Sensing Characteristics of Modal Interferometers based on HC-PCF

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***Abstract*— In this work, a modal interferometer based on hollow-core photonic crystal fiber is considered and sensitivity to strain, temperature and curvature studied. The sensing head was fabricated by connecting a piece of hollow-core fibre in both ends to standard single mode fibre. An interference pattern that is associated to the interference of the light that propagates in the hollow core fundamental mode with light that propagates in other modes is observed. The phase change of interferometer is measured using a white light interferometric technique.**

***Index Terms*— Hollow-core photonic crystal fibre, fibre sensors, white light interferometry.**

I. Introduction

The development of sensors based on hollow-core photonic crystal fibres (HC-PCF) has been a recent and active research topic in the context of fibre optic sensing. Particularly relevant is the application of these fibres for gas sensing in face of the large overlap of the optical field with the measurement volume [1], but other measurands have also been considered, for example bend and shape [2], strain and temperature [3], as well as hydrostatic pressure [4]. HC-PCF are made with hundreds of periodically spaced air holes in a silica matrix, typically arranged in a triangular lattice, using the photonic band gap concept to propagate light inside the core. HC-PCFs are multi-mode waveguides and other than the fundamental core mode, they can support higher order core modes, cladding modes and surface modes. However, the attenuation of the different types of modes varies a lot and after propagation along a long length of fibre only the fundamental core mode exists. The multi-mode operation of short lengths of HC-PCFs brings the possibility to build up modal interferometers with characteristics potentially interesting to perform optical fibre sensing.

In this work, a fibre optic modal interferometer based on HC-PCF was studied and its characteristics for sensing were investigated. The measurands addressed were strain, temperature and curvature. The readout of the interferometric phase was achieved combining white light addressing with pseudo-heterodyne signal processing.

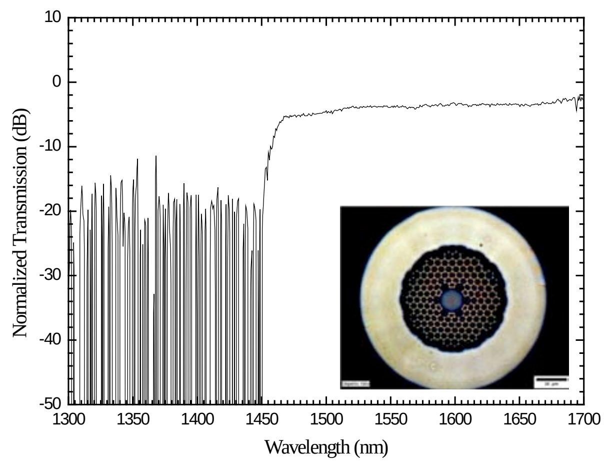

Figure 1. Normalized spectral transmission of ~ 1 m of HC-PCF fibre spliced to a SMF28 illuminating fibre and SEM image of the HC-PCF

II. Principle of Sensing and Results

The sensor was fabricated using a piece of HC-PCF directly spliced between two lengths of single mode fibre (SMF-28^{TM}) using a conventional fusion splice machine. A 7-cell HC-PCF with a core diameter of $\approx 16\ \mu m$ was used. Figure 1 shows the SEM image of this fibre and its transmission characteristics in the light injection conditions in which the experiments were performed. The developed sensing head uses the effect of modal interference at the exit of the HC-PCF to achieve measurement functionality. Indeed, when light travels through the single mode fibre and is injected into the HC-PCF the fundamental core mode (FM) and other modes are excited. After propagation of these modes in the HC-PCF, they become recombined at the output single mode fibre. This simple configuration is similar to an all-fibre Mach-Zehnder modal interferometer with two coupling points in series. Therefore, when light is injected into the input single mode fibre, it is

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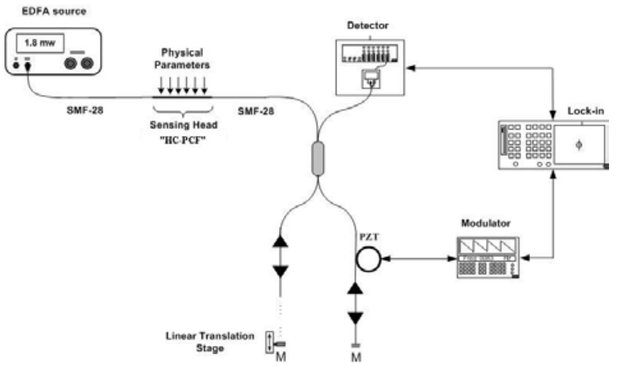

Figure 2. Scheme of the experimental setup for phase reading with white light interferometry.

expected to observe interference fringes at the output single mode fibre.

To measure the phase changes in the fibre modal interferometer, a second interferometer was built to implement coherence reading [5]. Figure 2 shows the setup implemented. The second interferometer is a conventional fibre Michelson interferometer with an open air path in one of its arms, which is adjusted to match the optical path difference of the sensing interferometer. The fibre in the other arm of this interferometer is wrapped around a ring-shaped piezoelectric transducer that is modulated with an electrical sawtooth waveform whose amplitude is adjusted to obtain a signal at the photodetection suitable for pseudo-heterodyne processing. After an adequate electronic filtering, this signal has the form of an electric carrier (90 Hz) with a phase that mirrors the optical phase of the tandem interferometric system. This pseudo-heterodyne processing technique is known to provide sensitive interferometric phase reading [5].

Figure 3 shows the phase changes associated with strain and temperature variations applied to the sensing head, now with L≈40 cm. corresponding to figure 3 the sensitivity is constant in the measurement range considered, with values of $0.76^{\circ}/\mu\varepsilon$ and 8.1º/ºC. To evaluate the measurand resolutions achievable with this sensing head structure, the sensor output was registered during a measurand step change. From the phase *rms* fluctuations during the periods of constant measurand values and the phase step change induced by a corresponding measurand step, resolutions of $\pm 1.4\mu\varepsilon$ and $\pm 0.2^{\circ}C$ were obtained for strain and temperature, respectively.

III. Conclusion

A sensing head based on hollow-core photonic crystal fibre for measurement of strain and temperature has been presented. The sensor consists of a piece of 7-cell HC-PCF connected to SMF-28 in both ends. The interference occurs between the fundamental mode and higher order modes inside the HC-PCF. A white light interferometric technique for coherent phase reading was used. Resolutions of $\pm 1.4\mu\varepsilon$ and $\pm 0.2^{\circ}C$ were obtained for strain and temperature, respectively. It was also found that the fibre structure is not sensitive to curvature.

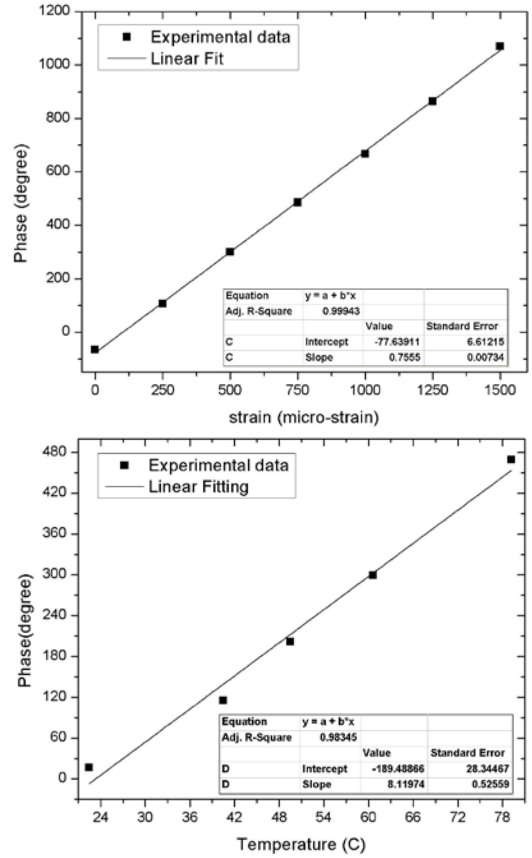

Figure 3. Phase changes induced by strain and temperature variations applied to the sensing head.

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