Optical fiber refractive index sensors based on hetero-core structures and in-fiber Fabry-Perot cavities

A. Bueno, C. Caucheteur, D. Kinet, and P. Mégret

Université de Mons, Service d'Electromagnetisme et Telecommunication, Boulevard Dolez 31, 7000 Mons, Belgique.

In this paper, several configurations of optical fiber refractive index sensors based on a hetero-core structure are presented. These sensors are made by splicing short lengths of several specialty fibers with different core and cladding diameters between two standard single-mode fibers. In addition, two fiber bragg gratings are inscribed in single-mode fiber at both sides of the specialty fibers in order to create an in-fiber Fabry-Perot cavity and the behavior of the transmission spectra is analyzed. The sensitivities and spectral behavior of the sensors are obtained by immersion in solutions of different refractive index.

Introduction

Optical fiber sensors have been widely used for measurement of physical and chemical parameters (refractive index (RI), pH, acidity, liquid concentration, liquid level, gas leakage, etc.) due to their high sensitivity, immunity to electromagnetic interferences, stability and many other advantages. In case of RI sensors, some techniques have been developed like long period fiber gratings (LPFG) [1], side-polished fibers [2], tapered fibers [3] and surface plasmon resonance [4]. However, these techniques present some drawbacks like etching, mechanical polishing or metal coating, making the fabrication process complex and unsuitable for mass production. On the other hand, fiber modal interferometers that produce multimode interference (MMI) have been proposed because of their good sensing abilities and their simple fabrication [5]. The concept of re-imaging in the MMI effects associated with multimode waveguides was widely used in planar waveguides [6]. A simple configuration with a three-segmented fiber structure enables the detection of a change in the RI of the surround medium.

In this paper, we demonstrate the feasibility of an RI sensor based on MMI made with three-segment hetero-core structures by splicing a length of a specialty fiber between two SMF28 fibers. Different lengths of a coreless silica fiber (CSF) and a thin core fiber (TCF) were used. In addition, fiber Bragg gratings (FBG) were inscribed to both sides of a TCF hetero-core structure to form a Fabry-Pérot interferometer in order to characterize the spectra changes with the surrounding RI.

Methodology

The three-segment hetero-core structures were fabricated by splicing a CSF or a TCF in the middle of a standard SMF28 single-mode fiber (Figure 1.a and 1.b). The CSF is made by pure silica with a diameter of 125 μm and the TCF has a core diameter of 5 μm and a cladding diameter of 125 μm. In addition, a new structure was made by the inscription of uniform fiber Bragg gratings (FBG) at both sides of a TCF hetero-core

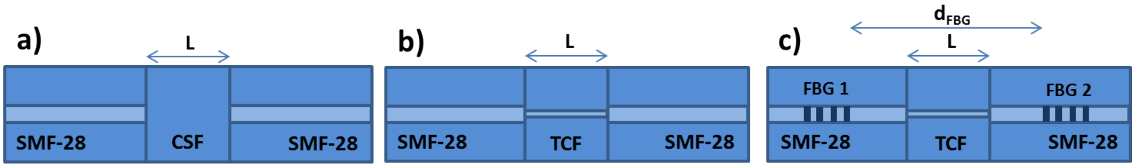

Figure 1. Hetero-core multimode interferometers made of a) coreless silica fiber (CSF), b) thin core fiber (TCF) and c) in-fiber Fabry-Pérot interferometer inscribed in a TCF hetero-core structure.

structure (Figure 1.c). In this case, the length of the TCF section was set to L = 5 mm and the distance between FBG was d_{FBG} = 15 mm. The FBG were uniform gratings with 50% reflection and a Bragg wavelength at 1549 nm approximately.

Concerning the experimental setup, a broadband ASE source was connected to an end of the hetero-core structures, whereas the other end was connected to an optical spectrum analyser (OSA) in order to acquire the transmission spectra of the structures (Figure 2). The RI characterization was achieved by immersing the hetero-core structures in a solution of lithium chloride (LiCl) with distilled water. The RI of the solution depends on the LiCl concentration. By means of a pipette, distilled water was added to the solution in order to decrease the LiCl concentration gradually and therefore its refractive index.

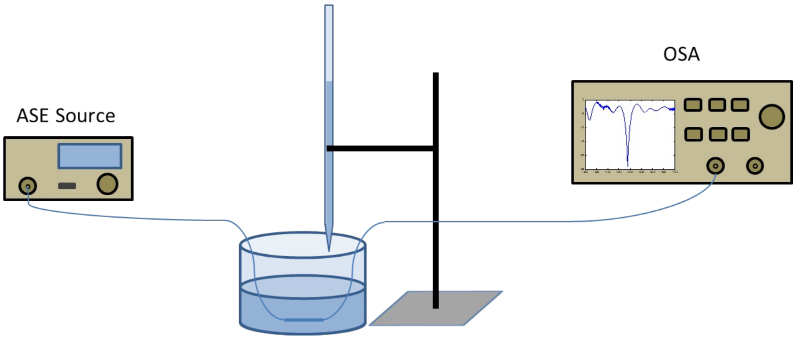

Figure 2. Setup for testing the hetero-core structures.

The lengths studied were 5 mm and 10 mm for the CSF structure and 5 mm and 15 mm for TCF structure. The transmission spectra were first recorded in air and then the structures were immersed in a LiCl solution with an initial refractive index value of 1.4220 and 1.4210 respectively. The refractive index of the LiCl solution was measured by an Abbe refractometer.

Results

As it can be observed in Figures 3 and 4, the transmission spectrum shows resonant wavelengths due to the cavity formed with the two interfaces in the hetero-core region, SMF28-CSF/TCF and CSF/TCF-SMF28. The spacing between these wavelengths dips decrease as the length of the fiber inserted between SMF28 fibers increase. It can be seen in Figures 3 and 4 that the transmission spectrum experiences a blue shift as the refractive decreases. In case of using TCF as sensing part, the dips were narrower and deeper and in the case of 5 mm length, the transmitted optical power of the wavelength dip decreases as the refractive index decreases.

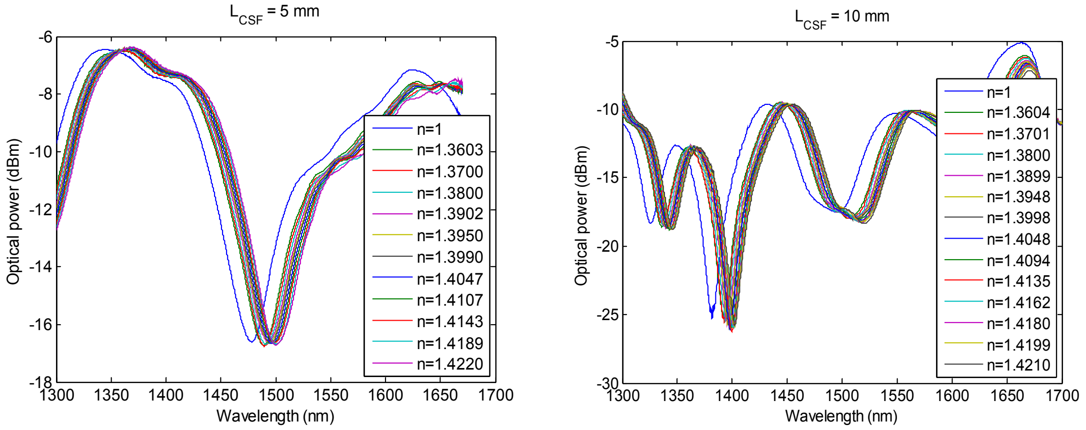

Figure 3. Transmission spectra of 5 mm (left) and 10 mm (right) length CSF hetero-core structures exposed to different surrounding refractive index.

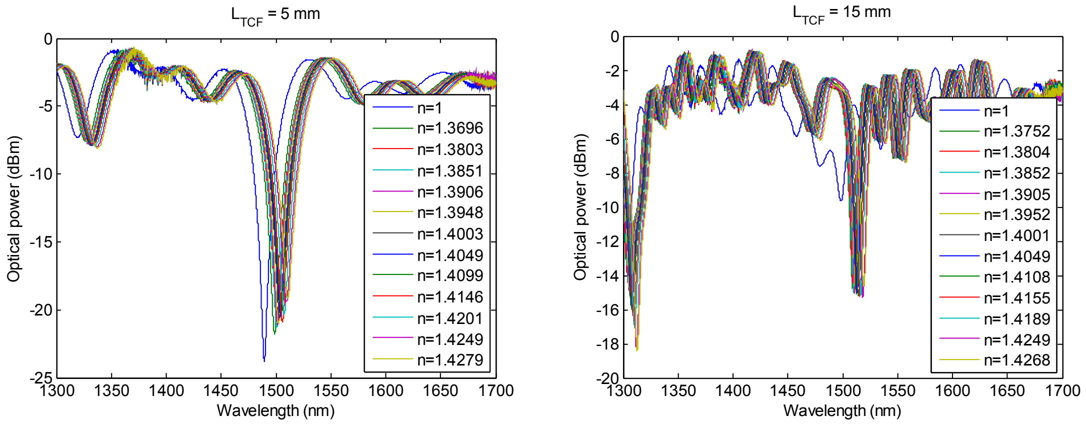

Figure 4. Transmission spectra of 5 mm (left) and 15 mm (right) length TCF hetero-core structures exposed to different surrounding refractive index.

The characterization of the different hetero-core structures with the RI of the LiCl solution in the range of 1.36 – 1.43 is depicted in Figure 5. It can be seen that the experimental data can be well adjusted by a quadratic fit. The sensitivities are different depending of the type and the length of the structure. The higher sensitivities were obtained with the CSF structures and the shorter the length of a hetero-core structure, the higher the sensitivity. The polynomial expressions of the fits are: $\lambda_{CSF\_5mm} = 1107.8\ n^2 - 2881.7\ n + 3558.7$, $\lambda_{CSF\_10mm} = 2000.7\ n^2 - 5412.9\ n + 5054.1$, $\lambda_{TCF\_5mm} = 2133.1\ n^2 - 5775.8\ n + 5408.4$ and $\lambda_{TCF\_15mm} = 2508.1\ n^2 - 6836.8\ n + 6168.1$.

The same procedure to characterize the in-fiber Fabry-Pérot interferometer inscribed in the TCF hetero-core structure was carried out. The resulting spectra show a decrease in the visibility of the fringes created by the Fabry-Pérot interferometer (Figure 6, left). Although it is difficult to quantify this variation in the spectra, in the Fourier domain one can see a reduction in the amplitude of the peak corresponding to the fringe separation. The variation of the amplitude of the peak in the Fourier domain can be adjusted by a quadratic fit in the RI range of 1.39 – 1.43 , as it can be seen in the inset of Figure 6 on the right. The polynomial expression of the quadratic fit is $A = 3.7986\ n^2 – 10.502\ n + 7.2745$.

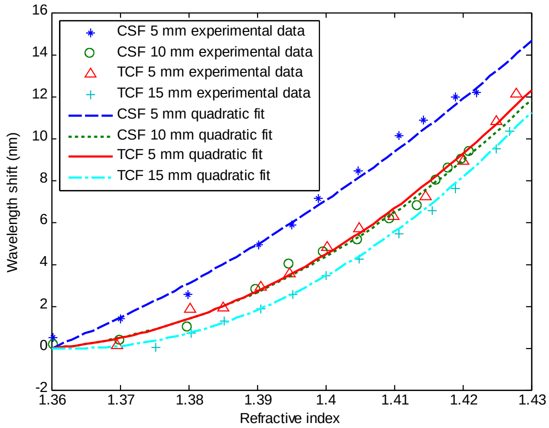

Figure 5. Wavelength shift in the spectra of the hetero-core structures.

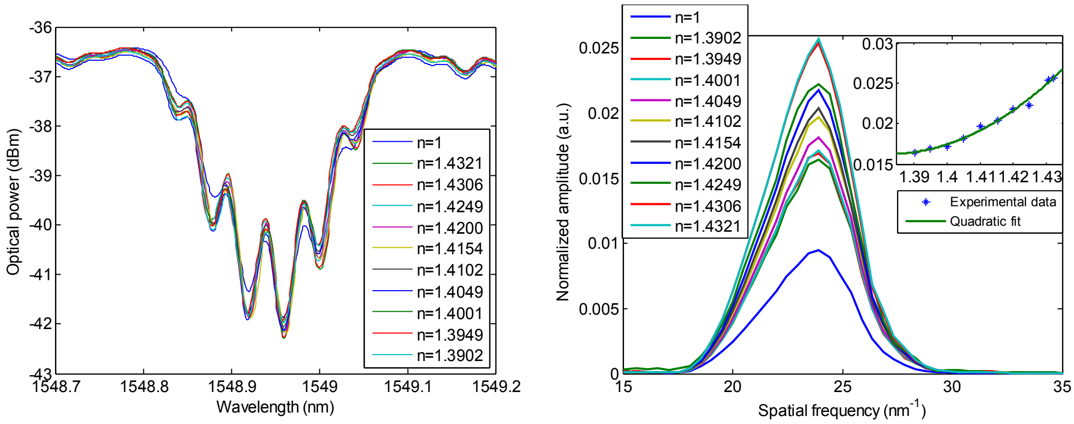

Figure 6. Spectra of in-fiber Fabry-Pérot interferometer (left) and Fourier domain spectra (left) with quadratic fit of the amplitude of the peak (inset).

Conclusions

In this paper we have demonstrated the feasibility to fabricate refractive index sensors by the creation of three-segment hetero-core structures by fiber splicing. A higher sensitivity is obtained using a CSF for the hetero-core region than using a TCF, and for the same type of fiber, the shorter the length the higher the sensitivity. Moreover, an in-fiber Fabry-Pérot interferometer was created at both sides of a TCF hetero-core structure and it was proved the RI sensing capabilities by Fourier domain analysis.

References

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