High-Quality Energy-Scalable Femtosecond Pulses from a Fibre-Based Chirped Pulse Amplification System via Adaptive Pulse Shaping

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Diode-pumped ytterbium-doped fibre lasers, coupled with the chirped-pulse amplification (CPA) technique, are promising for realising compact ultrafast laser systems with variable repetition rates. However, energy scaling in such a system is nontrivial, as the accumulation of high-order material dispersion and nonlinear phase modulation degrade the pulse quality upon compression. In our previous work [1], we demonstrated the generation of high-fidelity femtosecond pulses with a repetition rate of 50MHz in a fibre CPA system through the use of an adaptive pulse pre-shaping technique that compensated for high-order dispersion in fibres with a total length of <12m and a B-integral of up to 1.6π rad. In this paper, we show the versatility of adaptive pulse pre-shaping to generate a high-quality pulse train with a variable repetition rate and energy in a fibre CPA system consisting of a 1km fibre stretcher with a B-integral reaching 2.2π rad.

The fibre CPA system consisted of a self-similar oscillator, two core-pumped Yb-doped fibre pre-amplifiers that sandwiched a pulse shaper, and a final large-mode-area double-clad photonic crystal fibre amplifier. The oscillator generated a pulse train of 50MHz, which was reducible by electro-optic and acousto-optic modulators placed at appropriate places within the amplifier chain. We implemented an adaptive pulse shaping to maximise a two-photon absorption (TPA) signal from a GaAsP photodiode illuminated by the output pulse train, essentially maximising the peak power of the pulse train, by controlling the liquid-crystal spatial light modulator in the pulse shaper using a self-adaptive differential evolution algorithm [2].

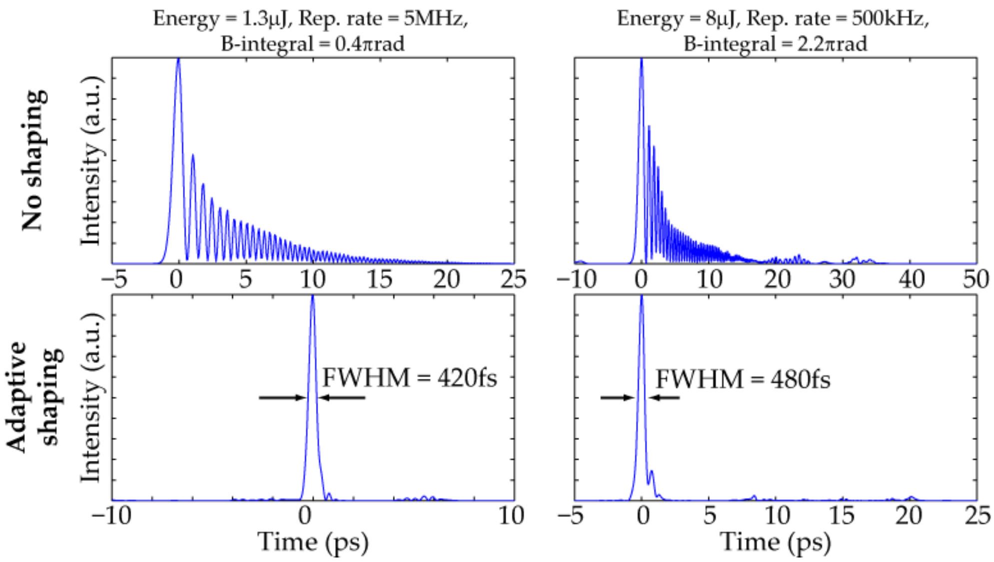

Fig. 1 Retrieved pulse intensity profiles of the output pulse train before and after implementing the adaptive pulse shaping at two different repetition rates.

Figure 1 shows FROG characterised pulse intensity profiles of the fibre CPA system before and after implementing the adaptive pulse pre-shaping. When the repetition rate of the pulse train was reduced to 5MHz, the energy per pulse was 1.3μJ with a B-integral of 0.4πrad, indicating that the main contribution to the pulse degradation at the output was the accumulation of third-order dispersion from the fibre stretcher and grating compressor. As the repetition rate was further reduced to 500kHz, the pulse energy increased to 8 μJ, and the B-integral increased to 2.2πrad, implying a non-negligible contribution of accumulated nonlinear phase to the degradation of the pulse quality. In each case, the separation of the gratings pair in the compressor was optimised prior to implementing the adaptive pulse shaping. The adaptive shaping improved the pulse quality as can be seen in Fig. 1, thereby increasing the peak power by a factor of 3.9 and 3.6 for the pulse trains with energy 1.3μJ and 8μJ, respectively.

In conclusion, we have demonstrated the adaptive pulse pre-shaping as a powerful technique to achieve high-quality energy-scalable femtosecond pulses in a fibre-chirped pulse amplification system, without a major system reconfiguration.

References

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[2] J. Zhang and A.C. Sanderson, “JADE: Self-adaptive differential evolution with fast and reliable convergence performance”, IEEE Congress on Evolutionary Computation 2007, 2251-2228