TEMPERATURE INDEPENDENT ON PLASTIC OPTICAL FIBER EVANESCENT WAVE SENSOR

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***Abstract*— We have developed a fiber optic evanescent wave sensor which is capable of monitoring the concentration of liquids by eliminating the changes in the temperature of the surrounding medium. This evanescent technique is based on the evanescent field interactions between the propagating light and the analyte under consideration. A step index polymer optical fiber is manually side polished such that the cladding gets exposed to the solution. Samples of different concentrations of D-Glucose anhydrous (Dextrose anhydrous) procured from Nice Chemicals Pvt Ltd. serves as the analyte. The optoelectronic system consisted of a 650nm narrowband laser, photo detector from Holmarc for light launching and detection respectively. In order to make the measurements independent of temperature effects of the surrounding environment, the POF, after polishing was treated to several cycles of heating and cooling in high temperature oil (Silicone oil). The POF (Plastic optical fiber) was jacketed in a PTFE tube with diameter 3mm during the heat-cool cycles to prevent the ingress of oil into the sensing region. Later, the solution concentration was again monitored and the results show the independency in the photocurrent output on temperature.**

Keywords*— *Evanescent fiber sensor, POF, U shaped metal groove, Photo-current, Temperature independent.

1. INTRODUCTION

Fiber optic evanescent wave sensors are widely used in biochemistry, chemistry, environmental research and life sciences [1]. These evanescent wave sensors provide accurate and fast while giving results in terms of chemical component analysis, measuring solution concentrations and absorption spectra of chemical during real time monitoring. These Fiber optic evanescent wave sensors are composed of silica and polymer optical fibers. These evanescent wave sensor measurements are not attracted for bulk solutions because the penetration depth of the evanescent field range is for few nanometres only. Currently available most of the fiber optic evanescent wave sensors are based on the polymer optical fibers. Because of their various potential advantages including large diameter core, high degree of flexibility, large numerical aperture and low cost these evanescent wave sensors attracted for many fields. Due to the high degree of flexibility in fibers many researchers have been fabricated different shapes, such as D-shaped [2], U-shaped [3] as show in fig. 1, spiral and taper sensors. Banerjee et al., reported that the effective influence fiber optic sensor on light absorption by solute and that of its chemical nature and sensing of refractive index variation [4]. Chenghura et al., claimed that fiber optic evanescent wave sensor has significant role in measuring variation in refractive index of solute [5]. In this paper, we addressed that, how to develop a consistent and stable fiber optic evanescent wave sensor to measure the concentration and chemical composition of the aqueous solution without affecting with temperature of the vicinity.

2. PROBLEM BACKGROUND

There are many problems which we need to overcome while measuring the concentrations and chemical composition of aqueous solutions. Our evanescent wave senor is having a problem of temperature dependency, while measuring the concentration of aqueous solution, we found that our sensor having temperature sensitivity. This temperature sensitivity leads to wrong results [6] for measuring the concentration of aqueous solutions. That is more affecting on sensitivity of the evanescent wave sensor [7]. So we should take care to reduce the Hysteresis in the evanescent wave sensor response. We have to overcome this temperature dependency problem.

A. Fabrication of Evanescent wave sensorand its working:

In this investigation we have fabricated the polymer fiber optic evanescent wave sensor by using the manual side polishing technique.

We have used the groove plate for fiber positioning The steps involved in the fabrication of Evanescent wave sensor are as follows:

Attached the HFBR connector to the both ends of one meter length optical fiber.

Exact middle portion of the optical fiber fixed using the epoxy, for positioning of optical fiber permanently without any further movement while polishing.

Side polishing was done with different grit papers, such as silicon carbide (thickness of 30, 15 and 5 microns) and aluminium oxide (thickness of 3, 1, 0.5 and 0.3 microns).

Side Polishing has been done with both the grit papers until the removal of core & cladding and finally to get smooth surface. Surface of the polished region is cleaned with iso-propanal and the surface of the polished region of the polymer optical fiber is observed with USB microscope.

This polishing process is continuously done until we get the respected removal of core and cladding of the polymer optical fiber and also the smooth surface.

By using this fiber side polishing mechanism, the groove plate is having groove length of 55 mm so that, the effective length of sensing region of the sensor was 55 mm as show in fig. 2.

Fabrication of evanescent wave sensor needs clean and fine removals of core cladding, for that we have designed groove plate, having different depths of grooves in which our fiber can fit [8]. The specified different depths like 1.1 mm, 1.2 mm, 1.3 mm and 1.4 mm (fig. 3). As we know our fiber outer diameter 2.2 mm (with buffer) and diameter of 1000µm (1 mm). if we kept our fiber in the groove depths 1.1 mm, 1.2 mm, 1.3 mm and 1.4 mm, we can remove the 500 µm, 400 µm, 300 µm and 200 µm of core cladding with respect to the depths by using manual side polishing technique

When the light enters at the one end of the optical fiber (fig. 4) due to the total internal refraction [9], it has been passed throughout the fiber and eventually it will reach the another end. when the light passed through the polished optical fiber some part of it get scattered to outside environment and some part of the light reaches to the another end of the optical fiber. This scattered light is useful to sense the analytes [10]. This is the polished region of evanescent wave sensor while light transmitting [11] shown in fig.5. This scattered light is useful to sense the change in the refractive index of different concentrations of aqueous solution and for chemical composition analysis [12].

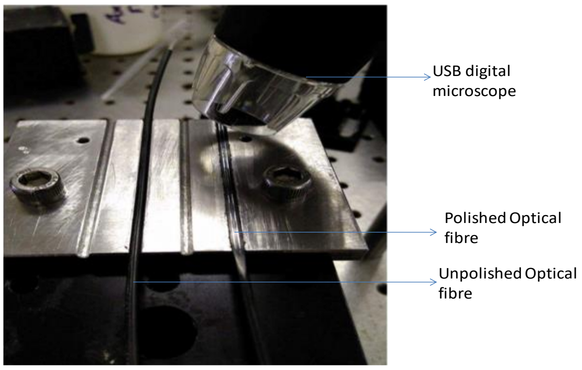

Fig.1: U shaped groove plate for fiber positioning

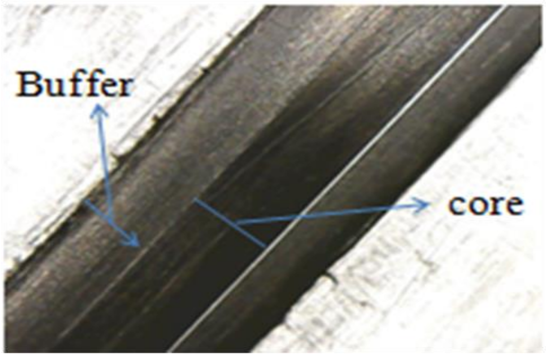

Fig.2: Microscopic image of side polished fiber

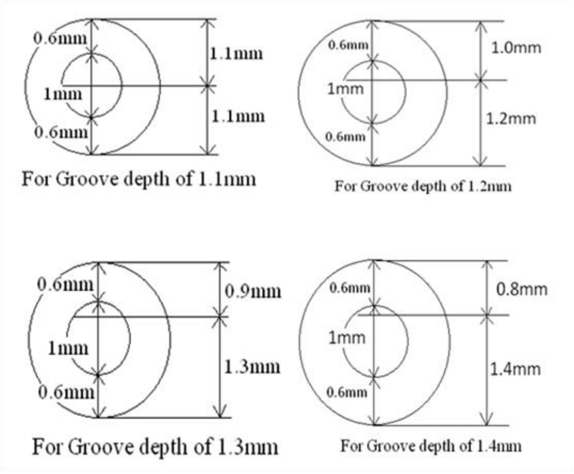

Fig.3: Different levels of core cladding removing by using the Groove plate

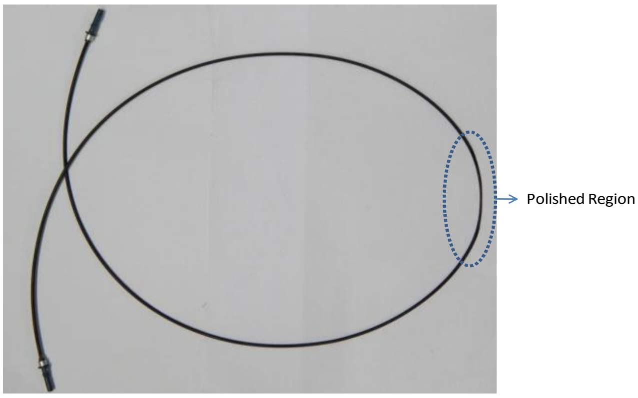

Fig.4: Fabricated evanescent wave sensor

Fig.5: Light transmission in the polished Plastic optical fiber

3. PROPOSED METHODS

B. Monitoring change in the sensor response for different bend radius of the fiber in the air medium

This investigation was carried out by using polymer based optical fibers with different curvature radius of 5, 7, 8.5 and 10 cm rings, which are having 55 mm length and 40 µm depth of polished regions. These circular rings were with various radii of curvatures, viz., 5, 7, 8.5 and 10 cm rings. The main reason behind the different curvature study is to improve the sensitivity of the sensor [11]. As the radius of the circular ring decreases the intensity of the emitted light from the polished region of the sensor was increased significantly, resulting to improvement in the sensitivity of the evanescent wave sensor. We observed effective emission of light from the polished region of fiber for a circular ring which has the radius of 5 cm.

In this different groove depth study the laser and detector mounted on the optical test bench in exact straight manner as shown in fig. 6. The investigation was done with 5 cm radius circular ring by attaching the polished optical fiber. The observation has been done for 2 hours. We have monitored the detector output. In the same manner we have done for 300 µm, 400 µm and 500 µm groove depth polished optical fibers. With this study of photo currents using various rings with different radii and depths of polished regions, we observed the highest sensitivity from a sensor, which has 500 µm depth of the polished region and the circular radius of 5 cm.

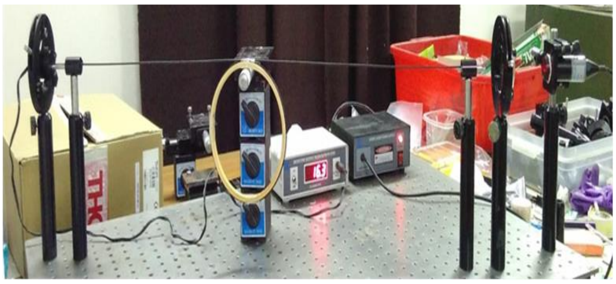

Fig.6: Experimental set up for different groove depth study

C. Monitoring the change in the Thermal treated fiber sensor response for varying glucose concentrations at different temperatures

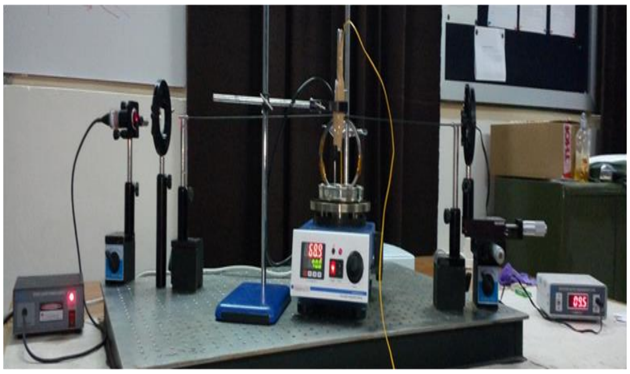

Fig.7: Experimental setup for measuring the glucose concentrations at different temperatures

We have tested our polymer fiber optic evanescent wave sensor with the different concentrations of glucose solution. We have performed this experiment with evanescent wave sensor of polished length and depth of 55 mm and 500 µm, respectively with the radius of 5 cm. We have prepared different concentrations of glucose solution of 5 grams, 10 grams and 15 grams per 100 ml solution by using the magnetic stirrer. The set up has contained laser source, hot plate stirrer, thermocouple to monitor temperature as shown in fig 7.

In this study the polished optical fiber has been attached to the 5cm bend radius ring. The laser, detector, hot plate and thermocouple all are positioned and fixed on the optical test bench. Later we have prepared the glucose concentration 5grm/100ml distilled water by using the magnetic stirrer. After the stabilization of the laser and detector, firstly we measured the sensor response in the air at room temperature. After that we have poured the glucose solution in the plate and observed and noted change of sensor response. And started heating to 80°C, observed the sensor response for every 5 °C rise. In same manner the sensor response is observed for glucose concentrations of 10, 15 grams per 100 ml solution. The top view of immersed sensor in solution is shown in Fig. 8. The further observations were done using photo current of evanescent wave sensor with different concentrations of glucose solution at room temperature. As the concentration of glucose solution increases the photo current also increases due to the variation of refractive index of the solution at room temperature. We have also tested the same evanescent wave senor for different concentration for different temperatures. For the same concentration of glucose solution it has started showing different photo current values for various temperatures in the range from 30 – 70 °C.

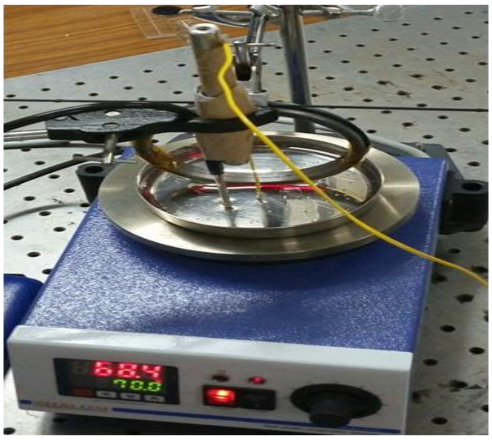

Fig.8: Top view of sensor immersed in glucose solution

From the results later we observed that the polymer fiber optic evanescent wave sensor is dependent to the temperature. As the temperature of the glucose concentration is changing according to that photo current value also changing.

This temperature dependency is the major problem of evanescent wave sensor, to overcome this dependency of temperature problem; we are subjected the polished optical fiber to several cycles of heating-cooling technique/thermal treatment. The experimental set up of thermal treatment is shown in fig. 9.

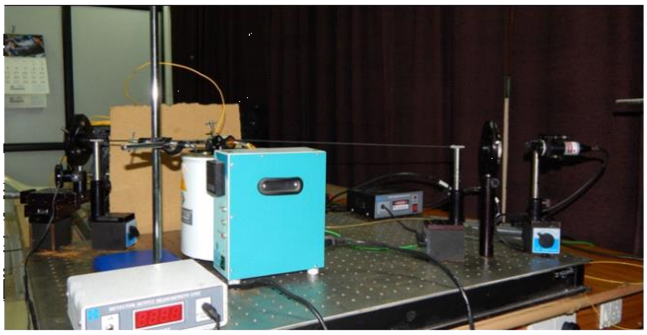

Fig.9 : Experimental setup for thermal treatment

Finally we observed that there was no significant impact of the vicinity temperature on the sensitivity of the sensor.

4. RESULTS AND DISCUSSIONS

4.1 Monitoring change in the sensor response for different bend radius of the fiber in the air medium

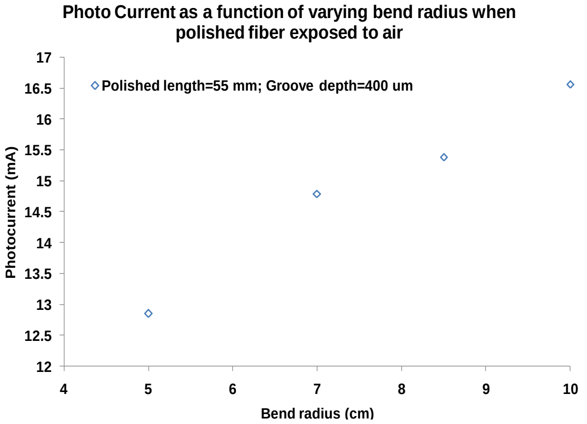

Fig.10: Photo current Vs Bend radius Graph

It is clear from the above figure that the photo current is dependent on ring bend radius. Observed that at bend radius of 5 cm we got minimum photo current is 12.9 mA. Hence at the bend radius of 5 cm effective light emitted from the sensor to interact with sensing environment eventually sensitivity will be increased.

4.2 Monitoring change in the sensor response for different groove depths of the fiber in the air medium

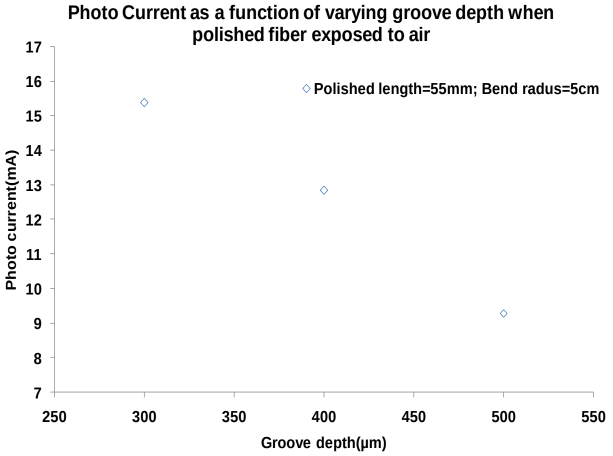

Fig.11: Photo current Vs Groove depth

Fig. 11 reveals that the groove depth and photocurrent were inversely proportional to each other. The groove depth of 500 µm given minimum photo current. It seems that the groove depth of 500 µm expels highest light leak out to interact with the external environment.

4.3 Monitoring the sensor response while Heating-Cooling treatment

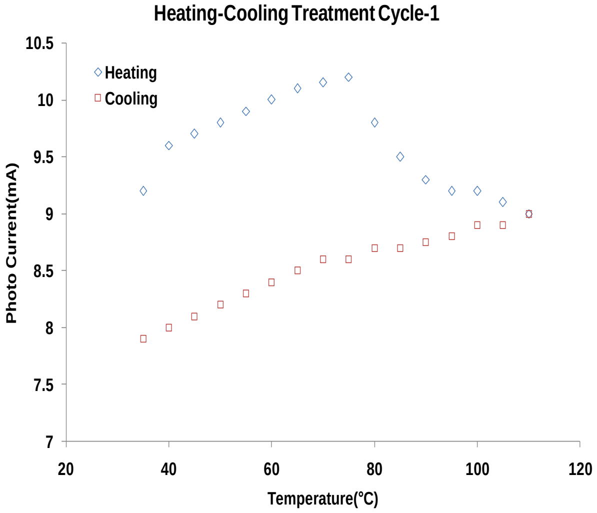

Fig.12: Monitoring the sensor response in Heating-cooling cycle-1

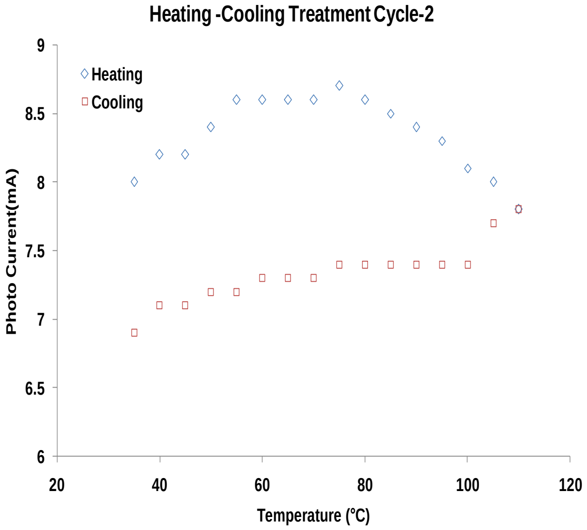

Fig.13: Monitoring the sensor response in Heating-cooling cycle-2

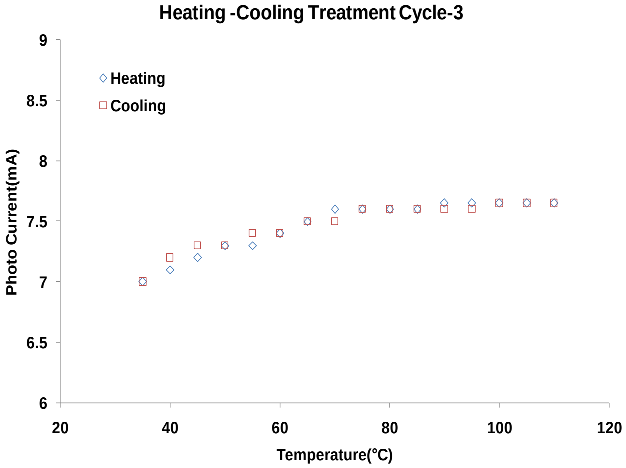

Fig.14: Monitoring the sensor response in Heating-cooling cycle-3

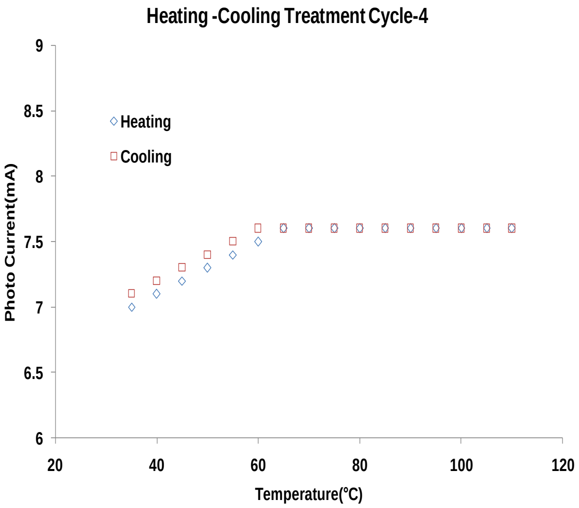

Fig.15: Monitoring the sensor response in Heating-cooling cycle-4

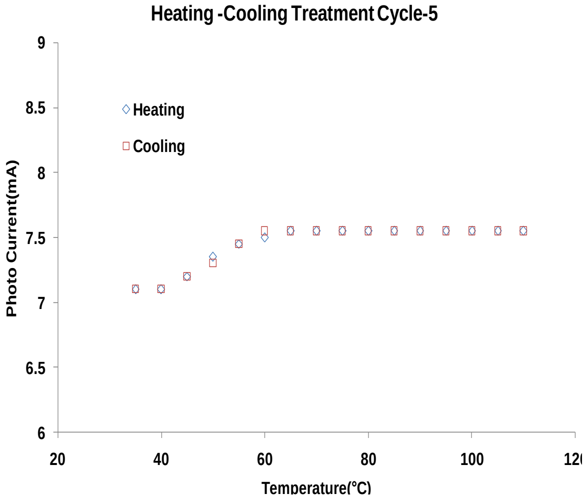

Fig.16: Monitoring the sensor response in Heating-cooling cycle-5

In the above figures the five cycles (fig. 12- 16) of heating-cooling treatment we have observed optical transmission in optical fiber. In the first cycle of heating-cooling treatment light has been increased by increasing temperature up to 70°C later it is decreased. Cycle by cycle the hysteresis in the sensor response has been reduced. At last in the fifth cycle of heating-cooling we have achieved the stable optical transmission through the polished fiber .

4.4 Comparisons between Normal fiber sensor and Thermal treated fiber sensor

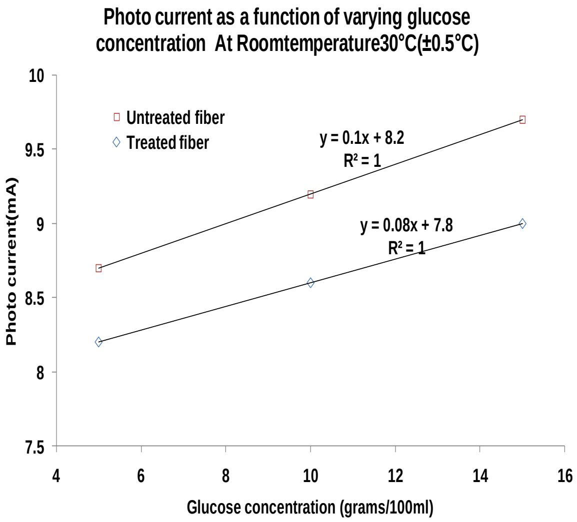

Fig.17: Photo current VS Glucose concentration

D. At Different temperatures

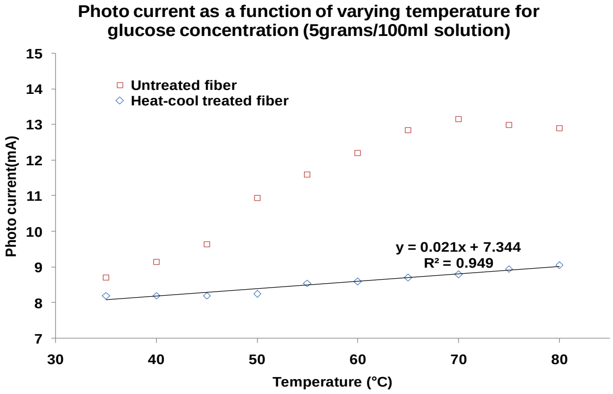

Fig.18: Monitoring for 5grams/100ml glucose solution

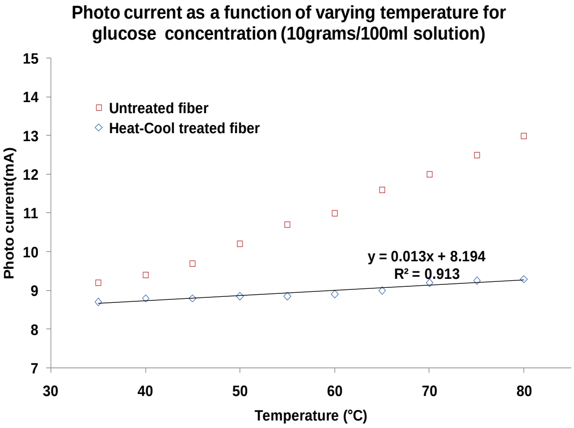

Fig.19: Monitoring for 10grams/100ml glucose solution

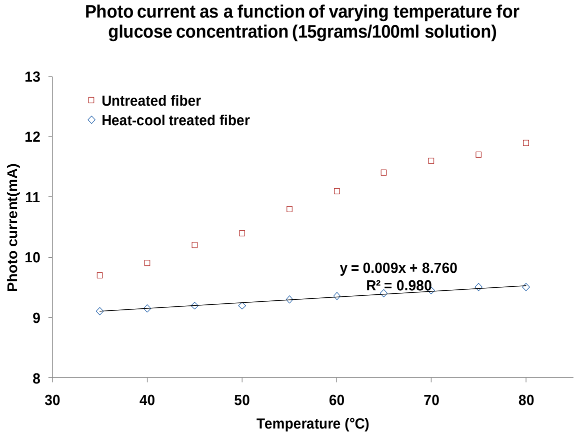

Fig.20: Monitoring for 15grams/100ml glucose solution

From the all above figures (fig. 17 to 20), we can find that first we have used normal side polished fiber sensor for sensing the glucose concentrations. At room temperature of 30°C(±0.5°C) the sensor response is good and linear, at different room temperatures we found that senor response is nonlinear. Later our fiber sensor subjected to five cycles of heating cooling treatment. Again, we have tested our thermal treated sensor for different concentration of glucose solutions. The response of the thermal treated senor is very good and linear at room temperature and different temperatures varied from 30 to 80 °C. We can clearly observe the responses of normal and thermal treated fiber sensors in the comparison graphs. The response of the thermal treated fiber sensors was optimal and linear at room temperature and at various temperatures for different glucose concentrations.

CONCLUSION

A low cost fiber optic evanescent wave sensor has been developed using manual side polishing technique. We have found temperature sensitivity, while measuring the concentrations and chemical composition of the aqueous solutions. Generally in this type of sensors the results were dependent on the surrounding temperature. In order to reduce the temperature dependency on the evanescent sensor response, the polymer optical fiber, jacketed in a PTFE tubing was subjected to several cycles of heating-cooling treatment in the temperature range of 30 to 110 °C. After the heating–cooling treatment of the fiber, the sensor response was again monitored for glucose solution concentrations of 5, 10 and 15grams per 100ml of de-ionized water. It was observed that there is a remarkable reduction in the temperature dependency on the evanescent wave sensor.

References

[1] P Suresh Kumar, C P G Vallabhan, V P N Nampoori, V N Sivasankara pillai and P Radhakrishnan “A fiber optic evanescent wave sensor used for the detection of trace nitrites in water” , J.Opt.A:Pure Appl.Opt. Vol 4 247-250(2002)

[2] Guanxiu Liu, Feng De-Jun, Liu Xi-Lu, Zhang Mao-Sen, and Jia Dong-Fang “D-Shaped Plastic Optical Fiber Sensor for Testing Refractive Index” IEEE SENSORS JOURNAL, VOL. 14, NO. 5, MAY 2014

[3] Xun Zhu, Nianbing Zhong,, Qiang Liao ,Yun Huang , Mingfu Zhao & Rong Chen “Temperature-independent polymer optical fiber evanescent wave sensor” Scientific Reports |5:11508 |DOI: 10.1038/ srep11508

[4] Argha Banerjee b, Sayak Mukherjee b, Rishi Kumar Verma c, Biman Jana d, Tapan Kumar Khand, “Fiber optic sensing of liquid refractive index” Sensors and Actuators B 123 (2007) 594–605

[5] Chenghua Sui, Pinghui Wu, and Gaoyao Wei “A Fiber Optic Evanescent Wave Sensor for Measuring Refractive Index Change of Liquids” PIERS Proceedings, Cambridge, USA, July 5-8, 2010

[6] A.A.Ehsan, S.Shaari, and M.K.A. Rahman, “Low cost 1X2 Acrylic based plastic optical fiber coupler with hollow taper waveguide,” PIERS, vol. 2, pp. 129–132, 2009.

[7] Y. Takezawa, S. Akasaka, S. Ohara, “Low excess losses in a branching plastic optical waveguide formed through injection molding,” Appl. Opt., vol. 33, no. 12, pp. 2307– 2312, 1994.

[8] W.Daum, J.Krauser, “Polymer Optical fibers for Data communication, (Springer, Berlin, Germany, 2002).

[9] Dae Geun Kim, Sae yoon woo, Dong kwan-kim and Seung Han park, “Fabrication and characteristics of Plastic optical fiber directional couplers”, Journal of the optical society of Korea, vol. 9, No.3, September 2005.

[10] A.A. Ehsan and S.Shaari, “Plastic optical fiber coupler with high index contrast waveguide taper”, Progress in electromagenetics research, vol. 20,125-138, 2011, Institute of Microengineering and Nanoelectronics Universtiti Kebangsaan Malaysia.

[11] Gravina, R., Testa, G. & Bernini, R. Perfluorinated plastic optical fiber tapers for evanescent wave sensing. Sensors 9, 10423– 10433 (2009)

[12] Merchant, D. F., Scully, P. J. & Schmitt, N. F. Chemical tapering of polymer optical fibre. Sensor. Actuat. A 76, 365–371 (1999).