Petawatt and Multy-Petawatt Lasers: Status Quo and Perspectives

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We discussed physical aspects and perspectives of three types of petawatt lasers (neodymium glass, Ti:sapphire, and optical parametric amplifiers) as well as new ideas how to overcome a petawatt barrier.

The petawatt laser power was achieved as early as in 1997 [1] based on chirped pulse amplification in Nd:glass. Many institutes are going to obtain this power level, but any substantial increase is limited in principle by the following reasons. All devices and projects now available may be classified into three types according to the gain medium they employ: 1) neodymium glass [1], 2) Ti:sapphire [2] and 3) optical parametric amplifiers with KDP and DKDP crystals [3], see Table. In all three types, energy (in the form of population inversion) is stored in neodymium ions in glass. In the first case, this energy is directly converted into energy of chirped pulse that is then compressed. In the second and third cases, the stored energy is converted into energy of a narrow-band nanosecond pulse which upon second-harmonic conversion serves as the pump for chirped pulse amplifiers.

Tab 1. Comparison of petawatt laser concepts. Symbols “+”,“□” and “0” denote advantages, disadvantages and the average in comparison with other concepts.

Gain medium	Nd:glass		Ti:sapphire		DKDP	
Energy source	Nd:glass		Nd:glass		Nd:glass	
Pump	no	(+)	2ω Nd	(–)	2ω Nd	(–)
Pump duration, ns	no	(+)	>10	(0)	1	(–)
Amplifier aperture, cm	40	(0)	8	(–)	40	(0)
Minimum duration, fs	500	(–)	25	(+)	25	(+)
Efficiency (1ω Nd → фс), %	80	(+)	15	(–)	10	(–)
Number of PWs from 1 kJ 1ω Nd	1.6 (1.5)*		6 (1.5)*		4	
Maximum power obtained, PW	1.36 [1]		0.85 [2]		0.56 [3]	

*) optical breakdown of diffraction gratings and Ti:sapphire crystals limit power to the 1.5 PW

Maximum energy is achieved in glass-based lasers, because energy that has been stored as population inversion is directly converted into a chirped pulse. However, a narrow bandwidth of Nd glasses restricts typically the compressed pulse duration to about 500 fs.

Ti:sapphire lasers have a large gain bandwidth, allowing pulse compression up to 10-20 fs. At the same time, available crystal growth technologies can produce Ti:sapphire crystals with an aperture of no more than 10 cm. When attempting to overcome the petawatt energy level, such a small aperture will limit chirped pulse energy due to optical breakdown and self-focusing.

Parametric amplifiers are free of above disadvantages. DKDP crystals have an aperture of 40 cm and more and the gain bandwidth corresponds to the 15fs duration of the amplified pulse. Moreover, parametrical gain is much higher than laser gain. Thus, using an optical parametric amplifier is one of the most promising ways of overcoming the petawatt power barrier.

In this paper we discussed all of these setups as well as future perspectives.

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