NEODYMIUM-DOPED SILICA SINGLE-MODE FIBRE LASERS

Indexing terms: Lasers and laser applications, Optical sensors

We report the first CW operation of a neodymium-doped silica single-mode fibre laser pumped by a GaAlAs laser diode. A laser threshold of less than 1 mW has been obtained.

Introduction: Rare-earth-doped single-mode fibre lasers and amplifiers could potentially find many important applications in optical sensors and communications. For example, the broad fluorescence linewidth of rare-earth ions in glass could allow the construction of tunable sources and broadband amplifiers for wavelength-division multiplexing. Moreover, doped-fibre amplifiers could provide a more versatile alternative to Raman gain, which has already been investigated in optical amplifiers for repeaters[1] and as a means of overcoming losses in soliton propagation.[2]

We present here first results on single-mode Nd^{3+}-doped fibre lasers employing low-loss fibres having very small dopant concentrations.[3] The low Nd^{3+} content has allowed the construction of long laser devices in an end-pumped configuration, using both Fabry–Perot and ring-cavity resonators. The high-reflectivity Fabry–Perot cavity has given a threshold as low as 100 μW of absorbed power from a diode laser pump. In this case, stable CW operation of a few microwatts output was observed at a wavelength of 1·088 μm, a shift of 30 nm from conventional Nd:glass lasers. Previously reported neodymium fibre lasers have either been pulsed[4] or multimode.[5]

An all-fibre neodymium-doped ring cavity laser has also been constructed. To our knowledge, this is the first to be demonstrated. When pumped with a dye laser at 595 nm, the output from one port was 2 mW for approximately 20 mW absorbed in the ring, with a threshold of a few milliwatts.

Experiment: The fibre used in these experiments had a GeO_2/SiO_2 core doped with ~300 parts in 10^6 of Nd^{3+}, a cutoff wavelength of 1 μm and an index difference of 1%. The fabrication method is described elsewhere in detail.[3] In contrast to previous fibre lasers, the loss at the lasing wavelength (1·088 μm) is less than 4 dB/km. This enables the construction of lasers up to hundreds of metres long, with a doping level selected sufficiently low to give a commensurate pump absorption length.

Diode-pumped Fabry–Perot fibre laser: For experimental convenience, a fibre having a length of 2 m and an absorption of 5 dB/m at the pump wavelength of 820 nm was chosen. Fig. 1 shows the experimental configuration. The fibre ends were cleaved and directly butted to dielectric mirrors having a high reflectivity (>99·5%) at the lasing wavelength and high transmittance (>80%) for the pump. In order to achieve an elevated cavity finesse, it is essential to minimise the fibre end angle and thus ensure intimate contact with the mirror. A commercial cleaving tool* was used and the fibre ends inspected before index-matching to the mirrors.

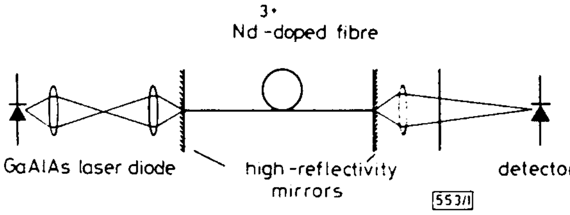

Fig. 1 *Experimental arrangement for diode-pumped fibre Fabry–Perot cavity laser*

End-pumping was by a single-mode GaAlAs laser (Hitachi HLP 1400), which was focused and launched into the fibre with an efficiency of 20%. Lasing threshold was observed for a total semiconductor laser power of 600 μW. This corresponds to an estimated absorbed pump power of only ~100 μW in the 2 m-long fibre, and is an indication of the very low intracavity losses.

The output power as a function of pump power for the fibre laser is shown in Fig. 2. No saturation of the output is observed at pump powers up to the maximum available (20 mW). Operation of the laser at reduced duty cycle gave no decrease in lasing threshold, indicating that thermal effects are negligible. The fibre laser can therefore be easily operated CW without auxiliary cooling, unlike conventional neodymium-doped glass lasers. Modulation of the pump produced relaxation oscillations, from which a cavity finesse of >300 was calculated.

The wavelength of operation of the fibre laser was measured to be 1·088 μm, i.e. shifted by approximately 30 nm to longer wavelengths than would be expected for neodymium glass lasers. This effect is due to the nature of the silica host, and has been observed previously.[6]

Dye-pumped fibre ring-cavity laser: The experimental arrangement is shown in Fig. 3. The fibre ring (diameter 70 cm) was produced by splicing together two ports of a fused tapered coupler made from an Nd^{3+}-doped fibre. The coupler was designed[7,8] so that more than 80% of the dye-laser pump at 595 nm was coupled into the ring, while at the lasing wavelength less than 10% per round trip was extracted. Coupler losses were measured to be 3 dB at 633 nm (fibre multimoded) and <1 dB at 1 μm. The fibre used is as before, although the absorption at the dye-laser pump wavelength of 595 nm is considerably higher (30 dB/m).

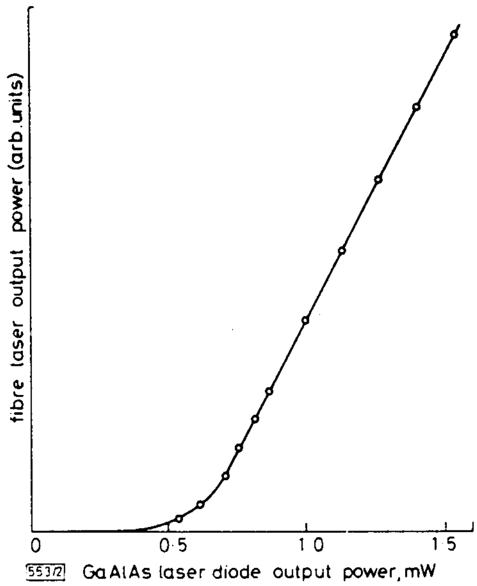

Fig. 2 *Output power against pump power for diode-pumped fibre Fabry–Perot cavity laser*

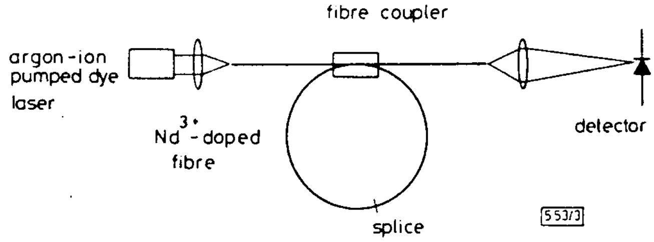

Fig. 3 *Experimental arrangement for dye-laser-pumped fibre ring-cavity laser*

Lasing threshold was observed at a dye-laser pump power of 80 mW, which, owing to coupler losses and lead absorption, corresponds to a few milliwatts absorbed in the ring. At the maximum dye-laser power of 280 mW (estimated ring absorption 20 mW), the ring-laser output was 2 mW. Allowing for bidirectional ring-laser output, the differential slope quantum efficiency is estimated to be approximately 20%.

The lasing wavelength was centred at 1·078 μm with an FWHM of 2 nm (see Fig. 4). The shift of 10 nm from the linear configuration is due to a slight mismatch between the coupler wavelength response and the laser gain curve. It may thus be possible to tune the laser wavelength over the full gain

* York Technology type C007

curve (30 nm width) by varying the coupler characteristics. The reason for the unusual nature of the lasing spectrum (Fig. 4) is not at present fully understood.

Conclusions: Neodymium-doped single-mode fibre lasers in two configurations have been demonstrated. A Fabry–Perot cavity with a finesse of > 300 has proved relatively easy to construct, and this has led to a very low threshold using a GaAlAs laser diode pump. In the ring-laser configuration, a potentially tunable output of a few milliwatts has been observed using a dye-laser pump source. These experiments confirm the potential for a wide range of active fibre devices based on low-level rare-earth doping in low-loss silica fibres.

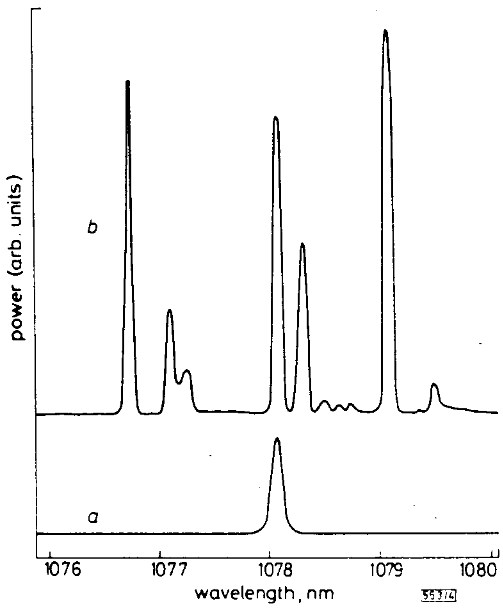

Fig. 4 *Output spectrum of fibre ring-cavity laser*

Cavity modes are not resolved by monochromator (monochromator resolution = 0·1 nm)
a Spectrum at threshold pump power P_{th}
b Spectrum at pump power = $1{\cdot}25P_{th}$

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