Highly Sensitive Fiber Optic Curvature Sensor

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Abstract: A curvature fiber optic sensor using a two-core fiber (TCF) is proposed and demonstrated. The TCF, which is designed to allow coupling between the cores, acts as a directional coupler and thus offers sinusoidal spectral response. The sensor is fabricated by splicing a 50 mm-long section of TCF between two SMFs. When the fiber is bent, the coupling coefficient between the cores is modified mainly due to stress-optic effect resulting in a blue shift of the sinusoidal spectral response and then allowing performing measurement of curvature. The sensor exhibits linear response in the range from 0 to 0.27 m^{-1} with sensitivity of -137.87 nm/m^{-1}.

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1. Introduction

The measurement of relative displacements and deformations plays an important role in several areas, such as structural health monitoring, since it is directly related to structural mechanical parameters, namely stress and deflection, thus allowing sketching the mechanical conditions of the structures in terms, for instance, of stress distribution and flexural loads. Generally speaking, sensors based on optical fibers have gained a lot of interest due to their well known advantages regarding to compactness and high sensitivity, among others. In the particular case of fiber optics curvature sensors those based on fiber gratings and specialty fibers have been widely investigated. Nevertheless, the common feature of the curvature sensors reported in the literature, beyond the natural implications related to the need to inscribe the grating, is their inability to perform measurements of small curvatures with high sensitivity. In terms of fiber gratings, the largest sensitivity reported, which was achieved with a long-period fiber grating (LPFG), is around 14 nm/m^{-1} [1]; on the other hand, in terms of specialty fibers, a double-cladd fiber has been reported with a sensitivity of 10.15 nm/m^{-1} [2]. In this work, a simple and cost-effective curvature sensor based on a two-core fiber (TCF) is demonstrated to operate, with linear response, in the range from 0 to 0.2653 m^{-1}, with a sensitivity of -137.8763 nm/m^{-1}.

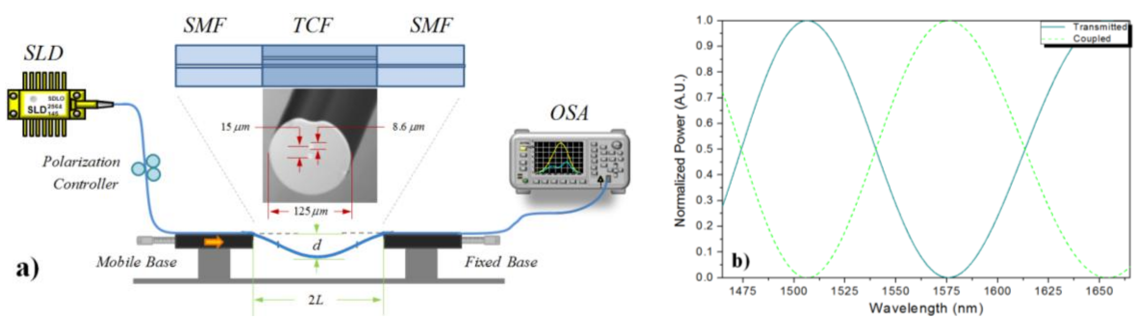

Fig. 1. (a) Schematic of the TCF-based curvature sensor. (b) Spectral response of the TCF.

2. Principle of Operation and Experimental Setup

The cross section of the TCF is shown in Fig. 1(a): the diameter of the cladding is the standard 125µm and it has two cores, both with a diameter of 8.6 µm. One of the cores is located at the center of the fiber, while the center of the other is located at a separation distance of 15 µm with respect to the center of the central core. The refractive index of core and cladding are 1.448 and 1.443, respectively. The fiber was manufactured at ACREO Fiberlab, in Sweden, and it was designed to accomplish two key functions: firstly, since one of the cores is located at the center of the fiber, special procedures are not required to splice it to a single-mode fiber (SMF); and secondly, the separation between the cores is small enough to allow coupling between the cores such that the fiber operates as an optical directional coupler, with spectral response similar to that shown in Fig. 1(b).

Fig. 1(a) shows a schematic of the experimental setup. The input SMF is connected to a polarization controller (PC), and the PC is connected to a broadband source (i.e. super luminescent diode centered at 1580 nm). The output SMF is connected to an optical spectrum analyzer (OSA) to monitor the spectral transmitted signal. In our particular case, the fiber is to be bonded to two translation stages, one fixed and one movable, and the polymeric coating is to be removed from the fiber in the bending section. Furthermore, since twisting of the fiber is assumed to be negligible due to accurate alignment and only bending is considered, the column theory can be suitable to model the behavior of the curvature sensor [3].

3. Experiments and Results

Based on the column theory, the stress induced to the fiber can be calculated in terms of the vertical deflection, the geometrical parameters of the fiber, and the material properties [3]. Furthermore, based on the stress-optic effect, the stress acting on the fiber can be transformed into a refractive index change for both core and cladding [4]. Consequently, when the fiber is bent and slight changes are induced on the refractive index of both core and cladding due to stress, the coupling coefficient will change. Fig. 2(a) shows numerical simulations of how the spectral behavior of the coupling coefficient is expected to change for several curvature conditions.

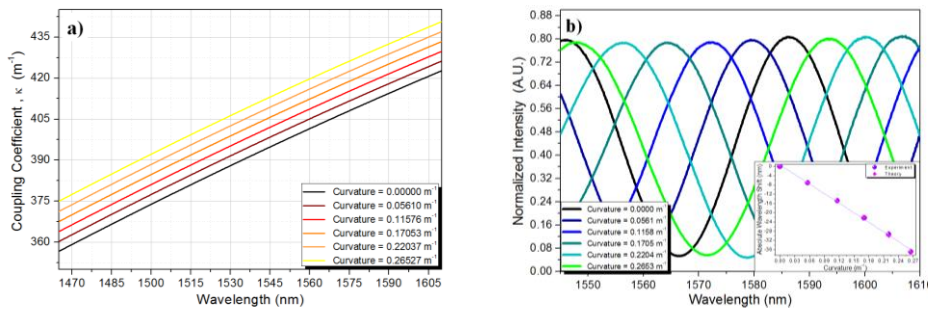

Fig. 2. (a) Spectral behavior of the coupling coefficient for several curvature conditions. (b) Experimental measurements of curvature and linear response of the curvature sensor (inset).

The sensor is fabricated by splicing a 5 cm-long section of TCF between two SMFs. The sensor was tested by moving the translation stage in steps of 50 µm. At each step, the transmitted spectrum was acquired with the OSA and the vertical deflection was measured to lately relate it to a curvature value. The experimental results of the curvature sensor based on the TCF are shown in Fig. 2(b), where the transmitted spectrum is plotted for different values of curvature. As can be noticed, the spectral response of the sensor experience a blue-shift as the fiber bends. We can observe that the shifting is quite uniform, and that the waveform is not deteriorated as the fiber bends. A total wavelength shift of -36.93 nm was achieved for the curvature range from 0 to 0.2653 m^{-1}. As shown in the inset of Fig. 2(b), the sensor offers linear response with a slope of -137.87 nm/m^{-1}. Furthermore, numerical simulations were found to differ from experimental results in less than 1%, which confirms the accuracy of the theoretical modeling.

4. Conclusions

A novel and simple curvature sensor based on a TCF has been demonstrated. The main advantages of the sensor are the direct splicing of the TCF to SMF and the outstanding improvement of the sensor sensitivity to perform measurements of small curvatures. The sensor exhibits linear response in the range from 0 to 0.2653 m^{-1}, with a sensitivity of -137.8763 nm/m^{-1}, and the mean error between the theoretical analysis and experimental data was less than 1%, which confirms the reliability of the theoretical model. Furthermore, the operation range can be extended to larger values of curvature by using a shorter section of TCF in order to achieve a larger free spectral range (FSR).
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5. References

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