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1.5μm Brillouin-based fibre optic distributed temperature sensor with high spatial resolution of 20cm

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ABSTRACT

We demonstrate a high spatial resolution single-ended spontaneous Brillouin-based distributed temperature sensor for a 500m length of single-mode silica fibre. Using a short pulsewidth laser source at 1.5μm, measurements down to a spatial resolution of 20cm and temperature resolution of 4.4°C were achieved.

1. INTRODUCTION

Fibre optic distributed temperature sensors based on Brillouin scattering have been researched for a number of years. Its advantages over Raman-based systems include longer sensing ranges [1] and sensitivity of the Brillouin signals to both temperature and strain using conventional single-mode silica sensing fibres [2,3]. There is also currently considerable interest in developing high spatial resolution distributed fibre sensors. In some applications, there is a need for fine monitoring of structures over a shorter sensing range, which require sub-metre spatial resolution. In many previous systems, minimum spatial resolution have been limited to a few metres and there has been debate as to whether the Brillouin linewidth ultimately limits the spatial resolution that can be achieved [4].

Recently, a novel method using direct-frequency-modulation of a tunable laser diode and electro-optic modulator (EOM) demonstrated a sensing spatial resolution of 45cms [5]. Distributed strain measurements with 25cms spatial resolution have also been performed, with the requirement that the sections under interrogation must be uniformly strained, identical in length and probed with two sources [6]. In this paper, we demonstrate a high spatial resolution Brillouin distributed temperature sensor using a single-ended source based on the OTDR principle without such restrictions. The sensors operate by measuring the ratio of the intensity of the spontaneous Brillouin to Rayleigh backscattered signal (Landau-Placzek ratio). This technique was initially performed for a 12.9-km sensing range with a 600m spatial resolution [7] and more recently for a 6.3-km sensing range with a 10m spatial resolution [8]. The time between sending the pulse of light and detecting the backscattered signal provides a measure of the distance along the fibre, whilst the intensity of the spontaneous Brillouin backscattered light provides the information on temperature. With the source pulse width being shorter than the acoustic damping time, the Brillouin gain spectrum broadens out, resulting in a lower peak gain but broader frequency spectrum.

2. EXPERIMENT

The main components of the sensor consists of the laser source to generate the Brillouin backscattered signal, the sensing fibre and a low cost filtering and detection system which comprises an all-fibre Mach-Zehnder interferometer and a sensitive InGaAs detector connected to a computer based averaging system. Figure 1 depicts the experimental set-up for measuring the temperature profile along the sensing fibre. To maximise the backscattered signal, there is a need to generate a high peak power within the short pulse. The signal pulse was generated from a narrow linewidth CW distributed feedback (DFB) laser diode with an output power of 2.5mW externally modulated using a $LiNbO_3$ EOM with a rise time of 100ps. This signal pulse was then amplified using an Erbium-doped fibre amplifier (EDFA1) and the residual ASE noise was filtered by an in-fibre Bragg grating (Reflectivity = 99.4%, $\Delta\lambda$ = 0.08nm, λ = 1533.4nm) in conjunction with a circulator 1 (C1). The reflected signal was then amplified using another Erbium-doped fibre amplifier (EDFA2) to overcome the loss of the acousto-optic modulator (AOM), which served to gate the pulse and filter the ASE generated by the second EDFA. The AOM was synchronised with the EOM and 2ns pulses were generated at a repetition rate of 6.5kHz. The signal was then launched into the sensing fibre through a circulator (C2).

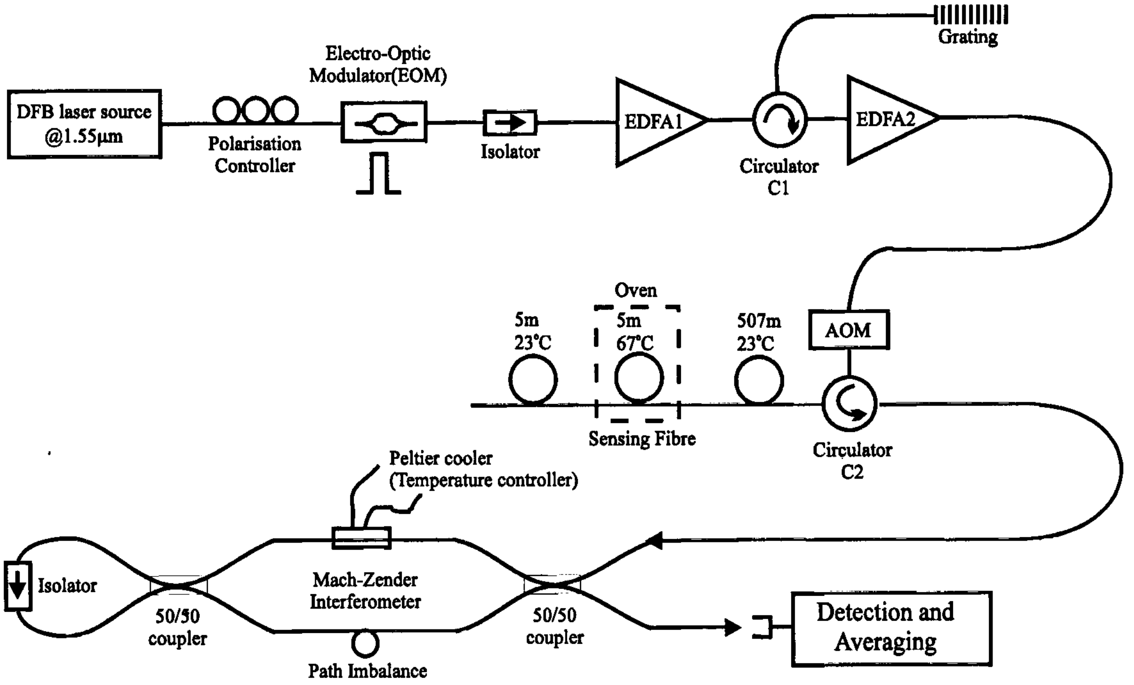

Figure 1: Schematic diagram of Brillouin-based distributed fibre temperature sensor.

In previous experiments, distributed Brillouin temperature sensors operated with the use of an expensive, high loss bulk Fabry-Perot interferometer [7]. In this experiment, a double pass configured in-fibre Mach-Zehnder interferometer was used to spectrally separate the Brillouin signal from the Rayleigh signal [9]. This low-loss interferometer provided in excess of 26dB extinction of the Rayleigh signal from the Brillouin and was locked using a peltier cooler in thermal contact with one arm of the device. The sensing fibre consisted of conventional single-mode silica fibre (NA=0.12, cutoff=1.2μm). The temperature measurement was performed over a 517m continuous length of sensing fibre with a 5m fibre section near the far end of the sensing fibre heated to 67°C and the remaining length at room temperature of 23°C. The Brillouin signal was measured with a detector and transimpedance amplifier with a bandwidth of 200MHz.

3. RESULTS

Figure 2 shows the plot of the spontaneous Brillouin backscattered signal taken at a distance of 505m down the sensing fibre. The 5m section in the oven was heated to a temperature of 67°C, an increase of 44°C from the room temperature of 23°C. It can be seen from the plot that there is a clear rise in the heated section. In order to make absolute measurements, the Brillouin intensity has to be normalised to the Rayleigh backscattered intensity which is independent of temperature fluctuations. To minimise coherent Rayliegh noise effects, the Rayleigh signal was obtained by using a broadband pulsed source in place of the DFB laser diode. The ratio of the Brillouin and Rayleigh signals (Landau-Placzek ratio) provides a temperature dependent signal which is corrected for splice/bend losses and fibre attenuation. The r.m.s. noise on the Landau-Placzek ratio was calculated to provide information on the temperature resolution of the trace, which corresponded to 4.4°C. Figure 3 illustrates an expanded trace of the step in Brillouin backscattered signal for the section at the end of the sensing fibre and the noise floor. By taking the 10-90% response time, the spatial resolution was calculated to be approximately 20cms.

4. CONCLUSION

With a spatial resolution shorter by an order of magnitude from previous systems, the reported results demonstrate the highest spatial resolution achieved to date using a distributed temperature sensing system based on the intensity dependence of spontaneous Brillouin scattering. The sensing measurement was made over a 500m continuous length of silica fibre, with a temperature resolution of 4.4°C. It is necessary that the bandwidth of the Brillouin signal has increased to that of the pump pulsed source for such spatial resolutions to be achieved. Although this source was used for monitoring temperature variations through measuring the Brillouin backscattered intensity, it is potentially possible to perform combined distributed temperature and strain measurements with a very high spatial resolution by measuring both the backscattered intensity and frequency shift [7,10] provided the frequency shift can be resolved with similar spatial resolution.

5. REFERENCES

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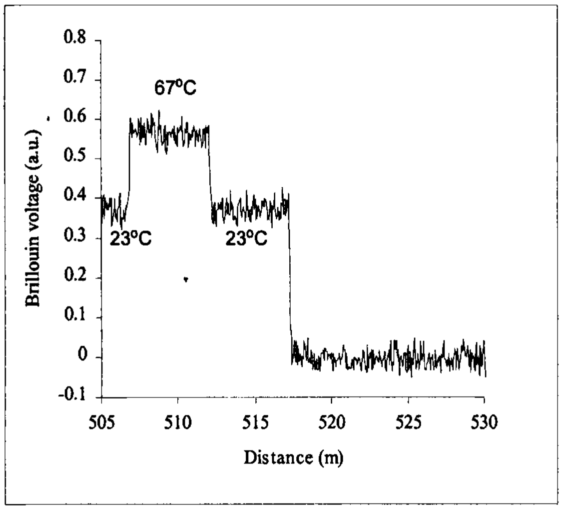

Figure 2: Spontaneous Brillouin backscattered signal with a 5m section of fibre at 67°C.

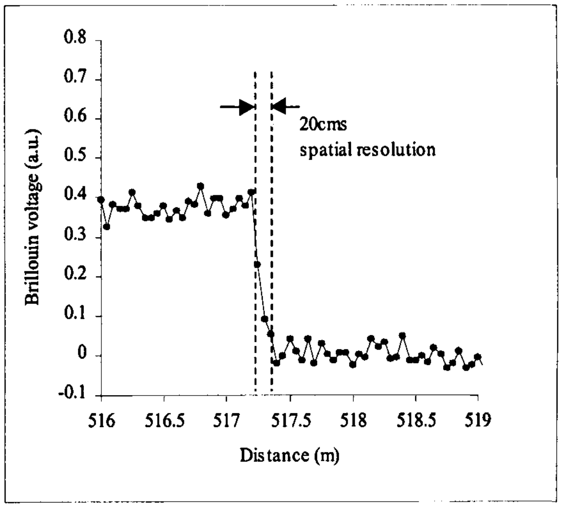

Figure 3: Brillouin signal illustrating the fall time of the trace indicating a 20cm spatial resolution.