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Single-Frequency, Single-Polarisation Tunable Miniature Erbium:Ytterbium Fibre Fabry-Perot Lasers by Self-Injection Locking

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Abstract

We demonstrate a successful single-frequency and single-polarisation operation of erbium:ytterbium fibre Fabry-Perot lasers with a frequency-selective and polarisation-selective optical feedback using a fibre Bragg grating and a polariser. A side-mode suppression over 60dB and a pure single-polarisation operation have been achieved.

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Short-cavity erbium:ytterbium (Er^{3+}:Yb^{3+}) fibre Fabry-Perot lasers (FFPL's) are attractive as compact, stable and tunable single-frequency laser sources[1][2], as well as compact and stable multiwavelength laser sources at the cryogenic temperature[3]. However, they have difficulties for the single-frequency laser applications. One is that the microcavity FFPL's output relatively small optical powers (typically tens of μW[1][2]) due to insufficient pump absorption of Er^{3+}:Yb^{3+} fibres. Longer cavity length (>1mm) can enhance the output power, but it results in unstable multiwavelength lasing even at the room temperature[3]. The other is that these FFPL's actually operate in two orthogonal polarisations as a result of polarisation independence in the fibre Fabry-Perot cavity[3], which is not desirable for most applications.

Injection locking techniques have been used for achieving single-mode operation[4] and chirp-free modulation[5] of semiconductor lasers. Self-injection locking configuration using a narrowband fibre Bragg grating (FBG) as a frequency-selective optical feedback element is more attractive because of its simplicity and robustness, and used to stabilise the wavelength of semiconductor lasers[6][7]. The authors have realised single-polarisation operation of fibre distributed feedback lasers with a polarisation-selective optical feedback[8]. In this paper, we demonstrate that the miniature FFPL could successfully operate in a single frequency and a single polarisation with a frequency-selective and polarisation-selective optical feedback.

The self-injection locked FFPL is illustrated in Fig.1. The FFPL consists simply of one millimeter of phosphosilicate Er^{3+}:Yb^{3+} fibre with high reflectivity (99.86%) dielectric mirrors deposited on the two polished end-faces, and single mode fibres epoxied on both ends for coupling the pump and output emissions. The Er^{3+}:Yb^{3+} fibre has Er^{3+}:Yb^{3+} concentrations of 1750:14000 parts in 10^6, a cutoff wavelength of 1300nm, small signal absorption of 0.1dB/mm at 1535nm, and small pump absorption of 2.4dB/mm at 976nm. The FFPL is pumped with a semiconductor laser operating at 980nm through a wavelength-division multiplexed (WDM) coupler, and the leftward lasing light is output through the WDM coupler and an isolator. At the another end of the FFPL, the rightward lasing light is fed into a frequency-selective and polarisation-selective optical feedback device composed of a narrowband FBG and and an inline polariser. The FBG used in the experiment has the bandwidth of 0.2nm and reflectivity of about 30%, and the inline polariser has extinction ratio more than 40dB and insertion loss of 1dB. Two polarisation controllers (PC's) are inserted between the FFPL and the polariser (PC1), and between the polariser and the FBG (PC2), respectively. We can select either of the two lasing polarisations to be fedback by adjusting the PC1, and the PC2 is used to cancel the birefringence between the polariser and the FBG. To enhance the feedback effect, a length of Er^{3+}-doped fibre (EDF) can be inserted between the FFPL and the polariser, and pumped with the residual 980nm light through the FFPL.

Figure 2 shows the output optical spectrum (Resolution: 0.08nm) without self-injection locking. The FFPL was operating at multiwavelength in spite of the homogeneous gain of Er^{3+}:Yb^{3+} fibre owing to the spatial hole burning effect[3], but the operation was not stable. The mode spacing is 0.8nm (100GHz), corresponding to the free spectral range (FSR) of a 1mm-long FFPL cavity. The output polarisation states were observed using a polarisation analyser (Hewlett Packard HP8509B), and it was found that the degree of polarisation (DOP) was about 10%, which means the output was almost depolarised. Heterodyne measurement with a tunable single-frequency laser as a local oscillator showed that all modes consist of two orthogonal polarisation modes separated by about 2GHz, as observed in Ref.[3].

Figures 3 show the output optical spectra with self-injection locking.

The centre wavelength of the FBG is tuned to one of the FFPL modes by stretching the FBG. Figure 3(a) is when it was tuned to the mode at 1544.8nm, and Figure 3(b) at 1545.6nm. Nearly single-mode spectrum was obtained in both cases as expected, although there remained a mode at 1541.4nm suppressed by about -15dB. This insufficient side-mode suppression is likely due to the insufficient feedback; 30% reflectivity and 1dB loss mean that 20% of the rightward lasing light is feedback to the FFPL. The output powers were also enhanced by about 7dB. The DOP's of these outputs were about 95%, which means they were nearly in a single polarisation. Remaining 5% is due to the insufficient side-mode suppression. Single-polarisation operation was also confirmed by the heterodyne measurement.

We inserted a 2m EDF pumped with residual 980nm light between the FFPL and the polariser to enhance the feedback effect. The output optical spectra with EDF-enhanced self-injection locking are shown in Figs.4(a)(b). In this case, the side modes were totally suppressed, and the side-mode suppression ratio is more than 60dB (sensitivity-limit of the optical spectrum analyser). The output powers were slightly enhanced compared with Figs.3(a)(b). The DOP's of these outputs were more than 99%, which means they were in a pure single polarisation, and this was also confirmed by the heterodyne measurement. We found that this single-frequency and single-polarisation operation was very stable.

In this experiment, the FBG has been tuned by stretching, which limits the tuning range to a few nm. However, wideband discrete tuning of the self-injection locked FFPL over the gain bandwidth of Er^{3+}:Yb^{3+} fibres is potentially possible by using compression tuning of the FBG[9]. Very narrow-band FBG's below 0.1nm are easily available, which can resolve the modes of ~10mm long FFPL's with much enhanced output optical power. A fibre polariser is easily obtained by side-polishing a fibre and coating a metal on it[10], and PC's are not necessary by shortening the optical feedback. From the above, we believe that the self-injection locking is a simple, robust and useful technique to realise single-frequency, single-polarisation tunable FFPL's.

In conclusion, we have demonstrated that the FFPL could successfully operate in a single frequency and a single polarisation with a frequency-selective and polarisation-selective optical feedback using a FBG and a polariser. A side-mode suppression over 60dB and a pure single-polarisation operation have been achieved.

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Figure Captions

Figure 1 Self-injection locked fibre Fabry-Perot laser (FFPL).

Figure 2 Output optical spectra of the FFPL without self-injection locking.

Figure 3 Output optical spectra of the FFPL with self-injection locking.
(a) FBG is tuned to 1544.8nm (b) FBG is tuned to 1545.6nm

Figure 4 Output optical spectra of the FFPL with EDF-enhanced self-injection locking.
(a) FBG is tuned to 1544.8nm (b) FBG is tuned to 1545.6nm

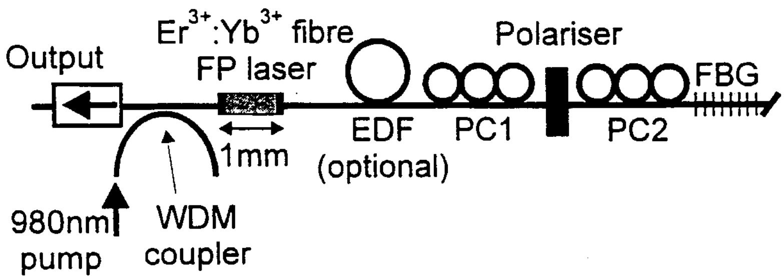

Fig.1
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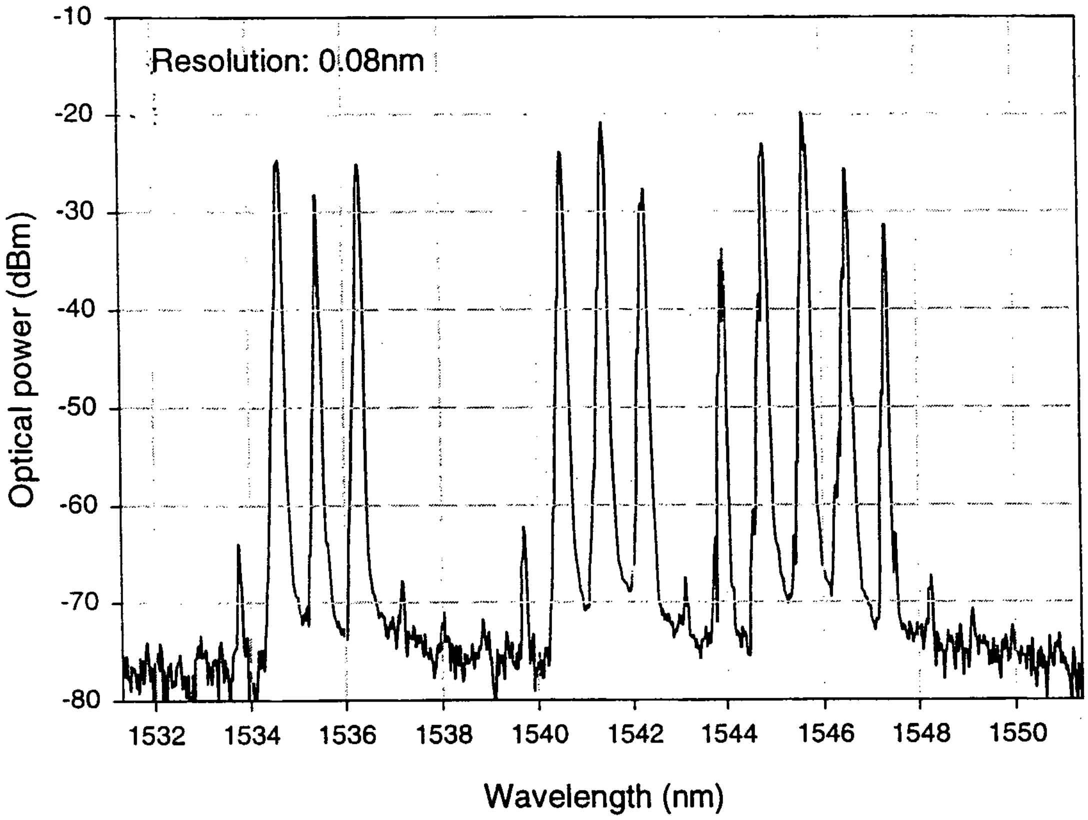

Fig.2
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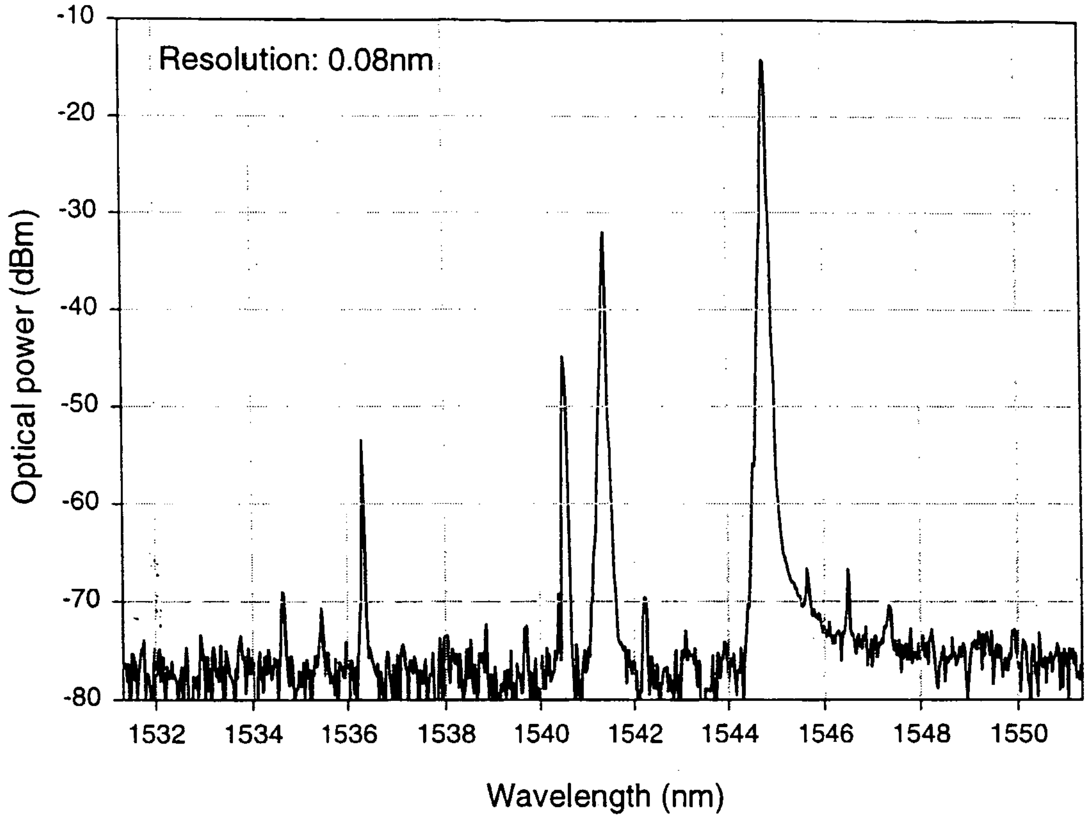
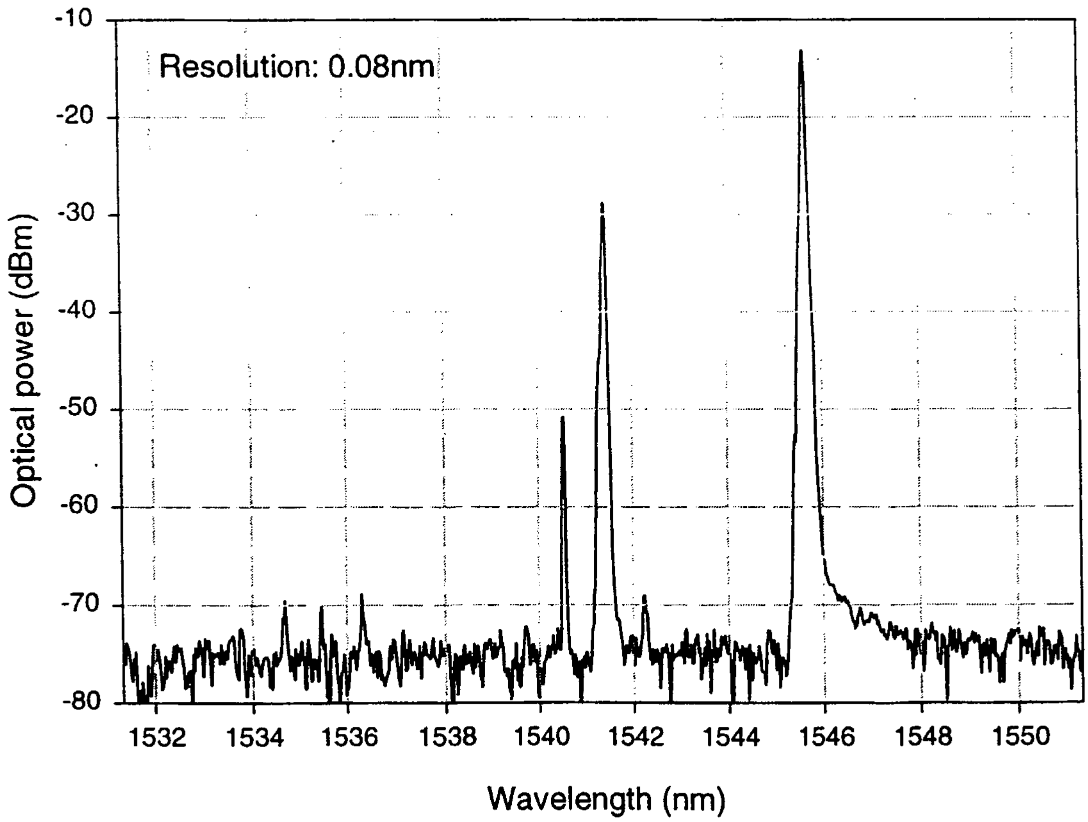


(a)



(b)

Fig.3
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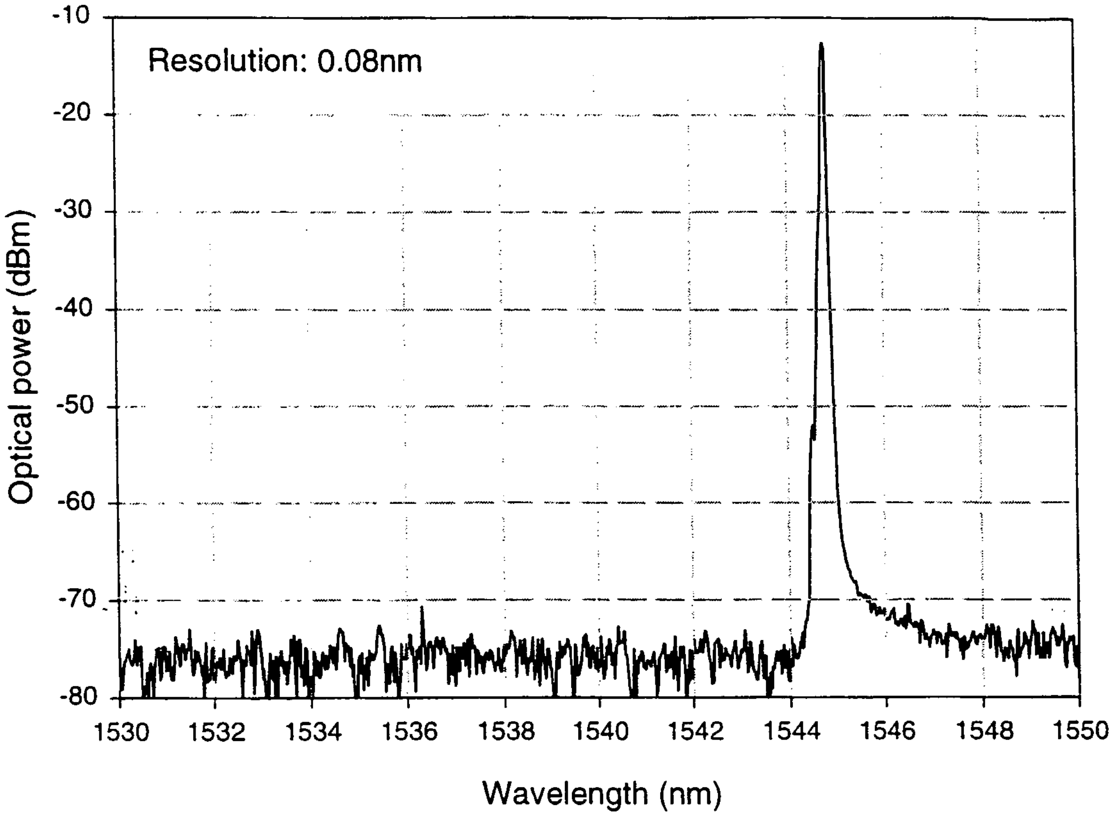
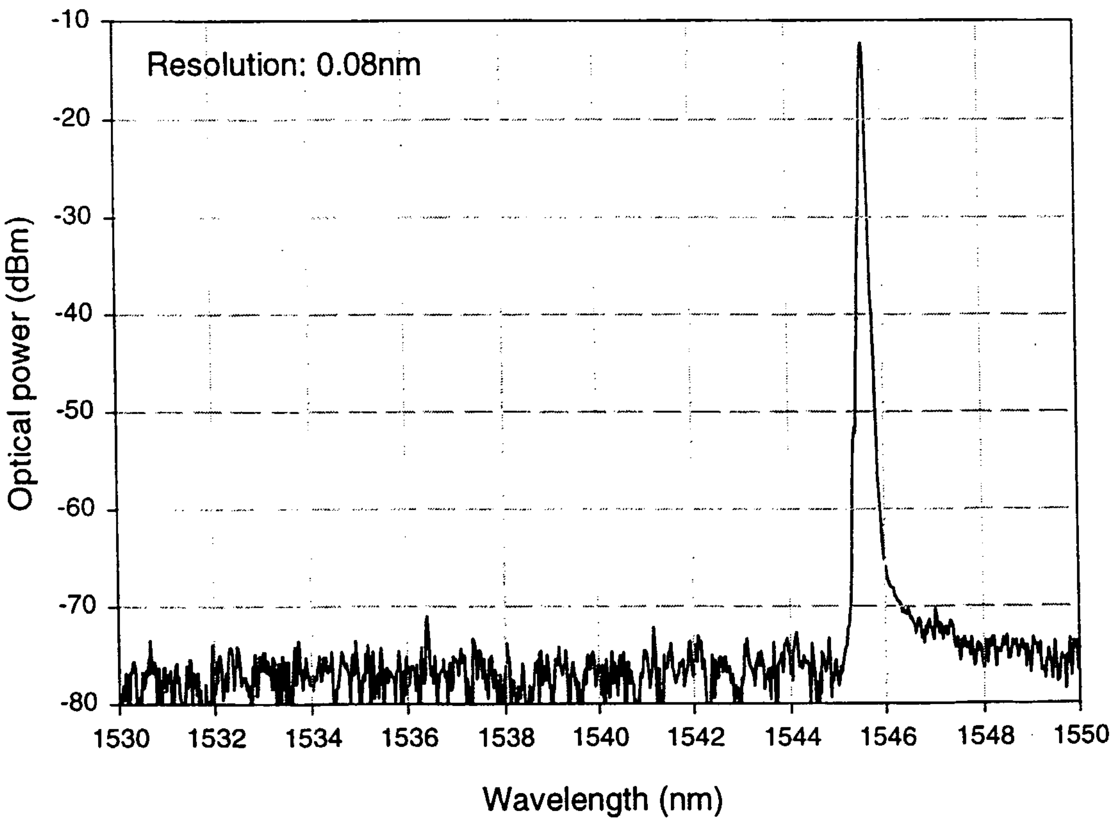


(a)



(b)

Fig.4
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