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LOW-THRESHOLD TUNABLE CW AND Q-SWITCHED FIBRE LASER OPERATING AT 1·55 μm

Indexing terms: Lasers and laser aopplications, Q-switching

A new single-mode fibre laser source is described. The laser is tunable over 25 nm in the wavelength region of 1·55 μm and produces in excess of 2 W peak power in a *Q*-switched mode.

Introduction: Single-mode fibre lasers tunable in the wavelength region of 1·55 μm, the lowest-loss window for silica, are of particular interest for long-distance optical communications and related measurements. Fibre sources and amplifiers have the advantage that they can be spliced directly into optical communications systems with negligible losses. Moreover, the availability of an increasing number of fibre devices, such as four-port couplers and wavelength filters, makes the concept of active fibre circuits attractive.

In a previous letter[1] we reported the first CW Nd^{3+}-doped single-mode fibre laser. More recently it has been shown that this laser can be tuned over an 80 nm spectral range around 1·08 μm[2*] and when *Q*-switched produces 10 W peak-power pulses.[3] The novel doping process we have developed[4] also permits the incorporation of erbium, which is known to lase at a wavelength around 1·55 μm. In this letter we report the first tunable CW and *Q*-switched Er^{3+}-doped fibre laser. The result is notable in that erbium is a three-level laser system and consequently normally operates in a pulsed mode. To our knowledge this is the first time CW laser operation at room temperature has been reported in a three-level glass laser.

Theory: Since Er^{3+}-ions in glass operate as a three-level laser system, special care must be taken in the fibre design. Saturation of the optical absorption, and consequently population inversion, can only be achieved at low power levels by using small-core single-mode fibres.

The saturation power P_s is given approximately by

$$P_s \simeq \frac{h\nu_a}{\sigma_a \tau} \pi a^2$$

where h is Planck's constant, ν_a is the frequency of the pumping radiation, σ_a is the absorption cross-section, τ is the fluorescence lifetime and a is the core radius.

To reduce the mode size and thus decrease the threshold, the fibre used in these experiments had a relatively high NA of 0·22 and a second mode cutoff at $\lambda = 1{\cdot}0$ μm. The measured absorption cross-sections were 2×10^{-21} cm² at 514·5 nm and $3{\cdot}5 \times 10^{-22}$ cm² at 800 nm. The fluorescence lifetime was found to be $14{\cdot}0 \pm 0{\cdot}5$ ms. From this we calculate a saturation power of only 1·3 mW using an argon-ion laser pump source and 4·7 mW using a semiconductor laser pump at 800 nm. In practice, the threshold power is slightly higher owing to cavity losses. Nevertheless, we have obtained CW lasing thresholds as low as 4 mW absorbed power using an Ar^+-ion laser pump.[5] With the increasing availability of high-power semiconductor laser diodes operating at or near 800 nm, we anticipate thresholds of less than 10 mW in this configuration.

Experiment: The experimental arrangement used to produce tunable CW and *Q*-switched operation of the Er^{3+}-doped fibre laser is shown in Fig. 1. A 90 cm length of Er^{3+}-doped fibre with an unsaturated absorption of 10 dB/m at 514·5 nm was cleaved and butted at the pump input end to a mirror with 77% transmission at 514·5 nm and 82% reflectivity at $\lambda = 1{\cdot}54$ μm. At the output end of the fibre, an intracavity objective was used to collimate light through an acousto-optic modulator on to a holographic diffraction grating (600 lines/mm, blazed at 1·6 μm) mounted on a sine-bar turntable. An intracavity pellicle was used as the output coupler. Neither the objective nor the modulator were optimised for operation at 1·55 μm, yet even in this lossy configuration the CW lasing threshold using the Ar^+-ion laser was only 30 mW. The CW lasing characteristic is shown in Fig. 2. Slope efficiency was somewhat low at 0·5% owing to the nonoptimum output coupling provided by the pellicle.

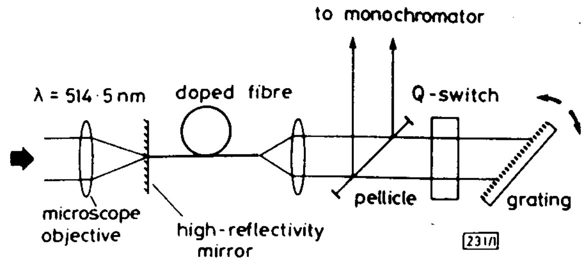

Fig. 1 *Experimental configuration for tunable CW and Q-switched fibre laser*

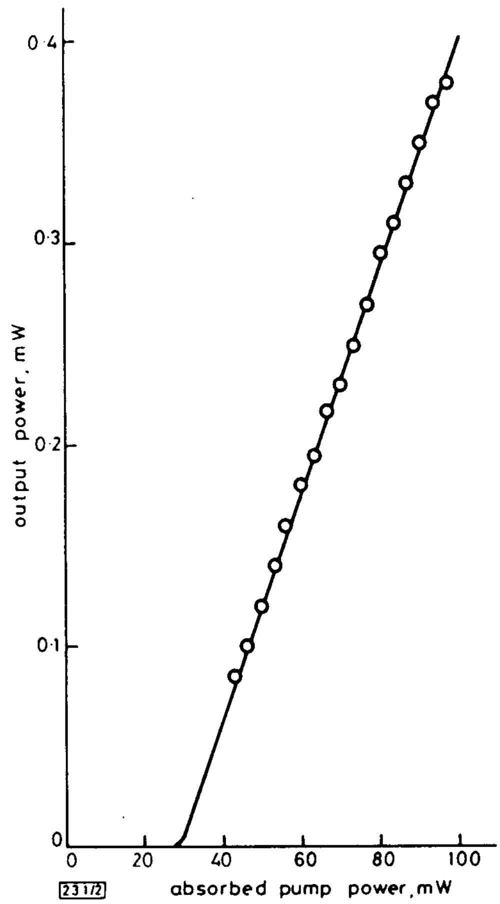

Fig. 2 *CW lasing characteristic*

In order to tune the fibre laser, the angle of the diffraction grating was varied using the sine-bar drive. A full tuning range of 25 nm, from 1·528 to 1·542 and from 1·544 to 1·555 μm, was obtained at a pump power three times that of threshold. This tuning range is shown in Fig. 3, with the erbium fluorescence curve included for comparison. It can be seen that the

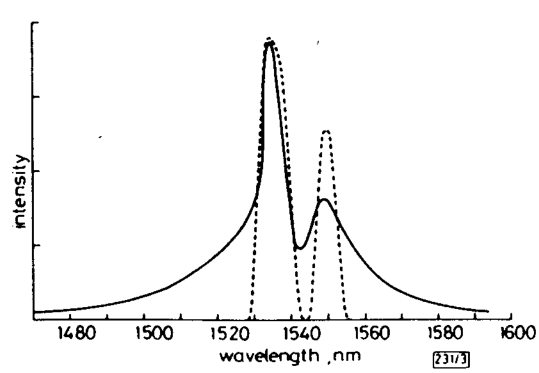

Fig. 3 *Laser tuning range (broken line) and fluorescence spectrum (solid line) of an Er^{3+}-doped fibre laser*

* REEKIE, L., MEARS, R. J., POOLE, S. B., and PAYNE, D. N.: 'Tunable single-mode fibre lasers' (submitted to *IEEE J. Lightwave Technol.*)

Er^{3+}-doped fibre laser spans much of the wavelength region of interest for long-distance fibre-optic communications.

Q-switching was effected by operating the acousto-optic modulator in a transmissive mode and switching off the modulator RF supply using 1 μs electrical pulses at variable repetition rates. Owing to the low diffraction efficiency of the modulator, it was not possible to completely hold off lasing while the RF was applied.

At a pump power 10% above threshold, pulse widths adjustable from 60 ns to 200 ns with a peak power of 2 W were obtained at a repetition rate of 200 Hz. A typical pulse is shown in Fig. 4. The repetition rate could be increased up to 2 kHz without seriously reducing the peak power. However, no significant increase in peak power was observed at larger pump powers, owing to the inability of the modulator to hold off laser action as the fibre gain increased. By optimising output coupling and modulator efficiency, it should be possible to obtain an increase in peak power of up to two orders of magnitude.

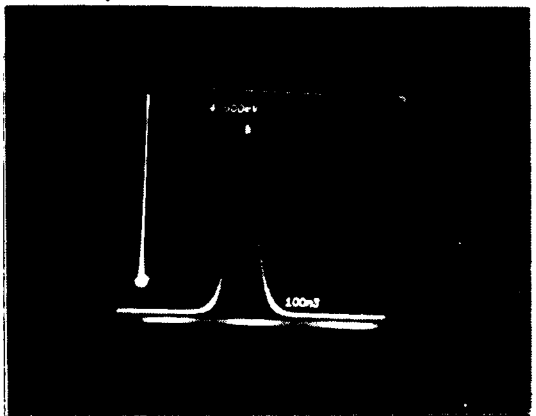

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Fig. 4 *Typical Q-switched pulse of 100 ns duration*

Conclusion: A new single-mode laser source operating at 1·55 μm has been deomonstrated which is both tunable and capable of peak output powers in excess of 2 W when used in a pulsed mode. It will find immediate application in tunable backscatter and chromatic dispersion measurements. In the longer term, fibre laser technology is expected to play an important role in sources and amplifiers for telecommunications, as well as in a number of active fibre devices and sensors.

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