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Diode-pumped, high-energy, single transverse mode a-switch fibre laser

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The authors report the generation of 180μJ, 3.6kW peak power pulses from a simple, diode-pumped large mode erbium doped fibre Q-switch laser system. This is believed to be the highest energy ever obtained from a single transverse mode fibre laser system.

Actively Q-switched, erbium-doped fibre lasers offer a simple and robust means for the generation of high energy, nanosecond pulses at eye-safe wavelengths around 1550nm suitable for a number of industrial, sensing and nonlinear optics applications [1 - 4]. For many of these applications, a high-quality, spatial mode-profile is a fundamental requirement, making single transverse mode per-formance a necessity. The maximum pulse energy we can obtain from a Q-switch system is ultimately determined by the energy storage characteristics of the gain medium. Conventional commer- cial erbium doped fibres are optimised for amplifier applications where a high gain efficiency is the main design criteria. Unfortu-nately, this optimisation, which demands the use of a tightly con-fined mode, compromises the energy storage characteristics of the fibre, since energy is rapidly lost in the form of amplified sponta-neous emission (ASE) as the pump power to the system is increased. If we use conventional erbium doped fibre, the maxi-mum extractable energy in a single Q-switch pulse is limited to ~10μJ. Recently, we have experimentally demonstrated that the use of a large mode area, low numerical aperture, singlemode waveguide design significantly reduces the small signal gain effi-ciency and thereby greatly increases the energy storage capacity of the fibre [5, 6]. Using such an approach, we achieved record actively Q-switched fibre laser pulse energies of 50μJ at pump powers levels (~600m W) commensurate with semiconductor laser diode pumping [7]. In this Letter, we present our latest results based on this concept. Using a laser diode pump source and a fibre with further increased mode area, we have improved the laser performance, obtaining pulse energies as high as 180μJ with corre-sponding pulse powers in excess of 3kW. To the best of our knowledge, this is the highest pulse energy ever reported for a single transverse mode fibre system.

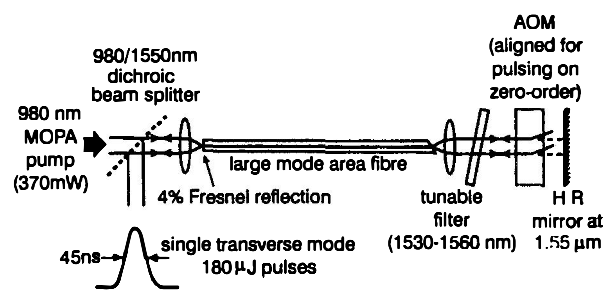

Fig. 1 *Laser configuration*

The laser cavity is shown in Fig. 1. Pump light from an isolated 980nm MOPA semiconductor pump source delivering 370mW is launched into the large mode area fibre through a 980/1550nm dichroic beam splitter using an appropriately matched lens combination. We estimate a launch efficiency of 80%. The 4m long fibre, doped with 400ppm of Er^{3+} ions, had an NA of 0.066, and a cutoff wavelength of 1450nm and was therefore single transverse mode at the operating wavelength. The estimated mode-field area for this fibre was 310μm^2 as compared to the 30–50μm^2 typical of conventional erbium doped fibres. The cavity is formed by the 4% Fresnel reflection at the pump launch end and the high reflector mirror, all other surfaces within the cavity being either anti-reflection coated or angle-polished. The Q-switch itself was an acousto-optic modulator which gave 85% coupling to the first-order dif-fracted beam under optimal focusing conditions. The laser was configured to run in the zero-order, Q-switch mode. An angle-tuned, dielectric bandpass filter of 1 nm width was included within the cavity to allow for laser tuning (between 1530 and 1560nm) and to further reduce the loss of energy to ASE. A polariser was also included in the cavity to ensure a (linearly) polarised output.

The laser was found to Q-switch stably for repetition rates between 200Hz and 1.5KHz. The upper limit was determined by our maximum pump power and the lower limit by the onset of pulse-pulse amplitude noise which proved difficult to suppress without compromise to the laser performance. The power characteristic for a number of operating conditions is shown in Fig. 2.

The slope efficiency for both CW and Q-switched operation is ~0.36 with respect to incident power, and corresponds to approximately 70% quantum efficiency with respect to launched power illustrating that the fibre is still highly efficient despite its unconventional design. The laser output was characterised against pulse repetition frequency for the maximum launched power of ~300mW at an operating wavelength of 1558nm. In Fig. 3, we plot the output pulse energy against repetition rate, where it is seen that at the lowest repetition rates (~200Hz) for which stable pulsing is observed pulse energies as high as 180μJ are obtained. A corresponding plot of both the pulse duration and pulse peak power is shown inset in Fig. 3. The pulse peak powers are derived by integrating the recorded pulse shape at each repetition rate and relating the pulse form to the measured pulse energy.

It is seen in Fig. 3 that the pulse duration decreases with repetition frequency from 120ns at 1 kHz down to a duration of 45ns at 200Hz with a corresponding peak power of 3.6kW. This variation of peak power and duration is typical of a Q~switch fibre laser. Note that slightly higher peak powers (4.2kW) were obtained in our previously experiments by virtue of the fact we were using a shorter length of active fibre (~63cm) and were thus able to get shorter pulse durations (~10ns) [7]. A plot of the 45ns pulse form obtained at 200Hz is shown inset in Fig. 2, the spectral width of the pulses in this instance was 0.15nm and the spectrum was free from distortion due to the effects of Raman scattering; slightly narrower spectra ~0. 1 nm were obtained at the higher repetition rates.

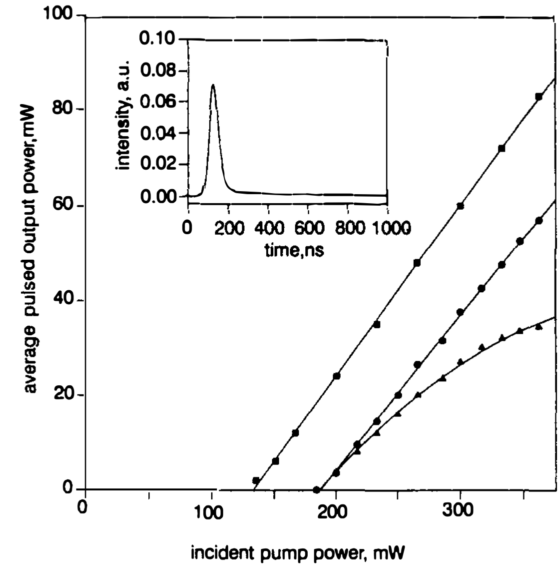

Fig. 2 *Laser power characteristics for a number of setups and operating conditions*

All measurements made at operating wavelength of 1558nm

▲ CW operation, with Q-switch, polariser and filter removed from cavity

● Q-switch operation at 1 kHz

■ Q-switch operation at 200Hz

Inset: 3.6kW, 45ns pulse shape obtained at 200Hz pulse repetition rate

In conclusion,It is seen in Fig. 3 that the pulse duration decreases with repetition frequency from 120ns at 1 kHz down to a duration of 45ns at 200Hz with a corresponding peak power of 3.6kW. This variation of peak power and duration is typical of a Q~switch fibre laser. Note that slightly higher peak powers (4.2kW) were obtained in our previously experiments by virtue of the fact we were using a shorter we have demonstrated an efficient all solid-state, Q-switch erbium doped fibre laser system based on large mode area erbium doped fibre. Pulse energies as high as 180µJ have been obtained which, as far as we are aware, represent the highest pulse energies obtained to date from a single transverse mode fibre system. It would undoubtedly be possible to reduce the pulse duration down to the <10ns regime, with a resultant increase in peak power, simply by increasing the erbium concentration and thereby reducing the cavity length. Furthermore, significantly increased average powers (> 1 W) and therefore correspondingly higher pulse repetition frequencies could be obtained by incorporating a large mode area inner core in a cladding pump fibre geometry [8].

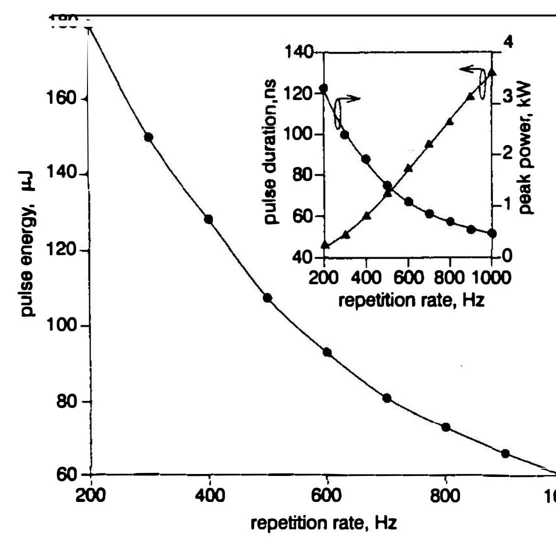

Fig. 3 *Pulse energy obtained against pulse repetition frequency*

Operating wavelength 1558nm

Inset: corresponding pulse duration and peak power against pulse repetition frequency

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