A high power, single-mode, erbium-doped fiber amplifier generating 30 fs pulses with 160 kW peak power

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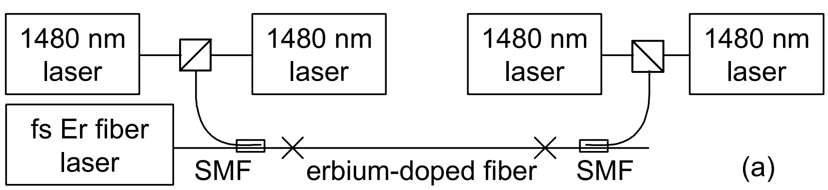
Abstract: We describe generation of 400 mW average-power, highly-chirped picosecond pulses at 46 MHz repetition rate in a single-mode erbium-doped amplifier. The pulses are compressed to 30 fs with 160 kW peak power in standard-single-mode fiber.
OCIS codes: (060.2320) Fiber optics amplifiers and oscillators; (060.5530) Pulse propagation and solitons

Erbium-doped fiber lasers are a reliable source of sub-100 fs pulses at 1550 nm. Nonlinearities make generation of multi-nJ pulses difficult. Multi-mode fibers can be used in amplifiers, to reduce the effect of nonlinearities, and compression of chirped pulses is usually performed with bulk-optic components[1]. However, for applications such as supercontinuum generation in fibers, it is desirable to generate compressed pulses in single mode fibers and fusion splice the supercontinuum generating fiber directly to the amplifier output[2]. Single mode fiber lasers with supercontinuum fiber fusion spliced to the amplifier output have recently been demonstrated to be ideal as all-fiber phase locked frequency combs covering the wavelength region from 1.1 to 2.3 microns[3]. Therefore, in this work we investigate a high power single-mode, erbium-doped amplifier for fs pulses, generating compressed fs pulses in the single-mode fiber pigtail. This system demonstrates, to the best of our knowledge, the highest reported peak-power femtosecond pulses from a single-mode erbium amplifier to date.

The amplifier schematic is shown in Fig. 1a. The pulses from a modelocked fiber laser[2,3] (2 mW, 250 fs pulses at 46 MHz) were launched into a 2m length of erbium-doped fiber. The amplifier was forward and backwards pumped with four 1480 nm diode lasers. Polarization multiplexing combined two lasers onto a single fiber. The maximum launched power of the forward (backward) pumps was 610 mW (571 mW).

The measured spectrum is shown in Fig. 1b. The output SMF lead was kept as short as possible (< 20cm). The maximum output power of the amplified pulses was 400 mW (8.7 nJ/pulse). A calculation of the amplifier output spectrum, from a nonlinear Schrödinger equation (NLSE) model including gain, is also plotted in Fig. 1b, showing good agreement with the experiment.

The erbium-doped fiber had normal dispersion. The combination of distributed gain, normal dispersion, and SPM leads to self-similar propagation, where pulses acquire a parabolic shape in time and linear chirp[4]. The measured autocorrelation in Fig. 2a, shows that the output consists of a single, highly-chirped pulse. NLSE



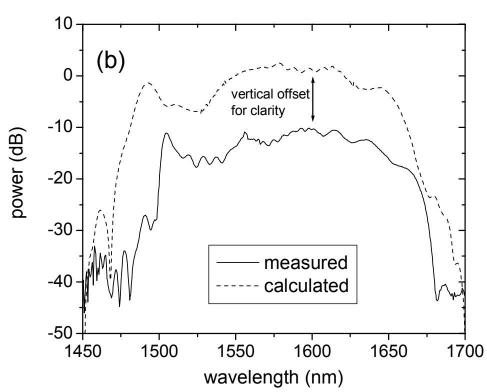


Figure 1: (a) Schematic of the erbium-doped fiber amplifier. (b) Spectrum measured at the output of the amplifier (solid line) compared to a nonlinear Schrodinger equation calculation. The spectra are offset vertically for clarity.

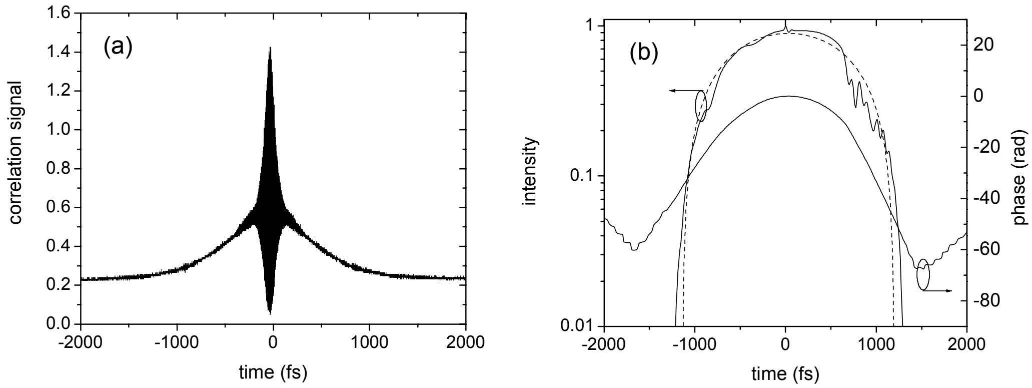


Figure 2: (a) Measured interferometric correlation at the output of the erbium amplifier. (b) Pulse intensity (solid line) and phase simulated using the NLSE. Dashed line is a parabolic fit to the pulse intensity.

simulations (Fig. 2b) also show that the pulses are approximately parabolic with quadratic phase. However, higher-order terms, such as self-steepening, cause deviations from a true parabolic shape (dashed line).

Similar, lower-power systems have shown efficient compression with bulk optics[5]. Alternatively, we investigated pulse compression in a short length of standard single-mode fiber. The optimum length of SMF, that generated the maximum two-photon signal in a Si photodiode, was 45 cm (including the pump/signal wdm). The measured autocorrelation and spectrum is shown in Fig 3a. The spectrum and interferometric correlation were input into the PICASO algorithm to retrieve the pulse intensity and phase[6]. The retrieved pulse (Fig. 3b) consisted of a 30 fs pulse on a low pedestal. Approximately 55% of the energy was in the central pulse, giving a peak power of 160 kW.

In conclusion, we demonstrated a single-mode erbium amplifier producing 8.7 nJ, highly-chirped, picosecond pulses. Compression in SMF generated 30 fs pulses with 160 kW peak power, delivered directly to the fiber tip. This system is ideal for inclusion in an endoscope for nonlinear microscopy, or for fusion splicing to a nonlinear fiber for supercontinuum generation.

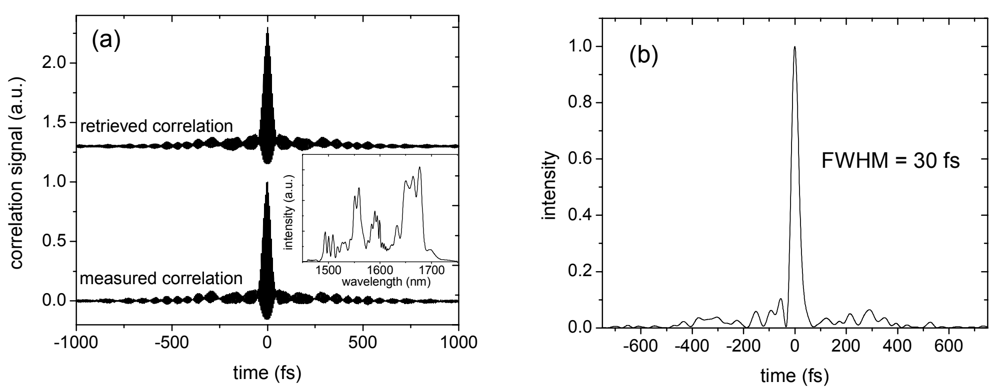


Figure 3: (a) Measured correlation after SMF compression fiber, compared to retrieved correlation. Inset : measured spectrum. (b) Retrieved intensity corresponding to correlation in (a), showing a 30 fs pulse.

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