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R. Kashyap, H.-G. Froehlich, A. Swanton and D.J. Armes (*BT Laboratories, Martlesham Heath, Ipswich IP5 7RE, United Kingdom*)

H.-G. Froehlich: on leave from Technical University of Dresden, Dresden, Germany

e-maol: raman.kashyap@bt.sys.bt.co.uk

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1.64μm pulsed source for a distributed optical fibre Raman temperature sensor

G.P. Lees, A.P. Leach, A.H. Hartog and T.P. Newson

Indexing terms: Raman effect, Raman lasers, Temperature sensors, Fibre optic sensors

The authors propose a novel source for distributed anti-Stokes Raman temperature sensing. A source generating 8W, 10ns pulses at 500Hz, at λ = 1.64μm is demonstrated. Operation at 1.64μm enables the temperature dependent anti-Stokes signal at 1.53μm to be generated in the low-loss window, facilitating a long range sensor.

Introduction: Optical fibre distributed temperature sensors (DTSs) which use Raman scattering effects have been widely developed and commercially exploited since the first demonstration in 1935 [1 – 4]. The current trend in DTS design is to increase the range while maintaining the spatial resolution. First generation distributed temperature sensors operated using high power 0.9μm laser diodes [2], these were followed by systems operating at 1.06μm. Pressure to provide a long range DTS system prompted a shift to λ = 1.55μm in the low-loss window for telecommunication grade fibre. Operating at 1.55μm, up to 30km of multimode [3] and singlemode [4] fibre have been monitored.

This Letter describes a novel source for distributed temperature sensing operating at 1.64μm. Operation at this wavelength produces a weak temperature dependent anti-Stokes signal in the low-loss window at 1.53μm. Previous DTS systems operating at 1.55μm generated an anti-Stokes signal at 1.45μm. The loss at this wavelength is dominated by the hydroxyl (OH) ions present in the glass, and is typically 0.3–1.0dB/km. A DTS system operating at 1.64μm would generate an anti-Stokes signal at 1.53μm, which lies in the centre of the low-loss window (0.2dB/km).

With this decrease in attenuation at the anti-Stokes shifted wavelength, a corresponding increase in dynamic range can be expected when the source is integrated into the DTS system.

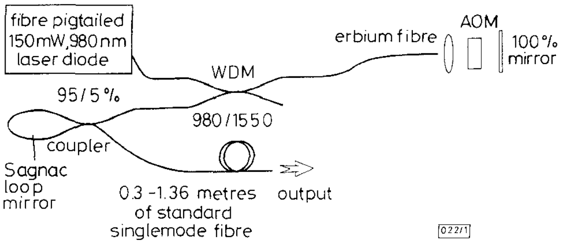

Fig. 1 *Experimental arrangement to produce pulses at 1.64μm*

Experiment: The principle behind the source is stimulated Raman generation. A probe pulse generated by a high power Q-switched erbium doped fibre laser is introduced into a length of fibre which then generates the Raman-Stokes shifted wavelength.

Fig. 1 shows the experimental arrangement. The Q-switched erbium doped fibre laser produces up to 125W of peak power with a 50ns pulse duration at a repetition rate of 500Hz. The output coupler of the laser is a Sagnac loop mirror with a reflectivity of 19%. A Sagnac loop is preferred over conventional dichroic mirrors due to the fibre compatibility of the device. It is important to ensure that the length of the loop arms does not exceed the nonlinear length. If this occurs, the reflectivity of the Sagnac loop will vary substantially over the pulse duration, producing pulse deformation. For a peak power of 125W and nonlinear coefficient γ of $5.135W^{-1}km^{-1}$, the nonlinear length is 1.55m which is higher than the 0.4 m used in the experiment. A typical output from the Q-switched laser is shown in Fig. 2.

The output from the Q-switched laser at 1.535μm is then spliced to a drum of telecommunications grade fibre, between 300 and 1360m long. This drum of fibre generates the stimulated Raman light. The generation of stimulated light requires the pump pulse to be above a threshold determined by [5]:

$$P^{th} = \frac{16A_{eff}}{g_r L_{eff}} \qquad (1)$$

where g_r is the Raman gain coefficient (1×10^{-13} m/W), A_{eff} is the effective core area ($80μm^2$), and L_{eff} is the effective length given by

$$L_{eff} = \frac{1}{\alpha}(1 - \exp(-\alpha L)) \qquad (2)$$

where α is the attenuation constant ($5 \times 10^{-7}cm^{-1}$). Using these values, the threshold for a 600m long fibre is calculated to be 21.7W. It is shown later that this calculation is in good agreement with experimental observations. From the above equations it is clear that the threshold will decrease with longer fibre lengths. However, one major limitation of generating 1.64μm wavelength pulses, is the generation of further orders of Raman light at wavelengths of 1.77μm and above. For long lengths of fibre, there is the possibility that the threshold for higher Stokes orders will be exceeded by the 1.64μm wavelength which will proceed to be depleted. The optimum performance of the system would therefore be achieved by increasing the threshold for higher (second order, and so on) Stokes orders, while producing the maximum amount of first order Stokes. Table 1 shows the results obtained for different lengths (300, 600, 1360m) of Raman generation fibre. The

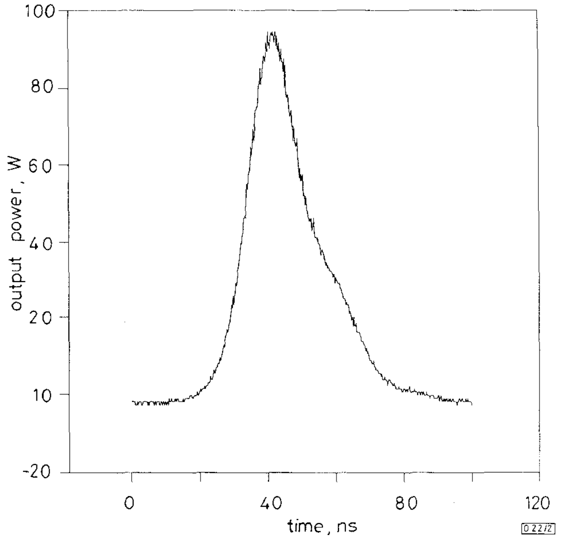

Fig. 2 *Typical output pulse at 1.53µm from Q-switched fibre laser*

Table 1: Thresholds for generation of Stokes for different fibre lengths

Fibre length	Input power at 1.535µm	Output power at 1.64µm, 25nm linewidth	Threshold for generation of Stokes at 1 = 1.64µm
m	W	W	W
300	62	8.4	31.6
600	92	7.7	22
1360	92	5.4	13.2

Table shows the input pump power at 1.535µm, the output power at 1.64µm, limited to a linewidth of 25nm and the threshold power for the generation of the 1.64µm wavelength pulses.

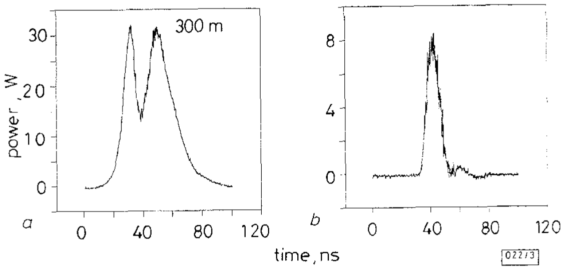

Fig. 3 *Plot showing Raman pulse and remainder of input pulse for 300m of Raman generation fibre*

a Output pulse at 1535µm
b Raman pulse at 1640µm

The results show that a short length of fibre with the highest threshold allows an increased amount of Raman light to be generated, given a sufficiently high pump power to overcome the threshold. The results also show that a maximum peak power of 8W was obtained at 1.64µm using a fibre length of 300m. Fig. 3 shows the remainder of the input pump pulse and the generated Raman pulse for the 300m length of fibre. The Raman pulse was extracted using a 25nm linewidth filter centred on 1640nm, which is the peak of the Raman gain profile [5]. The threshold for Raman light generation can be observed from the onset of the pump depletion occurring at 31.6W.

Fig. 4 shows the results obtained from the 600m length of fibre. The results show the generation of second order Stokes wavelengths pumped by the 1.64µm wavelength pulses. The threshold for the second order generation should be approximately the same as that for the first order; the observed threshold of 8W for second order generation is significantly smaller than the 22W for first order generation due to the presence of the bandpass filter, which blocks much of the generated Raman light.

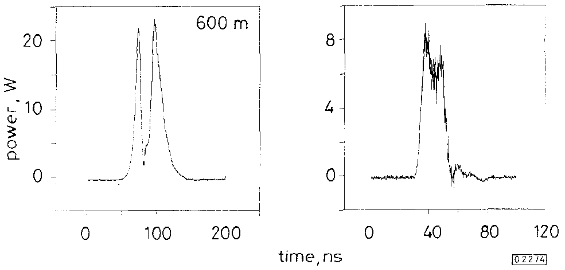

Fig. 4 *Raman pulse and remainder of input pulse for 600m of Raman generation fibre*

The distortion on the Raman pulse is due to stimulation of further Stokes orders
a Output pulse at 1535µm
b Raman pulse at 1640µm

For the available 92W of pump power, the length of generation fibre has to be sufficiently short to increase the threshold to a level so that no second order Raman light is produced. A length of 300m produces 8W of 1.64µm Raman power with a 25nm bandwidth. A power of 8W is sufficient for DTS applications, as any stimulated Raman light generation is undesirable and hinders temperature measurements.

Conclusion: This Letter proposes a novel source for long range DTS application. A pulsed source supplying 8W of 1.64µm with a pulse width of 10ns at a repetition rate of 500Hz is demonstrated.

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G.P. Lees and T.P. Newson (*Optoelectronics Research Centre, University of Southampton, Highfield, Southampton SO17 1BJ, United Kingdom*)

A.P. Leach and A.H. Hartog (*York Sensors Ltd., York House, School Lane, Chandlers Ford, Southampton, United Kingdom*)

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