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High-energy few-cycle pulse compression through self-channeling in gases

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Nonlinear spectral broadening of femtosecond optical pulses by intense propagation in a Kerr medium followed by temporal compression constitutes the *Holy Grail* for ultrafast science since it allows the generation of intense few-cycle optical transients from longer pulses provided by now commercially available femtosecond lasers. Tremendous progress in high-field and attosecond physics achieved in recent years has triggered the need for efficient pulse compression schemes producing few-cycle pulses beyond the mJ level. We studied a novel pulse compression scheme based on self-channeling in gases[1,2], which promises to overcome the energy constraints of hollow-core fiber compression techniques[3].

Fundamentally, self-channeling at high laser powers in gases occurs when the self-focusing effect in the gas is balanced through the dispersion induced by the inhomogeneous refractive index resulting from optically-induced ionization. The high nonlinearity of the ionization process poses great technical challenges when trying to scale this pulse compression scheme to higher energies input energies. Light channels are known to be unstable under small fluctuations of the trapped field that can lead to temporal and spatial beam breakup, usually resulting in the generation of spectrally broad but uncompressible pulses.

Here we present experimental results on high-energy pulse compression of self-channeled 40-fs pulses in pressure-gas cells. In the first experiment, performed at the Lund Laser Center in Sweden, we identified a particular self-channeling regime at lower pulse energies (0.8 mJ), in which the ultrashort pulses are generated with negative group delay dispersion (GDD) such that they can be readily compressed down to near 10-fs through simple material dispersion. Pulse compression is efficient (70%) and exhibits exceptional spatial and temporal beam stability. In a second experiment, performed at the LOA-Palaiseau in France, we successfully scaled this pulse compression regime to the multi-mJ level. In this case, temporally clean 10-fs pulses with energies up to 1.8 mJ could be generated through self-channeling of 3.5 mJ, 40-fs pulses. Again, the spectrally broadened pulses are seen to carry large negative chirps and the shortest measured pulse duration of 9.5-fs was achieved by inserting more than 1 cm of glass in order to compensate for the negative GDD. Single-shot measurements show the exceptional shot-to-shot stability of this pulse compression scheme.

In conclusion, we demonstrate a stable nonlinear pulse compression technique based on self-channeling of intense 40-fs pulses in gases, in which ultrashort pulses are efficiently generated with unexpected large negative chirp. The strongly pre-compensated spectral phase characteristics of such few-cycle pulses makes them a practical driving source for further high-field applications since the shortest pulse durations can be achieved on target by simple propagation through bulk material (e.g. vacuum window). Simulations involving the solution to the nonlinear propagation equation are underway in order to understand this unexpected pulse compression regime and to find optimal conditions for further scaling in energy.

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