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COMPUTATIONAL RESEARCH ON SENSING MECHANISM OF NANO-METAL DOTS BASED LIQUID FILLED FIBER

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A temperature sensor of liquid (Chloroform) filled fiber based on monometallic gold nano-dots is investigated and its numerical study is analyzed using Finite Element Method (FEM). The sensitivity is obtained by coupling mechanism between the liquid-filled modes and the Plasmon modes. The interaction place of two different modes gives the maximum resonance of loss spectra over the wavelength range from 900nm to 1150nm keeping the range of temperature from 20ºC to 60ºC with steps of 20ºC. The loss spectra of the proposed asymmetric structure at different temperatures exploited its sensitivity which is about 2.03 nm/ºC and 1.8703 nm/ºC for x - & y – polarization. Hence it shows that the resonance peak of x polarization provides much better wavelength shift than y polarization which makes it suitable for detecting the temperature over the wavelength range of 900 nm to 1150 nm.

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Keywords: Nanodots, Finite Element Method, Resonance, Sensitivity

1. Introduction

Optical fiber has been extensively used in many application and it is also used in the various of especially in sensing applications [1-3].The temperature sensor has its application in diverged fields because it indicates the initial failures in any system. A wide category of temperature sensors has been proposed based on analog devices. But sensors based on photonics score higher because of its sensitivity and capability for detecting wide temperature range. A sensor based on liquid filled core and six default cores was studied for temperature detection with the average sensitivity of -1.85nm/ºC was reported by Qiang Liu et al [4]. Wei Xu et al [5] projected that the temperature sensor can also be designed based on metal nanowire placed inside the liquid core. Photonic crystal fiber based on di-metallic nanocomposite which was discussed by Baolin Liu et al [6] and the SPR sensor based on optical fiber was studied by Xia Yu et al [7] for the better birefringence analysis. Recently metal coated d-shaped optical has been proposed for oil sensing [8] by Yusoff et.al, Since the gold nanomaterial-based PCF can be used for various applications due to easy fabrication of the fiber, the same nano-metal based fiber issued in this present work to study the fiber performance in various temperatures.

In this work, a simple design of photonic bandgap fiber was designed with gold Nano-dots in the surface of the core. The effective RI value for three different temperatures concerned for core mode and Plasmon mode was analyzed. Hence, the sensitivity of x polarization better compares with y polarization over the wavelength range from 900 nm to 1150 nm.

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2. Sensor design and numerical modeling

In Fig. 1, the cross-sectional view of the proposed model of the sensor is shown. The proposed fiber with silica cladding of diameter is 50 µm. The core of the diameter is 10 µm filled with chloroform over which the equally sized gold nanodots are placed on the surface of the core, with diameter is 900nm. The surface tension of the liquid makes the gold nano-dots suspend over the surface and due to the gravity effect, the nano-dots are migrated to the bottom of the core. The interaction of different modes between the liquid-filled core and the monometallic nano-dots is used to investigate the temperature sensing behavior over the wavelength ranges from 900 nm to 1150 nm.

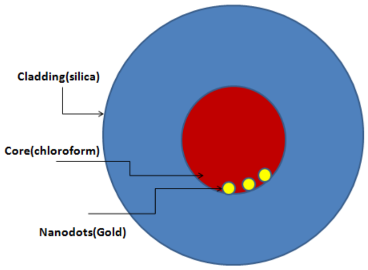

Fig. 1. Structure of Metal dotted Optical fiber.

The Refractive Index (RI) of silica fiber is estimated with temperature-dependent Sellmeier equation (1),

$$n^2(\lambda,T)=(1.31552+6.90754x10^{-6}T)+\frac{(0.788404+23.5835x10^{-6}T)\lambda^2}{\lambda^2-(0.0110199+0.584758x10^{-6}T)}+\frac{(0.91316+0.548368x10^{-6}T)\lambda^2}{\lambda^2-100} \tag{1}$$

Further, the liquid material chloroform is considered for the temperature sensing medium whose material dispersion with the function of temperature can be referred from ref.[9].

The sensor analysis is made using Finite Element Method (FEM) which splits the entire sensor surface into various triangular sub-sections and calculates the solutions of partial differential equations at each boundary by illuminating light along the Z-axis.

3. Results and discussions

The analysis of sensor is made for various temperature T = 20ºC, 40ºC, 60ºC. The surface plasmonic resonance (SPR) occurs at the boundary of the metal when its frequency of oscillation matches the frequency of incident light. The SPR wave helps in light confinement at the metallic surface which leads to light coupling between the liquid core mode and SPR mode at a particular wavelength.

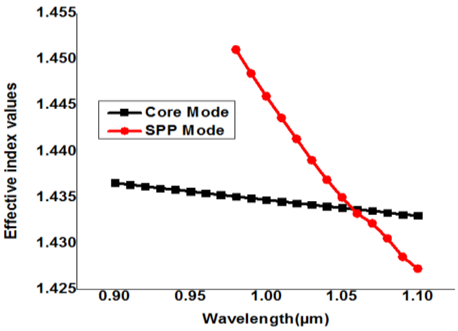

Fig. 2. Effective refractive index vs wavelength for core and SPR mode at 20ºC.

As shown in Fig. 2, the mode propagation of light pulse is studied by effective index analysis. Such that, the real component of mode field velocity gets decreasing with increasing wavelength. The same study has been carried over for the plasmon modes. The correlation between the silica and plasmon mode depicts that the mode index values of silica material have higher than the mode index values of plasmon modes. At the phase matching condition, the coupling between the core mode and SPR mode at 1.05µm for y polarized wave at the temperature of about 20 ºC. The meeting point of both the modes gives the maximum absorption point of proposed metal dotted fiber which can be calculated as given in ref. [4]. The point of maximum at the corresponding wavelength is known as resonance wavelength.

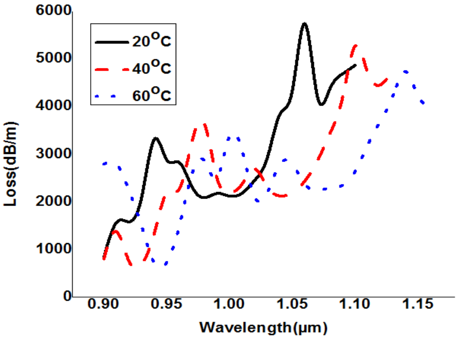

Fig. 3. Loss Spectrum Vs wavelength for x polarization.

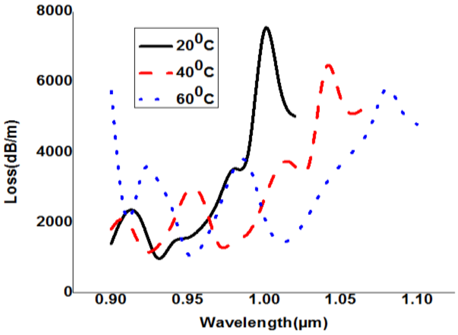

Fig. 4. Loss Spectrum Vs wavelength for y polarization.

As Fig. 3 and 4 shows the loss spectra for the different polarization having the wavelength range from 0.9µm to 1.15µm. The overall loss behavior shows that it is increased at the starting wavelength point and continuously rising with increasing the wavelength region. At the certain point of wavelength, the maximum loss is attained where that wavelength is called as resonance wavelength. This point of resonance wavelength is shifted with respect to the minimal variation of filling analyte. The analyte is varied depending upon the wavelength and temperatures. The peak point of loss spectra is shifted with respect to the change of analyte. It is proven that the shifting to the shorter wavelength region gives the maximum of temperature whereas shifting towards to the longer wavelength region denotes the minimum value of temperature. The overall resonance shifting for x polarization at 1060 nm, 1099 nm and 1141 nm for the temperature being 20°C, 40°C and 60°C respectively. Hence, the overall wavelength shift is obtained as 80 nm for x polarization. Similarly, the resonance wavelength shifts for y-polarization as 1000 nm, 1038n m and 1075 nm with overall wavelength shift of 75 nm for y polarization.

The calculated dip wavelength for both the polarization is plotted with the function of temperature as shown in Fig. 5 which shows that the variation in the shift is linearly increased. The linear curve characteristics are slightly greater for x-polarization than y-polarization. It is happened due to that loss spectra of y-polarization is higher values than the x-polarization. Hence, the propagation of mode field strength in the x-direction with greater velocity than y-polarization.

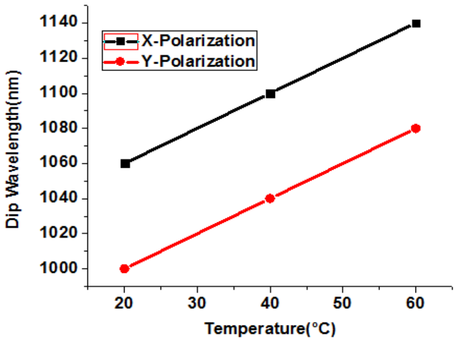

Fig. 5. Dip wavelength Vs Temperature.

By inspecting the loss plot of x polarization and y polarization, the sensitivity of x polarization is better. The sensitivity of the proposed metal dotted fiber is calculated by as per equation (2),

$$S\,(nm/^{\circ}\,C)=\frac{\partial\lambda_{peak}}{\partial T} \tag{2}$$

where λ_{peak} is the peak wavelength. By equation (2), the change in wavelength shift as shown in Fig. 6 is interpolated in the sensitivity equation

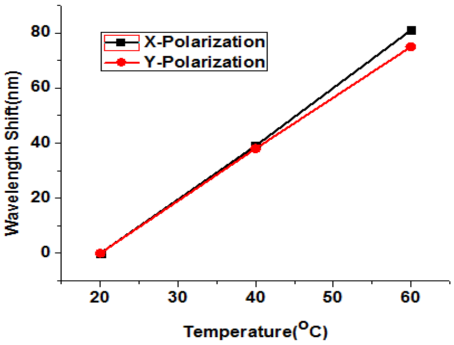

Fig. 6. Plot between Wavelength shift Vs Temperature.

Fig. 6 depicts the wavelength shift of the transmission spectrum with incremental temperature by 20°C. It is calculated that the wavelength shift of 40nm for x polarization and 38nm for y polarization by increasing the temperature 1^{o}C. It has been calculated from Fig. 6 that the sensitivity of the proposed low index sensor 2.03 nm/^{o}C for x-polarization and 1.875 nm/^{o}C for y-polarization.

4. Conclusions

In this work, we discussed and characterized a photonic band-gap fiber (PBF) model as a temperature sensor which uses liquid filled core and mono metal nano-dots as its sensing elements. The sensing behavior is investigated by coupling effect between the two modes and analyzed using FEM method.

The result of sensitivity show x polarization is better than y polarization. The analysis is done over the wavelength ranges from 900 nm to 1150 nm and temperature ranges from 20 ºC to 60 ºC in steps of 20 ºC. This preliminary work can be extended to develop the real world, high sensitive and promising temperature sensor.

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