Optics and Photonics Journal, 2018, 8, 309-316
http://www.scirp.org/journal/opj
ISSN Online: 2160-889X
ISSN Print: 2160-8881

Alcohol Sensing through Photonic Crystal Fiber at Different Temperature

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How to cite this paper: Podder, E., Jibon, R.H., Hossain, Md.B., Al-Mamun Bulbul, A., Biswas, S. and Kabir, Md.A. (2018) Alcohol Sensing through Photonic Crystal Fiber at Different Temperature. *Optics and Photonics Journal*, **8**, 309-316.
https://doi.org/10.4236/opj.2018.810026

Received: September 12, 2018
Accepted: October 19, 2018
Published: October 22, 2018

Abstract

This paper presents the investigation of relative sensitivity profile of Alcohol through Photonic Crystal fiber at different temperature. Here, 15%, 40%, 60%, 75% of Ethyl Alcohol-water mixture is inserted through the core of Photonic crystal fiber at temperature like 20˚C, 25˚C and 30˚C. COMSOL Multiphysics is used as simulation software and the simulation process is done at wavelength range 600 nm to 1600 nm. From this work, the relative sensitivity is obtained approximately 44, 44.59, 44.85, 45 in percentage at temperature 20˚C, 42, 44.2, 44.8, 44.9 in percentage at temperature 25˚C, and 42, 43.8, 44.5, 44.85 in percentage at temperature 30˚C for 15%, 40%, 60%, 75% of Ethyl Alcohol-water mixture at wavelength 1500 nm respectively. Again, higher sensitivity is achieved when this sensor is operated at lower temperature.

Keywords

Photonic Crystal Fiber, Relative Sensitivity, COMSOL Multiphysics

1. Introduction

Initially in 1966, Optical fiber technology was developed for telecommunication applications. After that this technology got a huge positive feedback among the researchers. Very soon optical fibers were seen to expand its application area like sensing field. The growths of photonic crystal fibers (PCFs) with their significant optical properties have confirmed the prospective benefits of optical fibers in chemical and biological sensing [1] [2] [3]. The outstanding characteristics of these micro structured fibers such as small size, freedom of design, and relative compatibility make them stand out for sensing applications [4] [5] [6]. Where in conventional fibers, designing is not so easy, core size is limited, material selection is tough etc. Moreover, these limitations on the geometry hamper the flexibility in recognizing fiber properties such as dispersion [2] [7], confinement loss [8] [9], birefringence [2] [9], relative sensitivity [10] etc. PCF provides us with long distance light propagation that was not possible previously. Light propagation characteristics can be controlled by adjusting the air holes in the core and cladding region. A lot of research studies are already done in the fields of optical communications [10] [11], nonlinear optics [11] and sensing [12] [13] [14].

Sensitivity vastly depends on refractive index of material. The higher the refractive index of a material, the higher the sensitivity. For this reason, Sensing material with lower refractive index is very tough, but with blessing of PCF lower index materials can also be sensed [13] [14] [15].

Water and alcohols are considered as the major analytes for these types of applications because they account for the immense majority of biological or chemical solutions [16] [17]. We need to know how much alcohol is mixed water within any drinking liquid as drinking large amount of alcohol is harmful for human body. Alcohols are also used to make different biomedical solution so sensing alcohol is a great issue. Sensing properties of alcohol highly depend on its concentration as well as in which temperature it is measured [18] [19] [20].

In this research work, we proposed a simple hexagonal PCF structure where ethyl alcohol-water mixture is inserted through the core region. In order to realize the sensitivity profile of ethyl alcohol-water mixture, we have varied the concentration of ethyl alcohol and also we have varied the operating temperature to investigate the sensitivity profile.

2. Materials and Methods

In this thesis, we have designed a hexagonal PCF structure in COMSOL Multiphysics (version-5).

Silica glass is used as core material which is surrounded by three layers of air holes with diameter, d1 = 1.6 um and pitch, Λ = 2.1 um. Air holes are used to guide the light propagation through the core. In the core area, 6 holes with diameter, d = 1.2 um and another 7 holes with diameter 0.8 um is filled with different concentration of Ethyl Alcohol at different temperature. A perfectly matched layer (PML) of 0.7 um is used. The designed hexagonal PCF structure is shown in **Figure 1**.

In this work, we have taken different mixture of Ethyl alcohol-water at different temperature and then we have investigated the relative sensitivity of ethyl alcohol at different temperature at wavelength range from 600 nm to 1600 nm. Refractive index of Ethyl Alcohol-Water Mixture changes with its concentration as well as its operating temperature. **Tables 1-3** show the refractive index for different concentration of Ethyl Alcohol-Water mixture and at temperature 20˚C, 25˚C, 30˚C respectively.

The relative sensitivity can be calculated by using the below equation [14] [15] [16]:

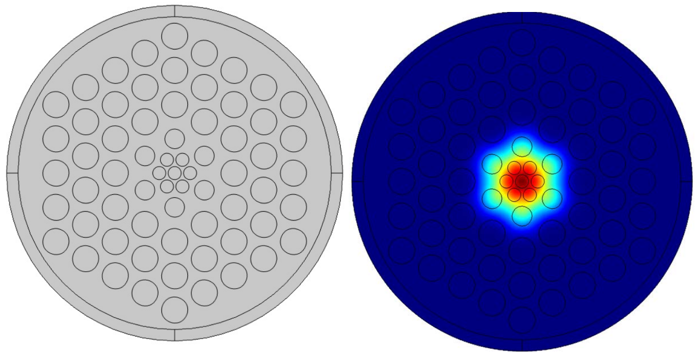

Figure 1. Proposed hexagonal PCF structure in COMSOL Multiphysics: (a) Transverse geometry and (b) Fundamental mode field of the PCF.

Table 1. Refractive index of ethyl alcohol-water mixtures at 20˚C.

Ethyl Alcohol amount (%)	Refractive Index at temperature 20˚C
15	1.34361
40	1.35855
60	1.36336
75	1.36472

Table 2. Refractive index of ethyl alcohol-water mixtures at 25˚C.

Ethyl Alcohol amount (%)	Refractive Index at temperature 25˚C
15	1.34298
40	1.35705
60	1.36185
75	1.36334

Table 3. Refractive index of ethyl alcohol-water mixtures at 30˚C.

Ethyl Alcohol amount (%)	Refractive Index at temperature 30˚C
15	1.34188
40	1.3558
60	1.35992
75	1.36114

$$r = \frac{n_r}{n_{eff}} f \tag{1}$$

Where n_r is the refractive index of sensed material and n_{eff} is the modal effective refractive index which is obtained from Comsol Multiphysics simulation. Again, f is the power ration in percentage which f can be obtained from Comsol Multiphysics simulation directly using the rule given below [14] [15] [16]:

$$f = \frac{\int_{\text{sample}} \text{Re}\left(E_x H_y - E_y H_x\right) \text{d}x\text{d}y}{\int_{\text{total}} \text{Re}\left(E_x H_y - E_y H_x\right) \text{d}x\text{d}y} \times 100 \tag{2}$$

Here, E_x, E_y and H_x, H_y are the transverse electric field and magnetic field in x and y axies respectively. Then putting the values of n_r, n_{eff} and f in MATLAB we can get relative sensitivity curve with respect to wavelength.

3. Simulation Results

We have got the simulated result for different concentration of Ethyl Alcohol-Water mixtures as well as for different temperature. Then the simulated result is inserted into MATLAB and then the relative sensitivity curves are obtained with respect to different wavelength. The sensitivity curves of Ethyl Alcohol water mixture for different concentration at temperature 20˚C, 25˚C, 30˚C are shown for wavelength range from 600 nm to 1600 nm. A tuning laser can be used to have light of different wavelength. The relative sensitivity profile for different concentration of Ethyl Alcohol at temperature 20˚C is shown in **Figure 2**.

For 20˚C temperature, the relative sensitivity is increasing with increasing amount of Ethyl Alcohol water mixture as the refractive index goes higher with increasing amount of Ethyl Alcohol. Again, the relative sensitivity is increasing with increasing wavelength. The relative sensitivity is obtained approximately 37.5, 40.6, 41.5, 42 in percentage at wavelength 1200 nm and 44,44.59, 44.85, 45 in percentage at wavelength 1500 nm when 15%, 40%, 60%, 75% of Ethyl Alcohol-water mixture is inserted through the core region respectively.

We performed the same procedure to investigate the relative sensitivity profile at temperature 25˚C and it is shown in **Figure 3**.

For 25˚C temperature, the relative sensitivity is also increasing with increasing amount of Ethyl Alcohol water mixture as the refractive index goes higher with increasing amount of Ethyl Alcohol.

Again, the relative sensitivity is also increasing with increasing wavelength. The relative sensitivity is obtained approximately 37, 40, 41.5, 41.8 in percentage at wavelength 1200 nm and 42, 44.2, 44.8, 44.9 in percentage at wavelength 1500 nm when sensing liquid is 15%, 40%, 60%, 75% of Ethyl Alcohol-water mixture respectively.

Again, we performed similar experiment to investigate the relative sensitivity profile at temperature 30˚C and it is shown in **Figure 4**.

For 30˚C temperature, the relative sensitivity is also increasing with increasing amount of Ethyl Alcohol water mixture as the refractive index goes higher with increasing amount of Ethyl Alcohol. Again, the relative sensitivity is increasing with increasing wavelength. The relative sensitivity is obtained approximately 36.9, 40, 41, 41.2 in percentage at wavelength 1200 nm and 42, 43.8, 44.5, 44.85 in percentage at wavelength 1500 nm for 15%, 40%, 60%, 75% of Ethyl Alcohol-water mixture respectively.

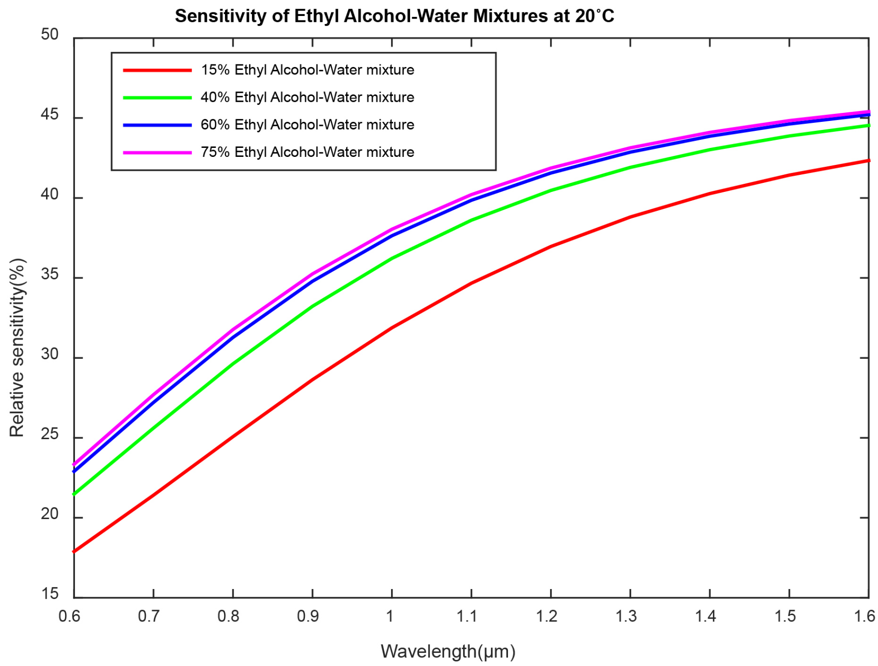

Figure 2. The sensitivity profile of Ethyl Alcohol water mixture for different concentration at temperature 20˚C.

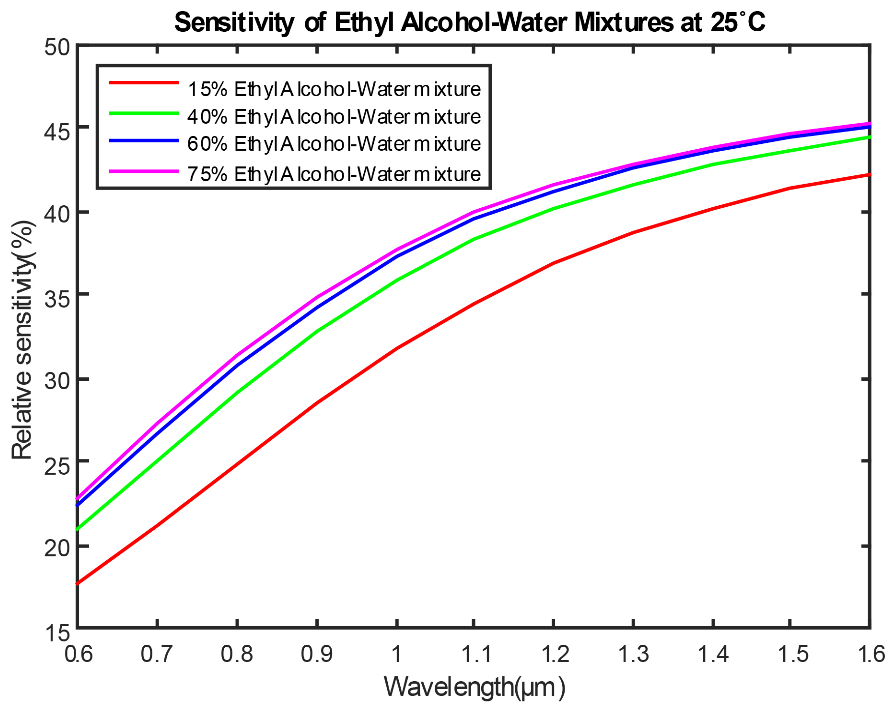

Figure 3. The sensitivity profile of Ethyl Alcohol water mixture for different concentration at temperature 25˚C.

Then we have taken 15% of Ethyl Alcohol-water mixture as sensing liquid and then we performed sensing operation at different temperature and the relative sensitivity profile for different temperature is shown in **Figure 5**.

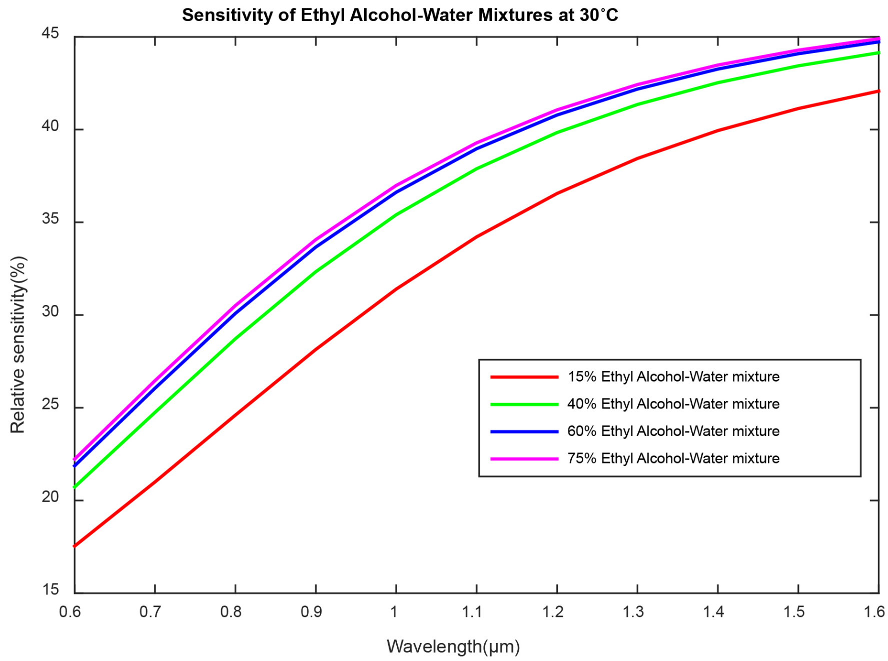

Figure 4. The sensitivity profile of Ethyl Alcohol water mixture for different concentration at temperature 30˚C.

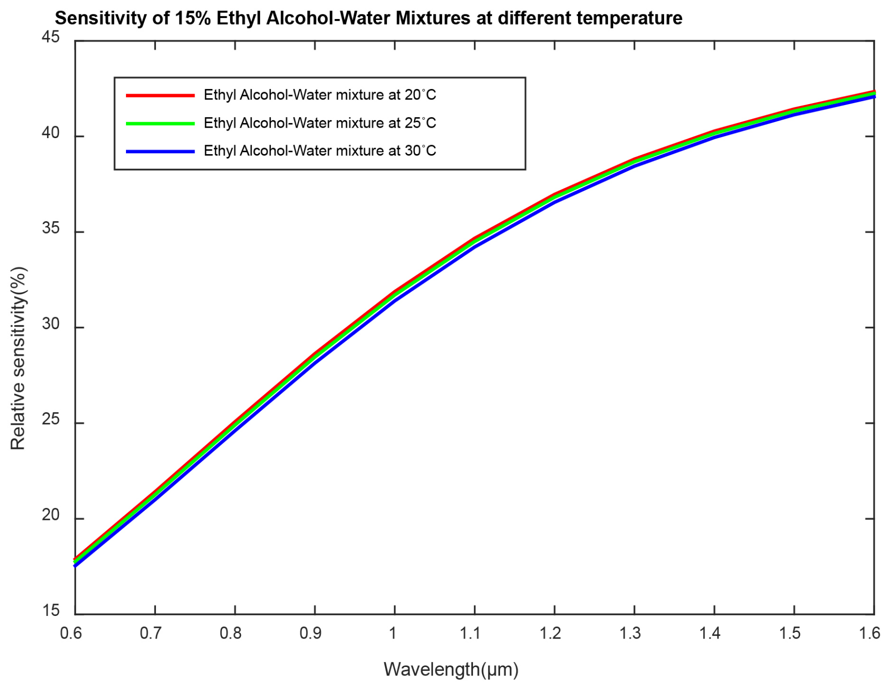

Figure 5. The Relative sensitivity profile of 15% Ethyl Alcohol water mixture at different temperature.

The relative sensitivity profile is increasing with increasing wavelength as like before. Again, it is decreasing with increasing temperature which means higher sensitivity will be achieved when we will operate this sensor at lower temperature. The relative sensitivity is obtained approximately 37, 36.5, 36 in percentage at wavelength 1200 nm and 42, 41.5, 41 in percentage at wavelength 1500 nm when sensing liquid is 15% of Ethyl Alcohol-water mixture at temperature 20˚C, 25˚C, 30˚C respectively.

4. Conclusion

In this research work, a simple hexagonal photonic crystal fiber (PCF) sensor has been designed in Comsol Multiphysics to sense Ethyl Alcohol. The main goal of this research is to investigate the relative sensitivity profile by varying the concentration of liquid as well as operating temperature. At wavelength 1500 nm, the relative sensitivity is obtained approximately 44, 44.59, 44.85, 45 in percentage at temperature 20˚C, 42, 44.2, 44.8, 44.9 in percentage at temperature 25˚C, 42, 43.8, 44.5, 44.85 in percentage at temperature 30˚C for 15%, 40%, 60%, 75% of Ethyl Alcohol-water mixture respectively. Again, lower sensitivity is observed when this sensor is operated at higher temperature.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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