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Future of Ti:Sapphire lasers: combining high peak and average power.

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Ti:Sapphire gain medium has exceptional spectral and thermal properties. This determines its wide use in most of modern high peak laser systems. As any laser medium, the bandwidth of Ti:Sapphire lasers is limited by gain narrowing, while the maximum repetition rate, or average power are limited by the efficiency of the homogeneous heat removal. A research and development project at ELI-ALPS, HF-100 is assigned to the development of specific technologies that, applied to Ti:Sapphire medium, will allow to overcome the currently existing technological limits of bandwidth and average power. The basis for that are the two new developments: Thin Disk Ti:Sapphire amplifiers with Extraction During Pumping (EDP-TD) [1,2] and Polarization encoded Chirped Pulse Amplification (PE-CPA) [3].

In a conventional CPA amplifier, only the π-axis of the Ti:Sapphire crystal is used due to its higher gain cross section value. However, in a PE amplifier, both π- and σ-axes are used, leading to the reshaping of the gain spectrum. The polarization state of the seed spectrum is encoded before amplification using the optical rotatory dispersion (ORD) effect. The central part of the seed spectrum is oriented close to the low emission cross-section (σ-axis), while the spectral wings are rotated towards the high emission cross-section one (π–axis). This results in the wings being more intensively amplified than the center of the spectrum and thus compensates for gain narrowing. The major properties of the PE-method amplification (broad bandwidth, recompressability of pulses, CEP - compatibility) were experimentally validated at a mJ energy level. The computer modeling of a PE-CPA Ti:Sapphire amplifier with seed pulses broader than the experimental bandwidth shows that a 200 nm spectrum is achievable at a multi-joule level.

Thin disk (TD) technology applied to Ti:Sapphire crystals may offer the possibility of systems with both high average and high peak power. In addition, comparing to a widely used YAG-based TDs the higher emission cross-section of Ti:Sapphire increases the longitudinal gain and thus reduces the number of required passes in the amplifier making the system more simple. Experimental testing of an Ti:Sapphire EDP-TD amplifier was recently performed [1] at Max-Born-Institute. In these experiments the final cryogenically cooled Ti:Sapphire amplifier in a 100 TW/10 Hz/28 fs laser system was replaced with a room temperature water cooled EDP-TD Ti:Sapphire arrangement. Amplified seed pulse energy of 2.6 J was reached with only three passes using 0.5 J of input and 5 J of absorbed pump energy.

Numerical simulations of EDP-TD Ti:Sapphire amplifiers [4] running at 100 Hz with disk sizes ranging from 6 cm to 20 cm were performed. Laser heads with a single disk and one/two cooling channels and two disks with three water cooling channels were considered. Based on these results, the output average power in a kW range is feasible using multiple disks and cooling surfaces at the proper coolant flow conditions. Application of solid absorbers at the edge of the Ti:Sa disks can lead to a much simpler mounting, which eventually could give rise to amplifier modules with several disks and simple channel formations.

The two new developments, in particular the Thin Disk Ti:Sapphire amplifiers with extraction during pumping and polarization encoded Chirped Pulse Amplification are compatible with each other. A combination of these technologies is able to support laser pulses of few oscillations at hundreds of TW peak and kW average power.

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