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Submitted to Photonics Tech. Lett.

10/12/97

Bidirectional 10GHz Optical Comb Generation with an Intracavity Fibre DFB Pumped Brillouin/Erbium Fibre Laser

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Abstract

We present multiwavelength and bidirectional operation of a novel Brillouin/erbium fibre ring laser. Multiwavelength operation is seeded by an Er^{3+}:Yb^{3+} fibre DFB laser inserted into the ring cavity. We realised lasing at up to eight wavelengths separated by 10.6GHz.

Index Terms

Optical fibre lasers, Brillouin scattering, multiwavelength lasing, bidirectional lasing, erbium fibres, fibre DFB lasers

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Multiwavelength laser sources are of great interest for wavelength-division multiplexed (WDM) communication and sensor systems. Erbium-doped fibre lasers (EDFL) can produce many wavelengths stably by cooling to the cryogenic temperature to reduce the homogeneous linewidth of the erbium-doped fibre (EDF) and prevent mode competition[1]–[3]. Recently, Brillouin/erbium fibre lasers (BEFL) have been demonstrated as a densely (10GHz) spaced robust multiwavelength laser source operating at room temperature[4]. To date, lasing up to 30 wavelengths has been realised[5]. In this paper, we present a novel configuration of a BEFL, in which Brillouin gain is initiated by an Er^{3+}:Yb^{3+} fibre distributed feedback (DFB) laser in the ring cavity. The laser output features multiwavelength and bidirectional operation. The latter feature makes this laser applicable to Brillouin fibre-optic gyros[6].

For maximum efficiency of the Brillouin gain, the Brillouin pump signal must have a linewidth less than the Brillouin gain bandwidth, and in previous BEFL demonstrations, external cavity semiconductor lasers have been used as the Brillouin pump. Single-frequency fibre lasers produce the appropriate power and linewidth characteristics for Brillouin pump requirements, as evidenced by multiwavelength BEFL operation in which each line uses the previous line as a Brillouin pump. The laser described here uses a fibre DFB laser as the Brillouin pump, and the DFB laser is integrated into the resonator. As a result, a single 980nm pump source is required to produce the Brillouin pump and the BEFL lines. The laser configuration is shown in Fig.1, similar to the distributed-feedback ring all-fibre laser[7], but with additional EDF and single-mode fibre (SMF). The Er^{3+}:Yb^{3+} fibre DFB laser[8] in the ring cavity is pumped with a 980nm MOPA through a WDM coupler. Clockwise (CW) and counter-clockwise (CCW) signals from the DFB laser generate Brillouin gain at the Stokes frequency (-10.6GHz) in a SMF in both directions. The stop bandwidth of the fibre grating for the DFB laser is less than 0.1nm, so it is highly transparent at the Stokes frequency. If the Brillouin gain and gain in the EDF overcome the cavity losses, the BEFL operation at the Stokes frequency is initiated in both directions. The bidirectional BEFL modes can in turn cascade Brillouin gain in both directions, hence multiwavelength and bidirectional lasing can be realised. As an output coupler, we used another WDM coupler to minimise the cavity loss, with output coupling ratio is about

0.01%.

Figure 2 shows the output optical spectra in both directions. The mode at 1548.78nm is the DFB lasing mode, and other modes at longer wavelengths are the BEFL modes. We realised stable BEFL lasing at seven wavelengths separated by 10.6GHz (0.08nm) in both directions using 1400m SMF and 1.5m EDF. Anti-Stokes light (+10.6GHz) was also observed by adjusting the polarization controller (P.C.) as a result of the bidirectional operation and four-wave mixing process.

Figures 3(a)(b) show the CW and CCW output modal powers as a function of pump power. The power characteristics of each line are nonlinear, reflecting that in the steady state each line depletes the previous line through the Brillouin gain and is depleted by the following line. Discrepancy in CW and CCW output modal powers is due to the the asymmetric ring configuration and the unequal output powers of DFB modes in both directions which is a consequence of nonuniform pumping.

We observed that both shorter SMF and shorter EDF reduced the number of BEFL modes, and longer EDF initiated lasing supported only by EDF gain. By replacing the output WDM coupler with 10% coupler, the output power was greatly enhanced by about 30dB at the expense of less stability and reduced number of BEFL modes, from increased cavity losses.

In order to observe the spectrum of each mode at higher resolution, we performed heterodyne detection with a tunable external cavity single frequency laser diode as the local oscillator. Figure 4 shows the heterodyne detected beat spectra of the BEFL mode #1. It is found to consist of two lines separated by 0.8GHz. By changing the polarization state of the light from the local oscillator, one of the lines was observed to be suppressed when the other reached maximum, indicating that the polarization states of the two lines are orthogonal. We also investigated all the DFB and BEFL modes, and observed similarly two lines separated by 0.8GHz. Thus it is found that this laser actually operates in two polarizations for each wavelength. This is because the DFB laser is operating in two polarizations separated by 0.8GHz, and each polarizations produces Brillouin gains in each polarization at each frequency. Single polarization operation is desirable, which will be the subject of later study.

Furthermore, we found that the lines of the DFB mode have the width of ~40MHz, although the linewidth of the isolated fibre DFB laser output is less than 100kHz. This characteristics is likely to result from the long external ring cavity, which makes the ring DFB laser multimode with spacing equal to the free spectral range (FSR) of the ring cavity (~140kHz) within the possible low-loss bandwidth of the DFB laser (~40MHz). This linewidth broadening of the DFB mode may account for the high lasing threshold (~70mW; Fig.3) of the BEFL mode #1.

In conclusion, we have demonstrated multiwavelength and bidirectional operation of a novel BEFL, which is pumped with a fibre DFB laser inserted into the ring cavity. We realised lasing at eight wavelengths separated by 10.6GHz.

The authors acknowledge Mr. Morten Ibsen, Mr. Erlend Ronnekleiv, Mr. Oliver Hadeler, Dr. Liang Dong, and Dr. Richard Laming of Optoelectronics Research Centre, University of Southampton, for the development of the fibre DFB laser.

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Figure Captions

Figure 1 Configuration of bidirectional BEFL pumped by an intracavity fibre DFB laser.

Figure 2 Output optical spectra.
SMF:1400m, EDF:1.5m

Figure 3 Individual output modal powers as a function of pump power.
(a) CW (b) CCW

Figure 4 Heterodyne beat spectra of the BEFL mode #1.

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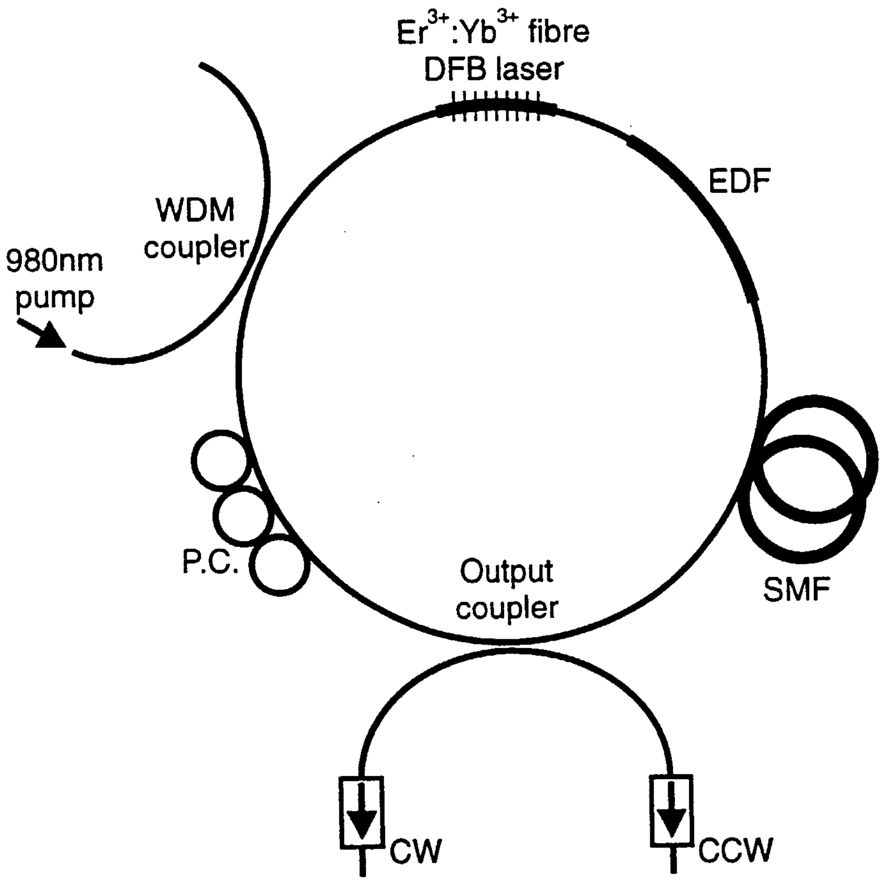

Fig. 1

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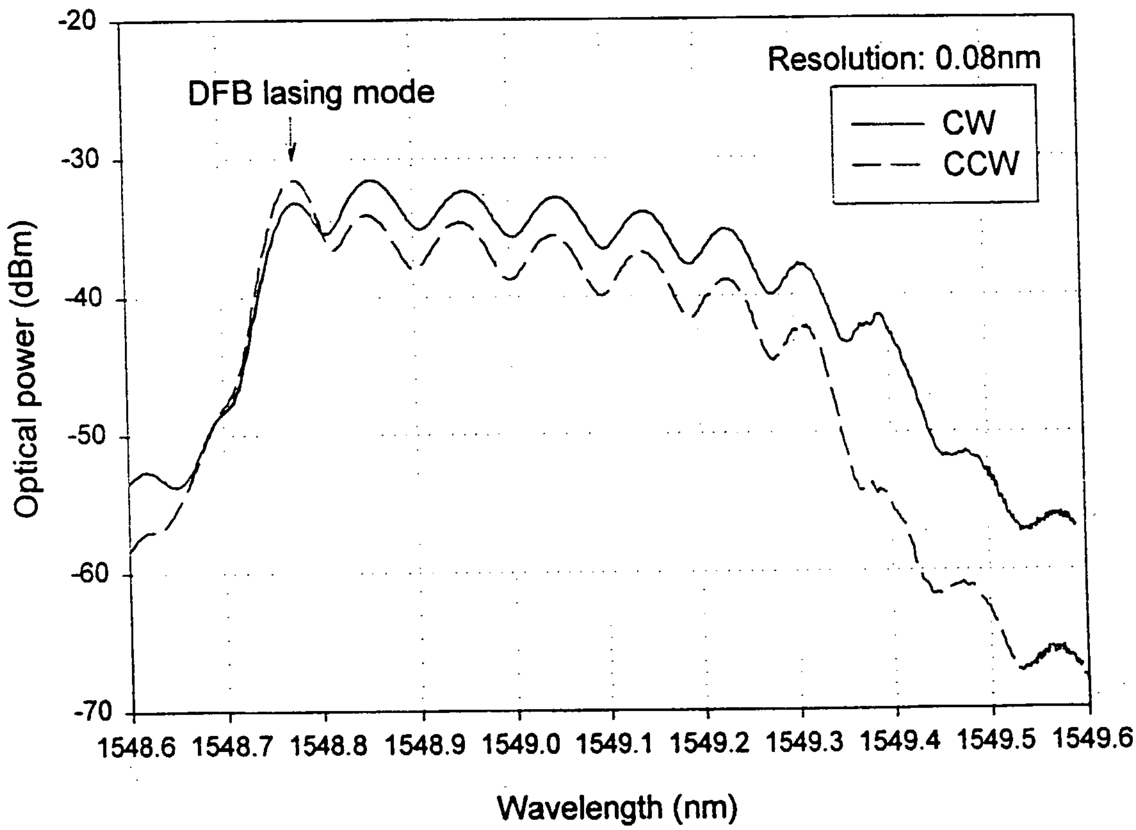

Fig. 2

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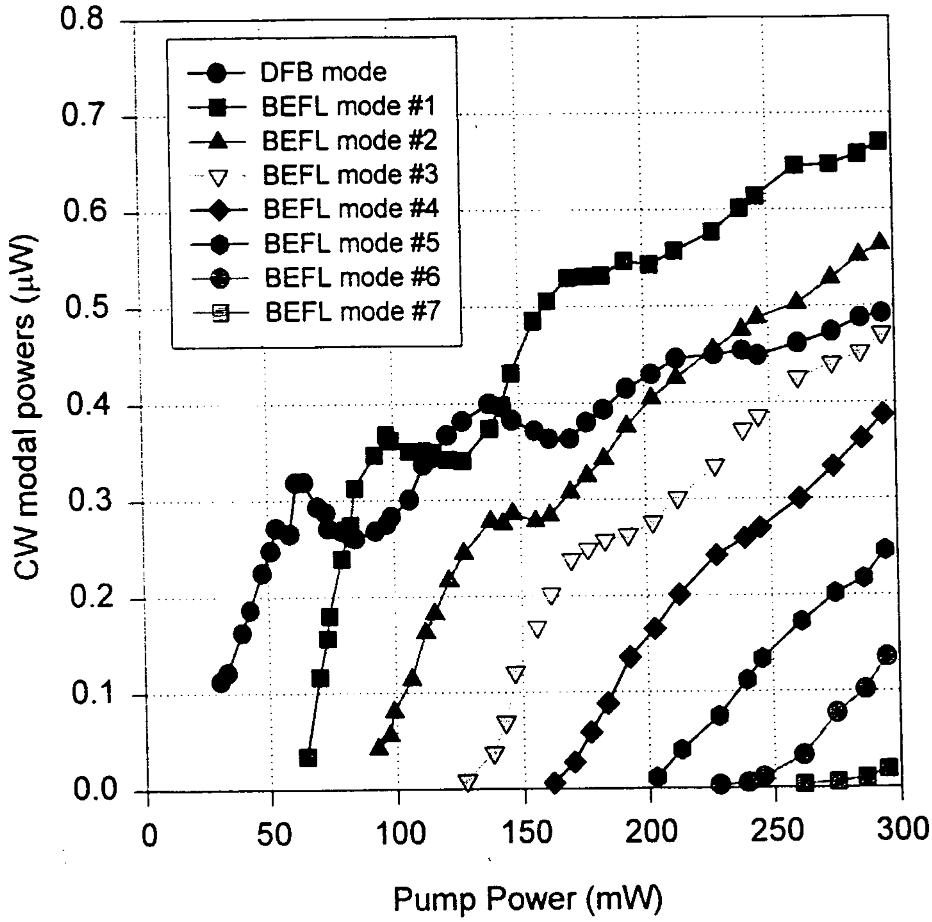

Fig. 3(a)

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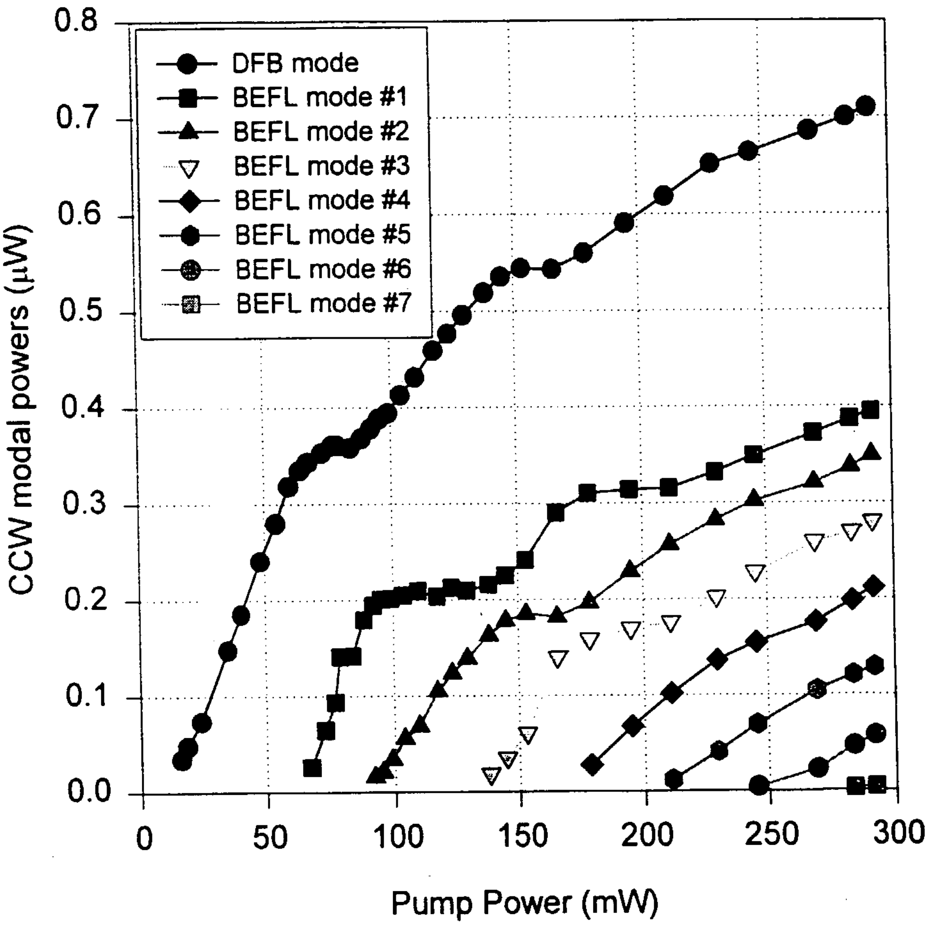

Fig. 3(b)

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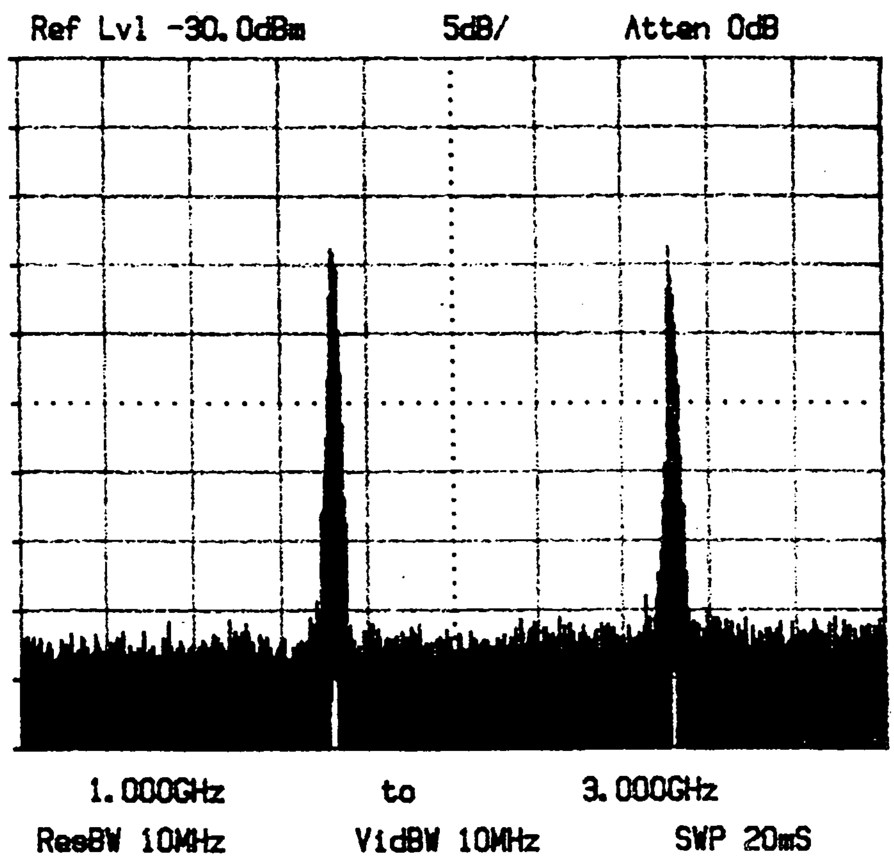

Fig. 4