Towards High Power, High Repetition Rate, Ultrashort Laser Pulses

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Diode-pumped solid-state laser media offer an efficient, high repetition rate alternative for pumping current and future ultrahigh-intensity laser systems. The conjugation of this approach with ultrabroadband parametric amplification techniques such as OPCPA is a promising candidate for generating high-energy, few-cycle optical pulses, bringing the focused laser intensities into the ultra-relativistic domain.

The advent of chirped pulse amplification [1] in the 1980's applied to solid state laser systems has allowed the pulsed peak power to grow systematically up to the current petawatt (10^{15} W) level, demonstrated for both Nd:glass [2] and Ti:sapphire media [3]. When focused to a diffraction-limited spot size through careful wavefront control, such powers are able to generate extreme intensities in excess of 10^{22} W/cm^2 [4], on the threshold of the ultra-relativistic regime (I>10^{23} W/cm^2).

Most high-intensity laser facilities nowadays rely upon rare-gas-filled flashlamps as a direct or indirect power source. There is a number of downsides to this approach: the poor electrical-to-optical efficiency (~0.1%), the limited lifetime, the vast amount of heat deposited in the main or preliminary laser gain medium, and the resulting thermally-limited low repetition rate. Diode-pumped solid-state media such as ytterbium-doped materials offer a much more attractive alternative, allowing energies beyond the Joule level at much higher efficiencies (>70%) and repetition rates [5].

On the other hand, although broadband materials such as Ti:sapphire are now a well-established technology for generating ultrashort, high-energy pulses, in practice the achievable output pulse duration for petawatt-level pulses is still of the order of a few tens of femtoseconds. High energy, few-cycle (sub-20-fs) pulses will require an approach based on inherently ultrabroadband, parametric amplification techniques such as optical parametric chirped pulse amplification (OPCPA) [6], which has already been used successfully to achieve petawatt-level pulses in sub-50 fs durations [7], and allows high energy amplification of octave-spanning bandwidths [8]. The challenges posed by successfully conjugating this technique with efficient pumping schemes are currently a subject of great interest in the high-power laser community, opening the door to ultrahigh power and high repetition rate laser systems. This will lead to a new paradigm in experimental laser-matter interaction, where data will be collected on a statistical (rather than single-shot) basis.

In this talk, we review the progress and trends in these areas, in particular analyzing the relevant issues involved in a diode-pumped-based OPCPA scheme. The experimental program of IST's Laboratory for Intense Lasers in these fields is also presented, towards investigating the implementation of an all-OPCPA-based high-power system.

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