OPTICAL TIME-DOMAIN REFLECTOMETRY MEASUREMENTS IN A 4 km FIBRE RING LASER

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The first experimental Rayleigh backscatter measurements in a passively modelocked fibre ring laser are reported. The Rayleigh backscatter data were used to identify and estimate splice losses as well as the back reflection of the intracavity optical isolator.

Introduction: The technique of optical time domain reflectometry [1] has proven to be a valuable diagnostic tool for characterising optical fibre systems. It is generally used to measure fibre attenuation and splice losses and may be used to determine structural parameter variations and examine polarisation effects. We present for the first time OTDR measurements performed on a 4 km passively modelocked fibre ring laser. This method may be applied to any modelocked fibre laser to determine the loss parameters of each of the intracavity elements (isolator, modulators, polarisers, splices etc.). Preliminary detection measurements of the spontaneous Raman Stokes and anti-Stokes lines demonstrate the feasibility of a distributed temperature sensor based on a modelocked fibre laser in which the actual sensing fibre forms part of the laser cavity.

Experimental: The experimental setup is depicted in Fig. 1. The pump source was an argon-ion pumped Ti : sapphire laser providing up to 3 W of CW light at 980 nm to pump the erbium doped fibre (Er concentration 800 *ppm*, $NA = 0{\cdot}15$ and cutoff wavelength $\lambda_c = 960$ nm) through a 980/1550 wavelength division multiplexing (WDM) coupler. A small amount of 980 nm light from the remaining output port of the WDM was fed back to an active stabilisation circuit, which by means of a Bragg cell compensates for any variations in the pump power. The cavity comprised 4 m of erbium-doped fibre, two reels of standard telecom fibre ($NA = 0{\cdot}11$, $\lambda_c = 1200$ nm) of lengths 1 and 3 km each, a fibre optical polarising isolator (BT&D Technology), two sets of polarisation controllers and a 1480/1550 WDM coupler situation between the erbium-doped fibre and the 1 km reel as shown. One free port of this coupler was used to monitor the backscattered light as shown in Fig. 1, whereas the other free port was tightly bent so as to eliminate any reflection. The output coupling of the 1480/1550 WDM at the lasing wavelength was 16%. A 1480/1550 WDM was used as an output coupler for the backscattered light to enhance the intensity of the spontaneous backscattered Raman Stokes and anti-Stokes wavelengths, located 100 nm away on either side from the main Rayleigh backscattered wavelength (1560 nm). An InGaAs detector (Analog Devices Model No. 713K-7-B) with 200 MHz bandwidth and transimpedance gain of 16 V/mW was used to detect the backscattered light. The signal was recorded using a digitising scope with time averaging capabilities (Hewlett-Packard Model No HP 54111D).

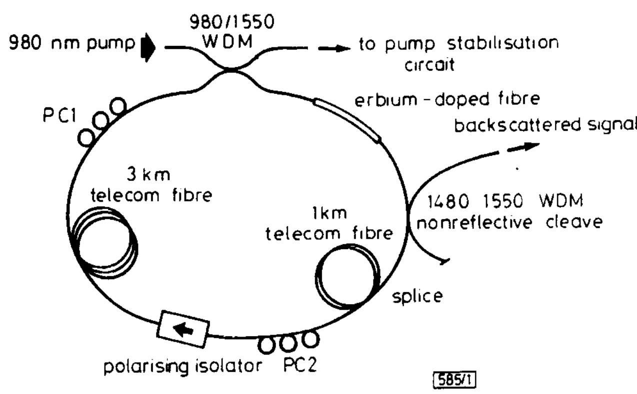

Fig. 1 *Optical configuration*

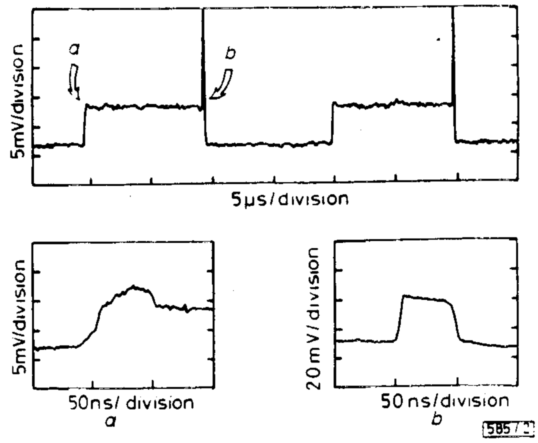

Fig. 2 *Rayleigh backscattered signal trace*

The modelocked operation of this laser was similar to that described in Reference 2. In short, the laser produces 'square' pulses of 40–50 ns duration which, by appropriate adjustment of the PCs, can be split into smaller tight pulse bunches, each pulse inside the bunch being typically 1–2 ns long. By gradually decreasing the pump power, only one of these pulses can be left to circulate inside the cavity.

Fig. 2 shows a typical backscatter trace obtained when a 43 ns square pulse was circulating in the laser cavity. The power of the circulating pulse just before the 1480/1550 WDM was estimated to be 15·3 W and the average backscattered output power was 325 nW. The trace is an average of 64 samples. Points *a* and *b* on the trace are shown in separate inserts for greater clarity. Point *a* represents the start of the Rayleigh backscatter signal with the small hump identifying the splice between the 1480/1500 WDM and the 1 km reel. The second, much bigger spike at point *b* originates from the optical isolator back reflection. This was estimated from our measurements to be 58 dB, in close agreement with the manufacturer's datum which is 60 dB. After the pulse has gone through the isolator, no backscattered signal is detected until the pulse passes the 1480/1550 WDM.

The optical spectrum of the backscattered signal is shown in Fig. 3. The solid line shows the optical spectrum of the detected signal, and the broken line shows the true optical backscattered spectrum after correcting for the 1480/1550 WDM transmission characteristics. Fig. 3 indicates that there is strong evidence of backscattered spontaneous Raman Stokes and anti-Stokes light; measurements of the backscattered spontaneous emission of erbium at wavelengths 1460

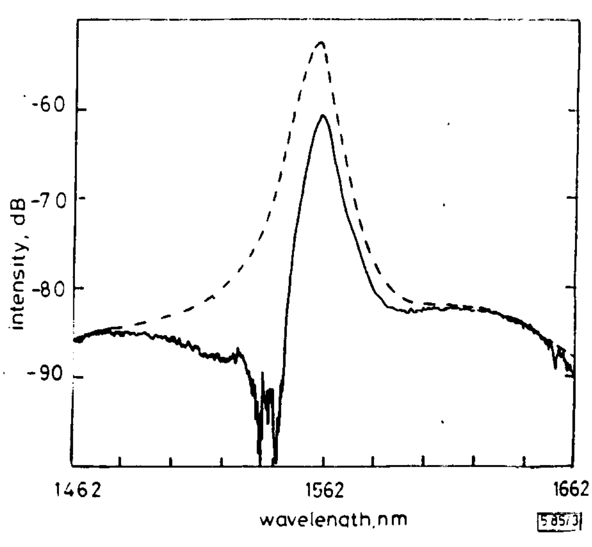

Fig. 3 *Optical spectrum backscattered signal shown in Fig. 2 and with coupler correction*

——— optical spectrum of backscattered signal
– – – – optical spectrum with coupler correction

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and 1660 nm corresponding to the peaks of the Raman gain spectrum are more than 15 dB below our recorded values. This implies that our system is not only able to measure attenuation by conventional OTDR but also has potential for distributed temperature sensing using the ratio of the Stokes/anti-Stokes Raman lines (distributed anti-Stokes Raman thermometry) [3].

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