Frontiers in ultra-high-power lasers. What adaptive optics can offer

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Abstract

Chirped Pulse Amplification, CPA, is a technique to obtain Terawatt (TW), and even Petawatt (PW) lasers relatively compact. Such systems are now possible. The interaction with atoms and nuclei does not depend on the peak power, it depends essentially on the intensity. The focusing of such pulses close to diffraction limit requires the use of adaptive optics specially designed.

Outline of the talk

Chirped Pulse Amplification, CPA, is a technique to obtain TW, and even PW lasers relatively compact. The underlying concept is the temporal stretching of the pulse before its amplification. Lengthening the pulse in time avoids damage of the optical amplifier and allows efficient energy extraction from the laser gain medium, while avoiding damage to the optical amplifier. CPA is particularly useful for solid-state laser media with high stored energy density. In this case full energy extraction by a short pulse would lead to intensities above the damage threshold of the amplifier materials. CPA lasers have, for the moment, several common characteristic components:

- Oscillator, to generate the short pulses to be amplified. Pulses leaving the oscillator have to be short not just for the need fs pulses but also for the need of a broad band.

- Stretcher, to increase the duration of the pulses. Typically those pulses are then chirped using a dispersive delay line consisting of a diffraction grating arrangement.

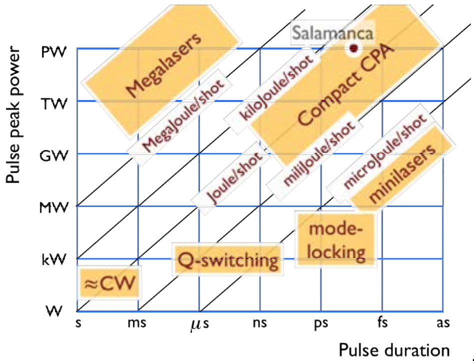
- Amplifier, a system with a laser active material, usually the same as the oscillator, that is optically pumped and that amplifies the stretched pulse. One or more stages of laser amplification are used to increase the energy of the pulse by several orders of magnitude.

- Compressor, to give the pulses back their initial duration. Typically a second grating pair of diffraction gratings "symmetrical" with the stretching one is placed to recompress the pulse back to fs duration.

The success of CPA techniques is the development of very sophisticated techniques to compensate dispersion induced by the laser components that light must cross inside the amplifiers (particularly the amplifying crystal itself). Moreover, at peak powers much beyond the Terawatt, the compressor has to work in vacuum and this complicates much more the technology. An excellent review of the ultrashort high-intensity laser pulse generation and amplification can be found in Reference 1.

Many of the applications of these lasers come from the nonlinearities they induce, and the nonlinearities come mostly from the peak intensity[2]. Thus, it is important to concentrate the peak power over a very small focal spot. At high powers the spatial profile of the pumping lasers modifies the profile of the generated laser beam and focusing is far from ideal (far from Fourier limit). Even with the PW lasers available, peak intensities need a very sharp focus and thus a very good beam profile. For that reason often record intensities do not correspond to record peak powers. Much more work is still needed to optimize the focusing. The interest of a tight focus is clear because most of the phenomenology depends on the electric field at focus.

We must indicate that it is extremely difficult to measure the intensity at such frontier region. We can assume that a PW laser with a good wave-front quality can arrive to 10^{23} W/cm2 without great difficulty. Observe that a PW focused into a spot of one squared micrometer corresponds to that intensity. However many times the best wavefront quality is achieved with a somewhat not so extreme intensity, and the reported records, much beyond 10^{22} W/cm2, correspond to lasers of multi-hundred TW power. For simplicity let's us consider 10^{23} W/cm2 as today's achieved limit, for Ti:Sapphire lasers (800 nm) and about 30 fs pulse duration.



a)


b)

Fig. 1. a) Diagram of the different regions of interest for pulsed lasers. Diagonals indicate the energy per shot. The red dot indicates the expected position of the future Salamanca PW laser. b) To reach the PW power region, beams of more than 10 cm in diameter are needed. This figure shows a Ti:Sapphire crystal for a PW amplifier.

Conclusions

Ultrafast ultraintense lasers allow a fantastic concentration of energy in time. Whether or no this energy can be concentrated in space close to the diffraction limit is due to several factors among which wavefront correction using adaptive optics is one of the most important. Maybe all that research will soon lead to a basic question: what is the most intense laser possible due to basic effects (as vacuum polarization)[3]. However, adaptive optics of such lasers, particularly for extreme high powers and low repetition rates, requires some special features to be developed in order to push the technology.

There are now many multi-TW lasers around the world and a few PW systems. The Ultra-short, Ultra-intense Pulsed Laser Centre (CLPU) is a new research facility that has been created as a Consortium of the Spanish Ministry of Education and Science, the Regional Government of Castilla y León and the University of Salamanca, as part of the implementation of the Spanish Scientific Infrastructures Roadmap. CLPU is a facility giving beam access to the domestic and international scientific community. CLPU is now operating a 20 TW system and is building the Spanish PW laser, where adaptive optics will be one of the key technologies involved.

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References

1. S. Backus, Ch. G. Durfee III, M. M. Murnane, and H. C. Kapteyn, "High power ultrafast lasers," *Rev. Sci. Instr.* **69**, 1207 (1998).

2. G. Mourou, Ch. P. J. Barty, and M. D. Perry, "Ultrahigh-intensity lasers: Physics of the extreme on a tabletop," *Phys. Today* **51**, January 22 (1998); G. Mourou, T. Tajima, and S. V. Bulanov, "Optics in the relativistic regime," *Rev. Mod. Phys.* **78**, 309 (2006).

3. A. M. Fedotov, N. B. Narozhny, G. Mourou, and G. Korn, "Limitations on the attainable intensity of high power lasers," *Phys. Rev. Lett.* **105**, 080402 (2010).