10 J/cm^2 as illustrated on figure 4 and the optical efficiency is well above 35%. The resulting optimum point of operation is derived for 2 passes through 2 amplifiers of 3 disks each:

- Extraction angle : 22°
- Aperture : $11 \times 11.7 = 129\,\text{cm}^2$
- Final extraction Fluence :$10\,\text{J/cm}^2$
- Energy extracted : 1.3 kJ
- Pump intensity : $6\,\text{kW/cm}^2$
- Yb Doping level : 0.15 at%

Luli is currently building a 10 to 30 Joules scale prototype aiming at addressing several of key laser physics issues (like thermal and ASE management) related to the laser driver HiPER proposal presented here.

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References

[1] M. Dunne, Nature Physics, **2**(1), 2–5 (2006)

[2] J.-C. Chanteloup and D. Albach, IEEE Photonics Journal, **3**(2) (2011)

[3] J.-C. Chanteloup, D. Albach, A. Lucianetti, K. Ertel, S. Banerjee, P. Mason, C.Hernandez-Gomez, J. Collier, J. Hein, M. Wolf, J.Körner and B. Le Garrec, 2010 *Journal of Physics: Conference Series,* **244**(1), 012010 (2010)

[4] B. Le Garrec, C. Hernandez-Gomez, T. Winstone and J. Collier, 2010 *Journal of Physics: Conference Series,* **244**(3), 032020 (2010)

[5] A. Bayramian, R. Campbell, C. Ebbers, B. Freitas, J. Latkowski, W. Molander, S. Sutton, S. Telford and J. Caird, 2010 Journal of Physics: Conference Series, **244**(3), 032016 (2010)

[6] H. Furuse, Y. Takeuchi, T. Nakanishi, A. Yoshida, R. Yasuhara, T. Kawashima, H. Kan, N. Miyanaga and J. Kawanaka, 6th International workshop on High Energy Class Diode Pumped Solid State Laser, Versailles, France, 8–10 Sept. 2010 (2010).

[7] D. Albach, G. Le Touzé, and J.-C. Chanteloup, Optics Express, **19**(9), 8413–8422 (2011)

[8] D. Albach, J.-C. Chanteloup and G. Le Touzé, Optics Express, **17**(5), 3792–3801 (2009)