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Chirped fibre gratings for temperature-independent strain sensing

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Abstract A temperature-independent strain sensor using a chirped fibre grating is demonstrated with a strain resolution of 0.1% over the total measurement range.

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Fibre Bragg grating sensors are of considerable interest for a number of sensing applications [1-6]. More recently, chirped Bragg gratings are attracting research interest for strain sensing [2,3]. However, undesirable temperature sensitivity of the fibre grating sensor may complicate its use as a strain gauge. Morey *et. al.* have suggested that the temperature can be measured and compensated for using a second grating element contained within a different material and placed in series with the first grating [4]. We have also demonstrated that the problem can be resolved by arranging for the simultaneous measurement of strain and temperature [5], or by arranging for the thermal response to be cancelled [6]. Nevertheless, all of the above methods are difficult to implement when a large number of fibre gratings are involved in a multiplexed sensing system. In this paper we describe a novel temperature-independent strain sensor based on the use of a chirped fibre grating in a tapered optical fibre.

In an unchirped fibre grating, both strain and temperature cause a shift in the Bragg wavelength, while the effective bandwidth remains essentially unaffected. As a result, on a single measurement of the Bragg wavelength shift, it is impossible to discriminate between the effects of strain and temperature. However, the bandwidth can be made to be strain-dependent if a strain gradient is introduced along the grating length [2]. Using this singular dependence of bandwidth on strain gradient, temperature-independent strain sensing is now possible. Employing a technique reported recently [7], a chirped grating can be written in a tapered fibre by differential etching. The taper profile can be designed such that the grating becomes linearly chirped when tension is applied thus creating a strain gradient along the grating. The average strain, defined as the integral of local strain over the grating length, is measured by the change in the effective bandwidth. Although both average strain and temperature still induce a shift in the Bragg wavelength, the effective bandwidth variation will only depend on the strain rather than the temperature.

The experimental system is shown in Fig.1. Light from a 1550nm ELED, having a FWHM bandwidth of ~96nm, was split via a fibre coupler to illuminate the chirped fibre grating and to provide reference. The ratio of reflected power over reference power provides the strain information and serves to eliminate the effect of intensity variation due to power fluctuations in the source. The sensing element was the linearly chirped grating described above, with nominal central Bragg wavelength of 1554nm, FWHM bandwidth of 2nm, and peak reflectivity of ~100%. The length of the grating was 20mm, in a 25mm taper. The taper diameter varied from 125μm - 78μm. Strain was applied by directly stretching the fibre using different weights to ensure good strain transfer, and temperature was accurately set by using a temperature controlled Peltier heat pump. When the grating simultaneously experiences changes in both strain and temperature, the back-reflected light intensity alters only if the strain changes, provided that attenuation due to microbending in the lead is insignificant and the splitting ratio of the coupler is constant. We assume that a strong grating is used, such that the reflectivity over most of the grating bandwidth is ~100% even under strain.

Fig.2 shows the ratio of the reflected to reference light was measured as a function of temperature from 10°C to 50°C for three different strain levels, showing excellent temperature-independent behaviour as predicted. For a shot-noise-limited system, a strain resolution of 0.8$\mu\epsilon$ normalised to a 1Hz bandwidth was expected for the interrogation system used. The measured strain resolution was 4.4$\mu\epsilon$, corresponding to a strain resolution of 1% over the full measurement range. The grating used in this experiment was fabricated under tension, resulting in significant pre-chirp. Thus the grating bandwidth decreased as tension was applied, and above a certain value of tension, equal to that at which the grating was written, the bandwidth would increase. By writing the grating without applying tension, the bandwidth would increase monotonically with increasing stress. Fig.3 shows the time response of the sensor. The output is monitored over 10 minutes as the strain of 928.13 $\mu\epsilon$ and 2108.34 $\mu\epsilon$ was applied, respectively.

If the sensor is to be embedded directly in a composite material, under conditions of no applied tension, the problem of thermally-induced apparent strain could occur due to the difference in the coefficient of thermal expansion between the host material and the fibre grating sensor. Therefore, to maintain the temperature-independent nature, it is an inherent requirement of this technique that the sensing element be kept in free space. A major source of error can be attributed to microbending loss in the lead. This uncertainty can be eliminated by monitoring the transmission loss in the lead at the far end of the fibre containing the grating at a wavelength different from that of the grating. The strain responsivity of the experimental system is limited by the characteristics of the chirped fibre grating used. The responsivity, and hence strain resolution can be enhanced by varying the taper profile, however a trade-off has to be made between the strain responsivity and the measurement range determined by the taper strength.

In summary, we have demonstrated a temperature-independent strain sensor using a chirped Bragg grating in a tapered fibre. The system developed provides a compact, rugged, low-cost and true strain measurement. A strain resolution of 4.4$\mu\epsilon$ over a total measurement range of 4066$\mu\epsilon$ has been demonstrated, which can be improved by optimising the design of the fibre taper. In addition, temperature can also be measured simultaneously by monitoring the wavelength shift of the grating if desired. However, more work will be needed if the sensor is to be embedded in or surface-mounted on practical structures.

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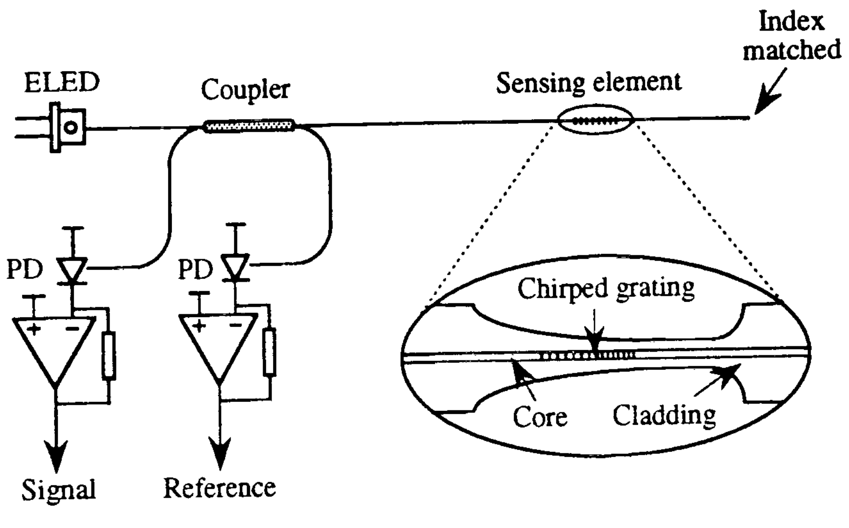

Fig. 1 Schematic of temperature-independent strain sensor using a chirped Bragg grating in a tapered fibre.

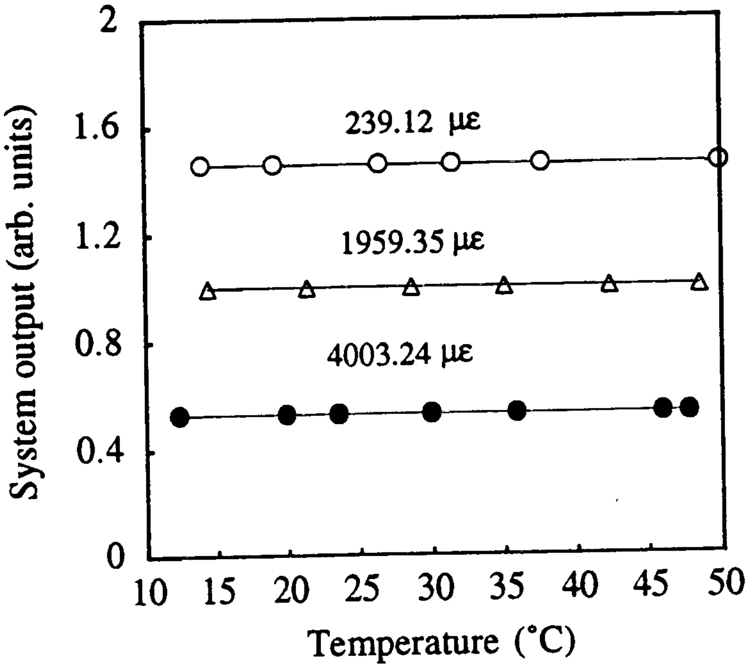

Fig.2 System output versus temperature at three different static strain levels.

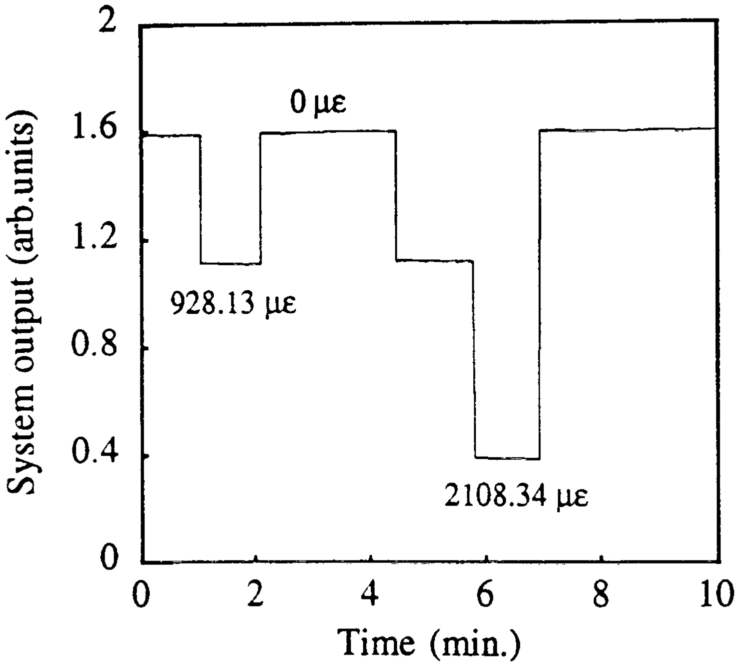

Fig.3 Time response of the sensor as the strain of 923.13με and 2108.34με was applied.