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Broad-area diode-pumped 1 W femtosecond fiber system

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Abstract

Up to 1 W of average power was obtained with a double-clad Er/Yb power amplifier in an all-fiber chirped pulse amplification system. Both the oscillator and the power amplifier were cladding-pumped with broad-area laser diodes. 310 fs recompressed pulse duration was achieved using a single 10 cm long chirped fiber grating as a pulse stretcher/compressor.

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Summary

High average power 310 fs pulses were obtained with an all-fiber chirped pulse amplification (CPA) system. Both the oscillator and the power amplifier are based on Er/Yb fiber for cladding-pumping with broad-area laser diodes. A single 10 cm long fiber grating is employed in the CPA system as a compact femtosecond-pulse stretcher/compressor.

The experimental set-up is shown in Fig. 1. The mode-locked cladding-pumped fiber oscillator produces 1 mW of 175 fs pulses at ~ 18 MHz repetition rate. The initial 24 nm wide pulse spectrum is centered at 1550 nm. The oscillator is pumped at 980 nm with 900 mW power from a broad-area (100 μm stripe width) laser diode. The broad-area laser diode offers an inexpensive and compact replacement to a single-mode laser diode MOPA.

The amplifier system consists of a standard single-doped single-mode preamplifier pumped by a pigtailed 1480 nm laser diode and a double-clad Er/Yb power amplifier. A standard Er-doped fiber preamplifier reduces the effect of the narrow gain bandwidth of the Er/Yb codoped power amplifier. Operating the preamplifier in deep saturation allows to balance the short-wavelength shift in the power amplifier and to retain the wide spectral content of the amplified pulses (Fig. 2a).

To take advantage of commercially available high-power broad-area laser diode systems a large-cladding Er/Yb codoped power amplifier fiber has been developed. The pump-cladding dimensions of the fiber are 250x180 μm (NA=0.4) and the Er doping level in the core is ~1000 ppm. This fiber is pumped with a broad-area diode system producing 12.4 W at 980 nm from the output of a 0.5 mm diameter and 0.14 NA fiber bundle (Applied Optronics Corporation). With aberration corrected optics up to 10 W is coupled into the fiber. In 13 m of the fiber 90 % of the pump is absorbed. The amplifier was arranged in a double-pass configuration by placing a normal-incidence dichroic mirror at the pumping end of the amplifier. The power characteristics of the double-clad Er/Yb fiber were measured in a laser configuration, obtained by cleaving the output end at 90° angle. The slope efficiency is 18% and the maximum output power of ~1.7 W (Fig. 3) is the highest reported with a single-stage Er-doped fiber. The maximum output power of the amplifier configuration with 20 mW signal input from the preamplifier is ~ 1 W. A further increase of the output power is possible by optimizing the double-clad fiber geometry and by power scaling of the system.

Pulse stretching and recompression for chirped pulse amplification was accomplished with a single 10 cm long grating. These gratings were UV photoimprinted into germanium-rich fiber using a 10 cm long step-chirped phase mask. Typical reflectivity is 60 to 80 % over a 18 nm bandwidth. Such long gratings provide ~ 1 ns duration stretched pulses, which are sufficient to eliminate nonlinear interactions in a fiber amplifier even at pulse energies of ~ 1 μJ [1]. Use of a single grating ensures the reciprocity of pulse stretching and recompression [2] and generation of transform-limited 310 fs pulses at the output of the system (Fig. 2b). Additional negative group-velocity dispersion of the fibers in the path of the stretched pulses is compensated by a proper length of positive-dispersion fiber. Note the dashed-line trace in Fig. 2b, which corresponds to a calculated transform-limited autocorrelation trace of the spectrum in Fig. 2a. It indicates the remarkable reciprocity of this stretching/compression scheme. For ~ 1 mW input and ~ 1 W output of the amplifier system, the leakage of the amplified power through the grating into the preamplifier input should be suppressed to better than 30 dB. We achieved ~40 dB leakage suppression by using polarizing beamsplitters, Faraday rotators and $\lambda/2$ waveplates at each side of the fiber grating to keep the polarizations of the two input beams orthogonal to each other. The peak performance of the compressor efficiency at 70 % is a product of the 80 % grating reflectivity and 90 % fiber-to-fiber coupling efficiency into the compressor port. A typical overall result is ~ 60 % due to losses in the optics. This allows to achieve up to 600 mW of recompressed power in the present system.

In conclusion, we have demonstrated that a fiber system can produce femtosecond pulses with average powers comparable with those from bulk solid-state lasers. The compact all-fiber design of the present system is an attractive alternative to large-frame table-top systems.

References

1. A. Galvanauskas, M. E. Fermann, P. Blixt, J. A. Tellefsen, and D. Harter, Opt. Lett. **19**, 1043 (1994)
2. A. Galvanauskas, M. E. Fermann, D. Harter, K. Sugden, and I. Bennion, Appl. Phys. Lett. **66**, 1053 (1995)

Figure captions

Fig. 1. High-power femtosecond fiber system.

Fig. 2. (a) Amplified pulse spectrum. (b) SH autocorrelation traces. Solid line - measured after recompression, dashed line - calculated for the transform-limited pulse of the spectrum (a). Deconvolved duration of the pulse is 310 fs. Shape of the compressed pulse is typical for square-like spectrum.

Fig. 3. Power characteristics of the Er/Yb double-clad fiber in a laser configuration.

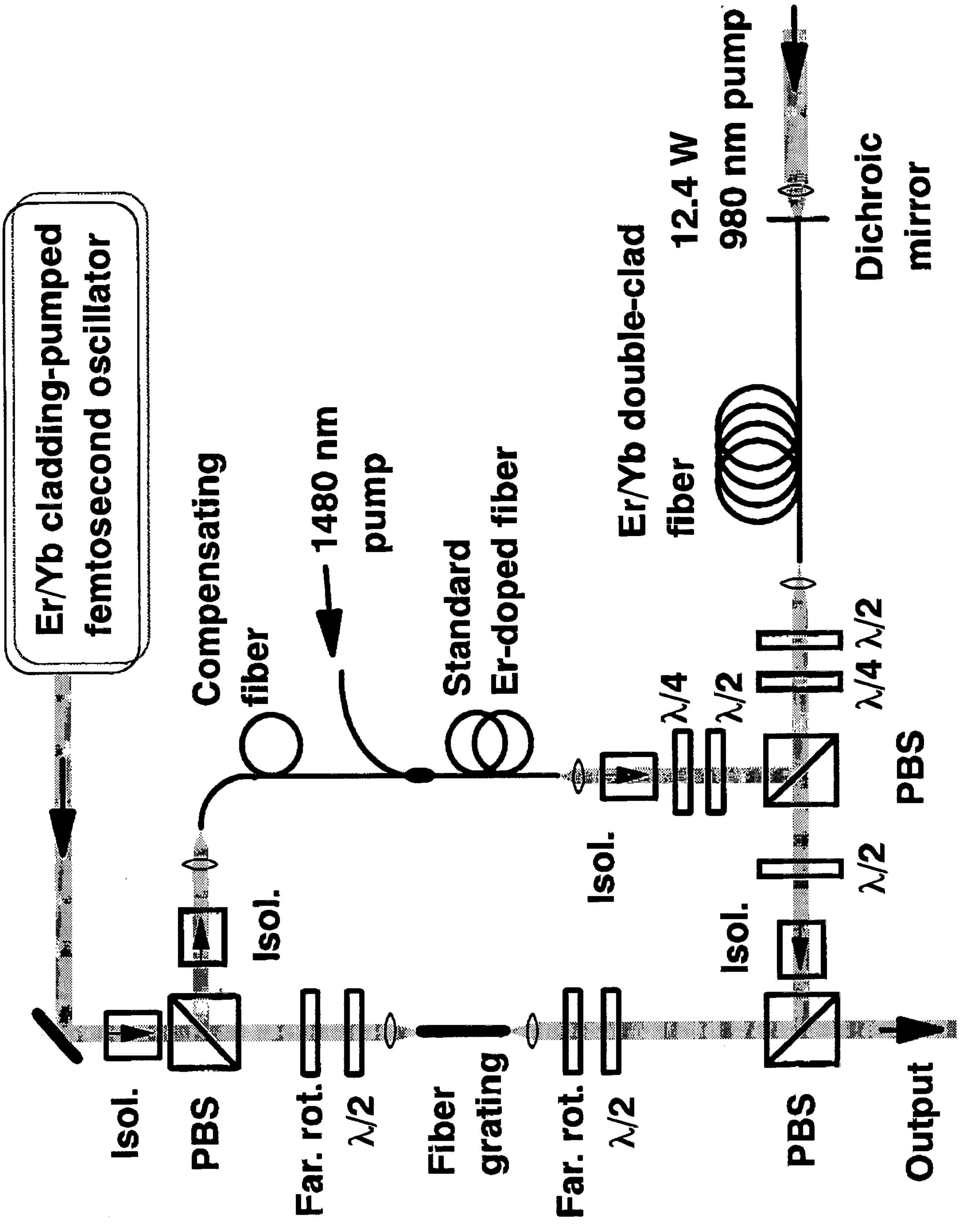
Er/Yb cladding-pumped femtosecond oscillator
Isol.
PBS
Far. rot.
λ/2
Fiber grating
Far. rot.
λ/2
PBS
Output
Isol.
Compensating fiber
1480 nm pump
Standard Er-doped fiber
Isol.
λ/4
λ/2
PBS
λ/2
Isol.
λ/4 λ/2
Er/Yb double-clad fiber
12.4 W 980 nm pump
Dichroic mirror

Fig 1

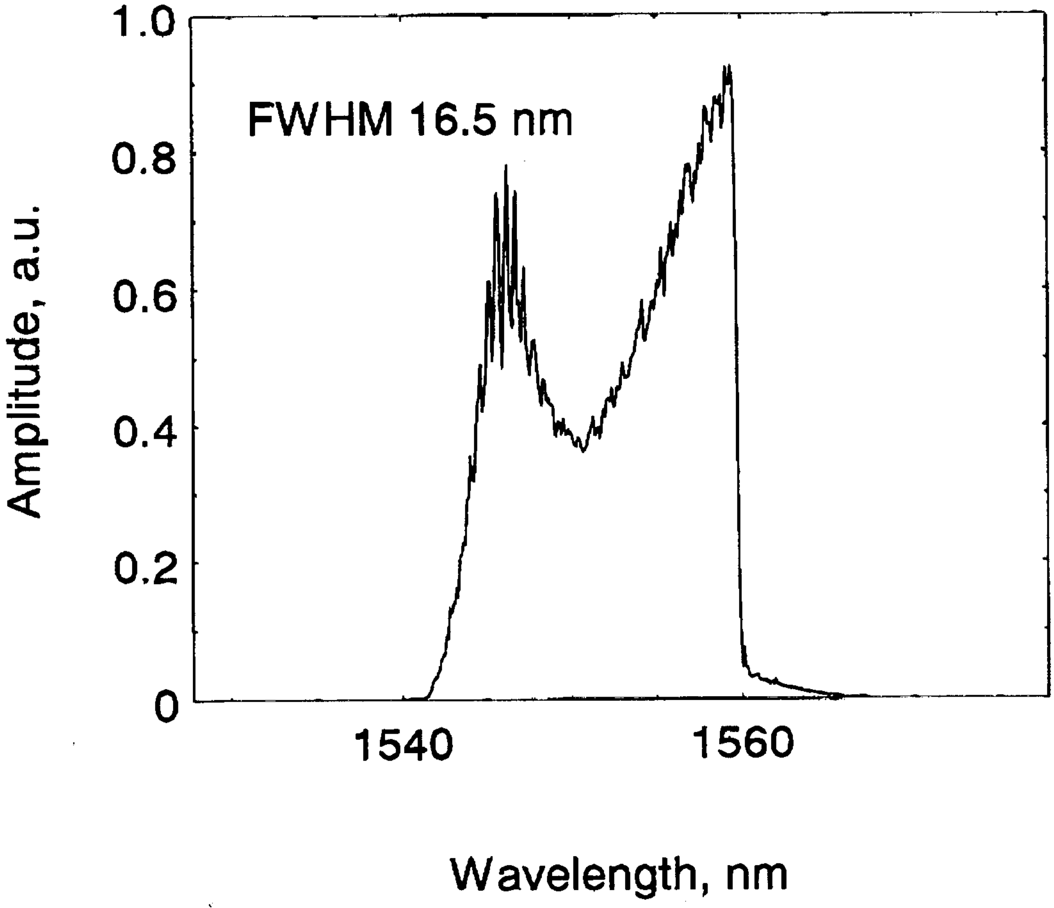
FWHM 16.5 nm
1.0
0.8
0.6
0.4
0.2
0
Amplitude, a.u.
1540
1560
Wavelength, nm

Fig. 2(a)

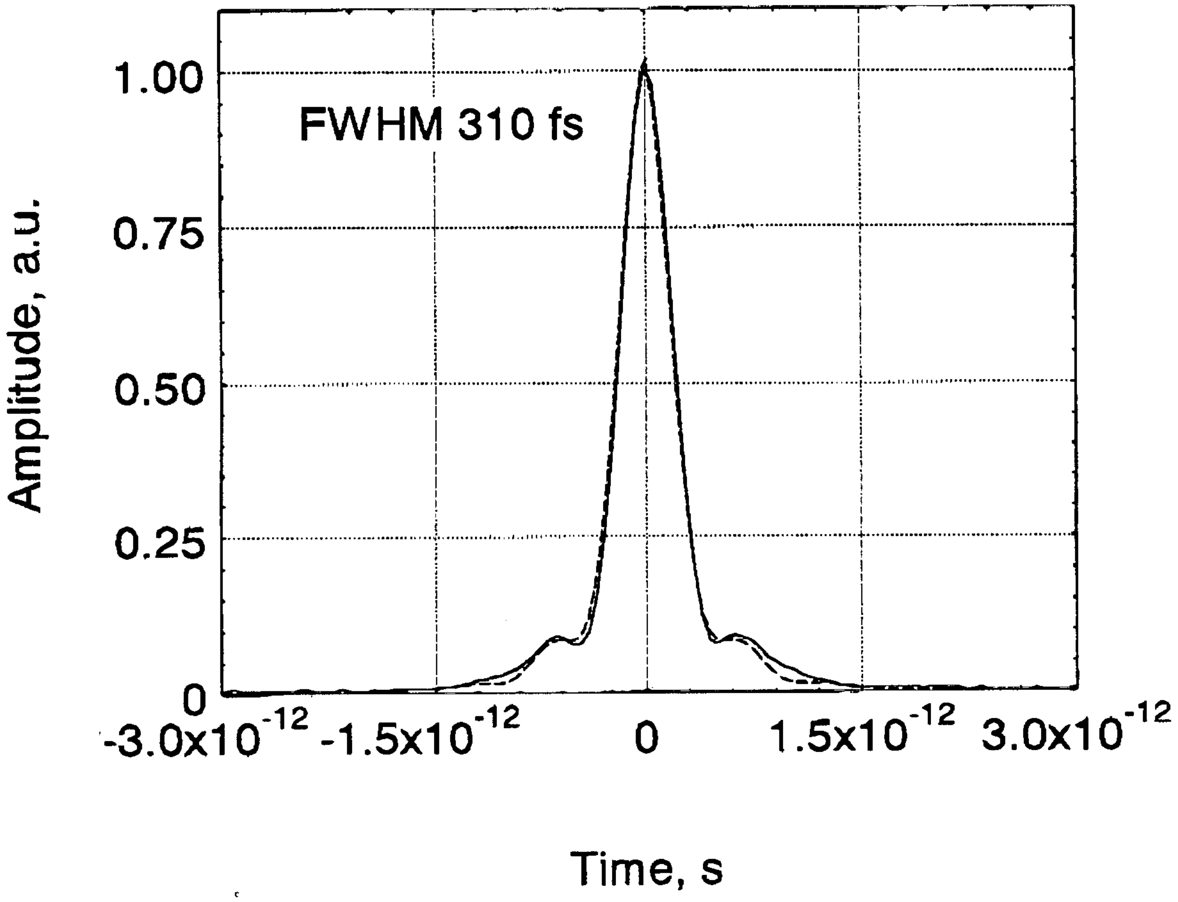
FWHM 310 fs
Amplitude, a.u.
1.00
0.75
0.50
0.25
0
-3.0x10^-12
-1.5x10^-12
0
1.5x10^-12
3.0x10^-12
Time, s

Fig. 2(b)

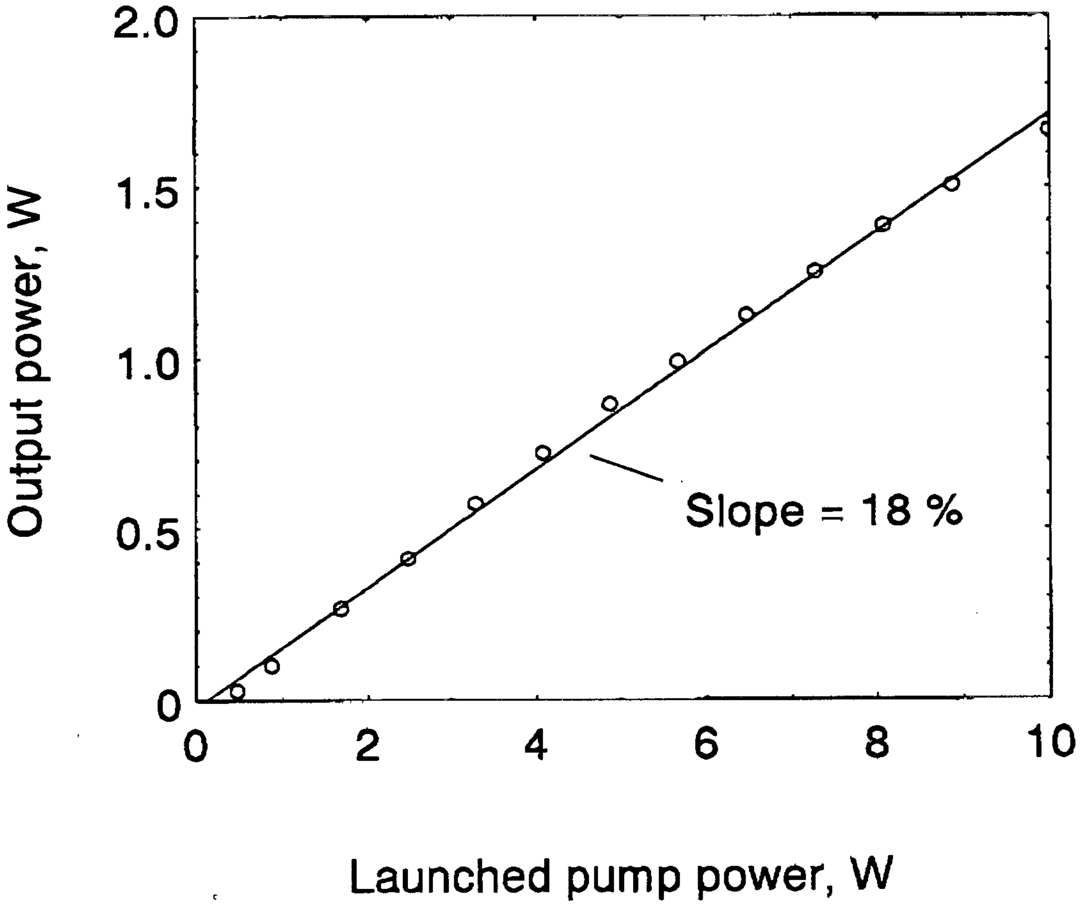
2.0
1.5
1.0
0.5
0
Output power, W
0
2
4
6
8
10
Launched pump power, W
Slope = 18 %

Fig. 3.