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Coherent temporal stacking of tens-of-fs laser pulses towards plasma accelerator applications

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A laser-plasma accelerator (LPA) could reach high energies with an accelerating length orders-of-magnitude shorter than in conventional RF accelerators. Compact LPAs will enable high-impact applications in science, medicine, security, and industry. As LPA applications will require new driver lasers with kHz to 10s kHz repetition-rates at high energy and efficiency [1], one promising laser approach is to combine many ultrashort pulses from high-power, high-efficiency fiber lasers, in space, time, and spectrum [2].

Coherent pulse stacking (CPS) temporally stacks many amplified laser pulses into a high energy pulse using cascaded reflecting cavities [3]. This largely reduces the number of spatial fiber channels needed, e.g. to a practical 100 level for Joule pulse energies. However, while LPA needs 30-100fs driver laser pulses, CPS has only been demonstrated experimentally with ~300fs pulse lengths and longer [3,4]. Thus, we propose to validate and demonstrate broadband CPS that can stack tens-of-fs laser pulses with high fidelity, critical for showing CPS is applicable to driving LPAs.

The main challenge associated with broadband CPS, limiting its stacking fidelity, is the unmatched dispersions accumulated for pulses undergoing different cavity roundtrips upon stacking. However, we validated via simulation that by using very low dispersion dielectric mirrors for stacking cavities, high fidelity CPS could be achieved for : 1) 4-cavity stacking of ~9 pulses at 30fs pulse lengths; 2) 8-cavity stacking of ~81 pulses at 50fs pulse lengths.

We experimentally demonstrated stacking of ~10 pulses with broad bandwidth supporting ~50fs transform-limited pulse lengths. The broadband CPS setup consists of a nonlinearly broadened source, pulse modulation and amplification, 4 stacking cavities, and diagnostics. With one cavity, we achieved stacking of ~3 broadband pulses with a pre-pulse contrast of 40:1. Using four cavities, we stacked ~10 broadband pulses with a pre-pulse contrast of 8:1, which is expected to be further improved after ongoing optimization of cavity alignment and phase control.

[1] Basic Research Needs Workshop report, 2019
[2] Brightest Light Initiative report, 2019
[3] Optics Express 23(6), 2015
[4] ASSL (OSA) AW4A.4, 2017

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