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# kW average power frequency doubled Yb:YAG amplifiers to pump high energy femtosecond lasers at kHz repetition rates

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**Motivation:**

Intense laser pulses propagating in plasmas can generate large electric fields for the acceleration of particles by charge separation through the excitation of wakefields. Wakes with electric fields orders of magnitude larger than in conventional accelerators have been demonstrated, which have the potential to greatly reduce the size of accelerators [1]. High intensity lasers have been used to demonstrate the acceleration of electrons to GeV energy in very short distances [2-4]. A femtosecond Ti:Sapphire laser producing 0.85 PW pulses has been used to demonstrate a 8 GeV electron beam [2]. The driving laser in this demonstration experiment was limited to 1 Hz repetition rate [5]. However, the majority of advanced accelerator applications require laser repetition rates and average powers that are 1,000 times higher, and beyond. At present the laser facilities capable of generating pulses of > 100 TW peak power are limited to repetition rates of 10 Hz or less. Moreover, the repetition rate of high peak power lasers decreases as they are scaled in energy to reach PW peak powers. This is mostly due to heat removal limitations in the pump lasers. The highest repetition rate reported for PW class lasers routinely used in accelerator applications has been limited to 1 Hz [2], or significantly less. Recently a diode-pumped Nd:glass pumped Ti:Sa laser was developed to generate PW pulses at 10 Hz [6]. Also recently a 0.85 PW Ti:Sa laser based on a flashlamp pumped Nd:glass slab amplifiers designed to operate at 5 Hz repetition rate was demonstrated to operate at 3.3 Hz [7]. Ti:Sa operating around $\lambda$=0.8 um is currently the most widely used laser material in ultra-high intensity science in general and in laser wakefield acceleration in particular, due to its ability to generate high energy laser pulses with pulse duration down to 20 fs. One of the key challenges towards higher average power operation is the development of suitable pump lasers that can provide energetic pulses at a wavelength of ~515-530 nm at the high repetition rates required.

**Frequency doubled kW average power Yb-YAG laser to pump high energy Ti:Sa lasers**

An approach to high intensity, high energy lasers operating at high (kHz) repetition rate relies on Ti:Sa pumped by pulses of Joule energy from diode-pumped cryo-cooled Yb:YAG laser amplifiers efficiently frequency doubled into the green. A challenge in the development of kW average power pump lasers is the thermal management of the amplifier medium. The cryo-cooled diode-pumped active mirror Yb:YAG laser technology developed by a collaboration between Colorado State University and XUV Lasers Inc. has demonstrated an average power of > 1 kW at $\lambda$=1.03 $\mu$m, and can be scaled to meet this challenge. An initial experiment with 1 Joule pulses has demonstrated that conversion into second harmonic with an efficiency of 80 percent can be achieved at high repetition rate.

A 100 TW, 1 kHz, 3 kW, fs laser system based on a Ti:Sa amplifier pumped by these diode-pumped bulk Yb:YAG laser amplifiers would be a compact system. In such laser system pulses from a conventional mJ-level, 1 kHz, Ti:Sa laser front end will be stretched and amplified in a chain of two multi-pass Ti:Sa amplifiers to reach an energy of > 3.5 J. These multi-pass amplifiers will be pumped by $\lambda$ = 515 nm pulses produced by the frequency doubled Yb:YAG laser amplifier modules. A prototype has already produced >1 J infrared pulses at a 1 kHz repetition rate which can be efficiently frequency doubled. The cost per Joule is lower than other conventional pump lasers. An additional advantage of this pump laser system is its modular architecture that offers flexibility for scaling and reduced risk. Different Ti:Sa amplifier geometries and cooling configurations are possible and must be evaluated.

**Summary**

Cryogenically cooled Yb:YAG amplifiers have recently been successfully demonstrated to generate > 1 J pulses at >1 kW average power lever. Efficient frequency doubling can produce Joule-level λ = 515 nm pulses to pump Ti:Sa amplifier for the production of high energy femtosecond pulses at kHz repetition rates. The successfully demonstrated high capacity heat removal technique can also be used to solve the thermal management challenge in the multi-kW Ti:Sa amplifiers.

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