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Characterisation of fibres containing rare-earth ions

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Introduction

A recent enhancement of the MCVD process(1) has permitted the fabrication of long lengths of both mono- and multi-mode optical fibres containing low concentrations (<0.25 wt %) of rare-earth ions. The fibres have the unique properties of very high absorptions at wavelengths in the visible and near infra-red (>1 dB/m) whilst maintaining the low-losses (<1 dB/km) inherent in optical fibres at wavelengths of interest for communications. Such properties make the fibres suitable for use as either optical fibre lasers or amplifiers(2). Moreover, distributed temperature sensors can be constructed using changes in either the absorption band strengths(3) or fluorescence lifetimes(4).

The further development of rare-earth doped fibres for amplifiers and sensors presents some special measurement problems. In addition to the standard fibre characterisation measurements, eg R.I.P and attenuation, measurements are also required of such properties as absorption and fluorescence spectra, fluorescence lifetimes and the variation of each of these with temperature. Furthermore, wavelength tunable backscatter measurements are needed to verify the consistency of the dopant concentration along the length of the fibre. Many of these measurements are particularly demanding with respect to dynamic range, owing to the large losses which occur in or near absorption bands. In this paper we describe the properties and the measurement techniques used to characterise these unique fibres.

Absorption spectra measurement

The absorption spectrum of an optical fibre doped with ~30 ppm Nd^{3+} ions is shown in Fig 1. This is typical of a fibre doped with rare-earth ions in that it has regions of high absorption in the visible and near infra-red wavelength regions whilst exhibiting regions of very low loss in the region above 1 µm. Because of the very large dynamic range required in the measurement, this spectrum was obtained by determining the attenuation of a number of different fibre lengths, in this case 500m, 100m and 10m. The results were then scaled and combined to form a single plot. In addition, the apparatus has been modified to give minimal stray-light levels and a very low noise level. In this way, a single mode fibre loss measurement of 44 dB is achievable.

The temperature variations of the absorption spectra of various fibres have also been measured and results will be presented.

Fluorescence spectra measurements

Fluorescence spectra of rare-earth doped fibres have been measured by using a laser source located at a suitable pump wavelength to excite the impurity ions. The resulting fluorescence is detected at the output of a double monochromator using either a Si photo-diode or liquid-nitrogen cooled Ge APD as the detector. Phase-sensitive detection techniques are used for signal recovery, since the low impurity dopant concentration within the fibre leads to a correspondingly small fluorescence intensity, even for (relatively) high-power pump sources. For example, a 15 mW laser pump typically yields only 50 fW of fluorescence in a 5 nm measurement bandwidth.

The fluorescence spectrum for a fibre doped with ~300 ppm Nd_{3+} ions measured by pumping with a 1 mW laser diode operating at 780 nm is shown in Fig 2. The well-known fluorescence bands at wavelengths of 950,1080 and 1370 nm can be clearly seen, although shifted somewhat to longer wavelengths as a result of the silica host.

Fluorescence lifetime measurements

For the development of optical fibre lasers, a knowledge of the fluorescence decay time is required to permit calculations of laser saturation intensities and lasing thresholds. In addition, for applications as a sensor, the temperature dependence of the fluorescence must be obtained. Measurements have been made using either a pulsed laser source or, for longer decays (>1 mS), a mechanically-chopped cw laser to excite the fluorescence. The fluorescent decay waveform is digitised and the 1/e fluorescence decay time obtained by computer processing the waveform. Results have so far been obtained on Nd^{3+} and Er^{3+} doped fibres. Data on these, including discussion of the non-exponential decay observed, will be presented.

Length-dependence of dopant incorporation

The consistency of dopant incorporation along the fibre length is of major importance when the fibre is intended for use as a distributed sensor. It is also of interest for long fibre lasers and during fabrication research. A wavelength-tunable backscatter technique allows length resolution of the strength of the absorption bands and can be used for both single and multi-mode fibres. The attenuation as a function of length for a Nd^{3+}-doped fibre is shown in Fig 3, together with a reference result for an undoped fibre. the measurements were made at a wavelength of 640 nm using a flash-pumped dye laser and pulse slicer. The data was acquired digitally, averaged and processed to give attenuation directly. The uniformity of dopant distribution can be clearly seen by comparison with the curve obtained for an undoped fibre.

Conclusions

A number of measurements have been made on a new class of doped optical fibres. The fibres are currently of great interest and measurement techniques have been developed to characterise their unique properties. However, further measurements are required, for example, to investigate a slight increase in scatter loss which appears to result from the rare-earth incorporation. Other remaining measurement challenges will be discussed.

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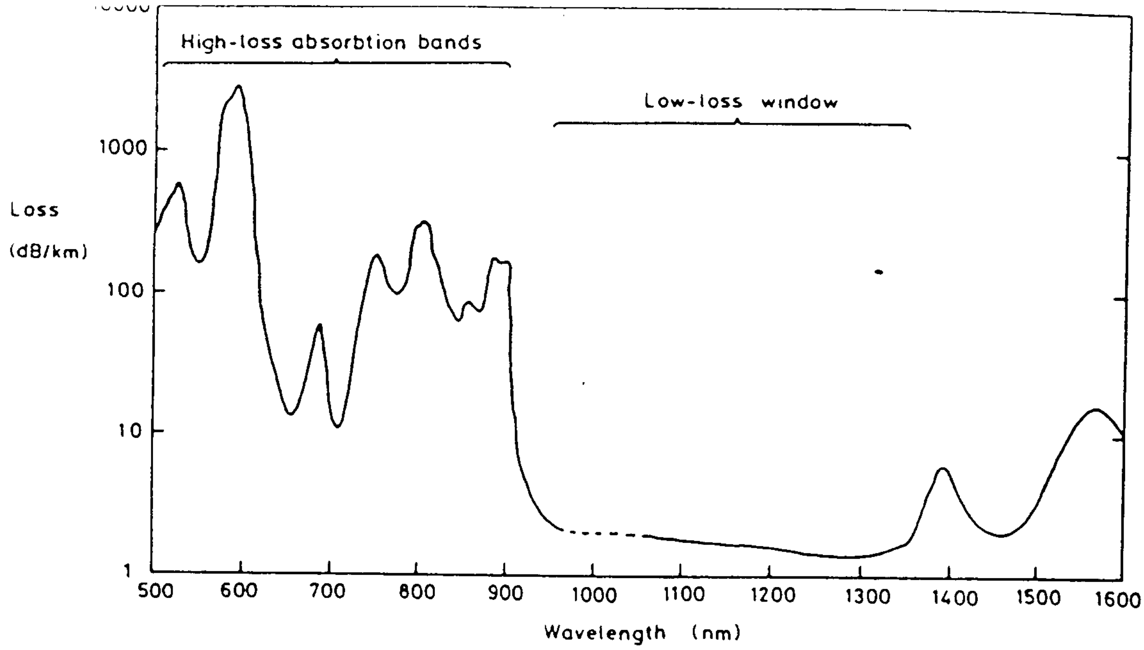

Fig 1 Absorption spectrum of fibre doped with ~30 ppm Nd^{3+} ions

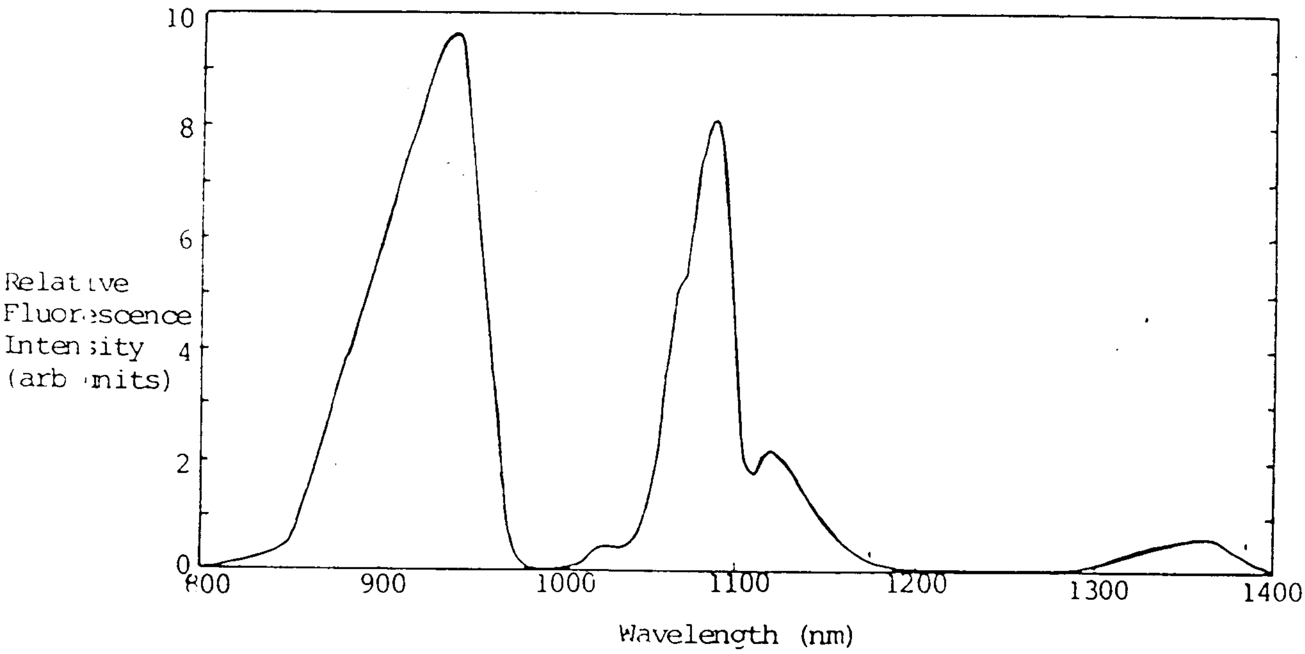

Fig 2 Fluorescence spectrum of fibre doped with 300 ppm Nd^{3+} ions

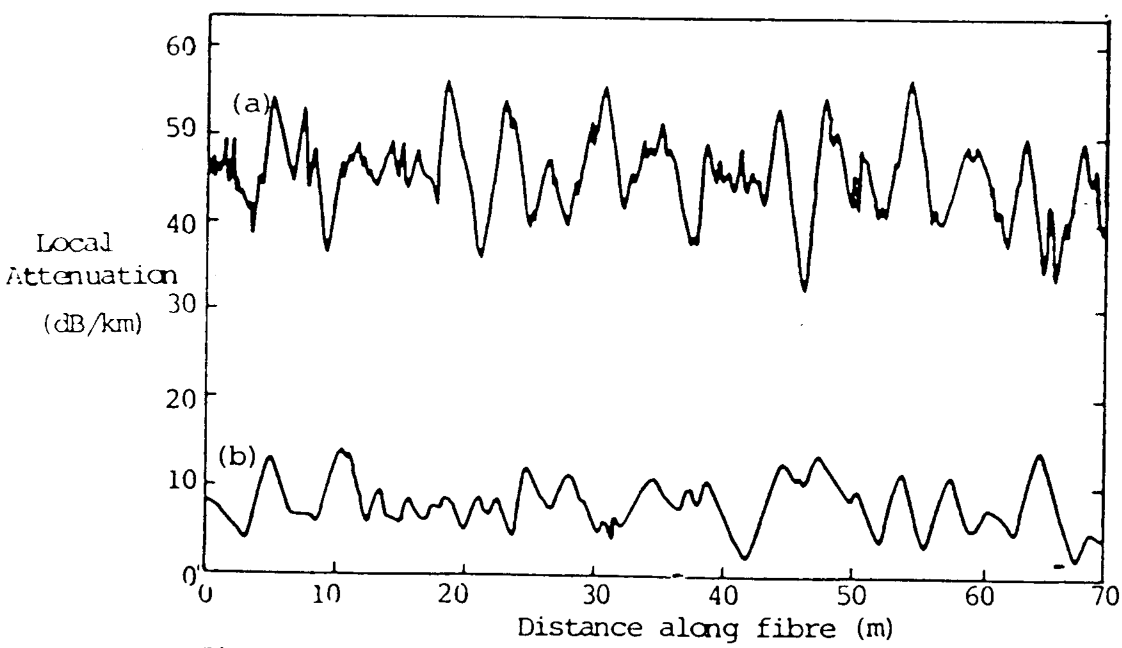

Fig 3 Local attenuation of (a) Fibre containing 30 ppm Nd^{3+}
(b) Reference 'telecomms' fibre