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Development of Coherent Spatially and Temporally Combined Fiber Laser LPA Driver Concept – Progress of the kW-Average and TW-Peak Power System Demonstraton

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Next generation particle accelerators based on laser plasma interactions are a promising path towards achieving GeV gradients in small volumes, thus substantially reducing the size of accelerators needed for both frontier science and practical applications from materials science to medicine. These accelerators will require laser drivers with ultrashort pulses, joule energy levels and 10s kHz repetition rates (100s-kW average power), a trio of requirements beyond current laser technology. We are developing a scalable laser approach based on coherent temporal and spatial combining of large core fiber amplifiers. It is based on coherent pulse stacking amplification (CPSA), a time domain technique that allows an arbitrary number of pulses to be time-domain combined into a single pulse. In conjunction with chirped-pulse amplification (CPA) CPSA allows for near full energy extraction from large core fiber amplifiers, increasing achievable energies by two orders of magnitude compared to traditional fiber CPA. This reduces the number of spatially combined parallel amplification channels used for power and energy scaling by ~100 times – a substantial reduction of the system size and complexity.

We have been validating this approach in a power scalable demonstration system, aiming to achieve ~100mJ and ~1kW coherently combined pulse energies and average powers from a 10-12 parallel-channel spatially combined CPSA system. We demonstrated robust temporal combining in CPSA architecture of 81 pulses to a single pulse with high efficiency and compressibility to approximately 300fs. At present, we have carried out 4-channel coherent spatial combining of 81-pulse CPSA bursts, achieving >25mJ at 2kHz (50W average power) in a combined beam. Pulse energy scaling of individual amplification channels is achieved by using 85μm chirally-coupled-core (CCC) fibers, which store more than 10mJ per fiber and provide high-efficiency extraction at multi-kHz repetition rates. Additionally, we have also demonstrated techniques for controlling gain narrowing, dispersion, and in-burst saturation control for achieving ~100fs duration pulses. Ongoing work is exploring simultaneous operation of coherent spatial and temporal combining at high energies and powers. Further work will extend system size from 4 to 10 channels and will carry out first high-intensity laser-matter interaction experiments with this table-top laboratory demonstration system.

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