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A Self- Starting Passively Mode-locked Fibre Ring Laser For Distributed Sensing

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Abstract

A twelve hundred metre long, passively mode-locked, fibre ring laser has been constructed using polarisation preserving fibre to ensure operational stability. A short length of lo-bi spun fibre has been included to exploit non-linear polarisation evolution (NLPE) as the mechanism for mode-locking the fibre laser. Pulses with durations in the range of 1 to 10ns with intensities of a few Watts centred around the 1.535μ wavelength were achieved. The circulating pulse within the laser cavity generates both Rayleigh and Raman scattered light. The former may be used to measure losses within the cavity, the latter permits the distributed temperature measurements of the fibre forming the cavity.

1. Introduction

Passive mode-locking of fibre ring lasers has received a great deal of interest for the telecommunications industry as a means for generating ultra-short pulses (<1ps). This work in contrast focuses on a very long mode-locked ring laser for distributed loss and temperature measurements and has particular relevance to distributed temperature measurement based on the temperature dependence of the ratio of the intensities of the Raman Stokes to anti-Stokes wavelengths[1]. For this application pulse widths in the range of 1 to 10ns are of interest.

Our previous work[2] has demonstrated the feasibility of generating such pulses with intensities of a few Watts, using a cavity of 200m length leading to a pulse repetition rate of 1MHz. Whilst this would appear to be a useful source for both addressing discrete sensors and distributed sensing in the conventional manner, our present interest is to incorporate the sensing fibre as part of the laser cavity. Since the pulse now remains in the cavity, ie the output coupling of the laser can be made close to zero, extremely high intracavity powers can be generated for modest pump powers. Only the signal of interest, ie. the Raman Stokes and anti-Stokes in the case of distributed temperature sensing, is coupled out of the cavity. This is readily achieved using a wavelength division multiplexor. For loss measurements based on Rayleigh scattering, the signal of interest has the same wavelength as the lasing wavelength and therefore the directionality of the laser may be exploited to separate the circulating pulse and the backscattered Rayleigh light. This may be achieved by using a circulator, to maintain a low output coupling of the circulating pulse and a maximum output coupling of the backscattered light. Owing to the much higher signal associated with Rayleigh scattering compared to the Raman scattering, it is possible to detect the back-scattered Rayleigh even using a 50/50 coupler.

We recently reported preliminary results of the first experimental spatially resolved Rayleigh measurements in a passively mode-locked fibre ring laser of 4km in length[3]. This laser was constructed using standard telecommunications fibre. Since mode-locking was achieved using non-linear polarisation evolution as the switching mechanism, the laser was naturally susceptible to environmentally induced changes in the linear birefringence of the fibre. If the device is to be used as temperature sensor, then clearly such a cavity would be unstable. We have now therefore constructed the cavity in polarisation preserving fibre to overcome this problem and report on our preliminary results.

2. Experimental

The experimental set up is depicted in Figure 1. The pump source was an Argon-ion pumped Ti-Sapphire laser providing up to 3W of cw light at 980 nm to pump the erbium doped fibre (Er concentration 800ppm, NA=0.15 and cut-off wavelength λ_{co}=960nm, estimated beat length 0.5m). The combined isolator and polariser ensures unidirectional operation and in conjunction with non-linear polarisation evolution occuring in the lo-bi fibre, provides the intensity dependent switch required for passively mode-locking the laser. The first length of highly birefringent (hi-bi) polarisation preserving fibre acts as the sensor; the second length of hi-bi fibre introduces a delay to separate the backscattered signals from consecutive pulses. The principal axis of the two hi-bi fibres were carefully aligned with respect to the axis of the isolator/polarizer.

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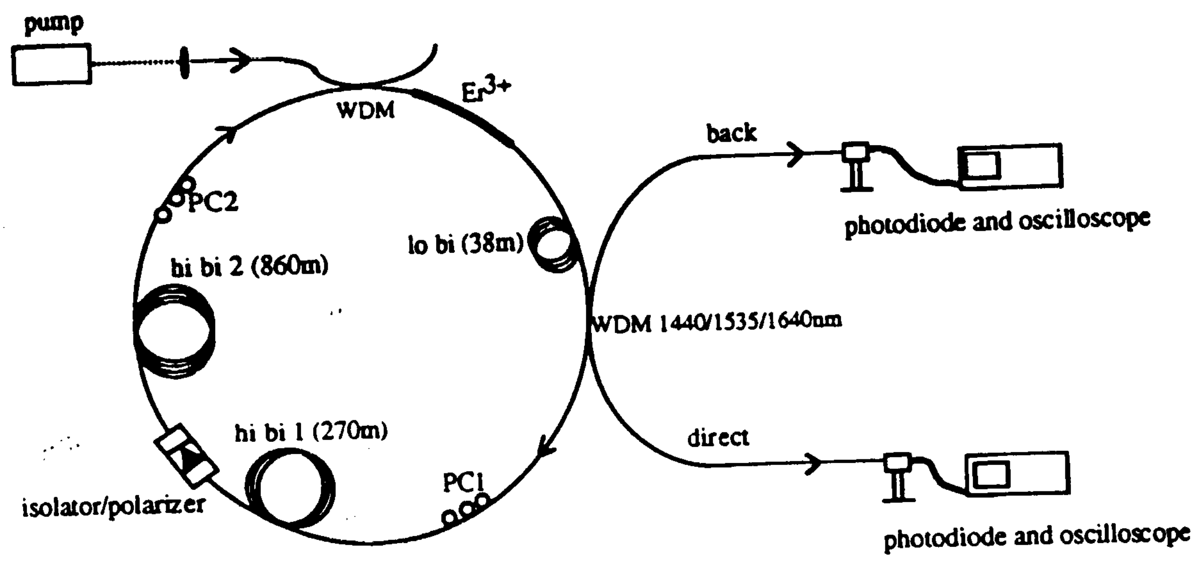

Figure 1: The optical configuration

In operation, the linear state of polarisation of light emerging from the second length of hi-bi fibre evolves to some other polarisation state which is dependent on the adjustment of the polarization controllers PC1 & PC2 and the linear birefringence of the other components in the cavity. For cw operation, the intracavity power is relatively low and no significant non-linear effects are observed. To minimise the threshold pump power for cw operation either polarisation controller can be adjusted to ensure the emerging state of polarisation from PC1 is linear and aligned to the principal axis of the first length of hi-bi fibre and polarizer. If instead of minimising the cw threshold, the PC's are adjusted to maximise the threshold or even prevent cw operation, then pulsed or mode-locked operation is encouraged. In this situation, the intensity of the pulse is sufficient to cause significant non-linear polarisation evolution, principally in the low-bi fibre.

The intensity of the pulse is determined by the switching intensity of the non-linear switch; ie the intensity required to ensure that linear polarised light emerges from PC1 and is aligned with the axis of the hi-bi fibre and polariser. This intensity may be controlled by adjusting the polarisation controllers. For a given setting of the PC's the duration of the pulse is then controlled by varying the 980nm pump power.

The backscattered light was measured using an InGaAs detector 200Mhz bandwidth and transimpedance gain of 16V/mW (Analogue Devices). The forward travelling pulses were measured using a fast detector 40GHz (New Focus). Experiments were performed using a variety of output couplers. Figure 1 shows the inclusion of a WDM for measurement of the Raman shifted signals.

3. Results

By careful adjustment of the PC's and pump power, a self starting passively mode-locked laser was demonstrated operating at 1532nm. Some hysteresis was observed in the threshold pump power. Mode-locked operation occuring at a pump power of 190 mW and maintained until the pump power was reduced to 95mW. This spread was most apparent using an output coupler with a 50% splitting ratio. Reducing the output coupling ratio to 10% the pump powers were reduced to 100mW and 70mW respectively.

The peak pulse intensities were measured to be 2.3W. It was possible to adjust the pulse duration from 700ps to 10ns. The pulses were square shaped and occurred at the fundamental frequency of 175kHz for a 1200m cavity, figures 2a and 2b.

The laser was extremely stable and maintained pulsed operation for three hours without any degradation. After adjusting the PC's to their optimum position, mode-locked operation started spontaneously whenever the pump was increased above threshold. The laser also maintained mode-locked operation even when the pump laser exhibited large fluctuations in output power.

Heating the hi-bi fibre did not affect the laser performance and the hi-bi fibre could be bent to a radius of curvature of about 5mm before any effects were observed. Severe bending of the hi-bi fibre eventually introduces a loss in the cavity and has a similar effect equivalent to reducing the pump power; ie the pulse width is reduced.

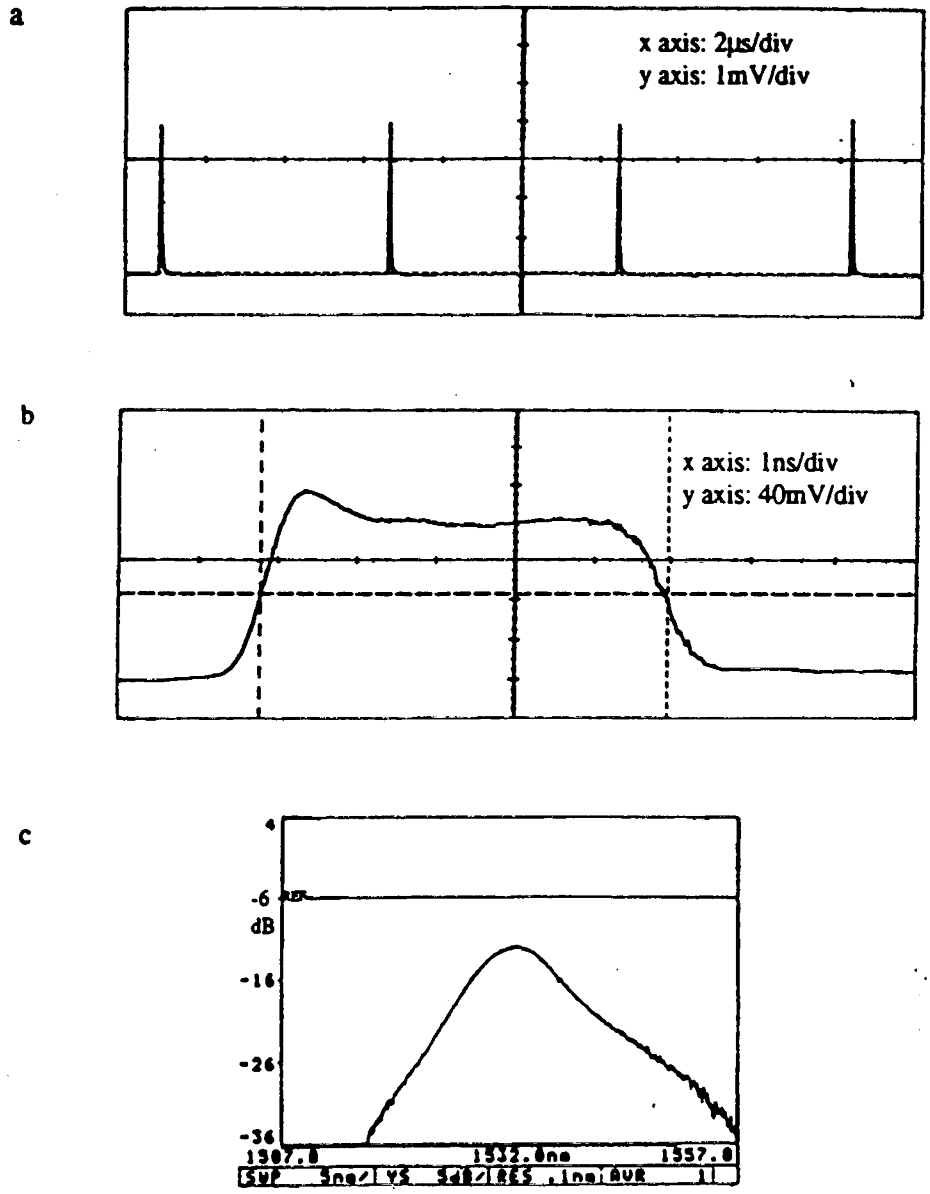

Figure 2: **a) fundamental modelocked operation of 1200m ring laser.**
b) detail of individual pulse.
c) optical spectrum of mode-locked laser

Figure 3 shows the Rayleigh backscattered signal. This signal is generated whilst the pulse is travelling in the first length of hi-bi fibre; the backscattered Raleigh signal from the second length of Hi-Bi fibre is blocked by the isolator. The two spikes correspond to reflections from the first splice after the output coupler and the combined polarizer and isolator.

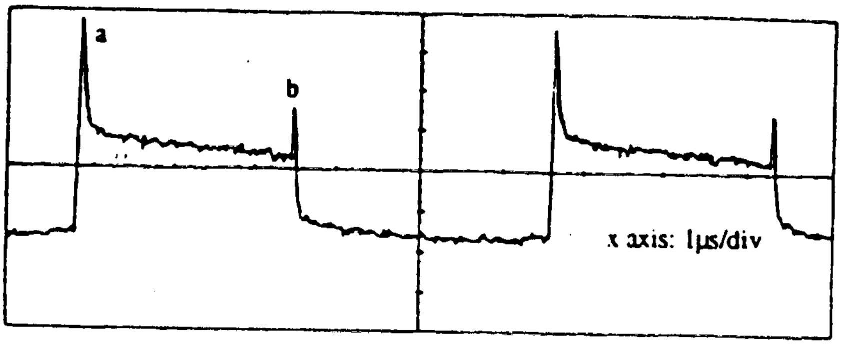

Figure 3: The Rayleigh backscattered signal. Positions "a" and "b" correspond to the positions of the first splice after the output coupler and the polarisor/isolator respectively.

4. Conclusion

A self starting passively mode-locked ring laser has been constructed using hi-bi fibre to overcome instabilities encountered using standard telecommunications fibre. A short length of lo-bi fibre is used in conjunction with a polariser to provide the intensity dependent switch based on non-linear polarisation evolution to provide the mechanism for passive mode-locking. This fibre and the other components in the cavity may easily be protected from environmental disturbances.

The principal advantage of using such a configuration for distributed temperature sensing based on Raman scattering is the large intracavity pulse intensities that can be generated with modest pump powers. This in turn lead to much larger and more easily detected Raman scattered signals with reduced signal averaging times. At present, pump powers as little as 100mW are required to reach mode-locking threshold. Further optimisation of the cavity eg. length of doped fibre, reduction of cavity losses and output coupling ratio is likely to lead to substantial reductions in the required pump power. This would permit a diode pumped system to be readily constucted; a necessary requirement for a practical commercial system.

5. References

1. Dakin, J.P., Pratt, D.J., Bibby, G.W., and Ross, J.N: "Distributed optical fibre Raman temperature sensor using a semiconductor light source and detector", Electron. Lett., 1985, 21, pp. 569-570.

2. Matsas, V.J., Newson T.P., and Zervas, M.N.: "Self starting passively modelocked fibre ring laser exploiting nonlinear polarisation switching", Opt.Commun., 1992, 92, pp. 61-66.

3. Matsas, V.J., Newson T.P., and Payne, D.N.: "Optical time domain reflectometry measurements in a 4km fibre ring laser", Electron. Lett., 1993, 29, pp. 1602-1603.