2008-09-11

All-fibre Temperature Sensor Based on Macro-bend Singlemode Fibre Loop

Ginu Rajan
Dublin Institute of Technology, ginu.rajan@dit.ie

Yuliya Semenova
Dublin Institute of Technology, yuliya.semenova@dit.ie

Gerald Farrell
Dublin Institute of Technology, gerald.farrell@dit.ie

Recommended Citation

Rajan, G., Semenova, Y., Farrell, G.: All-fibre Temperature Sensor Based on Macro-bend Singlemode Fibre Loop. Electronics Letters, September 11, 2008, Vol. 44, issue 19. doi:10.1049/el:20081233

All-fibre temperature sensor based on macro-bend singlemode fibre loop

G. Rajan, Y. Semenova and G. Farrell

An all-fibre temperature sensor is proposed based on a macro-bend singlemode fibre loop using a ratiometric power measurement scheme. The sensor has a linear characteristic with temperature at a fixed wavelength and bend radius. A direct linear relationship between the bend loss of the singlemode fibre and temperature is reported for the first time. By measuring the change in bend loss of the system a change in temperature can be measured assuming the system is calibrated. The proposed sensor has a higher temperature resolution than other conventional fibre-optic sensors and also benefits from simplicity.

Introduction: The bend loss properties of singlemode fibre have been studied intensively along with applications such as a fibre filter, based on the bend loss phenomenon, utilised as an edge filter for wavelength measurements [1]. Significant effort has been made by researchers to use the bend loss properties of singlemode fibre for temperature measurements. One method is based on interferometry [2] where the temperature sensitivity arises from the thermo-optic and thermal expansion sensitivity of the buffer coating leading to interference between the whispering gallery (WG) modes and the core mode. This method requires the determination of phase information at different wavelengths to extract the temperature information. High temperature sensing using whispering gallery mode resonance in bend fibres is also reported [3], which involves measuring the resonance wavelength peak shift with temperature. Both approaches lack a direct linear relation between bend loss and temperature and the need for phase measurements makes the system complex.

In this Letter we present a simple method to measure temperature which uses a bend sensitive bare singlemode fibre loop with an absorption layer utilised in a ratiometric power measurement scheme. The removal of the buffer coating eliminates the effect of the two different thermo-optic coefficients of the buffer and the cladding and the use of an appropriate absorption layer results in a monotonic increase in bend loss with bending radius [4] which is approximately equivalent to a core-infinite cladding structure. Given the simplicity of fabrication, the low cost of the sensor head, and the use of an unmodified singlemode fibre, it can be used as a disposable sensor where the sensor is expected to be destroyed after a period of time or is unrecoverable.

Theory: The temperature sensitive sensor head consists of a buffer stripped high bend loss singlemode fibre arranged in a loop with an absorption layer applied to the cladding. The absorption layer is chosen to absorb light at the wavelength of operation, absorbing the WG modes inherent in a bent singlemode fibre and reducing the reflections back from the air-cladding boundary. By eliminating the WG modes the bend loss variation with temperature at a fixed wavelength and loop bend radius depends only on the thermo-optic coefficients of the cladding and core. Since the cladding and core are made of silica material and have a positive thermo-optic coefficient, the thermally induced effective change in refractive index of the core and cladding is linear in nature, resulting in a linear variation of bend loss with temperature. Furthermore, there is a monotonic increase in bend loss with bend radius and wavelength and thus the temperature sensitivity of the sensor can be varied by changing the bend radius or the operating wavelength.

The temperature information is extracted using a simple ratiometric power measurement system as it measures a ratio which is independent of source power variations resulting in a more stable and accurate system. The input signal from the source splits into two equal power signals, one goes to the fibre sensor and the other is the reference signal, as shown in Fig. 1. Two photodiodes are used to measure the power at the outputs of the corresponding arms. By measuring the power ratio of the two signals, which is a function of temperature, temperature can be measured, assuming the system is properly calibrated.

Experiment: The fibre used in the experiment was a 1060XP singlemode fibre which has a high bend loss in the wavelength region of 1550 nm and gives a good bend loss response with wavelength, as we reported earlier [4]. From the middle section of a length of the fibre, the buffer coating is stripped and an absorption layer is applied. The absorption material used in the experiment was a black India ink [5], which we verified experimentally as absorbing more than 99% of radiation in the wavelength range 1500–1600 nm. The fibre sensor is formed by creating a single 360° loop by inserting the fibre ends to a small 2 mm polymer tube. To fix the radius of the loop, the junction of the fibre inside the tube is glued. This forms a stable macro-bend fibre temperature sensor. The bend radius used was 12.5 mm which gives a bend loss of 7 dB at 0°C for a wavelength of 1550 nm. The sensor is utilised in the ratiometric power measurement scheme, as shown in Fig. 1. The input wavelength to the system was 1550 nm. The fibre loop was fixed to a 5 cm diameter aluminium base plate, the temperature of which is controlled using a Peltier cooler driven by a temperature controller and full contact between the fibre sensor and the base plate is ensured. The expansion of the aluminium base plate and its effect on bend loss for a radius of 12.5 mm was calculated but is found to be negligible. Using an accurate independent temperature monitor for the purpose of calibration, the ratio response was measured at 1°C intervals for a temperature range of 0 to +75°C. The range employed was limited by the capabilities of the Peltier cooler used. The ratio response measured against temperature is shown in Fig. 2. From the Figure, it is clear that the average slope of the system is 0.012 dB/°C.

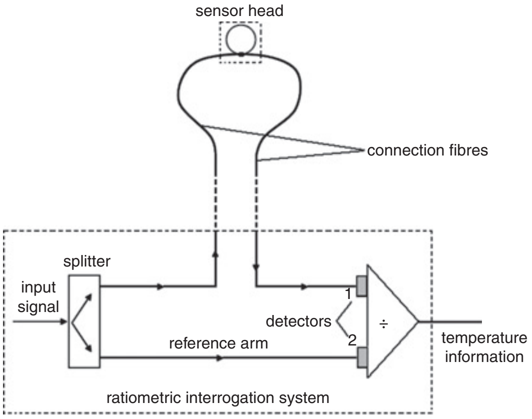

Fig. 1 *Schematic diagram of macro-bend fibre temperature sensor system*

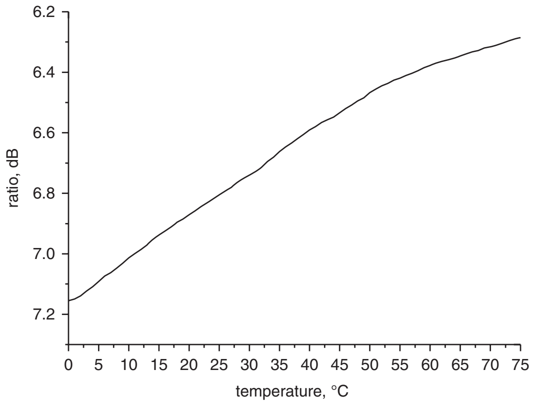

Fig. 2 *Ratio response of system against temperature*

To measure the temperature resolution of the system, a step change of 1°C from 30 to 25°C is applied to the fibre sensor over a time period of 60 s. The measured ratio variation is shown in Fig. 3, which proves that the system is very capable of resolving temperature changes less than 1°C. Fibre temperature sensors such as a fibre Bragg grating (FBG) typically provide a 10 pm wavelength shift for a 1°C temperature change. To resolve a temperature change of less than 1°C (or less than 10 pm), expensive active interrogation systems with high resolution are required. Hence, most low cost FBG interrogation systems use a passive wavelength demodulation system, which has a low resolution when compared to an active system. To illustrate this, for a ratiometric FBG interrogation system based on an edge filter, if a filter slope of 0.5 dB/nm is assumed (most edge filters slopes are circa 0.5 dB/nm [6, 7]), then the ratio variation is approximately 0.005 dB/°C. By comparison, a ratio variation of

0.012 dB/°C for the sensor proposed here confirms the competitive temperature sensitivity of this sensor.

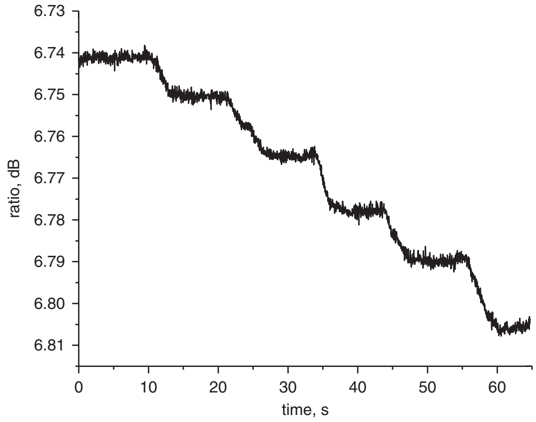

Fig. 3 *Variation in ratio for step change of temperature of 1°C from 30 to 25°C*

Since the sensor head is a silica fibre, then together with a high temperature capable absorption layer, it has the potential to be used for wide range and high temperature applications. Given the simplicity of fabrication, the low cost of the sensor head, and the use of singlemode fibre, it can be used as a disposable sensor in harsh environments or to measure the internal temperature of materials used as composites, where the sensor is expected to be destroyed after a period of time or is unrecoverable. Compared to existing fibre-optic sensors, this is a unique advantage of this macro-bend singlemode fibre temperature sensor.

Conclusion: An all-fibre temperature sensor based on macro-bend singlemode fibre using a ratiometric power measurement scheme is proposed and demonstrated. A linear variation in bend loss with temperature is obtained by using a buffer stripped singlemode fibre with an absorption layer applied. The sensor has a high temperature resolution and can reliably resolve temperature variations of less than 1°C. The proposed low-cost sensor can be used as a disposable sensor in a range of application areas.

1 May 2008
Electronics Letters online no: 20081233
doi: 10.1049/el:20081233

G. Rajan, Y. Semenova and G. Farrell (*Applied Optoelectronics Center, School of Electronics and Communication Engineering, Dublin Institute of Technology, Dublin 8, Ireland*)

E-mail: ginu.rajan@dit.ie

References

1 Wang, Q., Farrell, G., Freir, T., Rajan, G., and Wang, P.: ‘Low cost wavelength measurement based on a macrobending singlemode fiber’, *Opt. Lett.*, 2006, **31**, (12), pp. 1785–1787
2 Haran, F.M., Barton, J.S., Kidd, S.R., and Jones, J.D.C.: ‘Optical fiber interferometric sensors using buffer guided light’, *Meas. Sci. Technol.*, 1994, **5**, (5), pp. 526–530
3 Nam, S.H., and Yin, S.: ‘High temperature sensing using whispering gallery mode resonance in bent optical fibers’, *IEEE Photonics Technol. Lett.*, 2005, **17**, (11), pp. 2391–2393
4 Wang, P., Farrell, G., Wang, Q., and Rajan, G.: ‘An optimized macrobending fiber based edge filter’, *IEEE Photonics Technol. Lett.*, 2007, **19**, (15), pp. 1136–1138
5 Mourant, J.R., Bigio, I.J., Jack, D.A., Johnson, T.M., and Miller, H.D.: ‘Measuring absorption coefficients in small volumes of highly scattering media: source-detector separations for which path lengths do not depend on scattering properties’, *Appl. Opt.*, 1997, **36**, (22), pp. 5655–5661
6 Davis, M.A., and Kersey, A.D.: ‘All-fibre Bragg grating strain-sensor demodulation technique using a wavelength division coupler’, *Electron. Lett.*, 1994, **30**, (1), pp. 75–77
7 Ribeiro, A.B.L., Ferreira, L.A., Tsvetkov, M., and Santos, J.L.: ‘All-fibre interrogation technique for fibre Bragg sensors using a biconical fibre filter’, *Electron. Lett.*, 1996, **32**, (4), pp. 382–383