PHOTONIC CRYSTAL FIBER MAGNETIC FIELD SENSOR BASED ON AMPERE FORCE

Ayad Z .Mohammed[1], Bushra R.Mahdi[2],Lena K.Humdi[1]
[1]*Laser Science Branch, University of Technology, 10001 Baghdad, Iraq*
[2]*Ministry of Science and Technology/ Baghdad*
[*]For correspondence; Tel. + (964) 7713457675, E-mail: ayad_1967_2005@yahoo.com

ABSTRACT: *Magnetic field PCF modal interferometer sensor based on Ampere force is proposed . We fabricated this sensor by splicing section of PCF between two SMFs to achieved Mach-Zehnder interferometer. Ampere force is generated When electrical current flow in AL wire passes perpendicular magnetic field applied. It leads to vibration AL wire is installed with PCF. Cladding mode of PCF is sensitive to external effect. The magnetic field varies in range from (5.2mT) to (31.7mT). The greatest value of the sensitivity of this sensor reached equal to (31.2pm/mT).*

Keywords: photonic crystal fiber; magnetic field sensor; Ampere force; Mach-Zehnder interferometer

1. INTRODUCTION

Photonic crystal fiber (PCFs), which are also known as holey fiber or microstrucrured optical fibers, it have a periodic arrangement of microholes that run parallel along the entire length of fiber. They generally have two types of cross section: one is a solid silica core surrounding an silica-air cladding and the other is a hollow core surrounding an silica-air cladding. The guiding mechanism of light for the first type is by modifying total internal reflection (M-TIR). While the other type is based on photonic bandgap effect (PBG) [1-4].

Due to the freedom in design and novel guiding, PCF has been found in many applications, among these are sensing application, modal interferometer was introduced as new sensing scheme which built by fusion splicing [5-8]. Mach-Zehander interferometer (MZI) based on modal interference of PCF can be created for different measurement like temperature, refractive index, magnetic field [9-12].

There are several methods to realize MZI structure, like a fiber core mismatch splicing, a pair of long period grating and air-hole collapsing of PCF [13].

A compact PCF modal interferometer (PCFMI) built by spliced PCF between two SMFs. In spliced area, the holes of PCF are completely collapsed , which allowing for coupling and recombination of core and cladding modes, as cladding mode is sensitive to external effect, thus allowing for sense different parameter like magnetic field [14].

Magnetic field is important in various applications like military, medical and electrical power transmission. Fiber optic magnetic field sensor have been greatly studied due to their advantage over electronic counterparts, including small size, high sensitivity, light weight and for observation magnetic field in applications like power plants where electrical insulation and electromagnetic interference are problems, optical fibers are traditionally made of silica which is a very good insulator and immunity of electromagnetic interference [15].

Many researcher groups have been focused on expansion of magnetic sensor including Faraday effect [16] magnetostrictive [17] and magnetic fluid [20].

Faraday effect can be used to detect magnetic field but because of the veredet constant of silica precisely small thus the sensitivity are fairly low on the other hand magnetic field based on magnetic fluid and magnetostrictive have magnetic saturation and hysteresis which cause inaccurate measurement [17,13]. Thus magnetic field sensor based on Ampere force presented which the sensitivity is high and does not suffer any saturation thus we can obtain accurate measurement.

Recently the PCF magnetic sensor launched in attracting research concerns, use of PCF provide characteristics which can be further explored in order to produce smaller and more sensitive sensor. Here in this paper we demonstrate magnetic sensor based on PCF and Ampere force, when electrical current flowing through the conductor (Aluminum wire) which is connect with PCFMI with the presence of perpendicular magnetic field, a force of attraction and repulsion arise this force is called Ampere force (old force law first discovered by Ampere) that act on AL wire which is installed with PCF leads to curvature of PCF, as cladding mode of PCF is sensitive to external effect, thus magnetic field sensor can be achieved [18].

2. Sensor design and principle

In our experiment, we used PCF(LMA-10,NKT photonics). It consisting of a solid core surrounded by six rings of air holes, it has 10µm diameter of core, 3.04µm diameter of air-hole and 7.5µm hole to hole spacing as shown in figure(1).

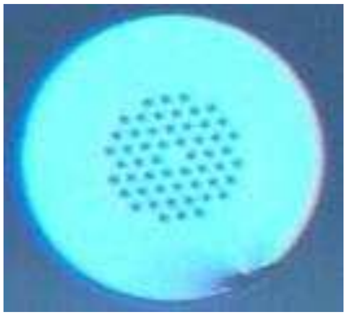


Fig : (1) microscope image of the cross section of the PCF.

To fabricate this sensor, 2cm of PCF spliced between two SMF using conventional fusion splicer. Both the SMFs and PCF are stripped off from polymer coating and cleaved by mechanical cleaver before fusion splicer. In the spliced point, the air holes of PCF completely collapsed, the total length of the collapsed region is about 300µm as shown in figure (2).

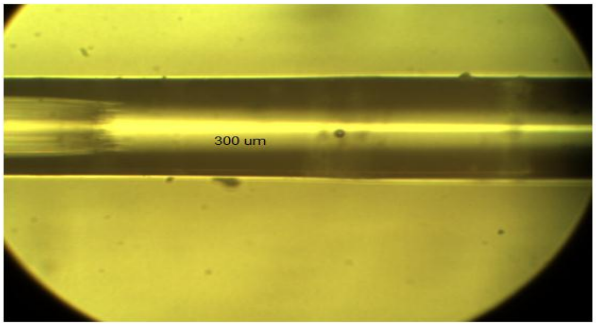


Fig. (2) microscope image of the splice zone between PCF on the left and SMF on the right, the collapsed length is 300µm.

We used Aluminum wire (Al) and fixed it with an SMF section of the PCFMI by using glue and kept AL wire straight with PCF. Then suspend Al wire and PCFMI by using stand lap between two poles of magnetic field in such way the length of wire and PCFMI aligned perpendicular to the direction of external magnetic field applied. The two ends of AL wire connect in series with a DC power supply and resistance.

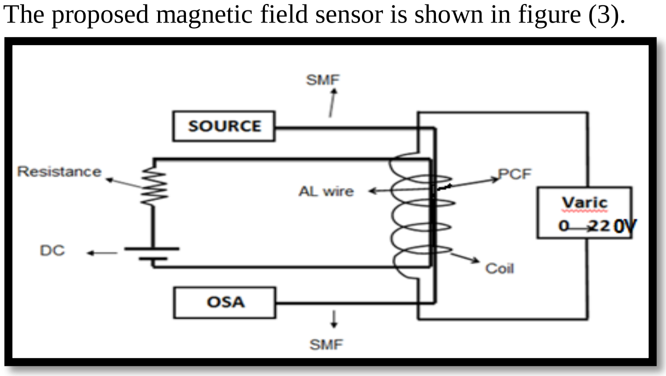
We used a motor coil to generate a magnetic field and the strength of the applied magnetic field was adjusted by changing the applied voltage and it measured by Gauss and Tesla meter which was placed at the center of one end of yhr coil. The Tesla was used to calibrate the relation between the strength of the generated magnetic field and the applied voltage. The magnetic field test was implemented from 5.2mT to 31.7mT.

When electrical current flowing through the conductor (AL wire) produced a magnetic field, when this wire pleased perpendicular to magnetic field, a force of attraction or repulsion acts on the wire this force is called Ampere's force. The direction of this force always perpendicular to both directions of current and magnetic field. The magnitude of this force increase with increase of current flowing in the wire, magnetic field and the length of the conductor, thus this force is given by [19] :

$$FA = I \cdot B \cdot L \qquad (1)$$

Where FA is the Ampere force, I is the electric current, B magnetic field and L is the length of electrical current experiencing the perpendicular magnetic field.

The proposed magnetic field sensor is shown in figure (3).



Fig(3) Diagram of the proposed magnetic field sensor.

Light from a laser diode source with 1550nm and output power 1.59 mW was launched into the sensor from one SMF and the transmission spectrum was measured at the other SMF with an optical spectrum analyzer (OSA) with resolution (0.2pm). By monitoring the wavelength shift of the transmission spectrum, magnetic field can be detected.

When the light transmits from the SMF to the PCF, the fundamental SMF mode begins to diffract when it enter to the first collapsed PCF region, part of core mode coupled to the cladding modes, after the PCF, the modes reach other collapsed region they will further diffract and will recombine through the filtering SMF, therefore the interference spectrum can be expressed as [13]:

$$I = ICO + ICL + 2\sqrt{I_{CO} + I_{CL}} + \cos\left(2\pi \Delta n_{eff} \frac{L}{\lambda}\right) \qquad (2)$$

Where ICO and ICL the core and cladding mode intensity and Δneff is the difference between the effective refractive index of the core (nco) and cladding (ncl) modes : Δneff = nco - ncl

And L is the length of PCF section over which the two modes travels, λ is the operating wavelength. At the second collapse region the phase difference generated in the PCF between two modes and can be defined as:

$$\Delta\emptyset = 2\pi \Delta n_{eff} \frac{L}{\lambda} \qquad (3)$$

From the above the maximum transmission of optical intensity will appear when 2πΔneff L/λ = 2mπ where m is an integer, therefore the transmission spectra exhibit peak at wavelength λm =Δneff L / m .

When electrical current passes through the AL wire with the presences of perpendicular magnetic field stems from motor coil. Generated Ampere force leading to the vibration of Al wire which installed with PCF, this vibration leading to induce variation of Δneff , as a result the λm will shift , thus the magnetic field can be detected by monitoring the shift of the spectrum.

3. RESULTS AND DISCUSSION

In conclusion, magnetic field sensor based on PCF modal interferometer and Ampere force is proposed and demonstrated. The modal interferometer is created by using two collapsed points of air-hole cladding on the length of the PCF to form Mach-Zehnder interferometer. The principle of the PCFMI is the interference between core mode and excited cladding modes, interferometers have advantage of simple fabrication and high sensitivity. When electrical current passes through Al wire with presence of perpendicular magnetic field applied, Ampere force generated which leads to vibration of Al wire which is connect with PCFMI, as cladding mode of PCF is sensitive to external effect, magnetic field can be achieved by monitoring shift of transmission spectra. The sensitivity of this sensor reach to (31.2pm/mT) when magnetic field strength (5.2mT) to (31.7mT).

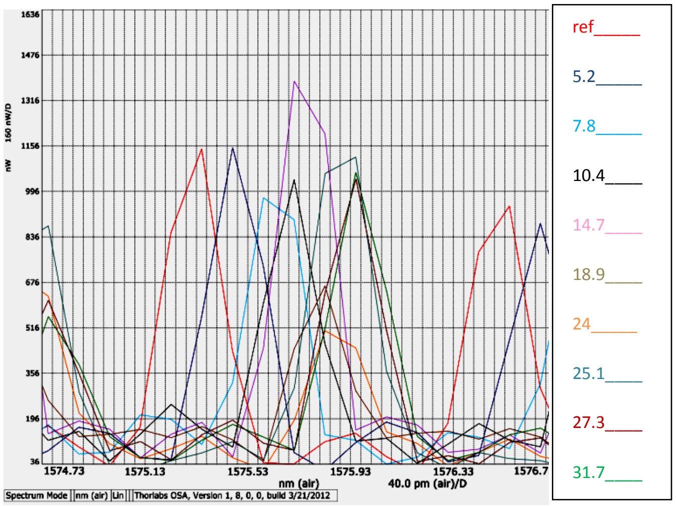
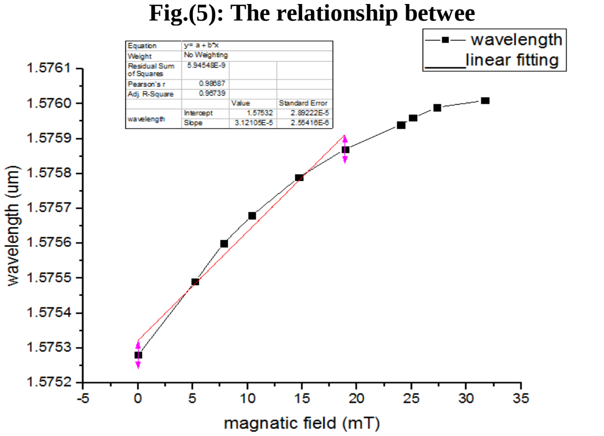


Fig.(4): Transmission spectra of the sensor under different magnetic field .

Fig.(5): The relationship betwee



n

wavelength and magnetic field (magnetic field sensitivity=31.2pm/mT).

4. CONCLUSIONS

In conclusion, magnetic field sensor based on PCF modal interferometer and ferrofluid (FF) is proposed and demonstrated. The modal interferometer is created by using two collapsed points of air-hole cladding on the length of the PCF which is spliced between two SMFs to form Mach-Zehnder interferometer . The principle of the PCFMI is the interference between core mode and cladding modes. When an external magnetic field applied to MZI which is inserted with ferrofluid, as the refractive index of ferrofluid changed with any variation of the magnetic field strength, as cladding mode of PCF is sensitive to external effect, magnetic field can be achieved by monitoring the shift of transmission spectra. The sensitivity of this sensor reaches to (13.2pm/mT) when magnetic field strength (5.2mT) to (31.7mT).

5. REFERANCE

[1] J. C. Knight, "photonic crystal fiber", *Nature*, **424** (6950): 847-851, (2003).

[2] Makram. A. Fakhri, Y. Al-Douri, Uda. Hashim, Evan. T. Salim "Annealing Temperature Effects on Morphological and Optical Studies of Nano and Micro Photonics Lithium Niobate using for Optical Waveguide Applications " *Australian Journal of Basic and Applied Sciences*, **9**: 128-133 (2015).

[3] Makram A Fakhri, Y Al-Douri, Uda Hashim, Evan T Salim" XRD Analysis and Morphological Studies of Spin Coated $LiNbO_3$ Nano Photonic Crystal Prepared for Optical Waveguide Application" *Advanced Materials Research*, **1133**: 457-461 (2016).

[4] Makram A. Fakhri, Y. Al-Douri, U. Hashim, Evan T. Salim, Deo Prakash, K. D. Verma" Optical investigation of nanophotonic lithium niobate-based optical waveguide" *Applied Physics B*, **121**: 107–116 (2015)

[5] Davide B. , Jeo V.,"Low-loss photonic crystal fiber interferometers for sensor networks" *Journal of lightwave technology* **28(24):** 3542-3547 (2010).

[6] Makram A Fakhri, Y Al-Douri, U Hashim, Evan T Salim" Optical investigations of photonics lithium niobate" *Solar Energy*, **120**: 381-388(2015).

[7] Makram A. Fakhri, U. Hashim, Evan T. Salim, Zaid T. Salim" Preparation and charactrization of photonic $LiNbO_3$ generated from mixing of new raw materials using spry pyrolysis method" *J Mater Sci: Mater Electron* **27**:13105–13112 (2016)

[8] M. A Fakhri, Y Al-Douri, ET Salim, U Hashim, Y Yusof " Effects of Chemical Stirring Time on the Physical Properties for $LiNbO_3$ Photonic Film Using of Optical Waveguide Applications " *Procedia Chemistry* **19**: 531-538 (2016) .

[9] Jian J. and Wei J., "photonic crystal fiber sensors for temperature and strain measurement" *Journal of sensors*, **2009:** Article ID 476267, 10 pages, 2009.

[10] Kwan P., Hae C., Seong P. , Un-chal and Byecong H., "Temperature roubust refractive index sensor based on a photonic crystal fiber interferometer" ,*IEEE sensors journal*, **10**: 1147 - 1148 ,2010 .

[11] Peng Z., Chi C., Wen L., Limin H.,Young J.,Li C.,Wei C.and Xinyoung D.," Temperature insensitive magnetic field sensor based on nanoparticle magnetic fluid and photonic crystal fiber",*IEEE photonics journal*, **4**: 491 - 498, 2012.

[12] MA Fakhri, U Hashim, ET Salim, ZT Salim " Preparation and charactrization of photonic $LiNbO_3$ generated from mixing of new raw materials using spry pyrolysis method " *Journal of Materials Science: Materials in Electronics 27 (12)*, 13105-13112 (2016)

[13] Xue C., Youngiqn YU, Xiaomei XU, Quandong H., Zhilong OU, Jishun W., Peiguang Y. and Chenline DU,"Temerature insensitive bending sensor based on in-line Mach-Zehnder interferometer", *photonic sensor*, 4: 193. doi:10.1007/s13320-013-0156-x (2014)

[14] Rajan J. Joel V., Goncal B.and Valerio P." Refractometry based on a photonic crystal fiber interferometer", *optics letterers*, **34**: 617-619 (2009).

[15] Erin Tate,"Fiber-optic magnetic field sensore", *Mississippi state University, Bagley collage of Engineering, ECE Department*.

[16] L.Sun, S. Jiang, J.R. Marcinte,"All-fiber optical magnetic field sensor based on Faraday rotation in high

terbium doped fiber", *Opt. express* **18(6)**: 5407-5412 (2010) .

[17] Sully M., Cicero M., Arthure M. Braga, Luiz Valente and Carla K." Magnetic field measurement based on Terfenol coated photonic crystal fiber", *Sensors*, **11**: 11103-11111; doi:10.3390/s111211103 (2011).

[18] Ayad Zwayen al-juboori et al" THz waves propagation through photonic crystal fiber" *IJISET - International Journal of Innovative Science, Engineering & Technology*, **2(6)**: 537-541 (2015).

[19] Sun-jie Q., Qi Lie, Fei Xu, Yan-qing LU," Ampere force based on photonic crystal fiber magnetic field sensor" *Sensors and Actuators*, **210**: 95–98 (2014).

[20] Hae C., Myoung K. and Byeong L." All-fiber Mach-Zehnder type interferometers formed in photonic crystal fiber", *Optics Express*, **15**(9): 5711-5720 (2007)