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Photonic crystal fiber microcavity based bend and temperature sensor using micro fiber

Jitendra Narayan Dash, Sumit Dass, Rajan Jha *

Nanophotonics and Plasmonics Laboratory, School of Basic Sciences, Indian Institute of Technology Bhubaneswar, Toshali Bhawan, Bhubansewar, India

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ABSTRACT

We propose a highly sensitive bend and temperature sensor employing a microcavity incorporated solid core PCF (SCPCF) concatenated with tapered single mode fiber (SMF) based on intensity interrogation. The tapered SMF is employed for bend and temperature sensing while the microcavity based PCF is used to modulated the interference pattern for high precision. The cavities in SCPCF are fabricated using a splicer machine while the tapered SMF is fabricated using flame and brush technique. The variation in wavelength of the interference pattern is found to be insensitive to bend and temperature while the intensity of the pattern is found to be sensitive to bend and temperature with sensitivity of 20 dBm/m^{-1} and 0.21 dBm/$^{\circ}$C respectively. Moreover, the resolution of the sensor for bending is found to be 5×10^{-3} m^{-1}. This may open a new window for economical and stable sensor for practical applications.

1. Introduction

Optical fiber based interferometers have attracted a special attention for their potential to be used in sensing applications. In particular, properties like electromagnetic immunity, compactness, high sensitivity and remote sensing ability have made them a better choice over conventional electronic sensors. These fiber based interferometers have been widely used for sensing several physical and chemical parameters such as displacement, strain, pressure, curvature, temperature and refractive index [1–6]. Among these applications, bend (curvature) measurement has been an important parameter widely used for monitoring structural deformation, pressure, micro-displacement, and robotic arms [7,8]. Several fiber base curvature sensors have been reported using tapered SMFs, Fabry-Perot interferometers (FPIs), Bragg grating, tapered PCF, Sagnac loop using birefringent PCF, three coupled core PCF, and periodically tapered fiber [4,9–16]. However, some of the limitations of the above mentioned sensors are high cost of fabrication, temperature insensitivity, and broad interference fringe pattern. On the other hand, the tapered fibers are more sensitive to the curvature and the interference pattern generated due to tapered fiber based interferometers can be changed by tuning the waist diameter and length of tapered section. Tapered fibers have been utilized for temperature measurement [17]. However, it lacks the analysis of both curvature and temperature measurement. Here, we report an interferometric bend sensor based on tapered SMF connected to a microcavity incorporated SCPCF. The tapered fiber is used to study the bend and temperature effect while the SCPCF with microcavity modulate the interference pattern. The proposed structure can be used for curvature measurement with negligible error due to the fluctuation in temperature. The period of the interference pattern can be efficiently tuned by changing the geometrical parameters of the cavities without changing the waist diameter of the tapered section.

2. Fabrication process & experimental set up

The fabrication of the proposed interferometer involves two steps: fabrication of a tapered SMF and a cavity in PCF. We will discuss both these fabrication process one by one. The cavity incorporated SCPCF is fabricated using a solid core PCF (SCPCF) and a hollow core PCF (HCPCF) (HC 1550-02). The fabrication is carried out using a commercial splicing machine. The SCPCF considered has a diameter of 125 μm with core diameter of 8.5 μm. The air holes have average diameter of 2.32 μm with pitch of 5.6 μm and the length of SCPCF taken is 20 mm. The HCPCF has a diameter of 122 μm with core diameter and pitch of the air holes present in the cladding being 10 μm and 3.8 μm respectively. The end sides of SCPCF and HCPCF are cleaved properly and spliced at an optimized arc current and arc time. During splicing, the air present in HCPCF is trapped to form an air cavity having an arbitrary shape as shown in Fig. 1(a). After repeated application of arc, the arbitrary shaped

* Corresponding author.
E-mail addresses: rjha@iitbbs.ac.in, rajaniitd@gmail.com (R. Jha).

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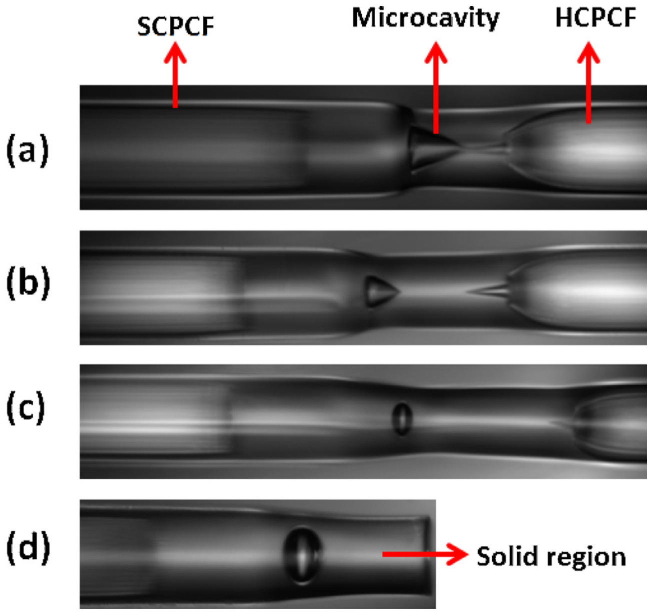

Fig 1. (a), (b), (c) and (d) show the stepwise formation of the microcavity in PCF during the splicing process.

cavity turns into an ellipsoid cavity as shown in Fig. 1(b) and (c). The length of the major and minor axis of the ellipsoidal cavity are 73 μm and 49 μm respectively. Here it is to be noted that the geometry of the cavity can be changed by tuning the arc time, number of times arc current applied and arc power. The above parameters can be precisely controlled by using a commercial splicer machine that helps in attaining consistent and repeatable parameters of the cavity. During the formation of cavity, the holes present before and after the cavity are collapsed. Unlike the previously reported structures [8], we precisely cleaved the portion present after the microcavity using a microscope. This leads to the formation of another solid region after the microcavity of length of 260 μm as shown in Fig. 1(d). This solid region acts as another cavity in addition to microcavity. The fabrication of these cavities results in the formation of a Fabry-perot interferometer (FPI). In principle, the geometrical parameters of the microcavity can be tuned by optimizing the arc current and arc time and that of solid cavity can be tuned by changing the cleaving position. On the other hand, the tapered section is fabricated by striping a section of SMF and fixing it on two sides of the computer controlled translational stage. The stripped section is tapered in a controlled manner using flame and brush technique based on oxy-hydrogen flame [18]. Using this technique we fabricated a micro fiber having a waist diameter of 17 μm and length of 6 mm. The taper diameter and taper length of the fiber can be well controlled by proper choice of fiber pulling rate and flame quality. In our case, the pulling rate can be precisely controlled by a computer controlled positioner while the flame quality can be controlled using a flow meter. Therefore, following the above describer method, the consistency of sensor can be achieved with precise repetition. After the fabrication of the tapered section, one of its ends is spliced with SMF connected to circulator and another end with PCF having the microcavity at its end .The splicing of PCF with SMF leads to the collapse of holes over a distance of approximately 180 μm.

The schematic of the proposed experimental set up is shown in Fig. 2(a). Light from a broadband SLED is coupled to the circulator which in turn couples the light into the tapered section of SMF. The transmitted light form tapered section is coupled to the SCPCF having a micro-cavity on its end face. The reflected light from SCPCF FPI is coupled back to the circulator via the tapered section and collected in another port connected to OSA. In order to study the bending effect, the tapered section along with the untapered section is fixed on a thin metallic sheet with center of the tapered section at the middle of the metal sheet as shown in Fig. 2(b).

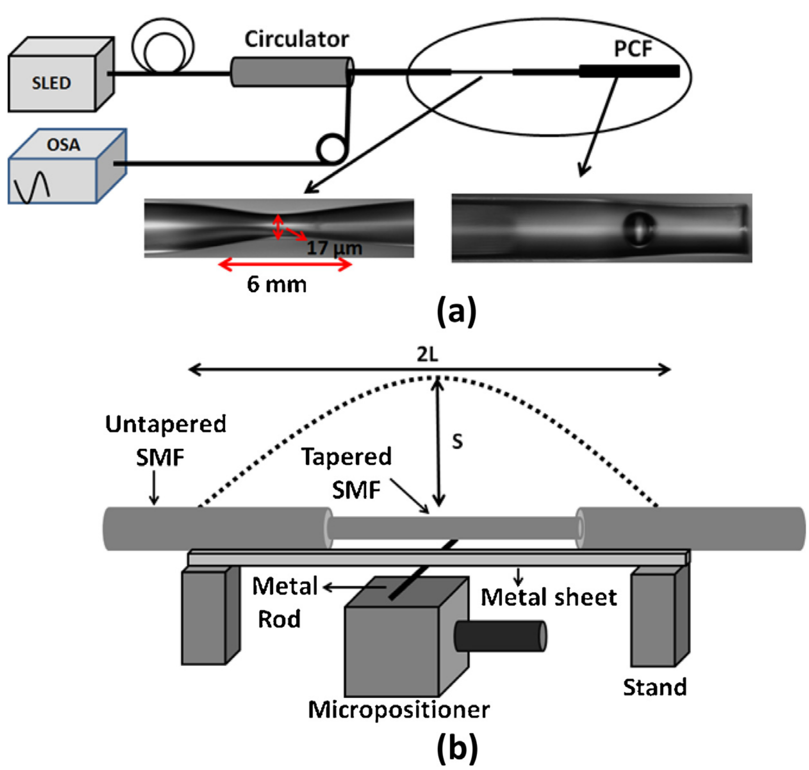

Fig. 2. (a) shows the schematic of the experimental set up while (b) shows the set up for curvature measurement. The inset in (a) shows the microscopic picture of tapered section of SMF and PCF with microcavity.