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Ultra-broadband spectral combination of fiber lasers with synthesized pulse shaping to reach short pulse lengths for plasma accelerators

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Laser-plasma accelerators (LPA) can significantly reduce the large sizes of conventional accelerators, showing great potential, but they are challenged by today's low operation repetition-rates (Hertz class). Achieving kilohertz repetition-rates is necessary to enable high impact applications in science, security, and medicine [DOE Basic Research Needs Workshop report, 2019].

One recognized laser technology towards kilohertz LPA drivers is multidimensional fiber laser combination [DOE Brightest Light Initiative report, 2019], due to its advantages in wall-plug efficiency and thermal management. While achievable pulse lengths from fiber lasers are limited by gain narrowing and high order fiber dispersions in high energy systems, coherently combining multiple fiber output spectra has been demonstrated to generate shorter pulses, with a shortest 97fs at one-micron wavelength [Proc. SPIE 9728, 2016]. However, LPAs need driver lasers with pulse lengths much shorter than ~100fs.

Thus, we propose ultra-broadband spectral combining of fiber lasers to reach short pulse lengths beyond the state of the art, using spectrally synthesized pulse shaping. We demonstrated a 54-fs, two-channel spectrally-combined fiber laser system, with two pulse shapers operating at different but partially-overlapped spectrum in each channel to control the spectral intensity and phase. Coherent synthesis of the two shapers was achieved by phase-synchronizing the two channels at the overlapped spectrum. 94.5% combining efficiency was obtained through an SPGD-based feedback loop.

To the best of our knowledge, 54fs is the shortest pulse length from a spectrally combined fiber system at one-micron wavelength, and we achieved the first demonstration of coherent spectral synthesis of two pulse shapers [accepted by Advanced Solid State Lasers (Dec 2022) and Photonics West (Jan 2023) as oral presentations]. We recently completed a three-spectral-channel combination setup, with a fiber amplifier in each channel and two synthesized pulse shapers covering all three spectra. We have demonstrated an 80nm spectrum combined from three channels, with a flat spectral phase, corresponding to <40fs transform-limited pulse length. Phase synchronization of all channels is in progress.

This ultra-broadband, energy-scalable approach of spectral combination with synthesized pulse shaping paves the way to high energy, tens-of-fs fiber lasers for driving plasma accelerators.

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Primary authors: CHEN, Siyun (Lawrence Berkeley National Lab); Dr DU, Qiang (Lawrence Berkeley National Lab); WANG, Dan (LBNL); VAN TILBORG, Jeroen (LBNL); SCHROEDER, Carl (LBNL); Dr ESAREY, Eric (Lawrence Berkeley National Laboratory); Dr LI, Derun; GEDDES, Cameron (Lawrence Berkeley National Laboratory); Dr WILCOX, Russell; Dr ZHOU, Tong (Lawrence Berkeley National Laboratory)

Presenter: CHEN, Siyun (Lawrence Berkeley National Lab)

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