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METAL-COATED OPTICAL FIBRE BRAGG GRATING FOR ELECTRIC CURRENT SENSING

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The use of optical fibres as sensing elements for electric current measurement has been developed by several methods such as those utilising magnetic field to generate the Faraday effect [1], magnetomotive force to make fibres bend [2], magnetostrictive material bonded on a fibre to constrict or lengthen the fibre [3], and heating effect to change the fibre's length and refractive index [3]. In all of the above methods, perturbations (e.g., magnetic field, pressure, strain and temperature) are induced by the measurand, i.e., the electric current, accordingly resulting in change of the optical fibre characteristics and then modulation of the light within the fibre. Recently, it has been shown that a system employing a fibre Bragg grating bonded to a piezoelectric transducer (PZT) in conjunction with an optical fibre Mach-Zehnder interferometer [4] can be constructed to measure alternating currents. There are, however, several disadvantages to the PZT scheme: 1) comparatively high voltages must be applied to the PZT; 2) the PZT's are fairly bulky and their frequency response is limited by circumferential resonance; 3) as an hybrid current sensor, in real applications they need a calibrated shunt resistor ('*burner*') which will increase considerably the cost of the system.

The sensitivity of optical fibres to minute changes in temperature suggests their potential use to measure electric current. The electric current measurement using the thermal characteristics of optical fibres was already implemented many years ago by detecting the heat generated by the electric current flowing through metallic coating on the fibre using a fibre Mach-Zehnder interferometer [3]. The strains and refractive index changes resulting from thermally induced stresses in the fibre alter the phase of the light propagating through it. However, unwanted changes in the amplitude of the detected signal, caused by differential drift in the arms of the interferometer, need to be eliminated through the use of an electronic compensation scheme.

This paper describes a current sensor device which utilises this temperature sensitivity to modulate the wavelength of the light reflected by an optical fibre Bragg grating (FBG). In the present work, the temperature change and, consequently, the wavelength change, is accomplished by passing electric current through a thin conductive coating on the surface of a short length of the fibre where the fibre grating is located. The measurement of the Bragg wavelength shift produced by the heating effect is obtained using a passive all-fibre demodulation scheme previously described by one of the authors [5]. The aim of the scheme is to combine the resolution of a conventional current transformer (CT) with the electrical insulation achievable with a fibre optic system.

The configuration of the optical fibre current sensor system is shown in Fig. 1. A pigtailed superluminescent diode (Superlum SLD 361), emitting at 830 nm with ≈2mW optical power and ≈20 nm linewidth, was used to illuminate the metal-coated FBG via one port of a standard 3 dB fibre coupler (C_1). The FBG was written using the phase mask method in a hydrogen loaded standard singlemode fibre, and demonstrated a Bragg wavelength of ≈836 nm at room temperature, with a reflectivity ≈85% and bandwidth of ≈0.3 nm. The inset box of

Fig. 1 depicts the FBG coated with a ≈1.4 mm layer of low ion conductive pure silver epoxy. Electrical contacts were made at both ends of the coated region (typically 2 cm long and having a ≈1.2 Ω total resistance). The electrical current to be measured (I_P) is converted by the CT (a Rogowski' coil with a current conversion of 4000:1) to a secondary current (I_s), which is passed directly through the metallic coating of the FBG. Since the FBG period and hence the reflected Bragg wavelength are dependent on the temperature or strain of the fibre, the $I_s^2 R$ heating produced by the secondary current (ranging form 0 to 1 A) in the FBG metal coating will shift the Bragg wavelength, and thus by monitoring this shift the value of the electrical current was recovered.

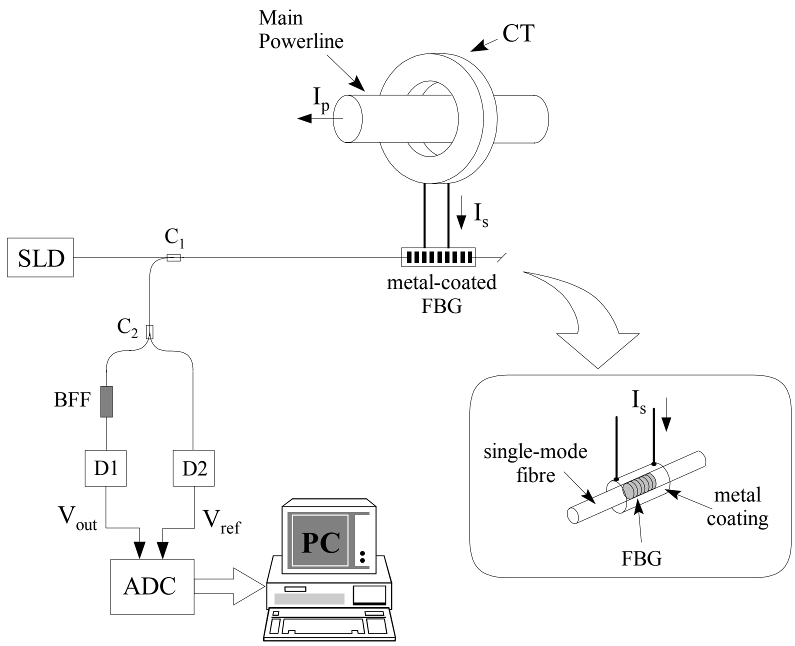

Fig. 1 Schematic design of the fibre-optic current sensor (inset box: the metal-coated FBG sensor head).

The returned wavelength component from the FBG was split by a second 3dB fibre coupler (C_2) into two paths: in one path the intensity was directly measured while in the other is passed through a biconical fibre filter (BFF) before reaching the detector. The BFF was fabricated with an oscillation period of ≈3.5 nm and an extinction ratio of ≈8.1 dB. Over the working range of the FBG (835.9 - 836.8 nm) the BFF had near linear response of ≈7 dB/nm, as shown in Fig. 2(a). The Bragg wavelength variation of the FBG as a function of the squared applied secondary DC current is shown in Fig. 2(b). To measure the wavelength shift of the FBG, and consequently, the secondary electrical current, the ratio of the two detected intensities was implemented by software using the LabView™ program. In this way, compensation is performed for time-varying intensity fluctuations and spectral intensity variations of the broadband source, and also for any coupling loss and microbend fluctuations up to coupler C_2.

The response of the current sensor to an alternating current is composed of two components, i.e., an AC component at twice the driving frequency (this terms predominates at low frequencies), and DC term which predominates at high frequencies. Both terms are proportional to the square of the electrical current. Fig. 3 shows the sensor output response to a sinusoidal secondary current with frequency 50 Hz and driving RMS current ranging from 0.04 A up to 0.4 A. It should be pointed out that these results were obtained without the CT and were simulated using a laboratory variable current source with capability to change the shape, frequency and amplitude of the test current signal applied to the metal-coated FBG.

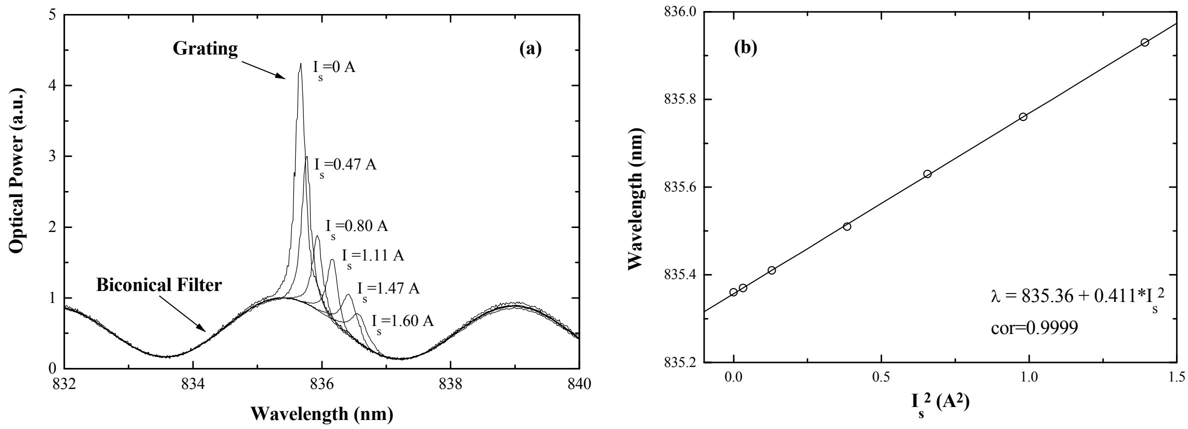

Fig. 2 (a) Biconical fibre filter transfer function superimposed with the FBG spectra for different values of the secondary current. (b) Bragg wavelength shift as a function of the squared secondary current.

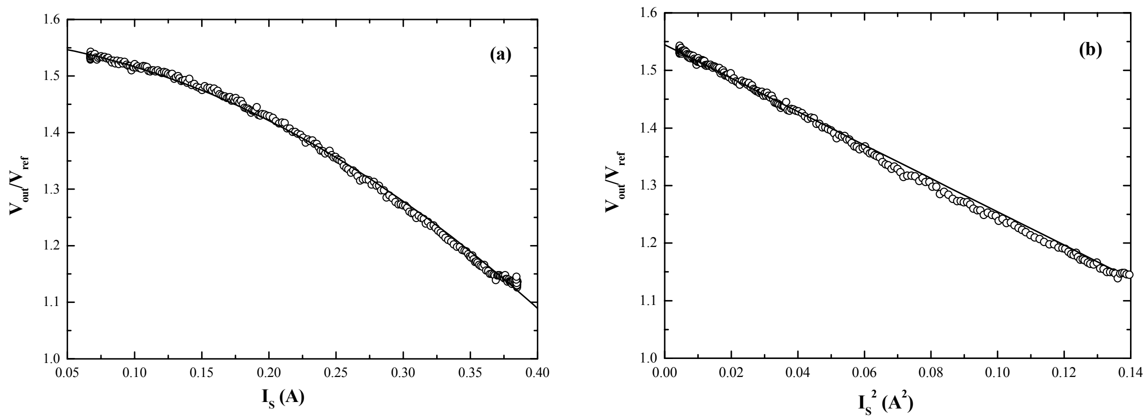

Fig. 3 Output of the sensor to an applied alternating secondary current with frequency 50 Hz as a function of (a) the driving RMS current, and (b) the square of the same RMS current (the solid lines represents curve fitting).

From the results of Fig. 3b, linearity can be observed throughout the measured region and the obtained data indicates a RMS current resolution of 2 mA. The bandwidth (at -3dB point) of the sensor system for a constant RMS current was found to be 2.2 Hz. For frequencies higher than this one, the sensor output produce the RMS average of the secondary current waveform, but the DC term cannot be easily distinguished from the low frequency drift due to environment temperature. Fig. 4 shows the response of the sensor to a secondary current step from 175 mA to 250 mA. The time constants for heating and cooling regimes are (0.46±0.01) s and (0.47±0.01) s, respectively (obtained from Fig. 4(b)). These AC results give a dynamic sensitivity of $\approx 1\text{mA}/\sqrt{\text{Hz}}$. This response behaviour is characteristic from this type of temperature devices [6,7]. Nevertheless, it should be possible to increase the frequency response up to tens of kilohertz using a sputtering technique to produce a thinner layer of metal along the FBG.

Because CTs are both used for metering (frequency of interest is 50 or 60 Hz) and relaying purposes (overload conditions and current spikes), it is also necessary that the frequency response of the sensor system be much higher than the line frequency. Improvements in the design and response of the described sensor system are presently being investigated in order to overcome these issues. Another drawback for this application is the sensitivity of the FBG both to the temperature and to the strain, which means that some kind of compensation scheme to de-coupling the two effects will be necessary.

The use of an hybrid scheme offers several advantages over more 'conventional' optical schemes, such as the ones based on the Faraday effect. The inherent wavelength encoded output information of these devices make them independent on light levels and good candidates for incorporation into wavelength-division multiplexing schemes. Also, this sensor configuration has the advantage of presenting a purely resistive impedance to the current source.

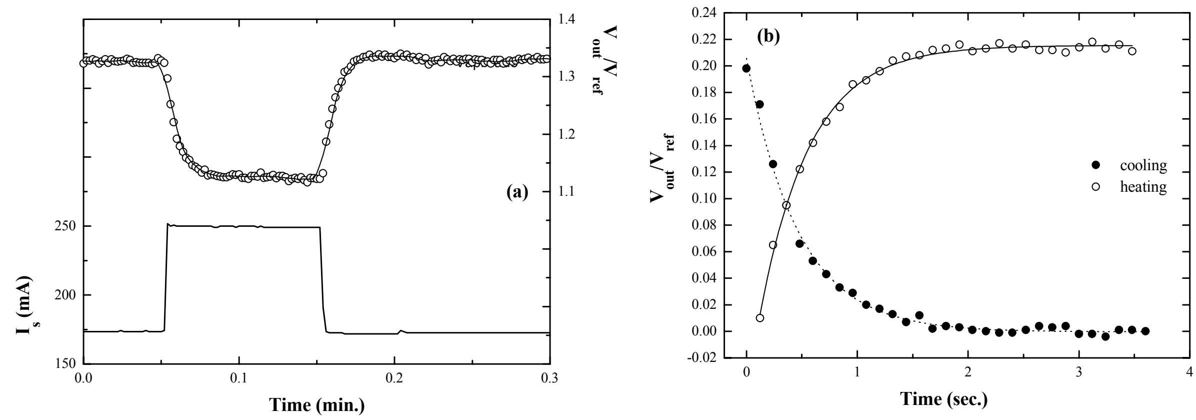

Fig. 4 (a) Response of the sensor (on top) to a step change of the secondary current (on bottom). (b) Detailed response of the sensor to the heating and cooling time intervals from fig. 4(a).

In summary, a metal-coated fibre Bragg grating sensor for measuring the RMS current of power lines at 50 Hz was constructed, providing a resolution of ±2 mA and a dynamic sensitivity of ≈1mA/√Hz at 2 Hz.

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