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# High-gain superfluorescent neodymium-doped single mode fibre source.


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**Abstract**

High brightness, low coherence sources are required in a number of optical sensor applications, particularly the fibre-optic gyro. An efficient superfluorescent, neodymium-doped phosphate glass fibre source has been developed which fulfils this requirement. The fibre shows a high gain efficiency at 1.053$\mu$m of 1dB/mW pump power and this permits pumping with an 810nm single-stripe AlGaAs laser diode to obtain >5mW CW output power at a wavelength of 1.053$\mu$m for only 45mW of pump power.

## Introduction

Rare-earth-doped fibres are excellent media for the generation of superfluorescent emission having low coherence and high brightness [1..5]. Superfluorescent sources are optical amplifiers in which spontaneous emission, or fluorescence, is amplified in a single or double pass of the device to give an output which is primarily due to stimulated emission but is broadband. If the amplifier gain is high enough then the output power can be greater than the saturation power of the amplifier, so enabling efficient energy extraction. Without round-trip feedback a superfluorescent source shows no modal structure and hence provides true low-coherence emission with high brightness. Such a source is of interest as a stable, high brightness replacement for ELEDs in a number of optical sensors, in particular the fibre optic gyro, where optical sources of low coherence overcome detrimental interference effects. These sources also exhibit excellent wavelength stability [6], which is a critical requirement for the gyro application. $Nd^{3+}$-doped devices emitting around 1.06$\mu$m are attractive in that they enable silicon photodetectors to be used.

Laser-diode pumping is a prerequisite in order to provide a compact superfluorescent source for practical applications. Whereas erbium-doped silica fibre sources have been demonstrated with laser-diode pump powers of only a few tens of milliwatts [5], because of their lower gain, neodymium-doped silica fibre devices have hitherto required the use of powerful multi-stripe laser diodes emitting several hundred milliwatts. These diodes require a double-clad geometry to accept their multi-moded output and by this means a superfluorescent output power of 80mW at a wavelength of 1.06$\mu$m has been reported using a 1W laser diode pump (250mW fibre coupled power) [4]. In this letter we describe an alternative approach to obtain diode-pumped superfluorescence from Nd-doped fibres using a special phosphate-glass fibre which shows a high gain efficiency at 1.053$\mu$m of approximately 1dB/mW of pump power. For such a high gain fibre, substantial superfluorescent emission can be obtained for only 20mW of launched pump power, a figure which is readily available from single-stripe AlGaAs laser diodes. Additionally, this fibre type also shows excellent wavelength stability with respect to variations in pump wavelength [6] which suits it ideally for gyro applications.

**Experimental**

Fig 1 shows the experimental configuration. A 50mm length of single-mode Nd-doped phosphate-glass fibre was fixed into a silica capilliary of 2mm outer diameter using conventional epoxy. The fibre was fabricated by pulling a core of 1wt% Schott LG750 glass in a cladding of compatible phosphate glass by the rod-in tube technique [7]. The core glass has an emission peak at 1.053$\mu$m, a fluorescent lifetime of 350$\mu$s and an emission cross section of $4.10^{-20}$ $cm^2$ [8]. Measurements of the far-field diffraction pattern of the fibre confirmed single-mode operation at 810nm and the mode-field radius at 1.053$\mu$m was determined from the diffraction angle to be approximately 2.2$\mu$m. Using the the 810nm and 1.053$\mu$m far field diffraction angles we were able to infer the NA of the fibre to be $\approx$0.2. In fibre form the fluorescent lifetime was measured to be 305$\mu$s, slightly shorter than that of the bulk laser glass.

In order to determine the gain of the fibre, a laser resonator was formed by carefully polishing the ends of the capilliary normal to the fibre axis giving a reflectivity of approximately 4% at each end and a resonator round-trip loss of $\approx$28dB. Pumping with light at 812nm from a laser diode (SDL 5411) gave a laser threshold (ie single-pass gain = 14dB) of 28mW incident pump power. This value agreed closely with the laser threshold power (30mW) obtained using a 10cm length of the cleaved bare fibre. The launched pump fraction could not be determined directly, although measurements on an un-doped silica fibre having a similar mode-field-radius indicated that 51% of the incident pump could be launched. We thus deduced that the fibre gain under these conditions was $0.95\pm0.1$dB/mW of pump power at 1.053$\mu$m. The capilliary was then polished at one end to a 14 degree angle to prevent feedback and a miniature dichroic mirror was bonded with conventional UV-curing adhesive to form the superfluorescent configuration. The mirror had >90% transmission at 810nm with >99% reflection at 1.053$\mu$m.

Pumping the fibre with a 100mW laser diode gave rise to the superfluorescence characteristic shown in fig. 2 in which the superfluorescent output is plotted against the launched pump power. The output increases exponentially up to around 1mW, after which it tends towards to a linear characteristic. The linear characteristic occurs when the superfluorescent output of the device is sufficient to cause gain saturation. The superfluorescence "threshold" can be obtained by extrapolating back the linear characteristic and is seen to be approximately 25mW pump power. We can determine the saturation power of the device by examining the point at which the measured output drops to half of the extrapolated exponential characteristic. From the data in fig. 2 the saturation power is approximately 2mW. Also shown in fig. 2 is the variation of the spectral width of the emission (FWHM) with increasing pump power. The spectral width decreases rapidly in the exponential output regime to approximately 6nm. In this regime the gain (in dB) increases linearly with pump power and a rapid reduction in spectral width is expected from gain narrowing. With the onset of gain saturation the spectral width decreases more slowly to approx 5nm. Fig 3 shows the superfluorescence spectrum observed at high output power (5mW). The spectrum is slightly asymmetric and shows a spectral width of 5nm FWHM. The superfluorescent spectra were observed under all conditions to be completely smooth and continuous at the maximum resolution of the instrument (0.1nm), exhibiting no residual Fabry-Perot resonances.

**Summary**

We have demonstrated the first single-stripe-laser pumped neodymium-doped fibre superfluorescent source which operates at 1.053$\mu$m. The result was made possible by employing a high-gain Nd-doped phosphate-glass fibre. A maximum output power of 5mW was obtained for just 45mW of pump power. The superfluorescence threshold of 25mW is a factor of 3 lower than that reported previously. Such sources are expected to find application in a number of coherence-multiplexed optical sensor systems and the optical fibre gyro.

## Acknowledgements

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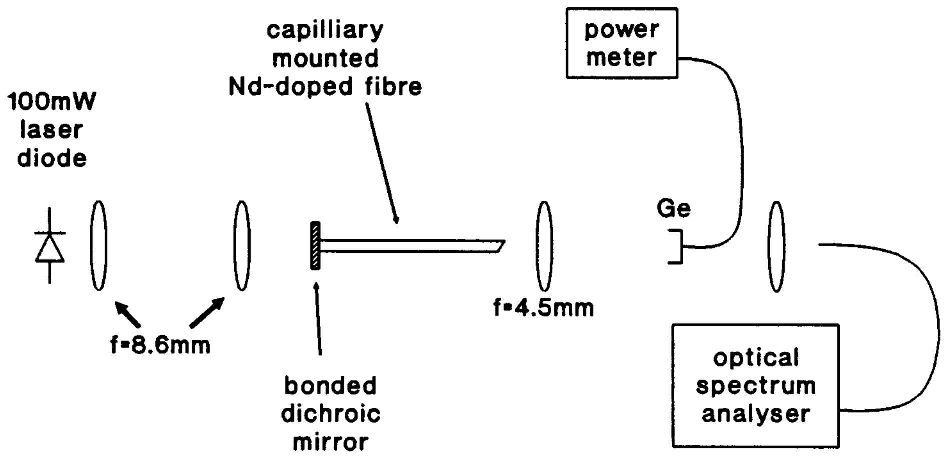
**Figure Captions**

Fig. 1 Superfluorescent source configuration

Fig. 2 Superfluorescent source output power and spectral width vs launched pump power at 810nm.

Fig. 3 Superfluorescent source output optical spectrum at 5mW output power.


capilliary
mounted
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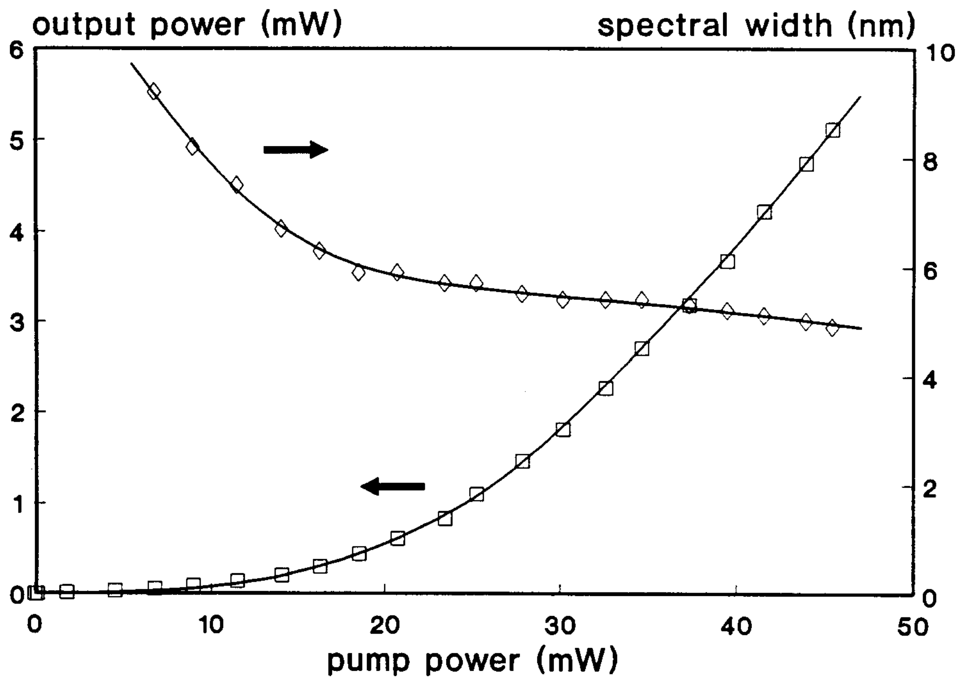
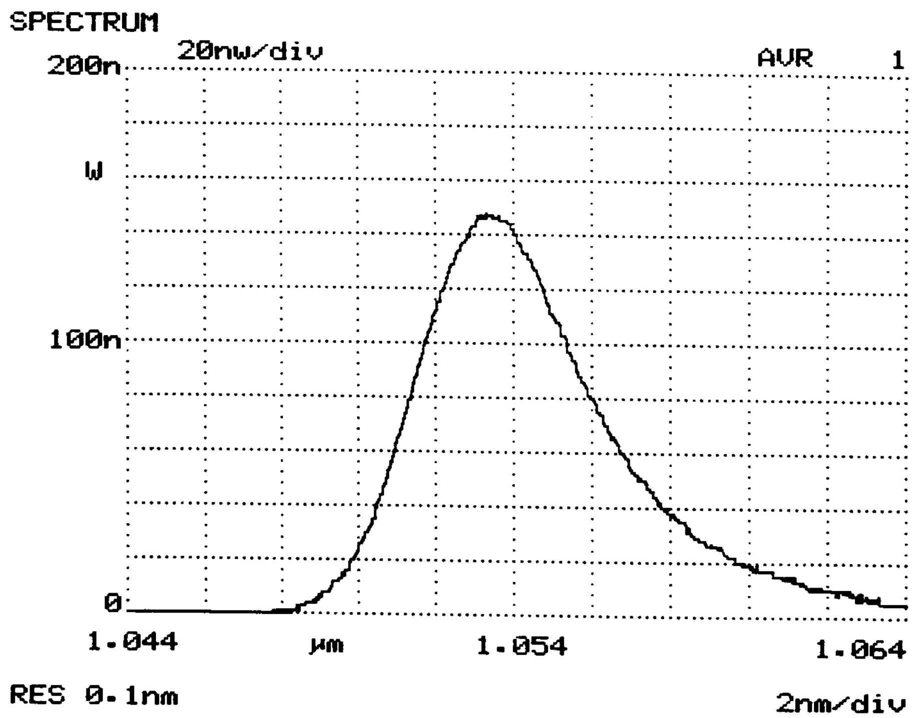
100mW
laser
diode
power
meter
Ge
f=8.6mm
bonded
dichroic
mirror
f=4.5mm
optical
spectrum
analyser


output power (mW)
spectral width (nm)
6
5
4
3
2
1
0
10
8
6
4
2
0
0
10
20
30
40
50
pump power (mW)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200n
AVR 1
W
100n
0
1.044
µm
1.054
1.064
RES 0.1nm
2nm/div