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Length Effects of Hetero-Core Optical Biosensor based on Evanescent Field Absorption

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Abstract : *Sensing performances of evanescent field absorption (EFA) hetero-core fiber sensor has been presented based on EFA by changing the length and the core diameter of the single mode fiber. Experimental results have demonstrated a good feature in their relationship between the length and the core diameter of the single mode fiber. The sensor consists of 2 fiber optics which have the same cladding diameter of 125 ㎛ However one fiber optic used is single mode and has varying core diameter ranging from 3.3 to 5.6 ㎛ The other fiber is multimode type and has a thicker fixed core diameter of 62.5 ㎛ The 2 fiber optics are thermally spliced together. Experiments conducted to measure the resonance wavelength were carried out over a range of refractive index, to find the optimum sensing length. Experiments show that core diameter of the single mode fiber and sensing length affects the linearity and sensitivity.*

Key words : *evanescent field absorption, hetero-core structure, resonance wavelength, biosensor, optical fiber sensor*

1. Introduction

Optical fiber is very much used in communication networks, replacing the conventional metal wires because of their much higher rate of data transfer, also known as bandwidth over longer distances. As technology advances, the transmission loss per unit distance also decreases significantly and optical fiber represents one medium of data transport with very acceptable loss rate. Thus, optical sensors are also replacing many conventional sensors and becoming the mainstream sensors because of its portability, relative low cost of production as well as immunity towards external electromagnetic interferences(John, 1992).

Nowadays biosensors have wide applications, including biomarker detection for medical diagnostics, and pathogen and toxin detection in food and water. Fiber-optic biosensors use optical fibers as the transduction element, and rely exclusively on optical transduction mechanisms for detecting target biomolecules. One reliable and sensitive optical method is evanescent sensing(George, 1994; Daniel, 2003; Angela, 2007). For this reason, among the various sensing techniques employed, detection through evanescent field absorption is investigated in this research study. The evanescent field absorption technique has been widely used since the early days of discovery and is a tried and tested method for consistent results(Choudhury, 2004; Athanasios, 2005; David, 2006).

To achieve good sensing as well as to avoid the vulnerable structure conventional techniques have confronted with, a hetero-core structure is proposed. The fabrication process is tremendously simplified and the improved strength of the optical fiber sensor is also a great advantage in deploying it in many different kinds of environments (Mitsuhiro, 2004). In this study, the evanescent field absorption method is considered and its effect and results studied. And the aim of this study is to investigate the effect of varying the length of the sensing optical fiber. In addition, we also look at the effect of varying the single mode fiber core diameter.

2. Experiment

2.1 Principle of Evanescent Field Absorption

An evanescent field absorption hetero-core structure dealt in this paper is illustrated in Fig. 1. The structure comprises of a segment of single mode fiber which acts as the sensing portion connected at both ends to multi-mode fibers which perform the role of light ray transmission. The core diameter of single mode fiber is varied from 3.3 ㎛ to 5.6 ㎛ while that of the multi-mode fiber is fixed at 62.5μm. The cladding diameter is constant at 125 ㎛.

Light rays from the multi-mode transmission fiber enters the cladding portion of the single mode fiber because of diameter difference. The single mode fiber's core diameter is much smaller than the multi-mode fiber's core diameter.

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When those rays reflect at the boundary of the cladding, they induce evanescent field under condition of internal total reflection. The analytes absorb the field of the wavelength used for transmission and the transmission power decreases. Different concentration of analyte gives rise to different refractive index. The absorption resonance wavelength is sensitive to the refractive index. Thus, analyte concentration can be analyzed and determined by analysing the shifts in the resonance wavelength(Fouad, 2008). In order to use this technique, the light source must be at a wavelength that is absorbable by the sample analytes. In this study, light source of wavelength from 400-1800 nm is used to cover an extensive range, after which it is narrowed down to the relevant wavelength for in-depth analysis.

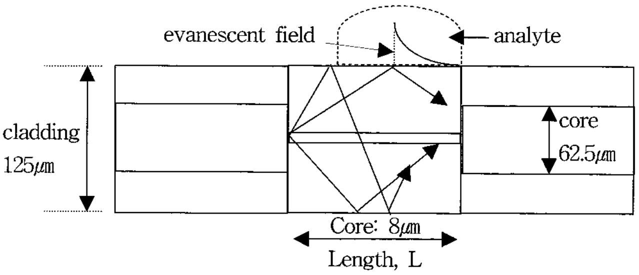

Fig. 1 Hetero-core structured optical fiber sensor. Light rays from the multi-mode transmission fiber enters the cladding of the single mode fiber, forming evanescent field that interacts with the surrounding analyte.

2.2 Experimental Setup

The setup for the experiment is shown as in Fig. 2. One end of the hetero-core optical fiber is connected to the light source while the other end is connected to a spectrum analyser to monitor the changes in the resonance wavelength. The connection is done in a straight configuration with minimal bends in the optical fiber to provide a standard way of testing and data collection. The sensing portion of each hetero-core fiber is the single mode fiber portion with its plastic cover removed. This sensing portion is immersed in the analyte solution to sense the concentration. The analyte used in this research is a solution made up of mixture of water and glycerine. When the proportion of glycerine is increased, the refractive index of the mixture also goes up. The sensor senses the different refractive indices and outputs them separately on the analyzer showing wave forms with different resonance wavelengths. Each resonance wavelength corresponds to each refractive index value. Thus, concentration of glycerine can be sensed and measured.

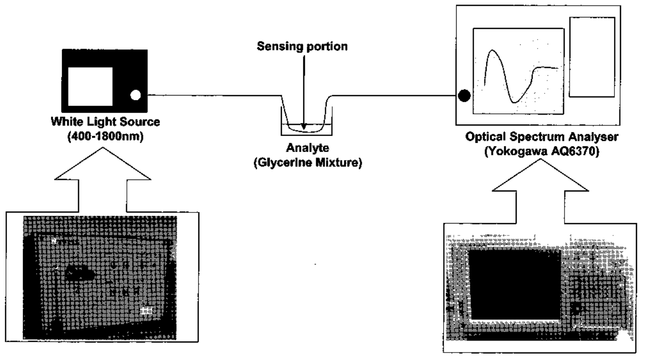

Fig. 2 Experimental setup consisting of white light source and optical spectrum analyzer with the optical fiber sensor immersed in the analyte.

3. Results and Discussion

The analyte used in the experiment is water glycerine mixture. Water by itself has refractive index of 1.33. Adding glycerine to water changes the refractive index (RI). The change of refractive index causes the absorption resonance wavelength to be changed(Gibson, 2007). Experiments were conducted for various sensor length and also single mode core diameters. We try to establish a relationship between the sensor length and core diameter of the single mode fiber. The single mode core diameter utilized in the experiments are 3.3, 4.3 and 5.6 μm whereas the sensing length ranges from 20 mm onwards.

3.1 Results of Hetero-core sensor

1) Single mode core diameter: 3.3 μm

Fig. 3 below shows the results obtained with hetero-core sensor of length 30 mm and of single mode core diameter of

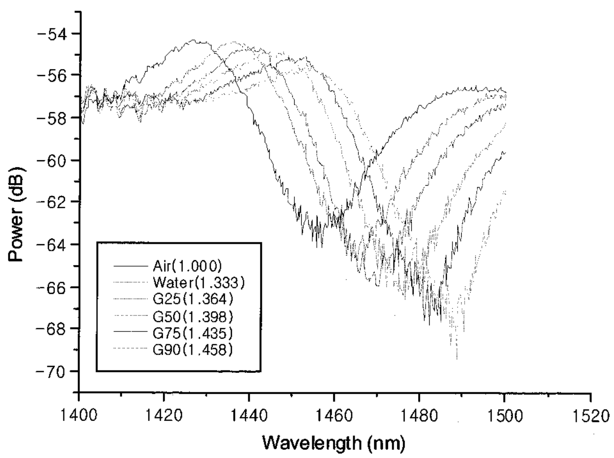

Fig. 3 Hetero-core sensor (length: 30 mm and single mode core diameter 3.3 μm) immersed in different concentration of glycerine concentration.

3.3 ㎛. Fig. 4 is a plot of the relationship between RI and resonance wavelength while Table 1 shows the relationship in numeric format. Similar experiments were conducted for the 3.3 ㎛ core diameter but with different sensing lengths. 20 ㎜ and 40 ㎜ were carried out. Results showed that among the range of 20 to 40 mm, 30 mm offers the best sensitivity and linearity.

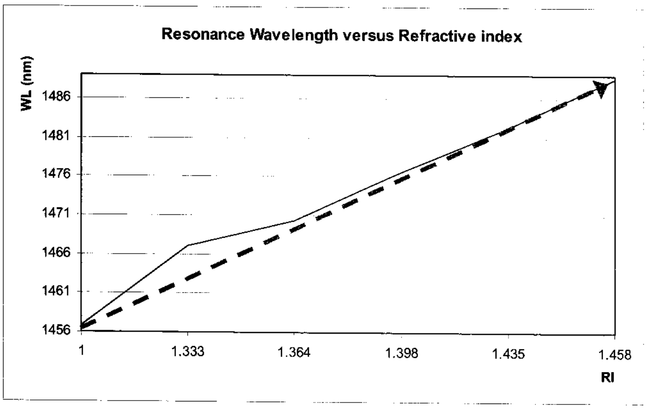

Fig. 4 Hetero-core of sensing length 30 ㎜ and single mode fiber core diameter of 3.3 ㎛.: Relationship between refractive index and resonance wavelength.

Table 1 Refractive index versus resonance wavelength (length: 30 ㎜ and single mode core diameter 3.3 ㎛).

Refractive index	1.000	1.333	1.364	1.398	1.435	1.458
Resonance wavelength (nm)	1.456.8	1467.0	1470.3	1476.6	1482.3	1488.6

2) Single mode core diameter: 4.3 ㎛

Next the hetero-core sensor of core diameter 4.3 ㎛ is examined. In the original experiments, the sensing length ranges from 20 ㎜ onwards. However the 20 ㎜ sensing length sample does not produce any relationship between the refractive index and the resonance wavelength. Nor does the sample with 30 ㎜ sensing length. The experiment is extended all the way to 60 ㎜ and result for the 60 ㎜ reflects the optimum sensitivity and linearity. Fig. 5 shows the 60 ㎜ sample with reasonable noticeable results

Fig. 6 is a plot of the relationship between refractive index and resonance wavelength. Table 2 shows the numerical relationship between the refractive index and the corresponding resonance wavelength for hetero-core sample with sensing length of 60 ㎜ and single mode fiber core diameter of 4.3 ㎛.

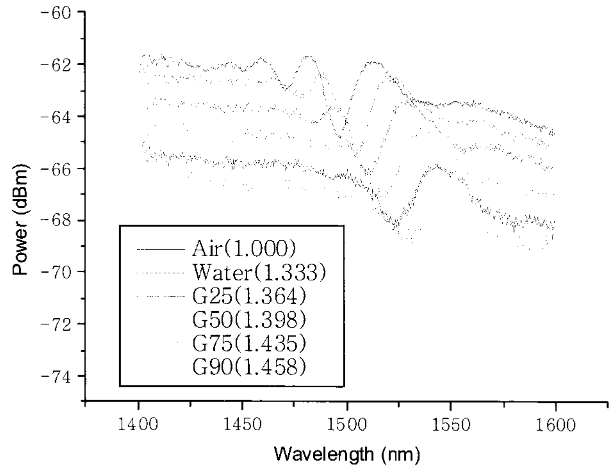

Fig. 5 Hetero-core of sensing length 60 ㎜ and single mode fiber core diameter of 4.3 ㎛.

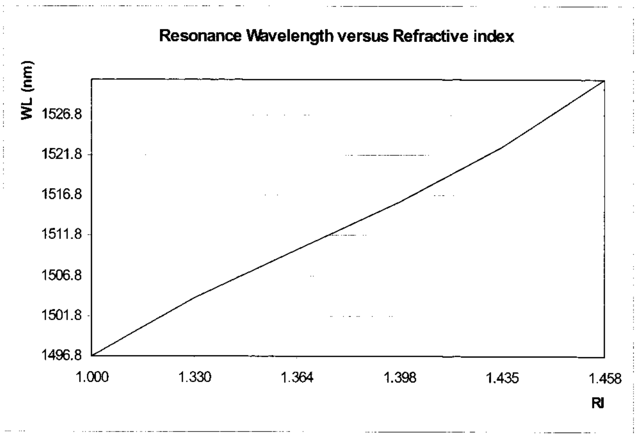

Fig. 6 Hetero-core of sensing length 60 ㎜ and single mode fiber core diameter of 4.3 ㎛; Relationship between refractive index and resonance wavelength.

Table 2 Refractive index versus resonance wavelength (length: 60 ㎜ and single mode core diameter 4.3 ㎛).

Refractive index	1.000	1.333	1.364	1.398	1.435	1.458
Resonance wavelength (nm)	1496.8	1504.0	1510.0	1516	1522.8	1531.2

3) Single mode core diameter: 5.6 ㎛

Next we examine the hetero-core sensor which has single mode fiber core diameter of 5.6 ㎛. For this experiment, the shorter sensing lengths do not produce any useful relationship. The sensing length is increased and tested all the way to 80 ㎜ before a correlation between refractive index and resonance wavelength was obtained. The results reflected a certain degree of relationship between the refractive index and the resonance wavelength. Fig. 7 shows the spectrum waveforms that were recorded. Fig. 8 plots the relationship between refractive index and corresponding resonance wavelength. There is a linear relationship. Table 3 shows the numerical relationship between refractive index and resonance wavelength

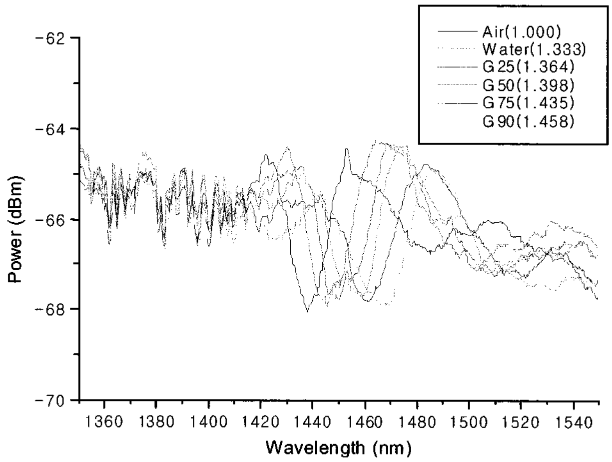

Fig. 7 Hetero-core of sensing length 80 mm and single mode fiber core diameter of 5.6 μm. No relationship between refractive index and resonance wavelength could be established.

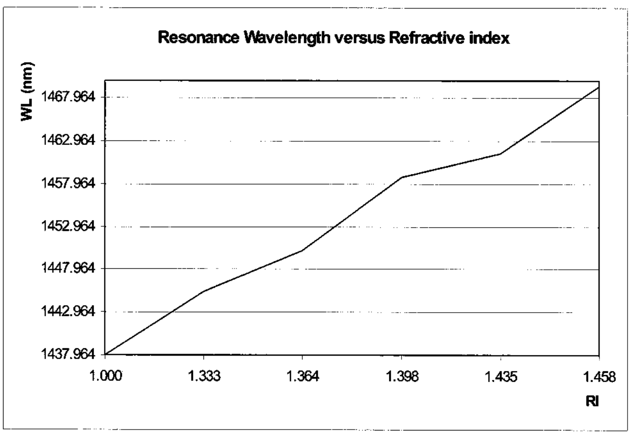

Fig. 8 Hetero-core of sensing length 80 mm and single mode fiber core diameter of 5.6 μm. Relationship between Refractive index and Resonance wavelength.

Table 3 Refractive index versus resonance wavelength (length: 80 mm and single mode core diameter 5.6 μm).

Refractive index	1.000	1.333	1.364	1.398	1.435	1.458
Resonance wavelength (nm)	1437.9	1445.4	1450.1	1458.8	1461.5	1469.4

3.2 Results Discussion

From the results obtained in this research paper, it appears that there is a strong direct relationship between the core diameter of the single mode portion of the hetero core optical fiber and its optimum length. This observation was achieved by testing various sample lengths of the same core diameter over the same range of refractive index. From the derived spectrum analysis, for core diameter of 3.3 μm, the ideal sensing length is 30 mm, for 4.3 μm, it is 60 mm and for 5.6 μm, the optimum sensing length is 80 mm. The testing range is non-exhaustive and can be easily extended to other lengths to achieve an even higher accurate sense of the relationship.

Table 4 shows the calculated sensitivity of the hetero-core biosensors. It is calculated by dividing the resonance wavelength range over the refractive index range of 0.458. This method of calculation may be rough in nature but from the results obtained, all the relationships follow a certain level of linearity which made it viable for such calculations to be supported in practice. RIU^{-1} means the refractive index unit. The "-" indicates that for that length of sensor, the result obtained is impractical for usage.

Table 4 Sensitivity of the Hetero-core Biosensors

Core Diameter/ Sensing Length	3.3μm	4.3μm	5.6μm
2 cm	56.6nm RIU^{-1}	-	-
3 cm	69.4nmRIU^{-1}	-	-
4 cm	50.2 nm RIU^{-1}	39.5 nm RIU^{-1}	-
6 cm	-	75.1nmRIU^{-1}	-
7 cm	-	42.6 nm RIU^{-1}	-
8 cm	-	-	68.6nmRIU^{-1}

For the 3 types of single mode fiber, their cutoff wavelengths are proportional to their core diameters. Thus a larger core diameter such as the 5.6 μm would have a higher cutoff wavelength of 800 nm as compared to the 3.3 μm fiber which has a cutoff wavelength of 450 nm. The 4.3 μm fiber has a cutoff wavelength that sits between the other 2 and it is 600 nm. Through this, we can deduce that the larger the core diameter of the single mode fiber is, the higher the cutoff wavelength which translates to a higher possibility of having more modes of light travelling down the single mode fiber. This in turn results in lesser cladding modes and thus the sensing ability is affected negatively. Thus in the experiments, we can see that the larger core diameter fibers display lower sensitivity for the same sensing length as compared to the fibers with smaller core diameters. To compensate the reduction of sensitivity, a large core diameter fiber needs to be longer in order for the cladding power to build up to the same level as the smaller core diameter fiber.

4. Conclusion

From the results obtained, we could detect a correlation between core diameter of the single mode fiber and the corresponding required sensing length. It appeared that the larger the core diameter, the longer the length has to be, in order for it to be effective as a sensor. However if the sensing length is too long, it may not serve well as a precise sensing instrument because usually the measurand and analyte to be measured is over a small area.

In addition, further research also needs to be supplemented in order to analyze and achieve an explanation for the correlation discovered. We believe with further research techniques and given more time, it can be analyzed and the results fully harnessed to produce useful applications in various fields of work and life. Further research can also be carried out in the area of surface plasmon resonance (SPR).

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