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# A RAMAN BACKSCATTER DISTRIBUTED TEMPERATURE SENSOR BASED ON A SELF STARTING PASSIVELY MODE LOCKED FIBRE RING LASER

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**Abstract**

This paper reports on intracavity Raman backscatter measurements in a passively mode locked 1200m long fibre ring laser for distributed temperature sensing. The high intracavity power leads to a relatively large and easily detected Raman backscatter signal, whereas the short pulse duration (0.7ns) promises high spatial resolution.

**Introduction**: This paper describes a 1200m mode locked fibre ring laser for intracavity distributed temperature sensing applications, based on the temperature dependence of the Raman scattering intensity [1]. For this application, pulses in the range 1 to 10ns are of interest.

Previous experimental work has demonstrated the feasibility of generating such pulses with powers of a few watts, using a cavity of 200m length leading to pulse repetition rates of 1MHz [2]. Whilst this would appear to be useful for distributed sensing in conventional OTDR system, our present interest is to incorporate the sensing fibre as part of the laser cavity. Since the pulse now remains in the cavity, the output coupling of the laser can be made close to zero and extremely high intracavity powers can be generated using relatively modest pump powers. Only the Raman backscatter Stokes and anti-Stokes signals are coupled out of the cavity. This is readily achieved using a wavelength division multiplexer (WDM).

Such an arrangement could form the basis of a compact distributed temperature sensor system suitable for high resolution short range measurements.

**Experimental**: Previously reported experimental results have demonstrated spatially resolved Rayleigh backscatter measurements in a passively mode locked fibre ring laser of 4km length [3]. This laser was constructed using standard single mode fibre. Since mode locking was achieved using non-linear polarisation evolution as the switching mechanism, the laser was susceptible to environmentally induced changes in the linear birefringence of the fibre leading to cavity instability. This current experiment is performed using polarisation maintaining fibre for the most part which results in stable operation.

The experimental schematic is shown in figure 1. The required gain is provided by an erbium doped fibre amplifier consisting of a 3m length of 800ppm doped fibre pumped at 980nm using an argon ion pumped Ti-sapphire. The polarising isolator ensures unidirectional operation and together with the non-linear polarization evolution occurring in the lo-bi fibre, provides the intensity dependent switch required for passive mode locking [4]. The sensing length of fibre consists of a 270m length of hi-bi fibre (Hi-bi1). A 40m length of this fibre approximately 50m from the front end was placed in an oven at a temperature of 40°C. The other length of hi-bi fibre (Hi-bi2, 860m) serves as a delay so that subsequent pulses do not interfere with the backscattered light from Hi-bi1. The principal axis of the two hi-bi fibres were carefully aligned with respect to the axis of the polarising isolator. As the two Raman signals (Stokes and anti-Stokes) are equally separated from the lasing wavelength, the characteristics of WDM2 ensure that both are coupled out of the ring to the detector. The Raman backscattered light was measured using an InGaAs PIN detector and transimpedance amplifier with a bandwidth of 28MHz and gain of 1MΩ. The forward circulating pulses were measured using the calibrated spare port on WDM2.

The PCs are adjusted to maximise the threshold pump power for cw operation which is then suppressed and pulsed operation occurs. The intensity of the pulses is then sufficient to induce non-linear polarisation in the lo-bi fibre and mode locked operation occurs .

The intensity of the pulse was determined by the switching intensity of the non-linear switch which was controlled by adjusting the PCs. For a given setting of the PCs, the duration of the pulse was then controlled by varying the laser pump power.

**Results**: By careful adjustment of the PCs and pump power, stable self starting passively mode locked operation was obtained at 1532nm. Hysteresis of the threshold condition was observed with mode-locked operation occurring at a pump power of approximately 100mW and maintained until it was reduced to approximately 70mW.

A typical pulse measured at WDM2 is shown in figure 2. The peak pulse power was measured to be 2.3W. It was possible to adjust the pulse duration from 0.7 to 10ns. The pulses were rectangular and occurred at a repetition frequency of 175kHz corresponding to the 1200m cavity length.

Figure 3 shows the Raman backscatter trace corresponding to the first 120m of sensing fibre. The large pulse at the beginning of the trace is due to the reflection of the pulse at the forward pulse monitor port on WDM2. The flat top is due to the limit of the data capture range on the digital oscilloscope. The increase in Raman backscatter due to the section of fibre at a raised temperature can be seen over the time base period 0.55 to 0.95$\mu$s. The pulse length was less than 10ns, although the relatively large rise and fall times are due to the detector bandwidth (28MHz).

It should be noted that the trace shows the combined power of both the Stokes and anti-Stokes signals. Although, the Stokes signal is approximately five times that of the anti-Stokes, it is the latter which possess the greatest temperature sensitivity. The change in intensity with temperature of the combined Stokes and anti-Stokes signal is 0.23%$K^{-1}$ [5]. The measured change in total backscattered power was 4.3%. This represents a change in temperature of 19K and is in agreement with the measured fibre temperature.

**Conclusion**: These results demonstrate that Raman OTDR may be used as a distributed temperature sensing mechanism within a passively mode-locked fibre ring laser. A short length of lo-bi fibre and a polariser where used to provide an intensity dependent switch to provide the mechanism for passive mode locking. The short pulses observed (0.7ns) suggest a spatial resolution of 0.7m is achievable. However, such a resolution would require a detector bandwidth of approximately 500MHz and as the performance of photodiodes is a compromise between speed and sensitivity, one of suitable bandwidth was not available for this experiment. Although the sum of the Stokes and anti-Stokes was measured in this experiment, a further WDM would enable these signals to be independently resolved and the absolute temperature determined.

The principal advantage of using such a configuration for distributed temperature sensing is the large intracavity pulse power that can be generated with modest pump powers. As it is the intracavity pulse which is used to generate the Raman backscatter directly, this leads to much larger and more easily detected Raman backscatter signals with reduced signal averaging times. Optimisation of the cavity is likely to lead to substantial reductions in the required pump power. This would permit a diode pumped compact system to be readily constructed; a necessary requirement for a practical commercial system.

**References**


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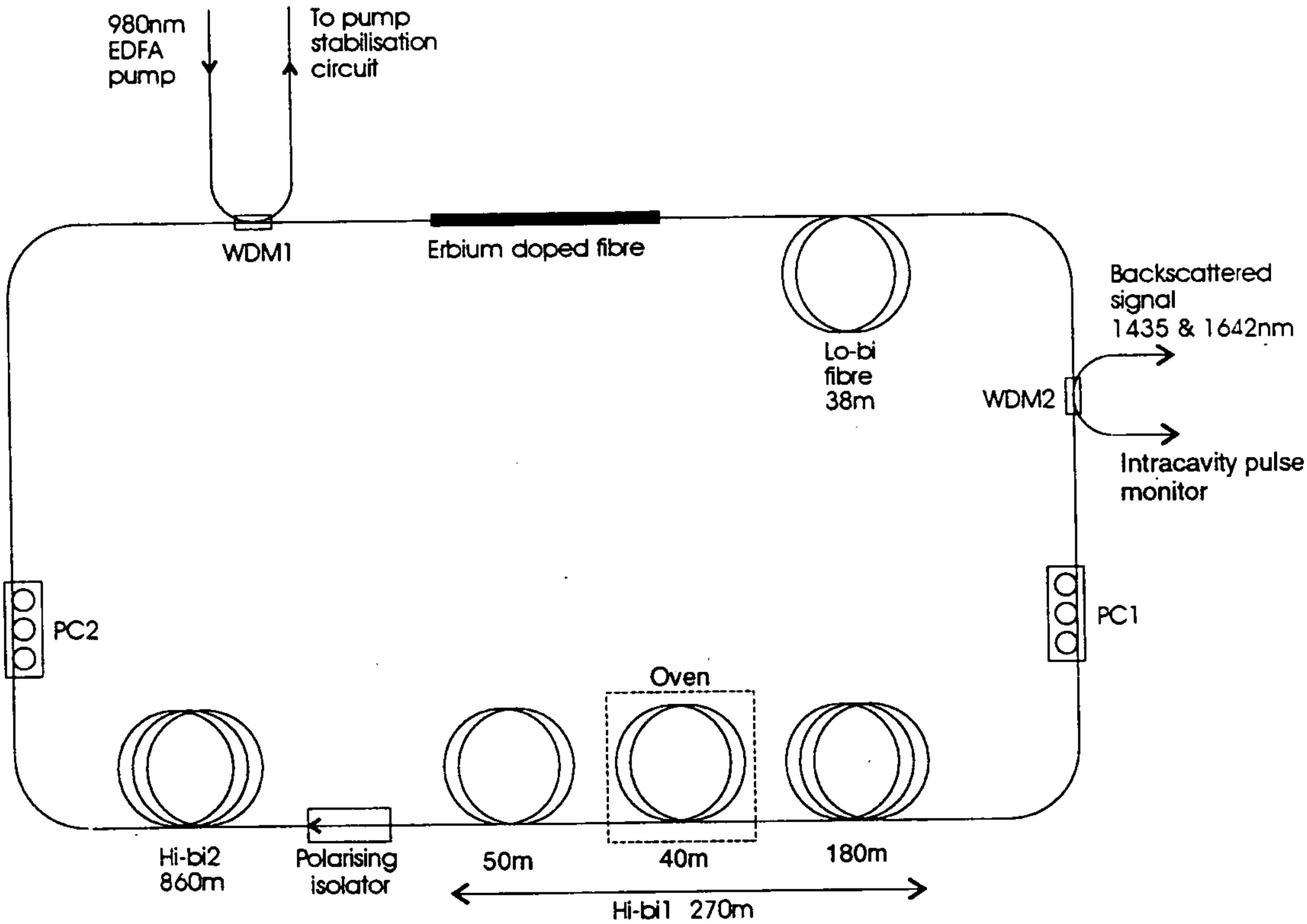
2. Matsas V. J., Newson T. P. and Zervas M. N: "Self starting passively mode locked fibre ring laser exploiting nonlinear polarisation switching", Opt. Commun., 1992, **92**, pp. 61-66.
3. Matsas V. J., Newson T. P. and Payne D. N: "Optical time domain reflectometry measurements in a 4km fibre ring laser", Electron. Lett., 1993, **29**, pp. 1602-1603.
4. Chen C. J., Wai P. K. A. and Menyuk C. R., "Soliton fibre ring laser", Opt. Lett., 1992, **17**, 417-419.
5. From information provided by A. Hartog of York Sensors Ltd.

**Figure captions:**

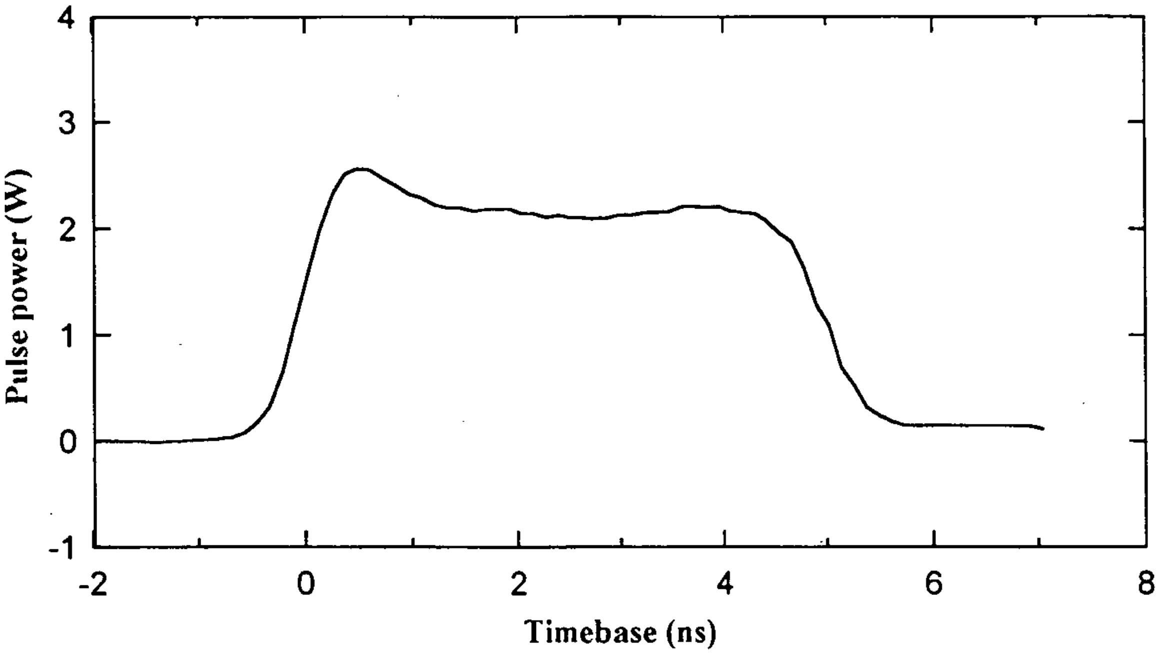
Figure 1. Experimental schematic.

Figure 2. Typical intracavity pulse.

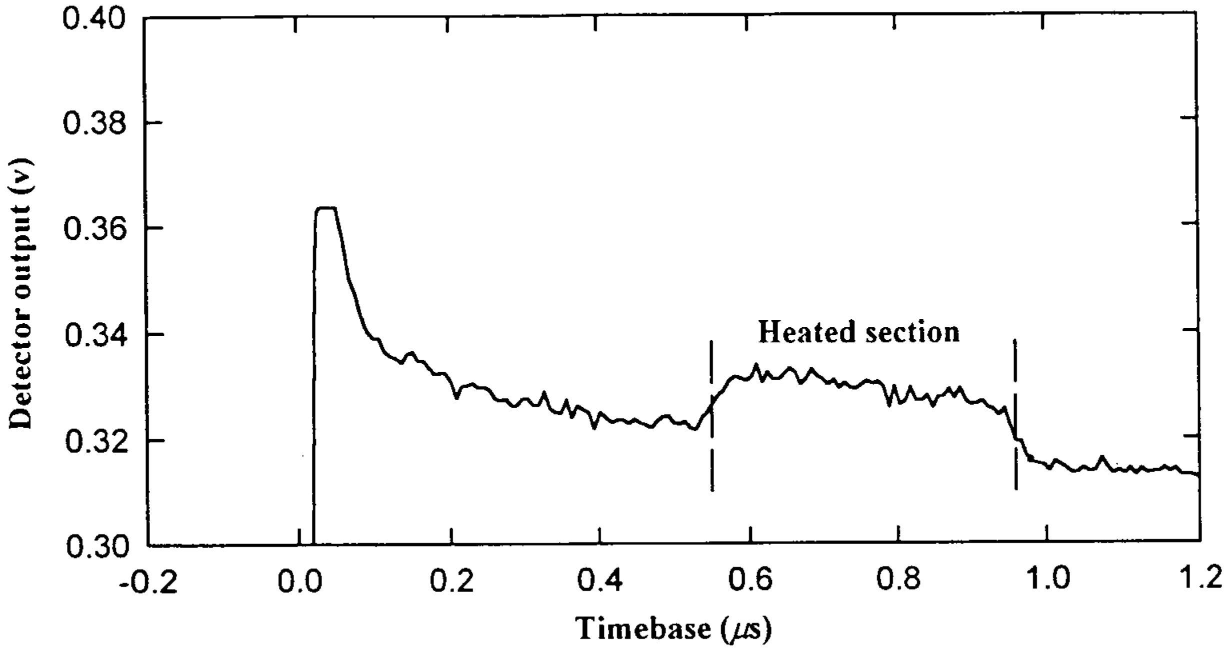
Figure 3. Stokes plus anti-Stokes Raman backscatter coupled out of the cavity by WDM2.



980nm
EDFA
pump
To pump
stabilisation
circuit
WDM1
Erbium doped fibre
Lo-bi
fibre
38m
Backscattered
signal
1435 & 1642nm
WDM2
Intracavity pulse
monitor
PC2
PC1
Oven
Hi-bi2
860m
Polarising
isolator
50m
40m
180m
Hi-bi1 270m



Pulse power (W)
4
3
2
1
0
-1
-2
0
2
4
6
8
Timebase (ns)



0.40
0.38
0.36
0.34
0.32
0.30
Detector output (v)
Heated section
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Timebase (μs)