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Advanced Lasers for accelerators at Colorado State University: advances in kW average power cryogenically-cooled ultrafast Yb:YAG lasers

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The petawatt-class multi-Hz Ti:Sa laser ALEPH developed at Colorado State University has recently enable major advances in laser wakefield acceleration [1]. However, progress on laser driven-particle accelerators for applications depends on the development of compact, more efficient lasers capable of producing of high energy ultrashort laser pulses at greatly increased high repetition rate. A promising laser gain material for such lasers is Yb-YAG, which has the advantages of millisecond upper level lifetime, low quantum defect, and high thermal conductivity that in combination facilitate high repetition rate operation. We have demonstrated a kW average power laser that generates picosecond pulses with energy up to 1.1 J at 1 kHz repetition rate [2]. The system uses cryogenically cooled Yb:YAG active mirror amplifiers to generate pulses >1.2 J energy at a repetition rate of 1kHz. After compression 1.1J pulses with < 4.5ps duration are obtained with good beam quality and shot-to-shot stability. To shorten the pulse we are investigating spectral broadening in a gas-filled hollow core fiber. In addition, we demonstrated the efficient generation of Joule-level $\lambda=515\text{nm}$ ns laser pulses at 1kHz repetition rate by frequency doubling in LBO crystals [3], a result that is of interest for pumping high average power femtosecond lasers. The seed pulses are generated by an arbitrary-waveform laser which can be programmed to produce square pulse shapes at the end of the amplifier chain for efficient doubling. The total 515 nm average power reached 1.04 kW (1.04J pulses at 1 kHz) in a beam with a measured $M^2= 1.3-1.4$.

[1] B. Miao, J.E. Shrock, L. Feder, R.C. Hollinger, J. Morrison, R. Nedbailo, A. Picksley, H. Song, S. Wang, J.J.Rocca, and H.M. Milchberg, "Multi-GeV Electron Bunches from an All-Optical Laser Wakefield Accelerator," Physical Review X, **12**, 10.1103, (2022)

[2]Y. Wang, H. Chi, C. Baumgarten, K Dehne, A. Meadows, A. Davenport, G. Murray, B. Reagan, C.S. Menoni, and J.J. Rocca "1.1 J, 1 kHz repetition rate, Yb:YAG ps laser," Opt. Lett. **45**, 6615 (2020).

[3] H.Chi, Y.Wang, A. Davenport, C.S. Menoni and J.J. Rocca, "Demonstration of a kilowatt average power, 1J, green laser," Opt. Lett. **45**, 6803, (2020).

Acknowledgments

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