40GHz optical-millimetre wave generation with a dual polarisation distributed feedback fibre laser

W.H. Loh, J.P. de Sandro, G.J. Cowle, B.N. Samson and A.D. Ellis

Optical-millimetre wave generation in a dual polarisation mode distributed feedback fibre laser is demonstrated by fabricating the laser in an elliptical core erbium doped fibre. The birefringence increases the frequency separation of the two polarisation modes, enabling a 40GHz heterodyne signal to be generated with a 3dB beat linewidth of 900Hz.

The use of optical fibre for site-to-site transmission of micro- or millimetre wave signals is attractive, particularly for applications involving phased-array antennas or fibre-fed radio systems, where the lightweight, low cost and high bandwidth properties of optical fibre are clearly advantageous. A key component of such systems is a fibre-compatible optical-millimetre wave generator. Proposed techniques for achieving this include the use of high frequency external modulators [1], optical injection [2] or mode locking [3] of laser diodes and, perhaps most general of all, optical heterodyning [4]. In a recent demonstration, results obtained with a frequency-locked dual longitudinal mode microchip laser yielded a heterodyned beat linewidth of just 430Hz [5]. While these demonstrations have relied on laser diodes or bulk solid-state lasers, recent developments in the area of distributed feedback (DFB) fibre lasers should also make them a very promising alternative.

Apart from their obvious fibre-compatibility and simplicity of construction, DFB fibre lasers typically exhibit narrow optical linewidths of ~10kHz [6, 7] and good frequency stability against temperature fluctuations (~1GHz/°C) without mode-hopping. One interesting feature of these lasers is their natural tendency to lase in both orthogonal polarisation modes [8, 9], which lends itself to additional applications, such as pressure sensing [9]. Although the frequency separation between the two modes observed in these lasers was small (a few hundred megahertz), this can be considerably increased by increasing the fibre birefringence. The wavelength separation of the two polarisation modes is determined directly from \lambda = 2B\lambda, where \lambda is the birefringence of the fibre and \lambda is the pitch of the Bragg grating. Thus, with \lambda = 0.5\mu m for 1550nm DFB fibre lasers, a fibre birefringence in the range \times 10^{-7} would yield wavelength (frequency) separations between 0.1-1nm (10-10GHz). In this Letter, we demonstrate a dual polarisation DFB laser, fabricated in a birefringent Er\textsuperscript{3+}-doped fibre, with a 40GHz optical frequency separation between the two modes.

The experimental configuration is shown in Fig. 1. The 9cm long DFB fibre laser was made by uv-writing an optical Bragg grating via a phase mask into an elliptical core germanosilicate Er\textsuperscript{3+}-doped fibre. The fibre core ellipticity, \epsilon, is 0.6, numerical aperture NA 0.3, and the small-signal 980nm pump absorption ~7dB/m. The large birefringence B = B_s + B_t is the combined effect of both the geometric anisotropy B_s as well as the thermal stress component B_t. For high NA fibres, the two contributions are expected to be comparable in magnitude [10]. The fibre laser is pumped by a 980nm 100mW diode, and the 1550nm optical output heterodyned in a pigtailed polarising isolator. The optical-millimetre wave signal is then amplified by an EDFA, and incident on a fast (40GHz bandwidth) photodetector. The output from the photodetector is fed directly to a harmonic mixer, and the resulting IF (intermediate frequency) spectrum monitored on a microwave spectrum analyser. To reduce the effects of temperature fluctuations and acoustic vibrations, the fibre laser was placed submerged in a water bath which had been left standing at room temperature for over a day.

The dual-wavelength spectrum of the DFB fibre laser, observed on a 0.1nm resolution optical spectrum analyser, is shown in Fig. 2. It is seen that the spectrum consists of two wavelengths \lambda = 0.32nm apart, corresponding to a fibre birefringence of \times 3 \times 10^{-7}. A scanning Fabry-Perot interferometer confirmed that the lasing spectrum consists of only two lines. The 0.2mW optical power from this laser is relatively low, owing to the low pump absorption in the short Er\textsuperscript{3+}-fibre cavity, but the efficiency can be increased with Yb\textsuperscript{3+}-codoping of the fibre [8]. Fig. 3 shows the IF frequency spectrum, centred around 317MHz (resolution bandwidth: 300Hz, sweep time: 1s). The frequency of the optical heterodyne generated signal from the fast photodetector is determined to be 39.7GHz, by observing the direction of the shift in IF frequency with corresponding shifts in the local oscillator frequency.

Fig. 1 Experimental configuration
OI: polarising optical isolator
DFB laser, erbium-doped fibre laser amplifier
EDFA: erbium-doped fibre amplifier
PD: photodetector
M: harmonic mixer
LO: local oscillator
RF SA: RF spectrum analyser

Fig. 2 Optical spectrum of dual polarisation DFB fibre laser
From Fig. 3, the beat signal has a 3dB bandwidth estimated at 900kHz, although it is subject to kilohertz frequency fluctuations. The dashed trace shows a calculated Lorentzian lineshape with a 3dB bandwidth of 900kHz. The comparison shows that the two traces are in reasonable agreement for power levels < 20dB from the peak, which suggests that with better stabilisation of the laser, possibly with active feedback control, 3dB beat linewidths of 300kHz or better should be possible.

![Fig. 3 Heterodyne beat signal from harmonic mixer](image)

An estimate of the temperature sensitivity of the beat frequency expected from the dual polarisation mode laser would be useful. As the wavelength separation of the two modes is given by $\Delta \lambda = 2\Delta A$, the temperature dependence is seen to be derived from the birefringence B, as well as the thermal expansion of the grating pitch A. Although the exact details are complicated, the dominant contribution should be due to the stress-induced birefringence, which is typically of the order of $(1/B)\Delta \lambda /dT = 10^{-3}-10^{-4}$°C [9, 11]. Thus, for a laser beat frequency of 40GHz, a temperature sensitivity in the range 4-40MHz/°C can be expected, an improvement by 2 orders of magnitude over that of the individual lasing frequencies. We confirmed this experimentally by heating up the water bath containing the laser, and the corresponding change in the peak, which suggests that with better stabilisation of the laser, possibly with active feedback control, 3dB beat linewidths of 300kHz or better should be possible.

Acknowledgment: This work was partially supported by the EC ACTS project PHOTOS. The Optoelectronics Research Centre is an EPSRC-funded Interdisciplinary Research Centre.

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Electronics Letters Online No: 19970371

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References


