Narrow linewidth CW and Q-switched Erbium doped fibre loop laser

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Abstract

The authors report the operation of a single-frequency, diode-pumped laser in CW operation with a linewidth of 10kHz, which provides a prelase for a narrow linewidth Q-switched laser. This was achieved by incorporating an unpumped low Er^{3+}-doped fibre. In Q-switched operation, a linewidth of less than 60MHz is reported for pulses of 1μs at a repetition rate of 960 Hz.

Indexing terms: Narrow linewidth, fibre loop lasers, Q-switched lasers

Introduction: Q-switched Erbium doped fibre lasers at the wavelength around 1.55μm with Fabry-Perot cavities [1-4] and ring cavities [5-6] have been the subject of intense research. These lasers are useful for applications such as sensing and laser range finding. For distributed strain sensing based on spontaneous Brillouin scattering [7], narrow linewidth pulsed sources with high peak powers are required to resolve the spectral information of the Brillouin signals. In this Letter, we demonstrate a simple method for the development of a compact narrow linewidth Q-switched Erbium doped fibre laser source, suited for applications of distributed sensing.

Principle: Conventional Q-switched fibre lasers buildup from spontaneous emission, which results in pulses with a mixture of different longitudinal modes. To achieve a single-frequency operation, the Q-switched laser needs to build up from a single longitudinal mode. In the prelase technique, the laser is allowed to oscillate at low powers on a single longitudinal mode prior to opening the Q-switch, and the Q-switched pulse builds up from this initial lasing [8]. It may be viewed as the laser being injection-seeded by its own prelase signal, avoiding the complexity of mode-matching and the use of two separate lasers in conventional injection-seeded Q-switched lasers.

The initial single longitudinal mode lasing was achieved by incorporating an unpumped Erbium doped fibre in the laser. It has been shown recently that standing-wave configuration for a saturable absorber Erbium doped fibre established a linewidth narrowing mechanism [9]. The standing wave section of the cavity imposes a spatial-hole burning pattern in the saturable absorber, forming a frequency selective element for one longitudinal mode and discriminating other adjacent modes. This discrimination is not possible with just the fibre grating reflector.

Experimental set-up and results: Fig. 1 shows the schematic diagram of the experimental set-up employed to produce the single-frequency Q-switched fibre laser. The gain medium consists of a 1.9m length of Erbium doped fibre (NA = 0.18, Er^{3+} concentration of 800ppm, second mode cutoff of 890nm and unsaturated absorption of 45dB/m). The amplifying fibre was pumped with a MOPA laser diode at an excited state absorption free wavelength of 980nm [10]. A wavelength division multiplexer (WDM) was used to couple the pump light to the amplifying fibre. The circulator ensures unidirectional operation for the fibre loop laser and feedback to the ring cavity was completed by 2m of an unpumped length of Erbium doped fibre (NA = 0.125, second mode cutoff of 910nm and unsaturated absorption of 5dB/m) and a 99.9% reflectivity fibre Bragg grating reflector (λ_g = 1530nm, $\Delta\lambda$ = 0.05nm). The circulator also minimises the loss from the feedback of the grating as compared to the loss when a fibre coupler is used. The output was extracted from the cavity using a 50/50 fibre coupler. An optical isolator at the output was used to prevent any feedback into the laser cavity which could cause instabilities. Q-switching operation was achieved by the use of an electro-optic modulator (EOM). The EOM (Quantum Technology, LN-9) consisted of a lithium niobate crystal within a sealed unit with anti-reflection coated windows to minimise transmission losses. It had a 10ns rise/fall time, and a maximum extinction ratio of 95%. To eliminate spurious reflections, all components were fusion spliced. The nonspliced ends of fibres were angle polished at 17° to minimise 4% Fresnel end reflections into the cavity. Efficient operation of the EOM relies on linearly polarised light, and two dichroic sheet polarisers were inserted into the cavity. To stabilise the laser, care was taken to thermally insulate the laser cavity.

Under CW conditions in the absence of the EOM, the lasing spectrum was initially observed on an optical spectrum analyser with 0.1nm resolution. A stable single peak at 1530nm was observed. To confirm single-frequency operation of the CW output, a scanning Fabry-Perot interferometer (SFP) with a free spectral range (FSR) of 1.9GHz and a finesse of 50 and a 3MHz photodetector were used. A single peak was observed which was resolution-limited by the SFP. It was typically stable for tens of minutes without any mode-hopping. In contrast, when the unpumped Erbium doped fibre was replaced by an equivalent length (2m) of undoped standard single mode telecommunications fibre, stability was poor and frequent mode-hopping was observed between adjacent cavity modes, on average every few seconds. Further investigation of the spectral behaviour in the fibre laser output was achieved using a delayed self-heterodyne interferometer. The interferometer provided a resolution of 7kHz with a 28km fibre delay line and the RF spectrum analyser (Marconi 2382) had a resolution of 1kHz. Fig. 2 shows the beat signal, detected by a photodetector and the RF output. The RF linewidth was measured to be approximately 10kHz FWHM.

In the Q-switched operation, typical pulses from the output of the laser with peak powers of 400mW were obtained with the EOM operating at a repetition rate below 1kHz and duty cycle of 10% (EOM in high-loss state for 90% of the period), and pump power of 200mW. The pulse output was measured using a 3ns rise time calibrated InGaAs *pin* photodetector and a 200MHz digitising oscilloscope. The variation of peak power and pulsewidth of the Q-switched pulses as functions of the modulation frequency of the EOM are shown in Fig. 3. Beyond 1kHz, there is a fall-off in the peak power and broadening of pulsewidth from 1.0 - 1.5μs with increasing repetition rates. The decrease in peak power with increasing repetition rate is due to the finite recovery time of the population inversion in the pumped Erbium doped fibre when the laser is in the low-Q state. The recovery time is related to the lifetime of the metastable level, typically 10-12 ms for Erbium. The effective lifetime of the metastable level is reduced to 1ms by the presence of amplified spontaneous emission which depletes the upper lasing level. The spectral behaviour of the Q-switched operation using the prelase technique is shown in Fig. 4 at a repetition rate of 960Hz. It was observed using the SFP and detecting the peaks of the pulses, and the linewidth formed was measured to be less than 60MHz (resolution limit of the pulsed measurement). In contrast, without any single-frequency self-seeding from the prelase, frequent mode-hopping of the Q-switched pulses was observed.

Conclusion: We have demonstrated the use of an unpumped section of Erbium doped fibre to achieve a single-frequency fibre laser. By using an electro-optic modulator as a Q-switch, narrow linewidth pulses of less than 60MHz were obtained. Further work is directed at reducing the pulse width to optimise the source for distributed strain sensing based on spontaneous Brillouin scattering.

Acknowledgements: This work is partially supported by a link scheme in collaboration with York Sensors Ltd and Pirelli Cables Ltd, and the Overseas Research Students (ORS) Awards Scheme. The authors thank M. J. Cole for providing the fibre grating.

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Figure Captions:

Fig. 1 - Schematic diagram of single-frequency Q-switched laser configuration

Fig. 2 - Output from self-heterodyne interferometer with a 28km delay line

Fig. 3 - Variation of peak power and pulse width of Q-switched pulses with repetition rate

Fig. 4 - Frequency spectrum displaying linewidth of Q-switched pulses with 60MHz linewidth using a scanning Fabry-Perot interferometer

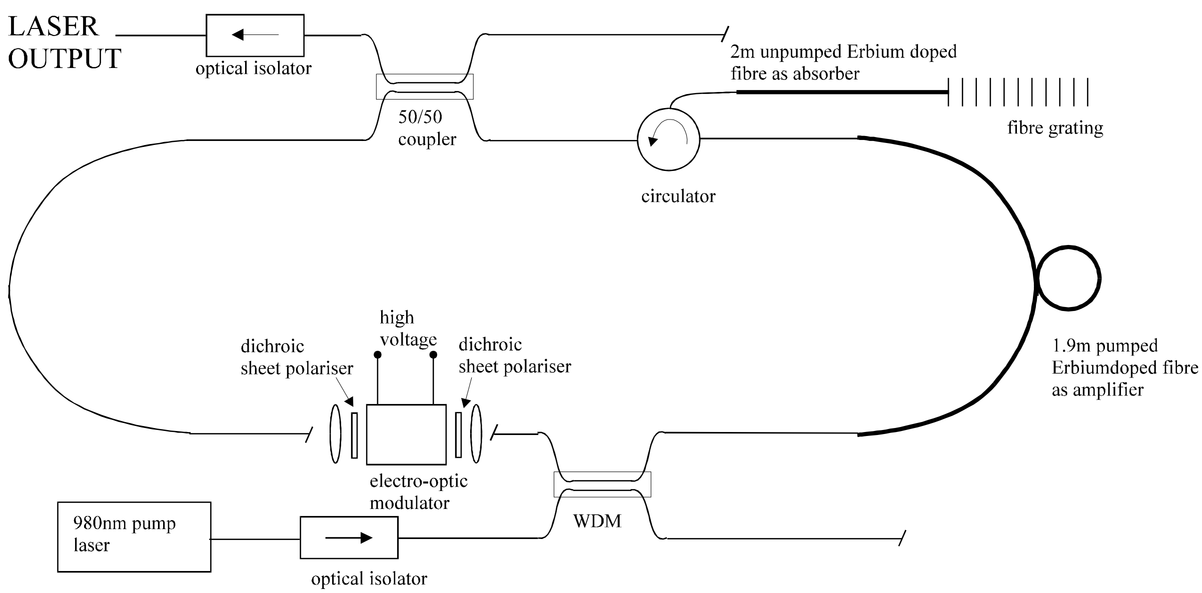

FIGURE 1

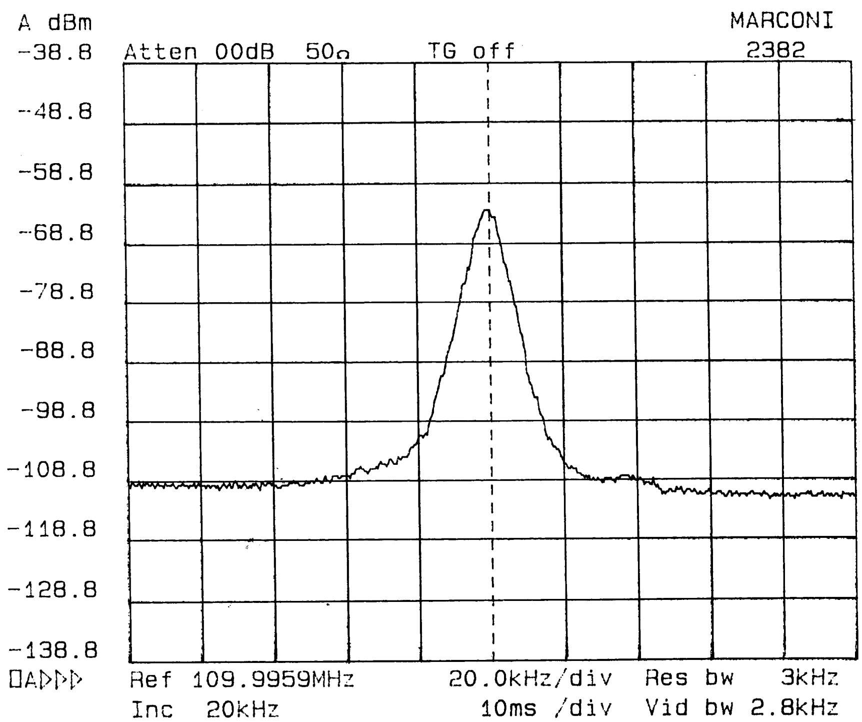

FIGURE 2

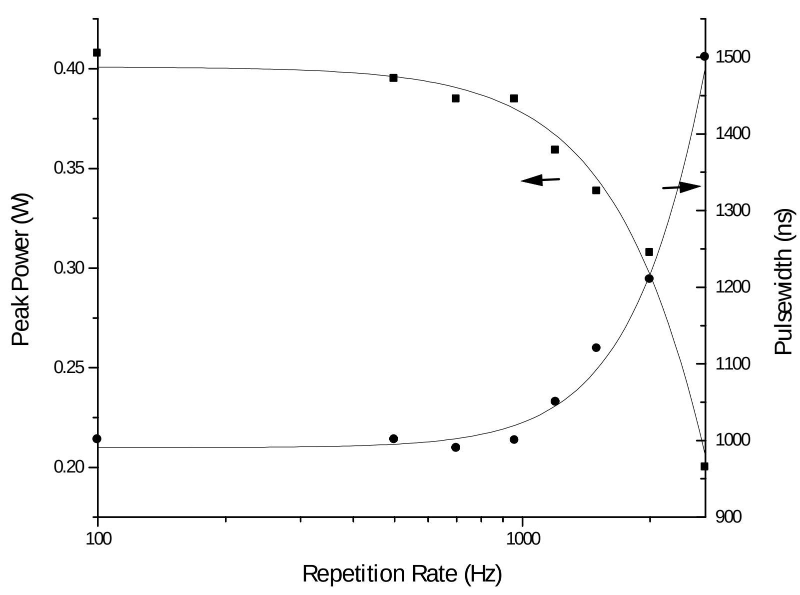

FIGURE 3

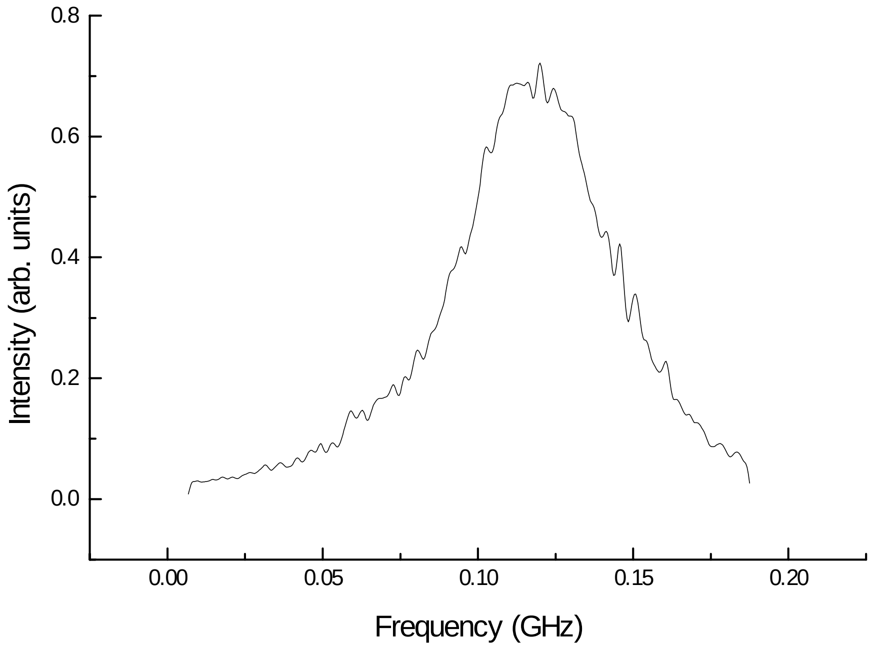
0.8
0.6
0.4
0.2
0.0
Intensity (arb. units)
0.00
0.05
0.10
0.15
0.20
Frequency (GHz)

FIGURE 4