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Cladding-pumped Fibre Laser/Amplifier system generating 100 μJ energy picosecond pulses

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Abstract

We report on a fibre amplifier system generating picosecond pulses with 100 μJ energy. A mode-locked fibre oscillator is used to seed a multi-stage acousto-optically gated fibre amplifier. The final stage comprises a cladding pumped multimode $Er^{3+}Yb^{3+}$ co-doped fibre pumped with 4 W of power at 982 nm and produces up to 250 μJ pulse energy.

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Summary

The dual techniques of cladding pumping, [1], and chirped pulse amplification (CPA), [2], have provided the means by which fiber lasers can be scaled in average power and pulse energy to levels rivaling other solid state laser systems, [3,4]. In cladding pumped fibre lasers the incompatibility of high power broad stripe diodes and diode arrays with small core fibres is overcome by the use of special double-clad fibres which allow for coupling into appropriate multimode waveguides. In chirped pulse amplification ultrashort pulses of subpicosecond duration are stretched before amplification to typically 1 ns using dispersive elements such as bulk gratings or chirped fibre Bragg reflectors. Thus unwanted nonlinear effects such as self-phase modulation and stimulated Raman scattering are eliminated. Following amplification the pulses are recompressed close to their original duration. Here we show how a combination of these techniques allows the realisation of a fibre laser system producing 100 μJ energy picosecond pulses at repetition frequencies up to 5 kHz.

The system comprises a femtosecond fibre oscillator, a pulse stretcher and a compressor and four stages of amplification. The mode size of the fibers comprising each amplifier is progressively increased to enable higher energy extraction from each stage. This increase in mode size is necessary to avoid self phase modulation of the propagating signal and self saturation by ASE in the amplifiers. The final power amplifier comprises

a 150 cm length of double-clad $E^{3+}Yb^{3+}$ fibre with a 200 μm cladding and a 30 μm core. The dopant levels in this fiber were approximately 15000 ppm Yb^{3+} and 1200 ppm Er^{3+}.

Figure 1 shows the gain characteristics of the final stage verses input energy measured after the final acousto-optic modulator. The small signal gain is approximately 19 dB. Output energy saturates at approximately 3 μJ of incident energy.

The output characteristic of pulse energy verses repetition frequency is shown in Figure 2 indicating rollover at around 5 kHz. Maximum total energy from the last amplification stage was 250 μJ. The average output power at high repetition frequencies was over 1 W. The launched power was approximately 4 W and the throughput pump approximately 800 mW. Allowing for a measured bleaching power of 500 mW absorbed the average power extraction efficiency is 38 % with respect to absorbed pump power.

After recompression the pulse energy was reduced to 100 μJ due to degradation of the degree of polarisation in the multimode amplifier. The second-harmonic autocorellation and streak-camera measurements revealed that recompressed pulse duration was less than 3 ps corresponding to a peak power of > 30 MW.

In conclusion we have to our knowledge achieved the highest peak power from a fibre based short pulse system. Compare to the best previous results [4] the energy of recompressed short pulses was improved by a factor of ~ 10. The demostrated cladding-pumping of a high-energy fibre amplifier is essential for developing inexpensive and reliable CPA systems. Higher energies can be expected from larger core fibres. The system is limited by the location of the ASE gain peak at 1535 nm being outside the pulse bandwidth. This problem can be partially alleviated by reducing the NA of the fibre since the input ASE noise is proportional to the square of the fibre NA. Also a larger cladding/core ratio will give a better relative gain within the pulse bandwidth although of course the pump absorption length would be increased.

References

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Figure captions

Fig. 1. Gain and output power vs injected pulse energy for 30 μm core fibre amplifier.

Fig. 2. Amplified pulse energy vs repetition rate for 30 μm core fibre amplifier.

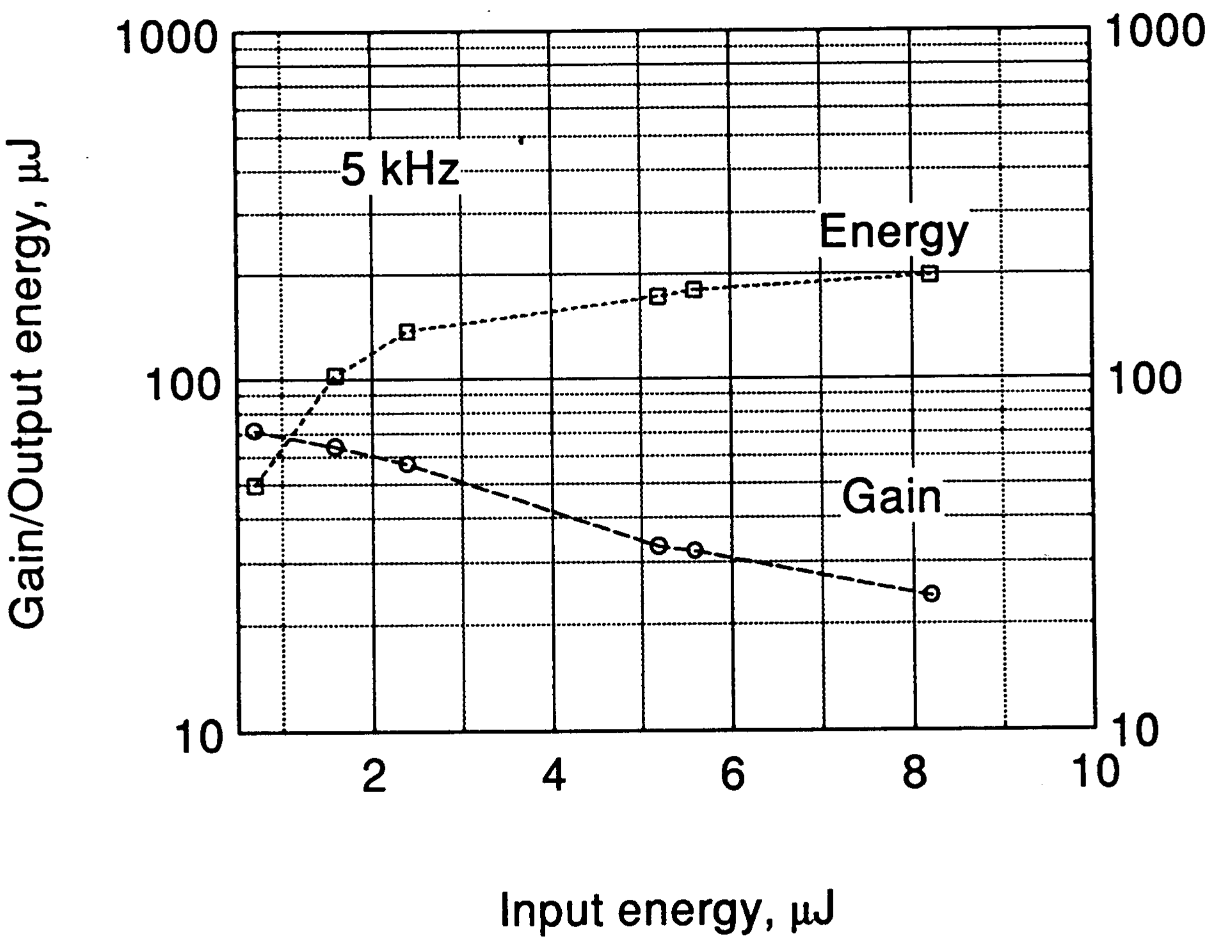
1000
100
10
1000
100
10
5 kHz
Energy
Gain
2
4
6
8
10
Gain/Output energy, µJ
Input energy, µJ

Fig 4

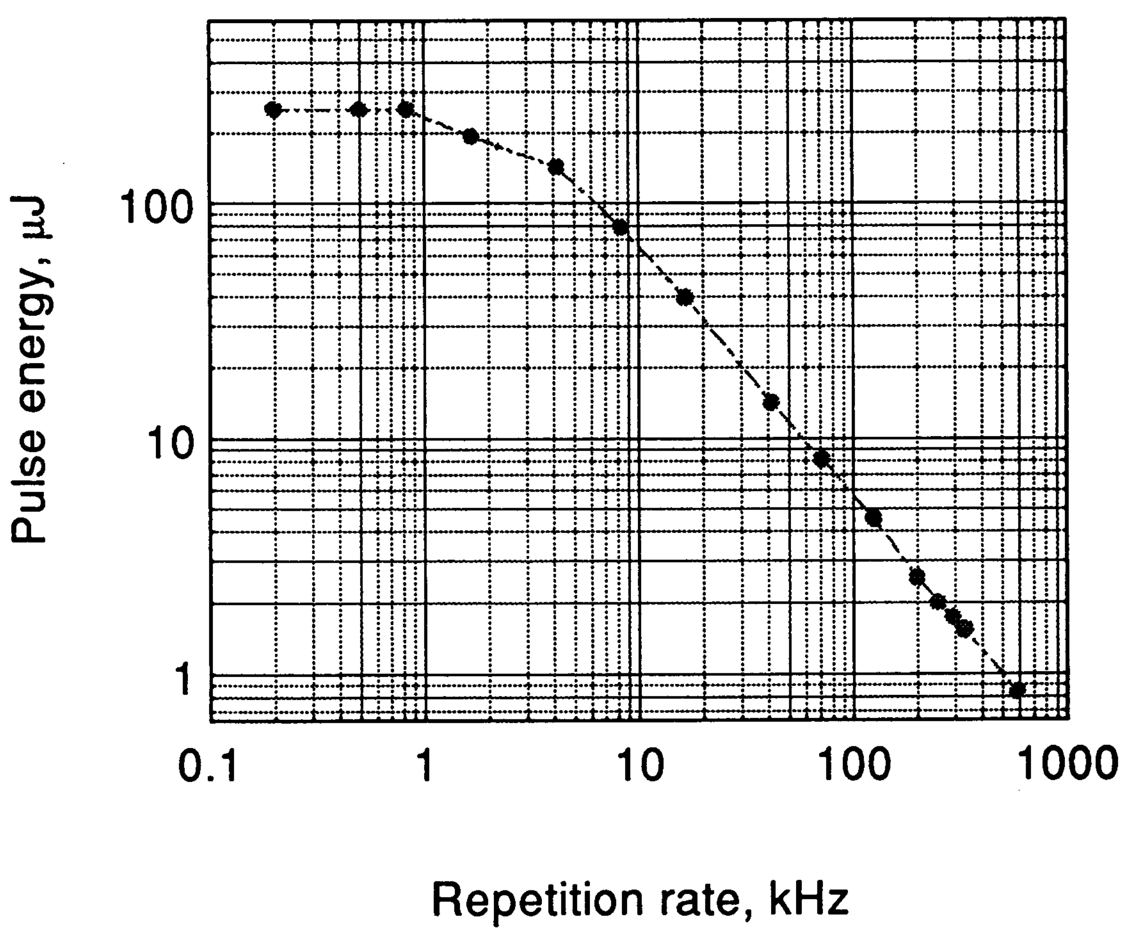

Fig 7