Cladding pumped Er^{3+} fiber amplifier generating femtosecond pulses with an average power of 0.26 W

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Abstract

Femtosecond pulse amplification in a cladding pumped fiber amplifier is demonstrated for the first time. A cladding-pumped Er^{3+}-doped fiber amplifier generates 380 fsec near-bandwidth-limited pulses at repetition rates up to 50 MHz with an average power up to 0.26 W.

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Summary

Fiber lasers are compact and stable sources of femtosecond pulses, but to date they have not been considered as serious alternatives to femtosecond solid state lasers due to their intrinsic power limitiations. Here we show that these power limitations are overcome by the use of cladding pumped fibers in conjunction with an all-fiber chirped pulse amplification system[1] based on strongly chirped fiber Bragg gratings[2].

The experimental set-up is shown in Fig. 1. The fiber seed oscillator (IMRA IM-150-FS) generates bandwidth limited 200 fsec pulses with pulse energies of 20 pJ at stable repetition rates that may be varied between 5 and 50 MHz. Prior to amplifieation the pulses are stretched to ≈ 50 psec using a 5 mm long positively chirped fiber Bragg grating. To operate the power amplifier in saturation the pre-amplifier is used, which boosts the average signal power to 10 mW.

Using a length of 2.5 m of an Er^{3+}/Yb^{3+} double-clad fiber as a power amplifier and a single 1 W broad-area pump diode at 980 nm, we obtained a signal power of 100 mW, limited at this time by the imperfect wavelength overlap between oscillator and amplifier.

To allow for the amplification of the shortest possible pulses and to generate even higher power levels, we developed a special double-clad Er^{3+} power amplifier[3] (Er^{3+} doping level = 1000 ppm, length = 3.8 m). Eliminating the Yb^{3+} as a co-dopant allows in turn to eliminate any P_2O_5 doping (in an Er^{3+}/Yb^{3+} amplifier P_2O_5 is necessary to dissolve the Yb^{3+} ions), which has the benefit of broadening the transition lines of the Er^{3+} amplifier and improving its efficiency compared to an Er^{3+}/Yb^{3+} system. In order to demonstrate a high-power output with the Er^{3+} system we used two polarization multiplexed MOPA laser diodes delivering a total pump power of 1.2 W at 980 nm launched into the power amplifier, where the cladding-pumping scheme ensures nearly perfect input coupling.

The efficiency curve of the Er^{3+} power amplifier is shown in Fig. 2. The Er^{3+} power amplifier boosts the average signal power to a level of 0.42 W. After recompression in a negatively chirped fiber Bragg grating an average output power of 0.26 W is obtained, limited by the 90% reflectivity of the grating and the presence of some un-coated optics. At a repetition rate of 50 MHz a pulse energy of 5.2 nJ is thus generated. Much higher pulse energies were obtained by simply operating the oscillator at a lower repetition rate, though self-phase modulation in the power amplifier limited the maximum extractable pulse energy to about 20 nJ in the present system.

An autocorrelation trace and the corresponding pulse spectra for a 5 nJ pulse are shown in Fig. 3 The pulse width is 380 fsec and assuming a $sech^2$ pulse shape the time bandwidth product is 0.5.

In conclusion we have demonstrated that femtosecond fiber lasers can produce average powers that are truly competitive with conventional solid state lasers. Even higher output powers and pulse energies will be possible by the incorporation of improved diode coupling schemes with broad area diode arrays and longer fiber Bragg gratings, where the obtainable pulse energies scale linearly with the lengths of the Bragg gratings.

References

1. A. Galvanauskas et al., Appl. Phys. Lett., **66**, 1053 (1995)
2. M. C. Farries et al, Electronics Lett., 30, **891** (1994)
3. J. D. Minelly et al., 'Efficient cladding pumping of an Er^{3+} fiber', subm. to European Conference on Optical Communication, ECOC, Brussels, 1995

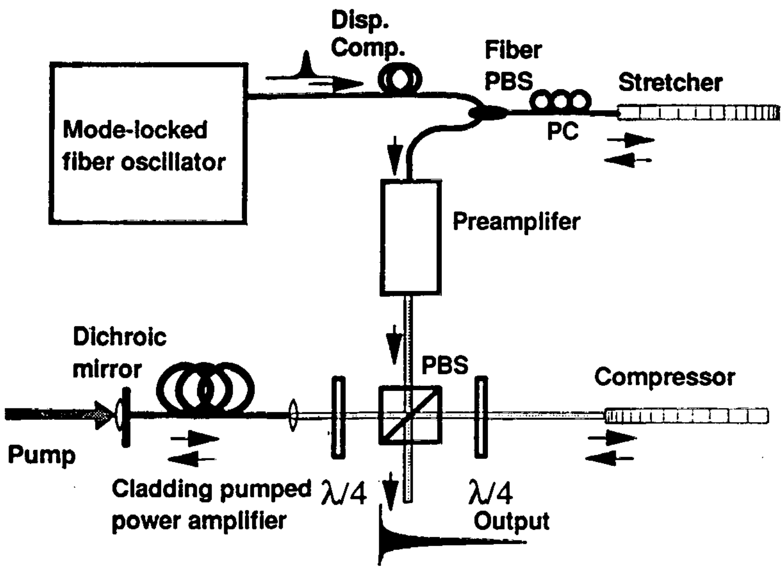

Fig. 1) Set-up of a high power femtosecond chirped pulse amplification systems employing a cladding pumped Er^{3+} fiber amplifier.

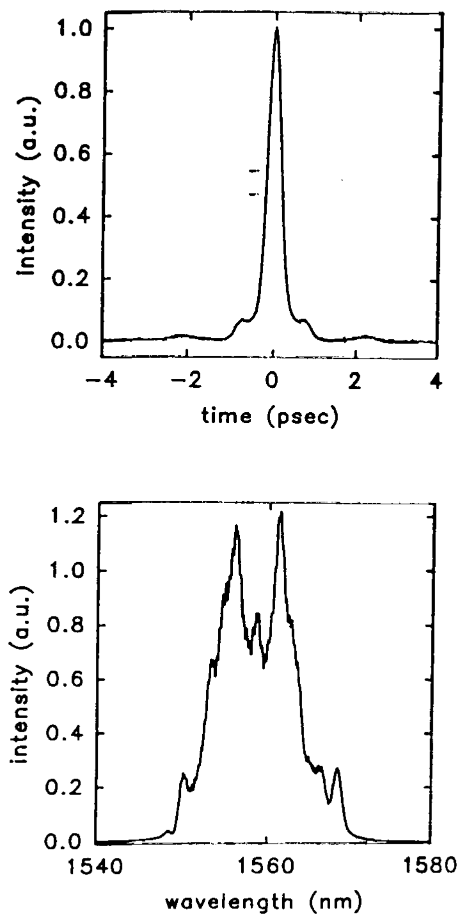

Fig. 3) Autocorrelation trace (top) and corresponding spectrum (bottom) of pulses generated with the fiber system operating at an output power of 0.42 W. The FWHM pulse width is 380 fsec.

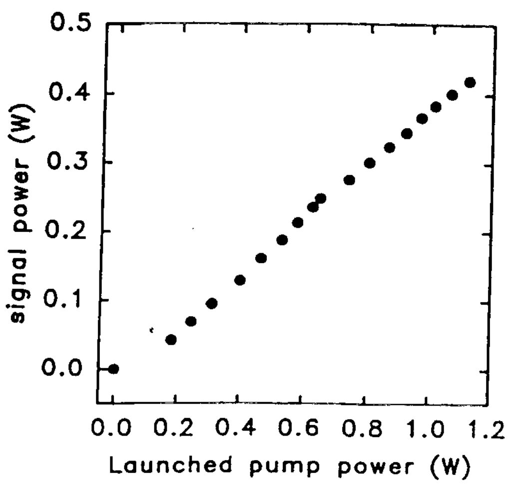

Fig. 2) Signal power versus pump power of an Er^{3+} cladding pumped femtosecond power amplifier.