Integrated Temperature Compensated Bragg Grating Refractometer – Benefiting from Birefringence

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UV written planar Bragg grating sensors have been shown to form effective refractometers. Here we show that by using the birefringence of an integrated waveguide a temperature insensitive Bragg grating refractometer can be realised.

OCIS code: (280.4788) Optical sensing and sensors; (230.3120) Integrated optics devices.

We shall present a method of making a temperature insensitive Bragg grating refractometer which makes benefit of the different properties of the transverse electric, TE, and transverse magnetic, TM, modes of the waveguide.

In recent years high sensitivity refractometers have received a great deal of interest for application in the fields of medical diagnosis, biochemistry and chemistry. There are many competing approaches capable of detecting refractive index changes of 10^{-6} within integrated optics. These include Surface Plasmon Resonance sensors (SPR) [1] and Mach Zehnder interferometers [2], however there are several key advantages to using a Bragg grating system. The avoidance of heavy metals (such as gold) within the device reduces both the cost and the environmental impact of the sensor, while still retaining a functionalisable sensor surface. Fibre-coupled integrated Bragg grating refractometers can be easily incorporated into distributed networks with centralised interrogation by standard telecoms test and measurement equipment. Furthermore, the small size and integrated nature allows the optical sensors to be deployed for a wide range of applications including within flammable environments.

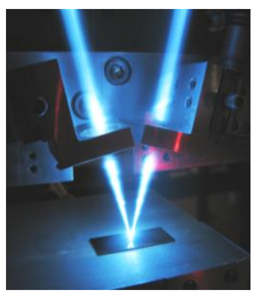

Fig.1 – The two interferometric UV beams allows Bragg gratings to be written directly into the core.

While UV written planar Bragg grating sensors have been shown to be effective devices for measuring refractive index. One of the fundamental resolution limiters for all integrated optical devices is thermal fluctuation. Bragg gratings intrinsically respond linearly with changes in temperature by ~11 pm /°C. In the past various temperature compensating systems have been suggested, from thermal control of the ambient environment to utilising an additional local Bragg grating of different Bragg wavelength. While these temperature referencing techniques are sufficient for simple systems; to detect the subtle changes in refractive index needed for practical sensors requires precise *in-situ* temperature referencing [3]. Here we shall present an alternative system which utilises the birefringence of a planar Bragg grating refractometer to provide temperature compensation.

In this work, a sample fabricated via flame hydrolysis deposition was used where the core layer was doped with germanium to provide photosensitivity. On exposure to UV light (λ = 244nm) the refractive index of the germanium doped glass was locally increased, forming the waveguide. Using an interferometer, Bragg gratings of different period may be simultaneously written into the device (Figure 1) [4]. In order to access the evanescent field of the optical mode the overclad was selectivity removed [5]. To increase the sensitivity of the device to liquids with refractive index less than that of silica, i.e. water with an index of ~1.33, a thin layer of high refractive index material was deposited onto the surface, as shown in Figure 2.a). The high refractive index material pulls the mode into the analyte, increasing the proportion seen by the mode [6]. As a consequence the birefringence of the waveguide is greatly increased as illustrated by the calculated mode profiles shown in Figure 2.b). This increase in the birefringence of the two modes is sufficient to spectrally separate the two Bragg reflections to allow simultaneous acquisition.

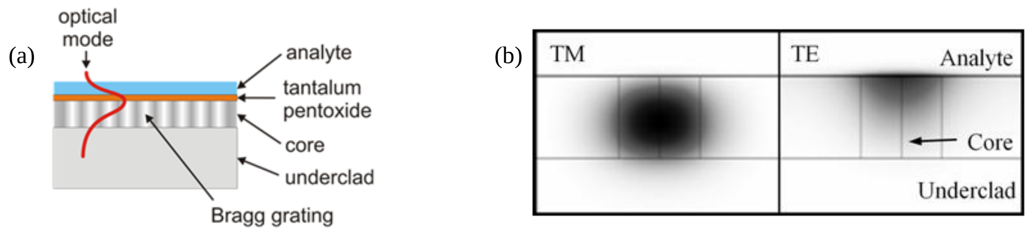

Fig. 2.a) – A schematic of the Bragg grating sensor showing the high index overlayer pilling the guided optical mode into the analyte.
Fig. 2.b) – The modelled TE mode is pulled up into the tantalum pentoxide overlayer, resulting in a greater modal overlap with the analyte, however the evanescent field of the TM mode penetrates less out of the surface, resulting in much lower sensitivity to surface changes.

The effect of this birefringence, B, is that the thermo-optic reponse of the TE mode is dominated more by the thermo-optic coefficient of the analyte than for that of the TM mode – which is still dominated by the intrinsic thermo-optic coefficient of the silica waveguide. To test this approach, the Bragg grating sensor was cooled with Cargille refractive index liquid (Series AAA, "1.3000") on the sensor window, while the temperature was monitored with a thermocouple. As shown in Figure 3, the TM mode and TE mode demonstrated very different behaviours during this cooling curve experiment. However applying a scaling factor removed the thermal component and in the absence of any refractive index changes in the analyte, gave the flat line (red dash). In contrast, applying a simple subtraction of the two modes without the scaling factor, *K*, it was shown to increase the thermal component of the TE mode rather than remove it (red dots).

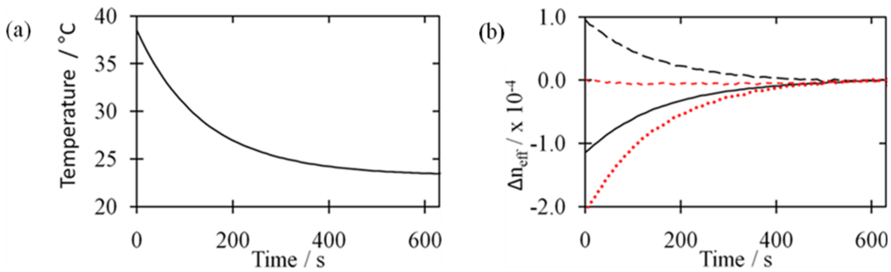

Fig. 3.a) The cooling curve recorded by the thermocouple.
Fig. 3.b) Applying the scaling factor to the TM (dashed line) and subtracting from the TE mode (solid line) makes the Bragg response insensitive to temperature changes (red dash) Without scaling TM by *K*, the thermal response of the TE mode is increased (red dots).

Although the two modes are different, an understanding of the system allows the temperature dependence to be compensated. For many sensing applications the solvent used is consistent or at least known in advance. For example, many bio-sensing devices are run in water or a saline solution of known concentration. Modelling the system for the desired analyte or solvent allows the thermal properties of the two modes to be calculated. In addition this model can be used to determine the scaling factor, *K*, between the modes:

$$\Delta B_{eff} = \Delta n_{eff}^{TE}(n,T) - K.\Delta n_{eff}^{TM}(n,T)$$

In summary, by using the TM mode to monitor temperature fluctuations and, in conjunction with the thermo-optic constants for the solvents of the system, a temperature-insensitive Bragg grating sensor can be fabricated. We shall show that for a real system this approach can successfully remove the thermal component from the Bragg response. Not only does this approach simplify the system, as no additional components are necessary, such as a second Bragg grating or thermocouple, but it also makes use of the previously redundant TM mode of the Bragg response. The high resolution of this temperature compensation combined with the high sensitivity of a planar Bragg grating makes this system ideal for detection of the subtle changes in chemical and bio-sensing applications.

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