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High Performance Ytterbium Regenerative Amplifier Based on Yb:CALYO with High Energy 100 fs Pulses

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The Yb-based chirped pulse amplification laser systems have been established as a viable technology for generating femtosecond ultrashort pulses of high multi-mJ energy at multi-kHz repletion rates for numerous applications. The laser transitions between $^2F_{5/2} - {}^2F_{7/2}$ manifold energy levels determine the unique properties of the Yb-doped crystalline materials of relatively broad, overlapping absorption and luminescence bands that can be pumped by widespread InGaAs laser diodes. However, one of the remaining challenges in the development of femtosecond Yb-based lasers is achieving high pulse energy of multi mJ-levels and high average power, combined with short pulse durations of sub-100 fs. Although there are Yb-crystals with broad bandwidth of emission such as Yb:KGW, disordered Yb:$CaGdAlO_4$ (Yb:CALGO), and Yb:CaF_2, obtaining high energy amplified pulses of more than 1 mJ with pulse duration down to 100 fs is still a technological quest. While Yb:CALGO is relatively well explored for generation of shorter femtosecond pulses, the state-of-the-art systems have either low energy of sub-60 μJ and short pulse duration of ~220 fs, or pulse energy at the mJ-level but with longer pulses, with most systems being limited to dual-crystal amplifying architectures [1]. On the other hand, Yb:$CaYAlO_4$ (Yb:CALYO) is not well investigated, and the most advanced amplifiers developed to date have sub-100 μJ energies, at high repetition rates, with long pulse durations of 190 - 215 fs [2].

Here we report the highest performance single crystal Yb-regenerative amplifier based on Yb:CALYO of 2.2 mJ energy at 1 kHz with record-short 102 fs pulses using a simple architecture. The system is seeded with pulses of 1 nJ energy at 52 MHz and a spectral bandwidth of 40 nm at FWHM (Fig.1a) which are then stretched up to 600 ps by a custom designed Martinez diffraction grating stretcher [3]. The Yb:CALYO crystal with a length of 8 mm has been doped with 2% of Yb^{+3} ions. A fiber-coupled diode laser with a volume Bragg grating at a central wavelength of 982 nm is used to reach near 89% absorption of the pump energy. The pump laser has a 500 μs pulse duration at 1 kHz with control and synchronization modules, developed in collaboration with IBPhotonics Ltd. The gain bandwidth of the Yb:CALYO, as well as the amplified pulse duration and spectrum, have been extensively investigated (Fig. 1a and 1b). Remarkably, a substantial pulse-shortening saturation effect is observed with the increase of the pump energy to ~25 mJ. A pulse energy of 2.75 mJ before compression or 2.2 mJ after compression is obtained at 29 mJ of pump energy. Finally, using a Treacy-pair compressor, near-Fourier transform limited pulse durations of 102 fs are reached, characterized with a phase-retrieval FROG apparatus (Fig. 1c).

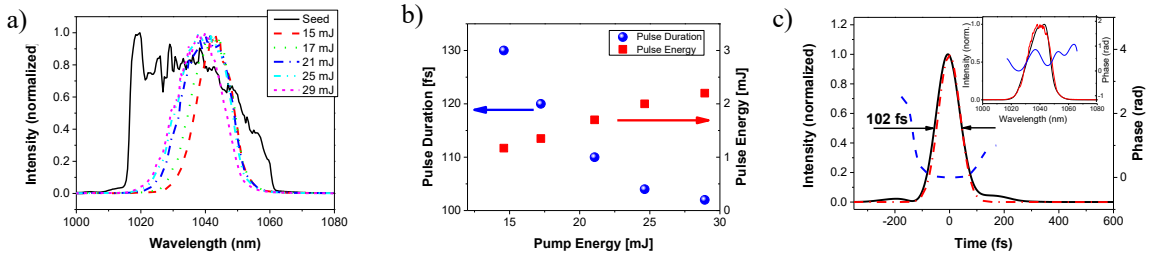

Fig. 1 a) Spectrum of the seed pulse (black), and spectrum of the amplified pulses broadened with increase of the pump energy (colored dashed). b) Output pulse duration with pulse shortening down to 100 fs at pump energy 29 mJ. c)Reconstructed pulse intensity (black) and phase (blue) for the record-short 102 fs pulses, and theoretical Fourier transform limited pulse duration corresponding to 93 fs (red dashed). Inset: measured (red line) and reconstructed FROG spectrum (black line), and spectral phase (blue).

In conclusion, we demonstrate an extensive study of Yb:CALYO regenerative amplification providing uncompressed 230 ps, 2.75 mJ pulses and compressed down to the record-short 102 fs, 2.2 mJ pulses, ideal for strong-field science and high harmonic generation techniques.

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