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1 Watt Er/Yb Single-mode Superfluorescent Optical Fibre Source

S. Gray, J.D. Minelly, A.B. Grudinin and J.E. Caplen

Optoelectronics Research Centre
University of Southampton
Southampton
SO17 1BJ
United Kingdom

Abstract

We describe a single-mode superfluorescent Er/Yb optical fibre source capable of generating greater than 1 Watt of output power. The spectral bandwidth of the source can be varied between 0.5 and 4 nm by filtering.

Superfluorescent sources based on rare-earth doped single mode fibres [1,2] are potentially useful in many applications requiring high brightness combined with broad bandwidth and low coherence. These include sensors such as fibre optic gyroscopes for rotation sensing and low coherence reflectometry systems used, for example, in imaging biological tissues [3]. Additionally, the quiet continuous wave (cw) output characteristics obtained with a fibre based superfluorescent source are in strong contrast to the self-pulsing and spiking behaviour observed over microsecond timescales in fibre lasers of similar power. These effects, attributed to the formation of ion pairs which behave as saturable absorbers [4], are undesirable where a stable output is required. It has been demonstrated that the self-pulsing behaviour can be eliminated by resonant pumping [5] but no suitable pump sources are readily available for creating lasers with high output powers. The objective of this paper is to describe the construction of a high power superfluorescent fibre source suitable for use in applications where a stable cw output is essential.

The schematic arrangement for the source described in this letter is demonstrated in fig. 1. It consists of an ASE seed source, a pre-amplifier and a power amplifier backward pumped by up to 6 Watts of light from a Nd:YLF laser operating at 1054 nm. In constructing a high power superfluorescent fibre source it is necessary to carefully design the system so as to avoid inducing laser oscillation from the feedback generated by Rayleigh scattering [6]. The fraction of optical power scattered in a section of fibre is given approximately by αL where α is the fibre loss coefficient and L the fibre length. A fraction $(NA)^2/(4n^2)$ of this light, typically ~0.005, is captured and guided in the reverse direction. To prevent lasing from this backscatter requires the amplifier gain to satisfy $G\alpha L(NA)^2/(4n^2)<1$. For fibre amplifiers of approximately 10 metres in length this limits the gain to a maximum of ~57 dB although in practice other factors such as reflections from splices may introduce a lower limit. Previous studies have demonstrated that lasing can be avoided by seeding a high power amplifier with a saturating signal from a low power amplified spontaneous emission (ASE) source [7]. By this method it is possibe to extract almost as much power as can be obtained from a fibre laser under similar excitation. The ASE seed source and amplifiers were constructed from 125 μm diameter Er/Yb fibre doped with 8000 ppm of Ytterbium and 600 ppm of Erbium and having a numerical aperture of 0.19 and LP_{11} cutoff wavelength of 1350 nm. The three stages are separated by polariztion independent isolators with >30 dB isolation to prevent feedback between each stage which may cause lasing. Wavelength division multiplexers link each section to allow the pump to bypass the isolators.

Construction of the source began with the ASE seed and pre-amplifier. Both sections were made the maximum length possible without lasing occurring. The power amplifier was then added and the length adjusted to maximise the output power. Without spectral filtering of the ASE source the maximum output power was 1.03 watts and the spectra of the seed source and output are shown in fig. 2a and b. The peak of the ASE source is at 1535 nm but the long second stage of the amplifier provides a high gain at 1544 nm and this peak begins to dominate at the output. The 1544 nm peak has a 3 dB bandwidth of 4 nm and by using an appropriate filter it should be possible to achieve a flat spectral profile over ~10 nm.

Some applications require narrow bandwidth sources and to achieve this a filter formed by a circulator and reflective Bragg grating with 100% reflection over a 0.5 nm bandwidth centred at 1535 nm was placed in the system immediately after the ASE seed source. The spectrum of the filtered source taken after the preamplifier is shown in fig.2c and shows strong suppression of spectral components away from the 1535 nm peak. After the power amplifier stage, which generated a maximum output power of 980 mW, the output from the source was transmitted through a 1535/1560 WDM to filter out ASE components away from the 1535 nm peak and the spectrum at the output of this WDM is shown in fig.2d [8].

In an effort to increase the power obtainable from the source the power amplifier was replaced by a more highly doped Er/Yb fibrehaving dopant concentrations of 1000 ppm of Erbium and 15000 ppm of Ytterbium. The length was varied to optimize the output power and for the maximum launched pump power of 6.8 watts the output power was 1300 mW giving an efficiency of 19%. For this configuration, the output power of the ASE seed source and the gain of each amplifier stage was characterized at different values of pump power and these results are shown in fig. 3. For the case of maximum output power the seed source generated 52 mW of which 9.2 mW was transmitted by the filter. This was amplified by gains of 14.4 and 7.2 dB in the preamplifier and power amplifier respectively.

To confirm the cw charactersitics of the superfluorescent source the output intensity was monitored on a fast photodiode and the spectral behaviour of the generated current was measured. Measurements of the frequency spectrum of the output intensity are shown in fig. 4 for both the superfluorescent source and the Nd:YLF pump. The only feature appearing in these spectra is a relaxation oscillation peak from the YLF laser at a frequency of 1.26KHz which is reproduced in the spectrum from the ASE source. These measurements confirm that the self-pulsing observed in fibre lasers is absent.

In conclusion, we have described a cw superfluorescent single-mode fibre source capable of delivering up to 1300 mW of output power at a wavelength of 1535 nm. Bandwidths from 0.5-4 nm have been demonstrated and the required bandwidth for a particular application can be selected by use of an appropriate filter.

References

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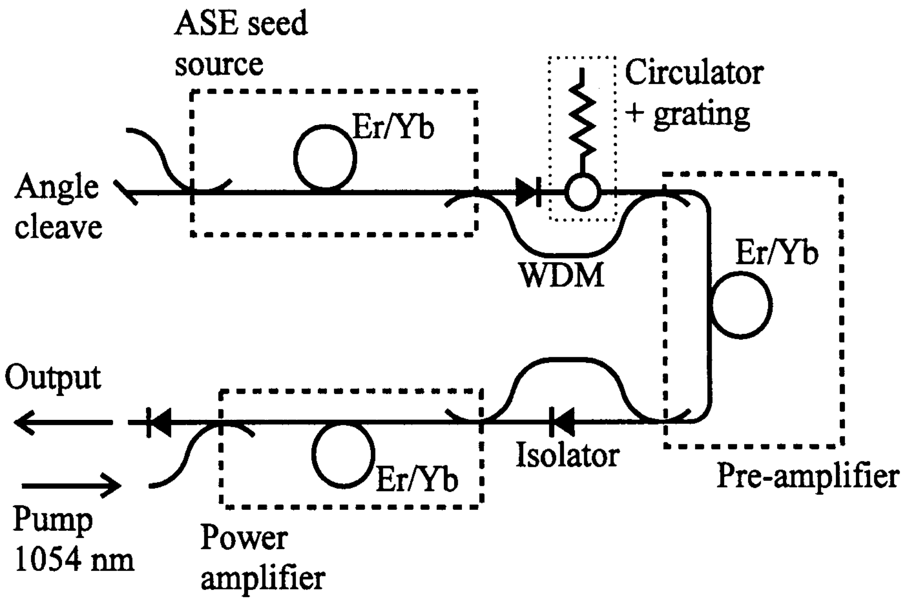
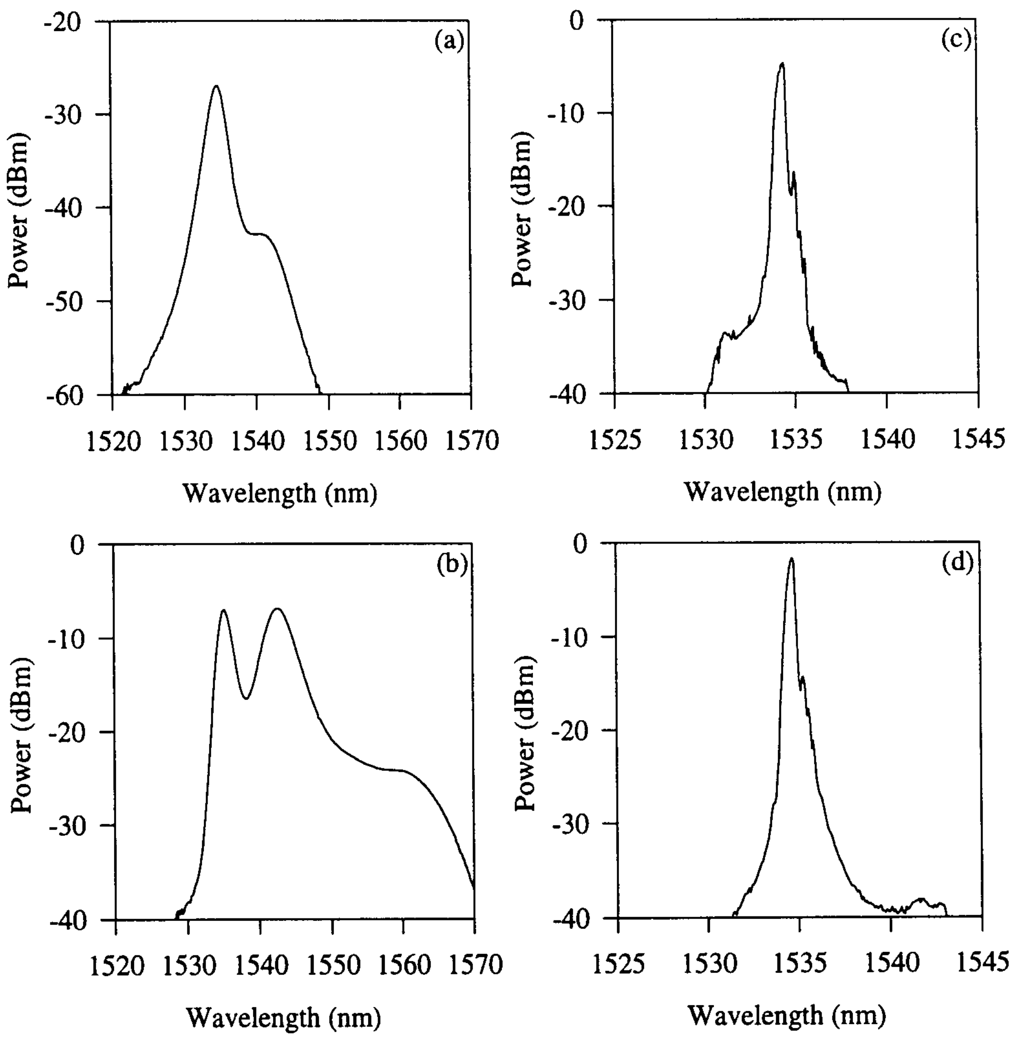
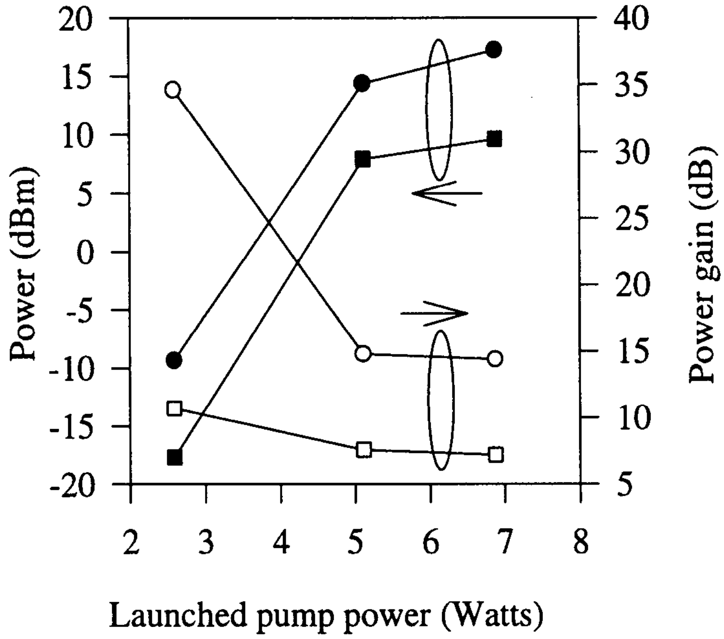
1. Configuration of the superfluorescent source.



2. Optical spectra of (a) seed source, (b) output for an unfiltered system, (c) preamplifier output of filtered seed source and (d) output of filtered source after a 1535/1560nm WDM.



3. Output power from ase seed source (filled circles) and filter (filled squares); gains of the preamplifier (open circles) and power amplifier (open squares).



4. RF spectra of (a) Nd:YLF pump and (b) superfluorescent source.