Narrow linewidth, Q-switched erbium doped fibre laser

G.P. Lees, M.J. Cole and T.P. Newson

The authors report a narrow linewidth, diode pumped, high power Q-switched erbium doped fibre laser for distributed temperature sensing applications using the Landau-Placzek ratio method. An output coupler consisting of an in-fibre Bragg grating enables narrow linewidth operation. A linewidth of 1.3GHz is reported with a peak power of 100W and a pulse width of 20ns at a repetition rate of 200 Hz.

Introduction: For distributed temperature sensing based on the Landau-Placzek ratio [1], narrow linewidth pulsed sources are required to spectrally resolve the backscattered Rayleigh and Brillouin signals. Typically, the backscattered Brillouin is separated from the Rayleigh by ~10GHz, the spectral linewidth of the pump should therefore be <10GHz if the signals are to be resolved. High power pump pulses are required to produce a strong backscattered Brillouin signal. A strong Brillouin backscattered signal was required to overcome losses (>10dB) in the Fabry-Perot interferometer detection system which was used to separate the Brillouin and the Rayleigh signals in order to determine the temperature [1]. The temperature being determined by the ratio of the backscattered Brillouin and Rayleigh signals (Landau-Placzek ratio). In this previously reported work the backscattered Rayleigh and Brillouin signals were obtained with a 1mW, narrow linewidth (2GHz) DFB laser, which was then amplified using an erbium doped fibre amplifier producing 18 dBm of pump power [1]. This Letter describes the development of a narrow linewidth, Q-switched erbium doped fibre laser, which is ideally suited for this application of distributed temperature sensing using the Landau-Placzek ratio.

Recent advances in Q-switched erbium doped fibre lasers [4 - 6] have yielded peak powers of 290W with pulse widths of 20ns at repetition rates of <500Hz [4], the wavelength of operation however is dependent on the repetition rate when using broadband output mirrors. At high repetition rates (> 1kHz) the population inversion within the cavity cannot fully recover between adjacent pulses and the wavelength of operation is shifted to longer wavelengths [4]. The use of a narrowband in-fibre Bragg grating as an output mirror causes the Q-switched laser to operate with a narrow linewidth at a fixed wavelength, while the Q-switched operation produces the high power pulses necessary to produce strong backscattered Rayleigh and Brillouin signals. The use of an in-fibre Bragg grating instead of a bulk mirror has the additional advantage of an output which is compatible with other fibre components and thereby avoids launch losses.

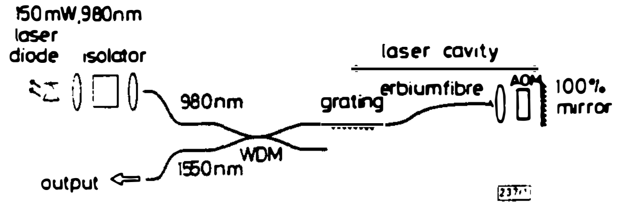

Fig. 1 *Schematic diagram of experimental arrangement for narrow linewidth Q-switched fibre laser*

Experiment and results: Fig. 1 shows a schematic diagram of the experimental arrangement used to produce the Q-switched laser. The erbium doped fibre is pumped with a 150mW semiconductor laser diode at a wavelength of 980nm. This pump wavelength is free from excited state absorption [2], and is therefore more efficient than pumping at the 810 nm pump band. A wavelength division multiplexer (WDM) is used to couple the pump radiation through the in-fibre Bragg grating into the doped fibre. The grating used in this experiment had a reflectivity of 60% and a bandwidth of 2GHz, at a centre wavelength of 1530.2nm. A 600mm length of erbium doped fibre was used as the gain medium and had an NA of 0.18, an Er^{3+} concentration of 800ppm, second mode cutoff of 890nm and an unsaturated absorption of 45dB/m at 1.55μm. The length of the fibre was optimised for maximum output peak power in Q-switched operation at a repetition rate of 500Hz. The fibre end was terminated using an angle polished (17°) ferrule to reduce the 4% Fresnel end reflections. This prevented any CW lasing from the end of the fibre. The output from the fibre end was focused using a graded index lens through the

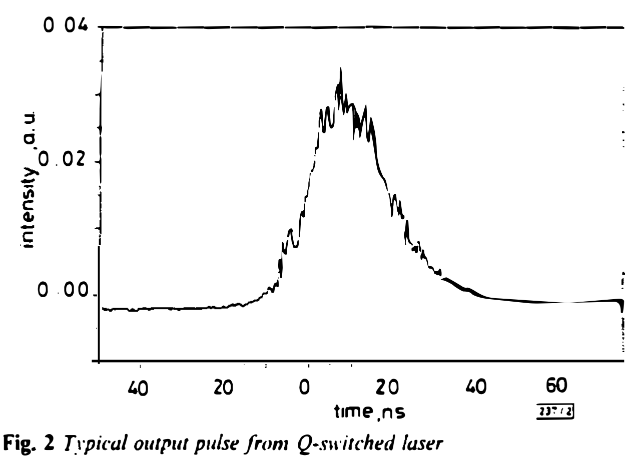

Fig. 2 *Typical output pulse from Q-switched laser*

acousto-optic modulator (AOM) which has a rise time of 100ns and a defraction efficiency of 80%, onto a plane mirror (99% reflecting at 1.55μm). The total laser cavity formed between the grating and the plane mirror had a length of 1.22m. Under CW conditions in the absence of the AOM an output power of 7.1mW was obtained with a threshold of 6.6mW of launched pump power and a slope efficiency of 17%. The low slope efficiency was caused by the grating, which forced the laser to operate at 1530.2nm. At this wavelength there was not sufficient launched pump power to bleach the 1530nm transition and hence a decrease in slope efficiency was observed [3]. Under Q-switched operation the AOM was operated in zero order mode. In this arrangement the feedback was provided by the undeflected zero order beam. At a repetition rate of 200Hz, a peak power of 100W and a pulse width of 20ns was obtained for 45mW of launched pump power. A typical pulse can be seen in Fig. 2, measured using a 3ns rise time InGaAs *pin* photodetector and a 200 MHz digitising oscilloscope.

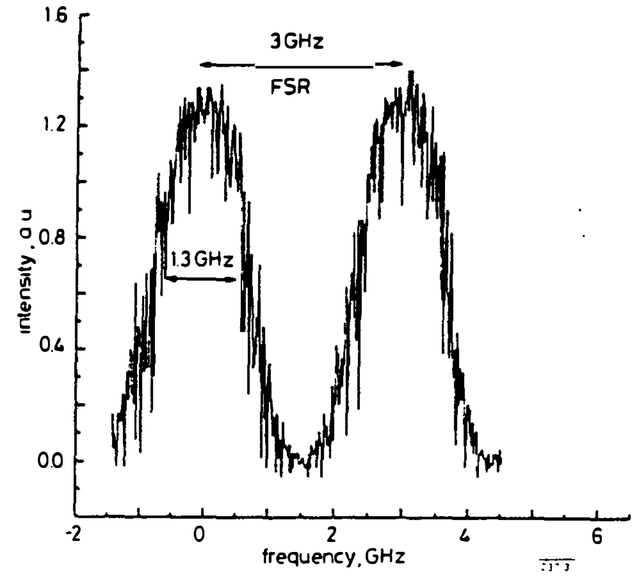

Fig. 3 *Scanning Fabry Perot trace showing 3GHz FSR and 1.3GHz linewidth of Q-switched source*

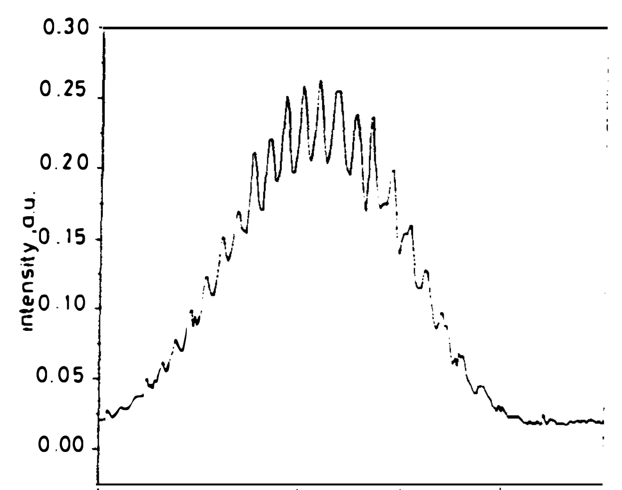

Fig. 4 *Scanning Fabry Perot trace of CW laser showing cavity mode spacing of 84MHz, and a 1.1GHz linewidth*

The linewidth of the laser was measured using a scanning Fabry Perot interferometer (SFP) with a free spectral range (FSR) of 3GHz and a finesse of 50. Fig. 3 shows the results obtained at a repetition rate of 5kHz. The spacing between adjacent peaks is 3GHz and the linewidth was measured to be38ecodb4-7dac-447o-b7ce-465a514a6283

1.3GHz. The noise on the signal was caused by the averaging which was needed to build up the frequency profile of the pulsed source. Using a broadband output mirror in place of the grating in a similar Q-switched configuration yielded a spectral linewidth of 4nm, in agreement with Seguin *et al.* [4]. The introduction of the grating has therefore decreased the linewidth by a factor of ~375 over a

Q-switched configuration using bulk mirrors. Under CW operation of the laser a linewidth of 1.1GHz was measured and by increasing the finesse of the SFP the longitudinal cavity modes could be resolved (Fig. 4). The cavity modes are separated by the FSR of the laser cavity (84MHz). The Q-switched laser linewidth is wider than the CW configuration because of the lower number of round trips the Q-switched pulse undergoes.

Conclusion: We report for the first time a narrow linewidth Q-switched erbium doped fibre laser. The use of an in-fibre Bragg grating enabled a linewidth of 1.3GHz to be achieved, and Q-switching produced a peak power of 100W and pulse width of 20 ns for a repetition rate of 200Hz. Such a source opens the path to produce a Brillouin based temperature sensor which will be comparable, if not better than, current Raman based systems.

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References

WAIT, P.C., and NEWSON, T.P.: 'Landau-Placzek ratio applied to distributed fibre sensing', *Opt. Commun.*, 1996, **122**, (1), pp. 141-146

2 LAMING, R.I., FARRIES, M.C., MORKEL, P.R., REEKIE, L., and PAYNE, D.N.: 'Efficient Pump wavelengths of erbium doped optical amplifiers', *Electron. Lett.*, 1989, **25**, (1), pp. 12-14

3 BARNES, W.L., MORKEL, P.R., REEKIE, L., and PAYNE, D.N.: 'High quantum efficiency Er^{3+} fibre lasers pumped at 980nm', *Opt. Lett.*, 1989, **14**, (18), pp. 1002-1004

4 SEGUIN, F., and OLESKEVICH, T.: 'Diode pumped Q-switched fibre laser', *Opt. Eng.*, 1993, **32**, (9), pp. 2036-2041

5 MYSLINSKI, P., CHROSTOWSKI, J., KONINGSTEIN, A., and SIMPSON, J.R.: 'High power Q-switched erbium doped fibre laser', *IEEE J. Quantum Electron.*, 1992, **28**, (1), pp. 371-377

6 CHANDONNET, A., and LAROSE, G.: 'High-power Q-switched erbium fibre laser using an all-fibre intensity modulator', *Opt. Eng.*, 1993, **9**, (32), pp. 2031-2035