EFFICIENT DIODE-PUMPED CW AND Q-SWITCHED SINGLE-MODE FIBRE LASER

Indexing terms: Lasers and laser applications, Doping, Q-switching

We report the efficient operation an Nd^{3+}-doped silica single-mode fibre laser pumped by a GaAlAs laser diode. A CW output power in excess of 1 mW at 1·088 μm has been obtained with a slope efficiency of 33%. *Q*-switched operation of this device is also reported.

Introduction: A class of active fibre devices compatible with single-mode optical fibre systems is highly desirable to supplement the semiconductor-diode/optical-fibre technologies currently in use. As a first step towards this goal we have demonstrated lasing action in rare-earth-doped silica single-mode fibres[1] with both semiconductor laser[2] and argon ion/dye laser[3]* pump sources. A powerful source capable of being directly spliced to standard single-mode fibres is required not only for telecommunications but also for a whole range of backscatter and sensor applications.

Semiconductor laser–diode pumping is highly convenient both in terms of cost and operational requirements. In this letter we describe an efficient, low-threshold single-mode Nd^{3+}-doped fibre laser. Over 1 mW CW power at 1·088 μm was obtained with a pump wavelength of 820 nm. *Q*-switched

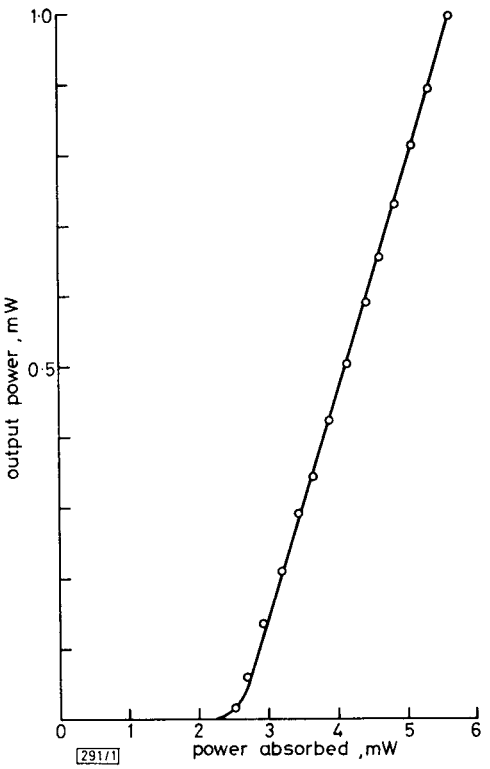

Fig. 1 *CW lasing characteristic of Nd^{3+}-doped single-mode fibre laser pumped by a GaAlAs laser diode*

operation produced pulses of more than 300 mW peak power with an FWHM of 500 ns at a repetition rate of 400 Hz.

Experiment: The experimental configuration is similar to that described previously.[2] The fibre used had the following characteristics: 3·5 μm core diameter, NA of 0·21, length of 3·2 m and a total absorption at the pump wavelength of 97% (corresponding to 300 parts in 10^6 Nd^{3+} content). The loss at the lasing wavelength was negligible (10 dB/km). The fibre ends were cleaved and butted to dielectric mirrors. The input mirror had a high transmission ($T = 85\%$) at the pump wavelength and a high reflectivity ($R = 99{\cdot}8\%$) at the lasing wavelength. In order to couple out maximum power it was found that, of the mirrors available, the optimum output mirror transmission was approximately 65%.

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

The pump source used was a single-mode GaAlAs laser (Hitachi HLP 1400), the light being launched into the fibre by microscope objectives with an efficiency of approximately 25%. The output power was measured using an InGaAs detector, and the lasing characteristic is shown in Fig. 1. The threshold for lasing action was 2·6 mW absorbed and a slope efficiency of 33% was obtained, indicating that these devices are very efficient sources. There was no evidence of saturation at the highest pump power available (5·6 mW absorbed). This is the largest reported CW output power obtained from a single-mode silica fibre laser using a semiconductor diode pump source.

Q-switched operation: In order to allow modulation of the cavity finesse by an acousto-optic deflector, it was necessary to expand the intracavity beam using the experimental arrangement shown in Fig. 2, in a manner similar to that used previously.[3,4] Owing to the intracavity components, this configuration was more lossy, yet the CW threshold was only slightly higher at 3·7 mW absorbed. The acousto-optic deflec-

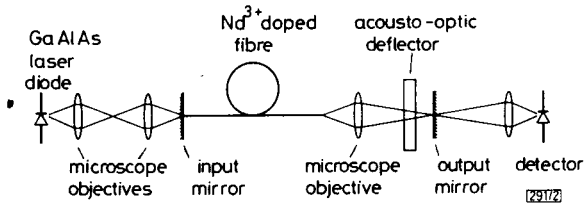

Fig. 2 *Experimental configuration used to generate Q-switched pulses*

tor was used in transmission mode, the high-*Q* state being achieved by electrically removing the applied RF with 2 μs-duration pulses. The output mirror used in this configuration had a transmission at the lasing wavelength of 12%. A typical *Q*-switched pulse is shown in Fig. 3 for an absorbed pump power of 5·6 mW. The pulse repetition rate was variable

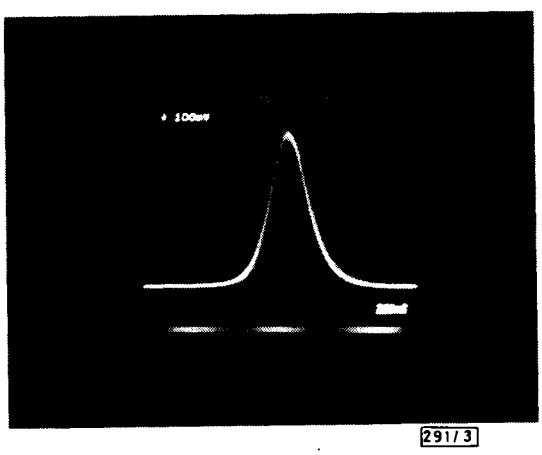

Fig. 3 *Typical Q-switched pulse generated using experimental configuration of Fig. 2*

Pulse duration is 300 ns

between single-shot and 4 kHz with no change in peak output power or pulse duration. The gain of the laser was such that, even when the acousto-optic deflector switched the cavity into its low-*Q* (i.e. 'off') state, some background CW laser action was observed at a threshold of 5 mW absorbed. This limited the peak output power attainable using this configuration.

Inserting a mechanical chopper having a mark/space ratio of 1 : 300 into the cavity produced an alternative method of *Q*-switching and prevented any laser action in the low-*Q* state. Using an output mirror with a transmission of 65% at the lasing wavelength, output pulses of peak power greater than 300 mW and FWHM of 500 ns at a repetition rate of 400 Hz were then obtained.

Conclusions: Efficient laser action in a single-mode Nd^{3+}-doped fibre laser using a GaAlAs diode source has been demonstrated. An output power in excess of 1 mW for 5·6 mW pump absorbed was obtained. In addition, *Q*-switched operation at similar pump powers gave pulses of over 300 mW peak power with an FWHM of 500 ns.

Acknowledgments: We would like to thank S. B. Poole for supplying the Nd^{3+}-doped fibre. A CASE studentship (IMJ) was provided by Plessey Research (Caswell) Ltd. The work was supported by the UK Science & Engineering Research Council under the JOERS programme.

I. M. JAUNCEY
J. T. LIN*
L. REEKIE
R. J. MEARS

Department of Electronics & Information Engineering
The University
Southampton SO9 5NH, United Kingdom

* On leave from Beijing Institute of Posts & Telecommunications, Beijing, People's Republic of China

13th January 1986

References

1 POOLE, S. B., PAYNE, D. N., and PERMANN, M. E.: 'Fabrication of low-loss optical fibres containing rare-earth ions', *Electron. Lett.*, 1985, **21**, pp. 737–738

2 MEARS, R. J., REEKIE, L., POOLE, S. B., and PAYNE, D. N.: 'Neodymium-doped silica single-mode fibre lasers', *ibid.*, 1985, **21**, pp. 738–740

3 MEARS, R. J., REEKIE, L., POOLE, S. B., and PAYNE, D. N.: 'Low-threshold tunable CW and *Q*-switched fibre laser operating at 1·55 μm', *ibid.*, 1986, **22**, pp. 159–160

4 ALCOCK, I. P., TROPPER, A. C., FERGUSON, A. I., and HANNA, D. C.: '*Q*-switched operation of a neodymium-doped monomode fibre laser', *ibid.*, 1986, **22**, pp. 84–85