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Multipass Spectral Broadening of Spatially Chirped Pulses

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External pulse compression using a multipass gas cell (MPC) is an extremely powerful technique for shortening the duration of sub-ps laser pulses [1]. Despite its tremendous success and versatility, the MPC method faces a challenge of handling high energy due to an unfavourable geometrical scaling requiring a rapid increase of the distance separating concave mirrors, and the corresponding size of the vacuum chamber. In this contribution, we propose and experimentally demonstrate the feasibility of reducing the MPC length relative to the target pulse energy by arbitrarily increasing the beam spot sizes on the mirrors, which is achieved through adding a spatial chirp on the collimated output beam from a grating-pair pulse compressor in a fs Yb CPA system.

Two material parameters—the ionization threshold of the gas, used as an SPM medium (typically Ar for higher pulse energies), and the damage threshold of the dielectric coating on the cell mirrors—determine the length scaling of the MPC with respect to the pulse energy. Whereas the strength of SPM can be controlled by adjusting the noble gas pressure, the same does not apply to plasma losses. The latter can only be suppressed by keeping a sufficiently large beam waist to maintain the pulse peak intensity at a safe low level. Because of the loose focusing, a long propagation distance to the mirror is required to expand the beam size and lower the fluence to a safe level, which is ~0.5-0.6 J/cm^2 for sub-ps pulses for currently available coatings. A successful attempt to reduce the fluence was demonstrated in [2] by converting the fundamental spatial mode of the laser beam to a higher order mode that gives a significantly larger spot size. Here we explore another degree of freedom, which is intrinsically available in CPA systems equipped with a standard Treacy-pair compressor: as shown in Fig.1a, a collimated, laterally expanded beam is obtained by breaking the symmetry between the incoming and outgoing passes through the grating pair while preserving the same dispersion compensation. The spatially chirped collimated beam is then injected in a standard MPC formed by two r=-300 mm low dispersion spherical mirrors (Optoman) separated by ~590 mm. As shown in the ray tracing render in Fig.1b, the 1-D beam spot elongation is periodically repeated by the 2f-2f reimaging condition such that the output plane of spatial chirp is not tilted. This flexible spot size adjustment provides an easy control of the fluence (Fig. 1c) on the mirror while preserving the peak intensity in the beam waist (Fig. 1d,e). Notably, the intensity on the mirrors is reduced even faster than the fluence because of the change of the effective pulse duration seen by the coating due to a monochromatizing effect of spatial chirping. This is significant, as the damage mechanism begins to change favourably from the avalanche-dominated (for fs pulses) to thermal-dominated (>>ps) thus permitting the use of higher fluences. Fig. 1f,g shows our experimentally obtained spectral broadening of 2.5-mJ 250-fs pulses that were spatially chirped to stretch the beam spot by ~ ×2 which was the maximum elongation technically limited by the aperture of the optics installed in the setup.

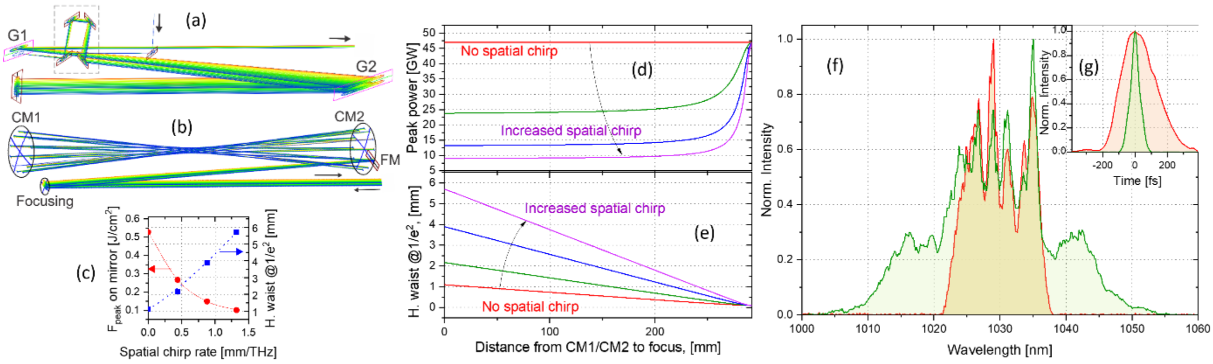

Fig.1 (a) Yb CPA grating compressor with a 4-mirror bypass introduces spatial chirp. (b) Round beam in the focus and elongated beam spots on MPC mirrors. (c) Reduction of peak fluence on the mirrors. Evolution of peak power (d) and spot size (e) on the way to focus. (f) Experimental SPM broadening of 2.5-mJ pulses in 1 bar Ar and the pulse Fourier limit (g). Input spectral & temporal intensities shown in red.

Note that the spatial chirp remaining on the beam after the spectral broadening and pulse recompression is not critical in many applications. Focusing converts spatial chirp into angular chirp which enables engineering of a phase-matching bandwidth in frequency conversion [3] and wavefront manipulation [4], whereas for processes like higher-order harmonic generation in a gas cell, confined to a tiny fraction of the driver beam Rayleigh length, both angular and spatial chirps are cancelled within the short interaction distance.

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