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Nonlinear Coherent Pulse Stacking enabling energy scalable several optical cycle pulses for the next generation drivers of laser plasma accelerators

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Laser-wakefield plasma accelerators (LWFA) promise compact sources of highly energetic electrons and photons, but for their practical use they need efficient and high repetition rate laser drivers. The current standard is the Ti:sapphire CPA system, which can produce multi-J pulses with bandwidths supporting ~30 fs pulses, but it has low wall plug efficiency (WPE) and ~Hz repetition rates. Fiber laser systems can operate with high WPE at 10's of kHz and are scalable to high energies and powers using spatial and temporal coherent combining but have bandwidths sufficient for only 50-100fs pulses. Additional spectral combining can extend this bandwidth, but by increasing overall complexity of the fiber laser driver. We propose a Nonlinear Coherent Pulse Stacking (N-CPS) technique, which could enable achieving several cycle pulses comparable to those of Ti:sapphire, while maintaining multi-kW power and the multi-J energy scalability of coherently combined fiber laser arrays with only a minor increase in the overall complexity of the system.
Coherent Pulse Stacking Amplification (CPSA) is critical for reducing spatially-combined fiber laser array sizes by approximately two orders of magnitude. In demonstrated CPSA systems [1] a stacking-burst of stretched pulses extracts nearly-all stored energy from the final amplification stage and is temporally combined (using GTI cavities) into a single stretched pulse for compression to the bandwidth-limit at the system output.
We show that N-CPS can extend CPSA by compressing the amplified stacking-burst first, then spectrally broadening each individual compressed pulse in, for example, a Herriott-cell gas chamber [2], and only then stacking the burst into a single pulse, which is subsequentially compressed using chirped mirrors to durations much shorter than fiber gain bandwidth supports. Stacking-burst in this case allows both near-complete energy extraction during amplification and overcoming individual pulse energy limitations (~10-20mJ) of the spectral broadening step. We also show via numerical simulations that N-CPS needs only a minor increase in a CPSA system complexity, because it can reshape unequal-amplitude saturated bursts from final amplifiers into equal amplitude burst necessary for spectral broadening using only a couple of additional GTI stages. We will report on the experimental progress demonstrating this new N-CPS technique.

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