Towards 100-PW class femtosecond laser systems – an approach based on OPCPA at critical wavelength degeneracy

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A couple of 100-PW class laser projects, based on optical parametric chirped pulse amplification (OPCPA) technique, are worldwide proposed for the next years.

Very broad spectral gain bandwidth can be obtained by non-collinear OPCPA in nonlinear crystals. Among the available nonlinear crystals for OPCPA, only the BBO crystal has an ultra-broad gain bandwidth which is overlapped on the Ti:sapphire amplification spectral band near 800 nm central wavelength, whereas LBO and KDP (DKDP) crystals have ultra-broad bands in the range of 900 nm central wavelength. BBO crystals can be grown only up to few-cm clear aperture. KDP and DKDP crystals can be grown with large size clear aperture up to 500 mm diameter, allowing amplification of nanosecond stretched broad-bandwidth laser pulses at kJ-energy-level. PW-class laser system configurations based on large size KDP (DKDP) crystals amplification of femtosecond pulses with shifted spectral band in the range of 900 nm were proposed by researchers from the Central Laser Facility, RAL-UK, and the Institute of Applied Physics, Nijjni Novgorod, Russia. At SIOM-Shanghai, China, 4.9 PW peak power (91.1 J/18.6 fs) has been reported by direct optical parametric amplification of Ti:sapphire chirped laser pulses in more than 100 mm clear aperture LBO crystals, pumped by a frequency doubled, few-nanosecond kJ pulse energy Nd:glass laser.

Super-broad gain bandwidths of several-hundred nanometers can be obtained in nonlinear crystals for the amplification of signal laser pulses with the spectral band centered around the critical wavelength of the crystal, in a collinear OPCPA geometry at degeneracy, namely for the pump laser wavelength equal to half critical wavelength. These super-broad gain bandwidths are large-enough to support the amplification of sub-10 fs laser pulses. A couple of high energy nanosecond green lasers are available for optical parametric amplifiers pumping, for example: Yb:YAG at 515 nm, Nd:glass at 527 nm, and Nd:YAG at 532 nm. To take advantage of the super-broad gain bandwidth at critical wavelength degeneracy (CWD), it is necessary to generate white light super-continuum femtosecond compressible signal pulses in the 1-μm spectral range and to amplify them in nonlinear crystals with the critical wavelength in the range of 1030-1064 nm, pumped by picosecond or nanosecond green lasers. A critical wavelength in the range of 1030-1064 nm can be obtained in case of partially deuterated DKDP crystals (P-DKDP) with a 40-65% deuteration ratio. A quasi-collinear geometry, optimized for preserving a super-broad gain bandwidth, could be used to separate signal and idler beams. Optical parametric amplification of super-broad bandwidth chirped signal pulses up to 1-kJ energy and their sub-10-fs pulse duration re-compression represents a promising solution for single-beam 100-PW femtosecond laser systems development.

The feasibility of a 100-PW laser system based on existing technology, using currently available optical-mechanical components and laser devices, is discussed. A possible schematic configuration and proposed following steps towards the development of a 100-PW-class laser system, based on OPCPA at CWD in P-DKDP crystals, are presented.