Wavelength stability of Nd^{3+}-doped fibre fluorescent sources

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Abstract

The output spectrum of Nd^{3+}-doped fibre fluorescent sources is found to vary with pump wavelength which presents a problem for their use in optical fibre gyroscopes. Different silica-based fibre types show different dependences. However, it is shown that single-mode fibre fabricated from phosphate glass exhibits a spectrum which is extremely stable.

Introduction.

The demonstration of superfluorescent emission at a wavelength of 1.06μm from neodymium-doped silica fibres1 has recently given rise to considerable interest in this device as a possible source for the fibre optic gyroscope [2,3] (FOG). Output powers in excess of 40mW have been demonstrated[3] and the potential for improved spectral stability compared with that of super-luminescent diodes has been identified[2]. However, to our knowledge the dependence of the output spectrum of such fibres on pump wavelength and fibre temperature has not been studied in detail and a comparison between different fibre types has not been made.

The dependence of the output fluorescence spectrum on pump wavelength is an important criterion for a practical laser-diode-pumped fibre fluorescent or superfluorescent device. For a typical AlGaAs laser-diode pump-source operating at ~810nm, a variation in output wavelength with temperature of approx. 0.4nm/^{o}C is commonly observed. Hence, variations in pump wavelength will occur with temperature and we show that this can produce major changes in output spectrum from the fibre. Temperature stabilisation of the pump source may be possible under certain circumstances. However, accurate stabilisation is not desirable in a number of applications, in particular in a FOG application with a rapid start-up requirement. For a fluorescent or superfluorescent neodymium-doped fibre FOG source, an intrinsically stable output spectrum with respect to pump wavelength is therefore required.

In this letter we report the results of measurements of the spectral stability of the $^4F_{3/2}$-$^4I_{11/2}$ fluorescence of a number of silica-based fibre types and also the spectral stability of a phosphate glass fibre. The latter fibre type is shown to give substantially improved stability over the silica-based fibres.

Experiment.

Using an experimental set up as shown schematically in fig. 1, the fluorescence spectra of several Nd^{3+}-doped fibres were measured at a number of pump wavelengths. The power from the Styryl-9 dye laser used as a pump source was kept relatively low at ~10mW in the fibre at each value of pump wavelength in order to simulate a diode laser and prevent significant amplification of the spontaneous emission which would distort the fluorescence profile. The single-ended output power of each of the fibres was of order 10μW in each case. The weighted mean wavelength $\overline{\lambda}$ of the fluorescence was computed at each pump wavelength according to the expression:

$$\overline{\lambda} = \frac{\int a(\lambda).\lambda.d\lambda}{\int a(\lambda).d\lambda}$$

Where a(λ) is the fluorescence power at wavelength λ . The weighted mean wavelength defines the gyro scale-factor and is the most meaningful way of determining the effect of spectral variations on scale-factor stability.

Fig. 2 shows the normalised spectra (2nm resolution) of Fibre 1, a 15m length of germania co-doped silica fibre (10% molar GeO_2, 150 ppm molar Nd^{3+}, 3.6μm core diameter), obtained at room temperature with pump wavelengths from 805nm to 840nm.

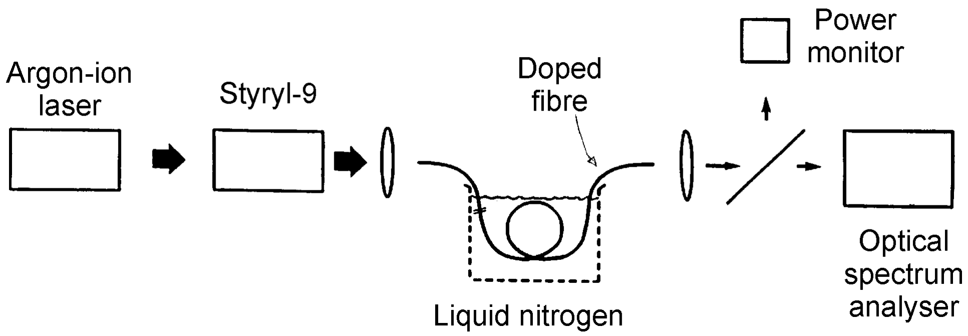

Fig. 1 Experimental set-up schematic.

At pump wavelengths between 805 and 815nm a 3-peak structure is observed, one of the peaks tracking with pump wavelength until it merges with the peak at 1088nm. At 835-840nm pump wavelengths the "travelling peak" is seen to emerge on the long-wavelength side of the 1088nm peak.

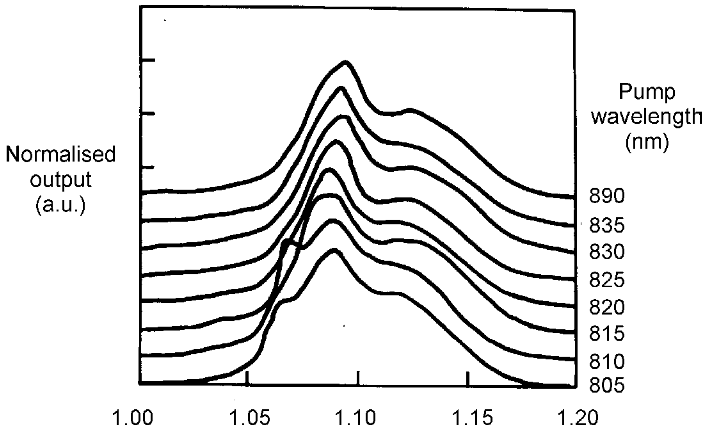

Fig. 2 Nd-doped germano-silicate fibre (fibre 1) $^4F_{3/2}-^4I_{11/2}$ emission spectra fn. pump wavelength.

Fibre 2, containing neodymium-doped alumino-phospho-silica (4 % Al_2O_3, 2% P_2O_5, 350ppm Nd^{3+}, 7μm core diameter) and fibre 3 , containing phospho-silica (14% P_2O_5, 50ppm Nd^{3+}, 19μm core diameter) were also examined at both room temperature and with the fibre at liquid nitrogen temperature. Fibre 4 was a compound glass fibre (NA 0.14, 5.5μm core diameter) fabricated by the rod-in-tube technique[4] and examined for spectral stability. In this case the core material was a high-gain phosphate laser glass (2wt% Nd^{3+} Schott LG750) and cladding material Schott PK50.

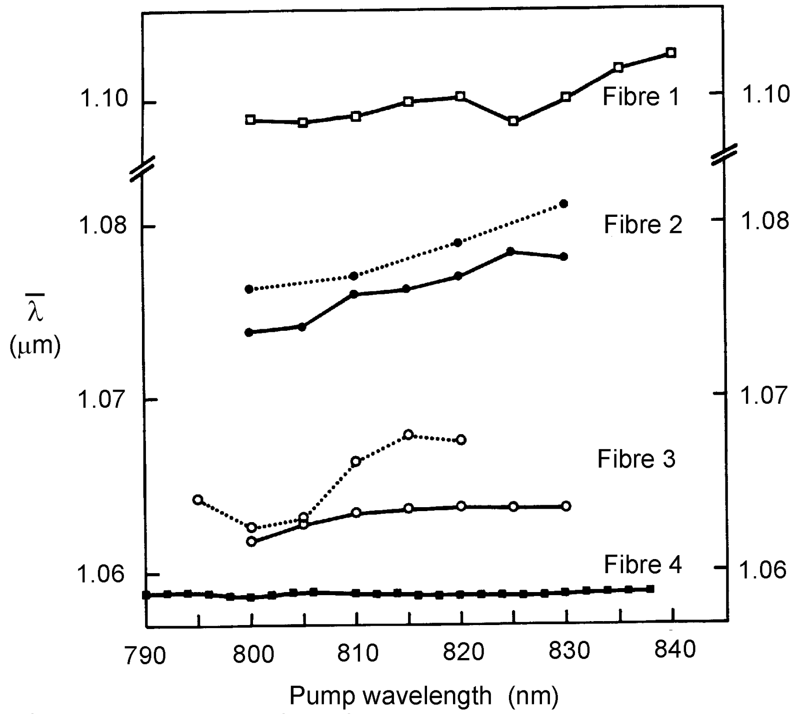

Fig.3. Weighted average fluorescent wavelength for all fibres vs pump wavelength. Dotted lines indicate liq. N_2 data.

Fig 3 shows the resultant averaged wavelength 1 obtained for each fibre type obtained at 1nm resolution. Along with a shift in wavelength between fibres a general trend of increasing wavelength with pump wavelength is observed for each of the silica-fibre types. Also an increase in average wavelength is observed on cooling fibres 2&3. The worst case pump-wavelength sensitivities of each fibre at room temperature are 0.25±0.03nm/nm, 0.32±0.03nm/nm & 0.19±0.03 nm/nm for Fibres 1-3 respectively. The worst case sensitivity to fibre temperature for Fibre 3 is only 15ppm/°C over this temperature range, indicating that the fibre temperature effect will be less than the pump wavelength effect for a typical laser diode pump source. Of the silica fibre types, the phospho-silicate fibre is clearly seen to show the most stable spectrum at room temperature, in particular for pump wavelengths greater than 810nm. However, the phosphate compound-glass fibre (Fibre 4) is seen to show an extremely stable spectrum within 200ppm variation over the entire pump wavelength range examined (790-840nm). Worst case pump wavelength sensitivity is only 0.05±0.03nm/nm, which is a factor of 4 less than that observed for the best of the silica-based fibres.

The variations in fluorescence spectra with pump wavelength are believed to be due to site-to-site variations in ionic environment within the glass lattice which give rise to slightly-different positions of the Nd^{3+} energy levels. Pumping the fibre with a narrow-line source around 800 nm preferentially excites particular subsets of the ionic population which have energy level spacings resonant with the pump source. This process is similar to non-resonant fluorescence line narrowing[5] (FLN). At low dopant concentrations (<1%), in the absence of significant cross- relaxation of excitation between dissimilar ion sites, fluorescence from the fibre will be characteristic of the excited subset of ions. The narrower inhomogeneous linewidth of neodymium in phosphate glasses compared to silica-based glasses indicates that less site-to-site variations are expected in such materials and hence less pump wavelength dependency is observed.

Conclusions

A number of Nd:silica fibre types with a range of additives have been investigated for spectral stability with pump wavelength. The results show a worst-case correlation between pump wavelength and fluorescence wavelength of approx 0.19-0.32nm/nm at room temperature. Single-mode fibres fabricated from Nd:phosphate glass do not show such a large correlation and the worst case sensitivity is approx 0.05nm/nm. This fibre type also shows a stability over the pump wavelength range 800-840nm of ~200ppm. Coarse wavelength stabilisation of ±5nm at an appropriate pump wavelength will be sufficient to produce wavelength stability of order 10ppm, suitable for high accuracy FOG applications, with the phosphate fibre type.

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