Sensitivity Improvement of Refractive Index Sensor Based on Mach-Zander Interferometer

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Abstract A simple structure is designed for The sensor for refractive index is based on A Mach–Zehnder interferometric To detect changes in the concentration of liquids. The sensor head is made using conventional fiber(SMF)–multi mode fiber–photonic crystal– conventional fiber(SMF). The collapsing approach is used to apply the modal interferometer theory. To stimulate higher order modes (LP_{01}

and $LP_{11)}$As a pump light source, a laser diode (1550 nm) was employed. The experimental result show effect of multimode fiber improves the interferometric device's refractive index sensitivity. A different length of PCFs (3.11, 6.31, 8.20) cm were used. the With a PCF length of 3 cm, maximum refractive index sensitivity of (245.7nm / RIU) is reached. This refractive index sensor is notable for its tiny size, excellent sensitivity, and quick reaction time.

Keywords: Sensitivity, Wavelength Shift, Photonic Crystal Fiber Refractive Index sensor, Mach–Zander Interferometer, Fusion Splicing OF MMF

1-Introduction

Refractive index (RI) sensing of liquids is critical for chemical and biological research because the RI directly reflects changes in liquid composition. RI sensors based on optical fibers provide numerous benefits over prism-based refractometers, such as tolerance to electromagnetic interference, high sensitivity, and low cost, particularly when biological sensing is constrained [1].

Optical Interferometers offer high resolution in metrology applications, For the design of interferometers, fibre optic technology also provides various degrees of freedom and some advantages such as stability, compactness, and the absence of moving components. Optical fiber interferometers are made using two methods. Splitting and recombining two monochromatic optical beams propagating on different fibers is the first step. Optical fibers and one or two couplers are commonly required for these two-arm interferometers. The second method involves utilizing the difference in phase between two modes, generally the first two modes, such as the HP01 and HP11. Modal interferometers are interferometers that use the latter technique. [2].

Sagnac, Mach-Zehnder, and Michelson interferometers were implemented using standard optical fibers. The benefits of these interferometers are high resolution, ease of configuration, higher electromagnetic interference immunity, and low cost. PCFs, on the other hand, offer two major advantages: a broad range of working wavelengths and long-term stability [2,3]

Due to its simple structure, ability to respond to a range of measures ands, ease of manufacture, and low cost, Mach-Zehnder interferometers (MZI) sensors have gained a lot of interest for many physical and chemical sensing applications [4]. The Mach-Zehnder interferometer (MZI) is made up of two fiber couplers connected in series., The input signal is separated into two arms, the reference arm and the sensing arm, by the first fiber coupler. The signal is then recombined by a second fiber coupler. According to the OPD between the two arms, the recombined light contains an interference component.

Photonic crystal fibers (PCFs) are a type of photonic crystal fiber that is also known as microstructure optical fibers or holey fibers. The advent of photonic crystal fibers (PCFs) in 1996 was a watershed point in fiber optic technology since these fibers not only had unique properties, but they also had the ability to overcome certain limitations that were contained in traditional optical fibers. [5,6].

Photonic crystal fiber form is defined by a periodic ,pattern of air holes along the length of the fiber and centered on ,a solid or hollow core. With a Modified Total Internal Reflection light directing mechanism, a solid silica core is surrounded by air–silica. cladding (MTIR) ,or a hollow Core surrounded by air–silica cladding, where the light-guiding Mechanism is based on the Photonic Band Gap (PBG).

Photonic crystal fibers feature a vast, number of geometric factors that may be changed allowing for a lot of design flexibility. Furthermore, these fibers have the ability to guide light in a hollow core. In fields such as, nonlinear fiber optics, fiber lasers, supercontinuum production, and fiber sensors. [7].It is possible to generate PCFs with totally different behaviors by modifying the geometric parameters of the air-holes in the fiber cross-section, that is, their location or dimension. [7,8].

Multi mode fiber was used in our current investigation between the SMF and length of PCF because it can link light from the core to the PCF Cladding mode. A typical fusion splicer was used to splice MMF–PCF and SMF–PCF. The splicing optimization criteria for this specialty fiber were found utilizing a hit-and-trial technique. Air-holes run the length of the photonic crystal fiber in the cladding area, which couple waves more than cladding because confinement loss is smaller in PCF. The various amounts of sucrose solution resulted in refractive indices ranging from 1.33 to 1.42.

1. Experimental

Fabrication of the refractive index sensor, PCF(LMA-10) with several lengths of fiber (3.11, 6.31, and 8.20) cm utilized in this experiment, spliced with MMF between two sections of conventional single-mode fibers using fiber splicer FSM-60S. SMF(10/125), MMF(50/125) lm. As shown in Fig.1, PCF has an outer diameter of 125 lm and is made up of a solid core surrounded by four rings of air holes arranged in a hexagonal pattern around a solid silica core. The fiber has a core diameter of 10 m, air-holes with an average diameter of 3.1 m, an average separation between the voids of (6.6 m), and an outer diameter of 125 lm. splicing with the SMF with a splicing machine, and the loss was reduced due to a mode-field diameter mismatch compared to other PCFs.

Fig. 1 shows a cross-section of PCF (LMA-10).

The standard parameters of the direct splicing process are set to the arc fusion splicer (FSM-60S) to obtain optimized splice loss. These parameters are concise in the table (1).

Table (1): The standard parameters of fusion splicer (FSM-60S) for direct splicing SMFwith PCF (LMA-10)

Splice parameters	**Prefusion time (ms)**	**Prefusion power STD (bit)**	**Gap (µm)**	**Overlap (µm)**
SMF PCF(LMA-10)	180	STANDARD	15	10

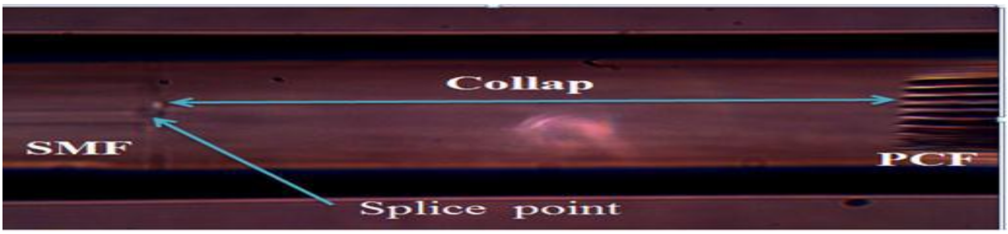
Before splicing the fibers are stripped and cleaved. Then,the PCF (LMA-10) is spliced at both sides to SMF with a conventional splicing machine. The dimensions of PCF simplify the aligning and splicing to SMF when splice fibers by a standard splicing machine.

Fig. 2 The splicing process and losses obtained in (db)

Table (2): The standard parameters of fusion splicer (FSM-60S) for splicing MMFwith PCF (LMA-10)

Splice parameters	**Prefusion time (s)**	**Prefusion power STD (S)**	**Gap (µm)**	**Overlap (µm)**
MMF PCF(LMA-10)	2	0.15	10	10

As air holes collapse during splicing, the Multi mode fiber–PCF and PCF–single mode fiber splice are collapsed. As a result, there will be no cladding section in the collapsed zone, and PCF will no longer be conventional fiber. A portion of the light wave from the MMF's core can couple to the PCF's cladding. Light recombination occur at the splice point no. 2, and interference occurs at the single mode fiber's core. An optical spectrum analyzer is used to analyze the intensity at the ends of the SMF.



Fig(3)Splice zone between PCF (LMA-10) on the right and SMF on the left, as seen via a microscope. 300m in collapsed length

2. Results and Discussion

PCF interferometer is able to detect change in the surrounding solution. Different concentrations (0%, 5%, 10%, 15%, 20%, 25%) of these solution were used to show the least detection of the refractive index. The values of these liquids are shown in Table3.

Table (3): Refractive indices of different concentrations of solution in the Experiments

Refractive Index	Concentration %
1.33	**0**
1.34	**5**
1.35	**10**
1.36	**15**
1.37	**20**
1.38	**25**

The response of the refractive index sensors is tested by immersing the whole length of pcf in varied concentrations of liquid, and The sensors' reaction to the surrounding refractive index (RI) is analyzed.. MMF acts as a mode coupler in this case. To demonstrate the benefits of multimode fiber,

The experimental ,data for the SMF -PCF -SMF and SMF– MMF–PCF–SMF structures are presented. Figures 3,4,5, and 6 are, correspondingly.

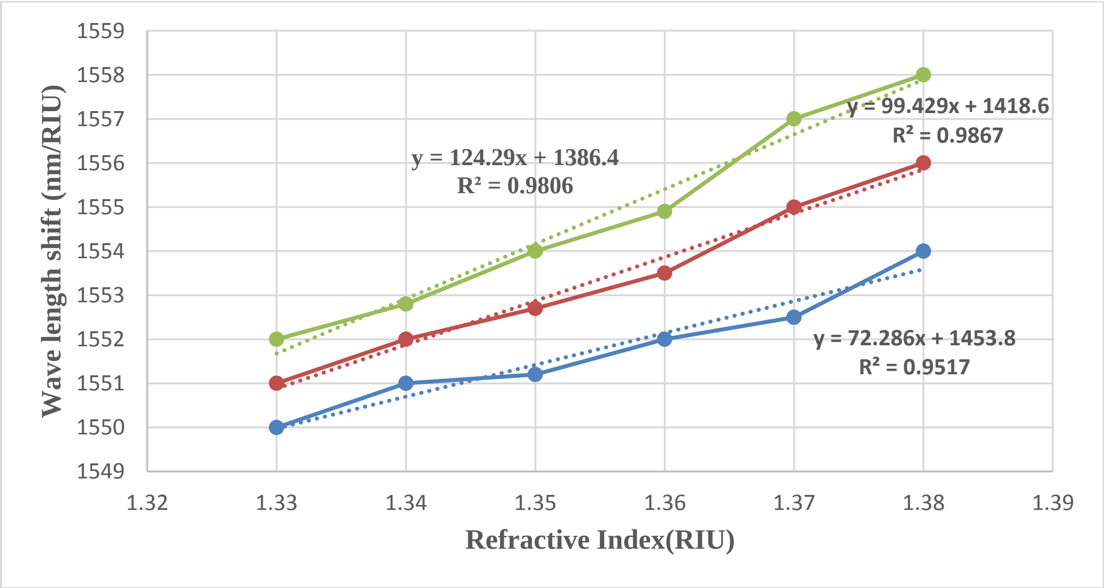


Fig.4Measuring the sensitivity of an SMF-PCF-SMF Mach-Zehnder interferometer with varying PCF lengths.

From the previous Figure (4) it The direct splicing SMF-PCF structure, interface spectrum is formed, as can be shown. owing to collapsed, spliced section, point Light waves, on the other hand, were unable to travel through the outer ring of holes in PCF. The more a light wave passes through the core and nearer ring of holes in the PCF, the smaller the chance of light refraction at the outer surface of the PCF during index sensing. While a consequence, as the environment changes, light wave transmission remain constant.. When photonic crystal fiber length is (3.11, 6.31` and 8.20) cm, the refractive index measurement sensitivity is (72.2, 99.4 and 124.4) nm/RIU respectively and the corresponding fitting degree (R2) is 0.969, 0.9174, and 0.9899.

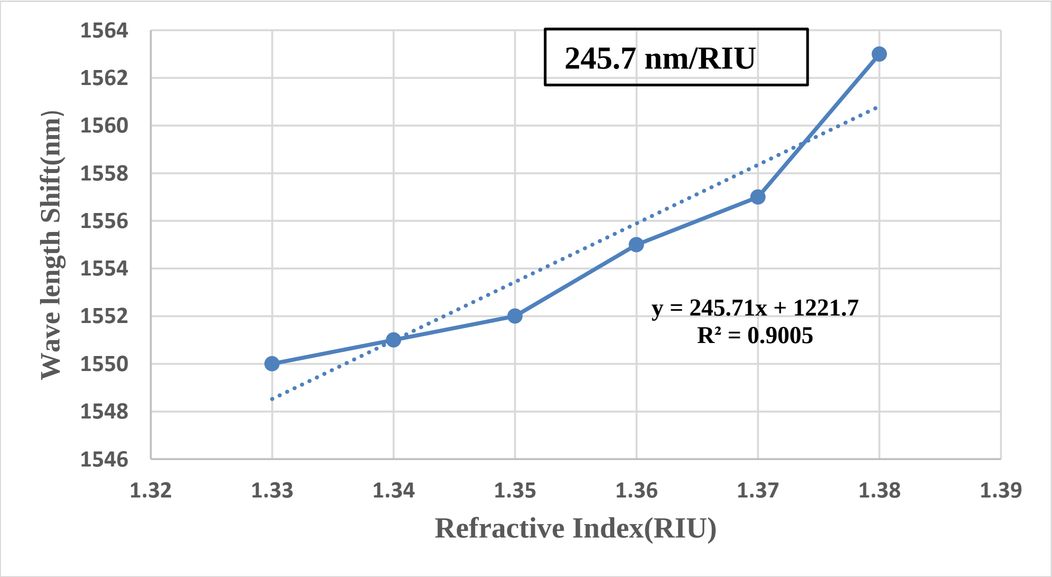


Fig. 6. Transmission power and refractive index charts using SMF–MMF–PCF–SMF structure for sensing lengths of 3.11 cm and 3.11 cm, respectively.

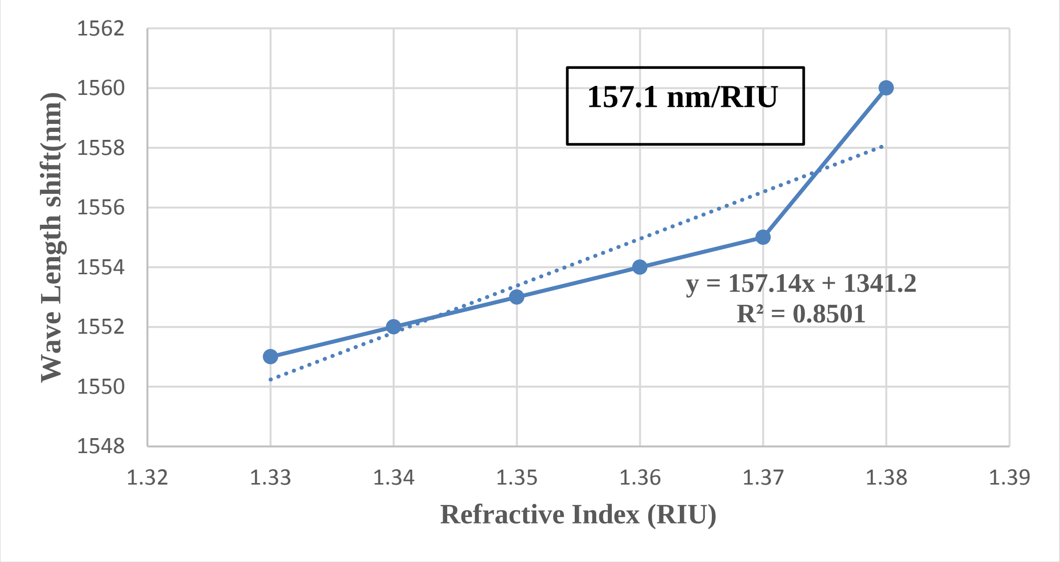


Fig. 7. Transmission power and refractive index charts using SMF–MMF–PCF–SMF structure for sensing lengths of 6.31 cm respectively.

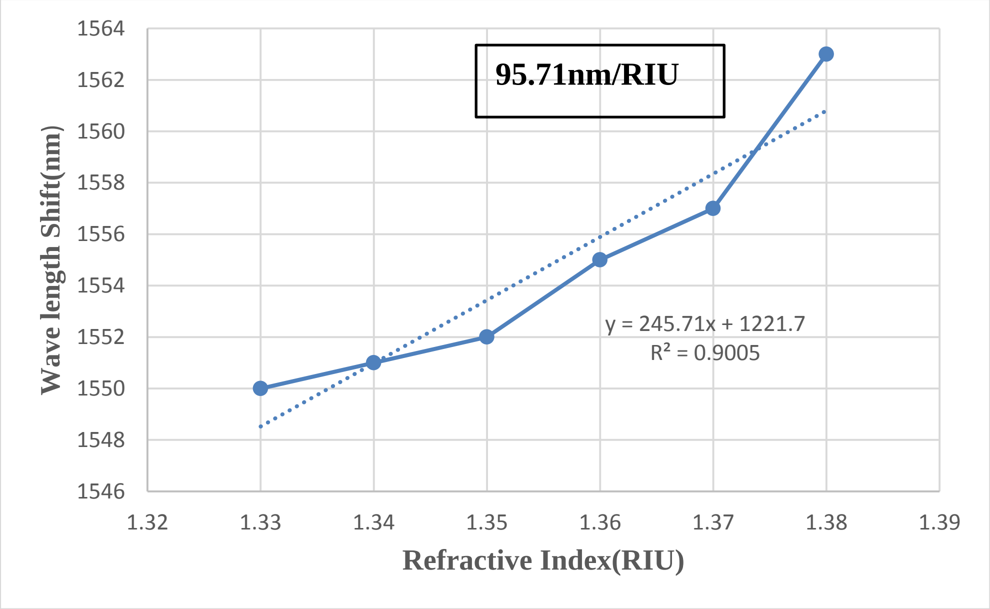


Fig.8. Transmission power and refractive index charts using SMF–MMF–PCF–SMF structure for sensing lengths of 8.20 cm respectively.

The introduction of MMF couples the majority of light within the core and outer ring of holes in PCF. As light refracts from lighter to denser material, it results in a rapid fall in transmission power as the surrounding RI increases. The linear fit graph's R2 values to the relationship between transmission power and RI of sucrose solution are almost more than 0.9, indicating that our device is linear. These sensors exhibit sensitivities of 245.7nm/RIU, 157.1nm/RIU, and 95.71 nm/RIU, respectively, according to current investigations with sensing lengths of PCF 3.11 cm, 6.31 cm, and 8.20 cm.

CONCLUSIONS

The research designed and investigated an interferometric refractive index sensor in Mach-Zehnder mode based on splicing MMF with short solid core of photonic crystal fiber(LMA-10) between two sections of conventional fibers. The index sensitivities of the interferometric devices with sensing lengths of 3.11 cm, 6.31 cm, and 8.20 cm are 245.7nm/RIU, 157.1nm/RIU, and 95.71 nm/RIU, respectively. Thus, The development of a sensing device that may be utilized to detect different biological and chemical characteristics is presented.

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