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Post-Compression of High-Power CO2 Lasers to sub-ps Levels Using an Ultrathin Tailored Nonlinear Element for Advanced Accelerator Applications

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High-power long-wavelength infrared lasers (e.g. CO_2 laser) are of great interest for acceleration of electrons and ions. For LWFA, pulses as short as 300-500fs are required to drive relativistic plasma wakes at 10^{16}-10^{17} cm^{-3} densities. The shortest pulse length demonstrated so far in CO_2 lasers is 2ps; these multiterawatt pulses are generated using a multistage MOPA system at ATF BNL.

One way to generate sub-picosecond pulses is post-compression of longer pulses after final amplification. Current LWIR post-compression schemes involve two stages of bulk materials; the first stage provides spectral broadening via self-phase modulation, while the second stage with negative GVD compresses the pulse. This arrangement has been experimentally demonstrated [1,2]. A main drawback is inhomogeneity of compression along the beam's radial distribution, leading to inefficient use of energy and unwanted spatio-temporal coupling.

At UCLA, we have been studying nonlinear optical responses of LWIR transparent semiconductor materials over the last several years using picosecond CO_2 laser pulses and, recently, with a newly acquired sub-picosecond solid-state-based OPA/DFG system. We measure nonlinearities of GaAs, n-Ge, and ZnSe for <1ps long, 10μm pulses and show they are close to literature data, however the Kerr nonlinearity of Te, never reported before, is extremely high on the order of $\geq 5 \times 10^{-12}$ cm^2/W. We propose and numerically show how an ultrathin and radially engineered Te nonlinear optical chirping element can be used for generation of homogeneous spectral broadening of an initially picosecond CO_2 laser pulse.

Modeling of post-compression is done by solving the 2D nonlinear Schrödinger equation. Using 2ps Gaussian pulses containing 400mJ centered at 9.2μm, similar to that in [2], sufficient broadening is achieved in a Te layer ~50μm thick. A structured layer with Gaussian thickness is used to give identical spectral broadening across the full beam. The pulse is then numerically propagated through 5 cm of BaF_2, after which it is compressed to a pulse duration less than 300 fs, homogenous across the whole beam. This compression results in a several times increase in peak-power. One can foresee that thin film and etching technology could be used for fabrication of such a large aperture pulse compressor.

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