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DEVELOPMENT OF RARE-EARTH-DOPED FIBRES AND SINGLE-MODE FIBRE LASERS

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Abstract

Single-mode fibres containing several different rare-earth dopants have been fabricated. Characteristics of the fibres, including absorption and fluorescence spectra, fluorescence lifetimes and uniformity of dopant incorporation have been measured and the results obtained and their influence upon the performance of these fibres as fibre-lasers and amplifiers will be discussed.

Use of these fibres as tunable CW lasers centred on 1.088μm (Nd^{3+}-doped fibres) and 1.54μm (Er^{3+}-doped) with tuning ranges of 80nm and 25nm respectively are described. High peak-power output pulses have also been obtained by operating fibre-lasers in a Q-switched mode, with maximum peak-power of 2W in a 1μs pulse for a 200Hz pulse repetition rate.

Introduction

A class of active fibre devices compatible with single-mode optical fibre systems is highly desirable to supplement the hybrid 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]. These single-mode fibre lasers (SMFL) possess a number of advantages over their bulk counterparts. By virtue of their small active areas, very-low thresholds and high gains can be achieved. Since the typical fibre diameter is about 100μm, thermal effects which plague bulk-glass lasers are minimal. Silica, the host material, has good power handling characteristics; moreover, it broadens the rare-earth transitions, enabling tunable lasers and broad-band amplifiers for optical communications to be constructed.

Fabrication and Characterisation

A simple, reproducible fibre-fabrication technique has been developed[2] which allows the uniform incorporation of low levels of rare-earth ions in the core of many types of optical fibres. The technique is not limited to the rare-earth elements and could be applied to any dopant with a solid precursor material, for instance the transition metals.

Using this technique, single-mode fibres have been fabricated containing various rare-earths (Nd, Er, Tb, Eu and Pr) with dopant levels of between 0.2ppm and 900ppm (0.25wt/o). Remarkably, all exhibit windows in which losses are comparable with conventional fibres, despite the close proximity of very high-loss dopant absorption bands (see Figure 1). These low fibre losses, combined with the consistency of dopant incorporation along the fibre length, make the fibre suitable for use in distributed sensors, fibre lasers and non-linear devices, and in signal processing and switching. Measurements of the fibre characteristics relevant to these applications namely uniformity of dopant incorporation, absorption and fluorescence spectra, and fluorescence lifetime will be presented, together with their respective temperature dependencies.

Nd^{3+}-doped fibre lasers

Nd^{3+}-doped fibre lasers operate on the familiar $^4F_{3/2}$-$^4I_{11/2}$ transition usually associated with 1.059μm emission in bulk glass lasers. However, in silica, the maximum of the gain profile is at 1.088μm with a FWHM of ~50nm and a fluorescence lifetime of 470 ± 20μs. Lasing thresholds as low as 100μW have been obtained in a low-loss, end-pumped cavity configuration using a semiconductor laser pump source[1].

The excellent tunability of these lasers has been demonstrated using the experimental arrangement of Figure 2 and the tuning curve obtained is shown in Figure 3. The Ar-ion laser pump power used was 125mW, corresponding to an absorbed pump power in the fibre of 51mW. The fluorescence spectrum of Nd^{3+} ions in silica is shown for comparison. Tuning is accomplished by varying the angle of the intra-cavity grating and a tuning range of 80nm has been obtained, corresponding to most of the available gain profile. To our knowledge this is the most extensive tuning range obtained in a Nd:glass laser.

The use of an intra-cavity grating to tune the output wavelength also reduces the output linewidth from that observed in the untuned configuration, as can be seen from Figure 4. With the grating present, the output power was similar to that obtained when replaced by a mirror. However, the spectral linewidth was reduced to 0.25nm, giving an increase in spectral brightness by a factor of 20. Pulsed operation of a Nd^{3+}-doped fibre-laser has also been reported[3] and peak output powers of several watts in a 1μs pulse have been observed.

Er^{3+}-doped fibre lasers

For use in the important "third window" for optical communications, it is necessary to obtain lasing action at, or near, the attenuation minimum in silica fibres of 1.55μm. This may be achieved using an Er^{3+}-doped fibre, the fluorescence spectrum of which, shown in Figure 5, consists of two peaks at 1.534μm and 1.549μm. These correspond to the $^4I_{13/2}$-$^4I_{15/2}$ (groundstate) transition. The fluorescence lifetime has been measured to be 14 ± 0.5ms. Lasing action has been observed[4] at the peak gain wavelength of 1.534μm where erbium operates as a three-level laser with a threshold of only 4mW. To our knowledge, this work represents the lowest threshold and only room-temperature CW three-level glass laser yet reported.

Using a similar configuration to that shown in Figure 2, a tunable Er^{3+}-doped fibre laser has been constructed, the tuning curve for which is shown in Figure 5. This curve was taken at an absorbed pump power of 90mW, three times that of threshold in this configuration. Again, threshold is rather high as result of the intra-cavity components. At this pump level it was not possible to achieve continuous tuning over the range concerned. Nevertheless, two broad tuning bands of approximately 14nm and 11nm respectively were obtained. Thus, the lasing output could be tuned over most of the important "third window" for optical communications.

High peak-power pulsed operation of an Er^{3+}-doped fibre has been achieved using an intra-cavity acousto-optic modulator and operating the laser in a Q-switched mode[4]. Pulses as short as 60ns have been measured and to date the maximum peak output power obtained is ~2W in a 1μs pulse with a 200Hz pulse repetition rate. However, as the output coupling from the laser was non-optimal, improvements are expected and further details of this work will be presented.

Conclusions

A novel fabrication technique for incorporating rare-earths into the core of single-mode fibres has resulted in a new class of active fibre devices. The fibres are fully compatible with existing fibre components such as fused couplers, polarisers, filters and phase modulators and have been shown to provide both tunable CW laser output and high peak-power pulsed output. Consequently, it is possible to envisage a new all-fibre laser technology. It is anticipated that these single-mode fibre lasers will be useful in making dispersion and tunable backscatter measurements in optical fibres for telecommunications.

References

1. R.J.Mears, L.Reekie, S.B.Poole and D.N.Payne, "Neodymium-doped silica single-mode fibre lasers", Electron.Lett., Vol.21, pp.738-740, 1985.
2. S.B.Poole, D.N.Payne and M.E.Fermann, "Fabrication of low-loss optical fibres containing rare-earth ions", Electron.Lett., Vol.21, pp.737-738, 1985
3. I.P.Alcock, A.Tropper, A.Ferguson and D.C.Hanna, "Q-switched operation of a neodymium-doped fibre laser", to be published in Electronics Letters.
4. R.J.Mears, L.Reekie, S.B.Poole and D.N.Payne, "Tunable, Q-switched operation of a single-mode fibre laser at 1.55μm", to be published in Electronics Letters.

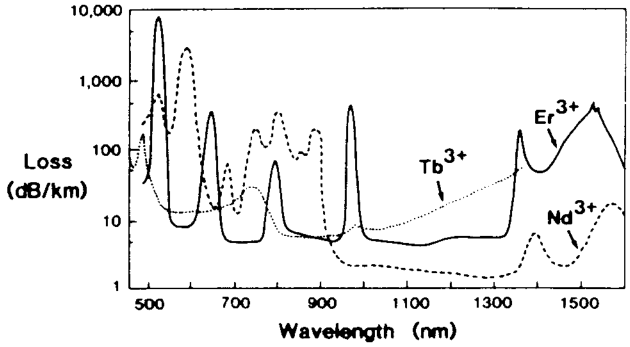

Fig. 1. Absorption spectra of fibres containing (a) 30ppm Nd^{3+}, (b) 10ppm Er^{3+} and (c) 450ppm Tb^{3+}. Note low-loss windows and high-loss absorption bands.

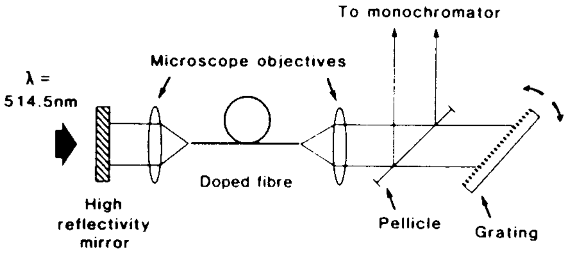

Fig. 2. Experimental arrangement for tunable fibre laser. Output coupling is via the pellicle.

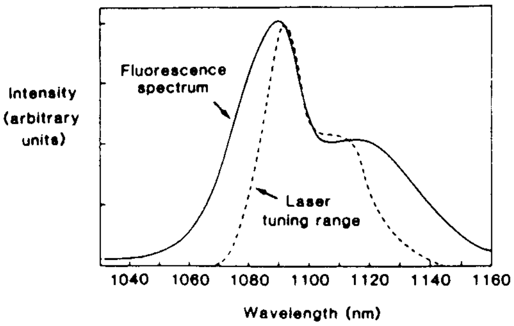

Fig. 3. Tuning curve of Nd^{3+}-doped fibre laser with Nd^{3+} fluorescence spectrum shown for comparison.

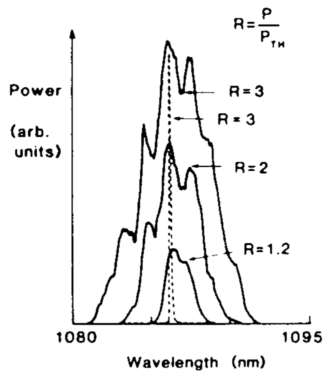

Fig. 4. Output spectrum of Nd^{3+}-doped fibre laser showing line-narrowing obtained by use of an intra-cavity grating.

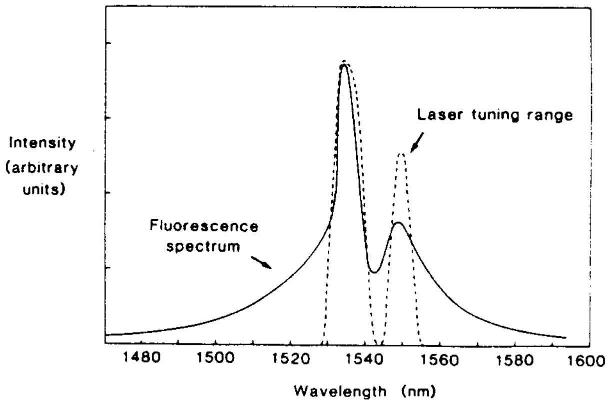

Fig. 5. Fluorescence spectrum of Er^{3+}-doped fibre and tuning curve of an Er^{3+}-doped fibre laser .