Fiber optic coupler displacement sensor for detection of glucose concentration in distilled water.

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Submission date: 10-May-2019 07:40PM (UTC+0800)
Submission ID: 1128285125
File name: 9Yasin.pdf (502.13K)
Word count: 2254
Character count: 11467

Fiber optic coupler displacement sensor for detection of glucose concentration in distilled water

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A simple intensity modulated displacement sensor is demonstrated using a fused coupler as a probe for measuring glucose concentration in distilled water. It uses a plastic optical fiber (POF) based multimode fused coupler as a probe and a flat mirror as a reflector is captured by the same coupler. The light source is a He-Ne red laser (peak wavelength of 633 nm) which is chopped using a mechanical chopper. The reflected optical signal is detected by the silicon photodiode and the electrical signal is then fed into the lock-in amplifier together with the reference signal of the mechanical chopper. The fiber optic probe is first immersed in de-ionized water to measure the output voltage of a 0 % glucose concentration, followed by liquid with glucose concentrations from 5 % to 25 %. It is found that the peak voltage or the collected light intensity linearly related to the glucose concentration. The sensitivity is measured to be around 0.012 mV/(%) when the glucose concentration is varied from 0 to 25%. It is also observe that the slope of the displacement curve increases linearly with the glucose concentration at a rate of 0.0035 mV/(%)^2.

(Received January 30, 2016; accepted June 9, 2016)

Keywords: Fiber optic glucose sensor, Glucose in distilled water, Coupler probe, Intensity modulation detection

1. Introduction

Fiber optic sensors provides a great chance for developing of a variety of sensors for a wide range of applications [1–4]. A vast range of physical quantities can be sensed optically such as light intensity, vibration, temperature, pressure, calibration of accelerometers, strain, liquid level, pH, chemical analysis, concentration, density, refractive index of liquids etc [5]. Recently, various kinds of optical fiber sensors have been proposed for glucose measurement. For instance, study by non-invasive sensors is reported using polarimetric method to measure the glucose concentration of the aqueous humour of the human eye in vivo [6]. In another work, Yokota et al., [7] have measured glucose concentration of 0.01 g/dl using fiber Faraday rotator as the polarization modulator and or the polarization compensator.

Glucose detection is very important in diabetic patients and an integral part of pancreas with its controlled insulin release. Fiber optic sensors are commonly constructed from plastic multimode optical fibers, which benefit from low optical signal transmission loss, low cost, compact and compatibility with optical fiber technology. In our earlier work, a fiber-optic displacement sensor was proposed for measuring the refractive index of liquid [8]. In this paper a simple, rugged, low cost and very efficient intensity modulated fiber optic glucose sensor is demonstrated to detect the changes in concentration of the liquid. The sensor consists of a light source, a fused coupler fiber optic probe and a silicon detector. A red 633 nm light from He-Ne laser is launched into the coupler and directed to a region where the light interacts with the glucose liquid. This interaction results in a modulation of optical intensity and the modulated light is collected by the same optical probe and measured by a detection system. The characteristic of the displacement curve of the sensor is investigated for various concentrations of glucose in distilled water.

2. Experimental setup

The schematic diagram of the experimental set-up for sensing various concentrations of glucose in distilled water is shown in Fig. 1. It uses a plastic optical fiber (POF) based multimode fused coupler as a probe and a flat mirror as a reflector to provide the necessary reflection that will be captured by the same coupler. The light source used is a He-Ne red laser (peak wavelength of 633 nm) which is chopped using a mechanical chopper at 210 Hz to avoid the harmonics from the line frequency andreduce the interference of ambient stray light [9]. The reflected optical signal is detected by the silicon photodiode (818 SL, Newport) and the electrical signal is then fed into the lock-in amplifier (SR-510, Stanford Research System) together with the reference signal of the mechanical chopper. The output result from the lock-in amplifier is then connected to a computer through a RS232 port interface and the signals are processed using Delphi software. The flat mirror is fixed on a piezoelectric stage that can be moved with a 0.1 mm resolution.

The output light from the mechanical chopper is launched into port 1 of the fused coupler. The output powers at ports 3 and 4 are divided equally since the coupling ratio of coupler is 50:50. The light is then launched into the glucose solution via port 3 while port 4 of the coupler can be used to monitor the launched light intensity. The reflected light from the mirror is reflected back to enter the same port of the coupler before the collected light intensity is split equally and routed to port 2 as output. The output light is then sent into the silicon photodetector which is connected to the lock-in amplifier for processing. In this experiment, the displacement of the mirror is done in steps of 50 μm. The fiber optic probe was first immersed in de-ionized water to measure the output voltage of a 0 % glucose concentration, followed by liquid with glucose concentrations from 5 % to 25 %. The measurements were carried out for glucose solutions (Merck KGaA Darmstadt, Germany) with concentrations of 2.5, 5.0, 7.5, 10 and 12.5 g per 50 ml of de-ionized water. During the experiment, the error due to this temperature variation is negligible [10] as the temperature is kept constant at 25°C.

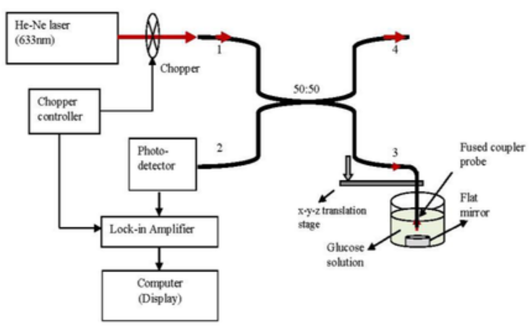

Fig. 1. Experimental setup of FODS for glucose detection using fused coupler

3. Results and discussions

Fig. 2 shows the output voltage characteristic of the proposed sensor against displacement within a range up to 5 mm. The sensor output curve (i.e., light intensity versus distance to flat surface target) indicates only one slope instead of two slopes in the case of bundle fiber [11]. The front slope disappears in this sensor because the transmitting and receiving of light occurs through the same fiber of the coupler. When the gap between the fiber tip and the mirror is zero, the fiber receives the maximum light and thus the measured intensity of the reflected light is the highest at this point as shown in Fig. 2. However, the measured intensity of the reflected light decreases almost linearly with the gap distance especially for close distance target. Theoretically, the distance and the reflected power vary according to the inverse square law, where the output transmission function is given by

$$\frac{P_r}{P_t} = \frac{d^2}{(2x\tan\theta)^2} \qquad (1)$$

Where P_r, P_t, d, x, and θ are the reflected power, transmitted power, core diameter, axial displacement and fiber's acceptance angle, respectively. As shown in Fig. 2, the displacement curve has a slope sensitivity of 0.003 mV/μm with good linearity of more than 99% within the range of 1.2 mm. The highest resolution of approximately 1 μm is also observed. The stability of the displacement sensor is also investigated and the measurement errors are observed to be less than 0.5%for this sensor.

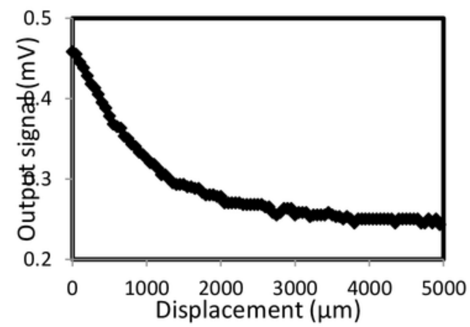

Fig. 2. The Output signal of the sensor as function of displacement

Fig. 3 shows the reflected light intensity versus distance of the reflecting target from the fiber optic probe at various glucose concentrations. In the experiment, the glucose concentration is varied from 0 to 12.5 g per 50 ml of distilled water. As expected, the voltage is highest at zero displacement and the displacements of the receiving fiber away from the flat mirror resulted in a reduced output voltage. The output voltage starts to decrease as the receiving fiber is moved away from the target due to the size of the light cone, which increases with the displacement. The power density decreases with increment in the size of the light cone and thus the reflected light intensity, which was measured in term of output voltage, decreases with the displacement. The voltage power at the zero displacement of the curve in Fig. 3 is observed to increase with the concentration of glucose in the de-ionized water. This indicates that the mode coupling with the receiving fiber improves as glucose concentration increases. The variation or modulation of the received light intensity is due to the change of the immersion concentration, which actually changes the emitting and acceptable angle of the fiber probe. The performance of the sensor is summarized in Table 1. The sensitivity can be found from the slope of the curve and obtained at 0.012 mV/% with a good linearity more than 95%. The resolution for the sensor is 2.5% and is sufficiently stable with a standard deviation of 0.016-0.030 mV.

Inset of Fig. 3 shows the variation of peak voltage (maximum voltage at zero displacement) with increasing concentration of glucose. As seen, it is found that the peak voltage increases linearly with the glucose concentration at a rate of 0.012 mV/(%). This is attributed to the refractive index, which proportionally increases with glucose concentration. The increase of refractive index reduces the acceptance angle cone of the fiber-optic probe and the light intensity received by the receiving fiber due to the reduced acceptance angle cone. The glucose concentration fiber optic has a measured error of less than 0.51% and the results are repeatable more than six times to get an average.

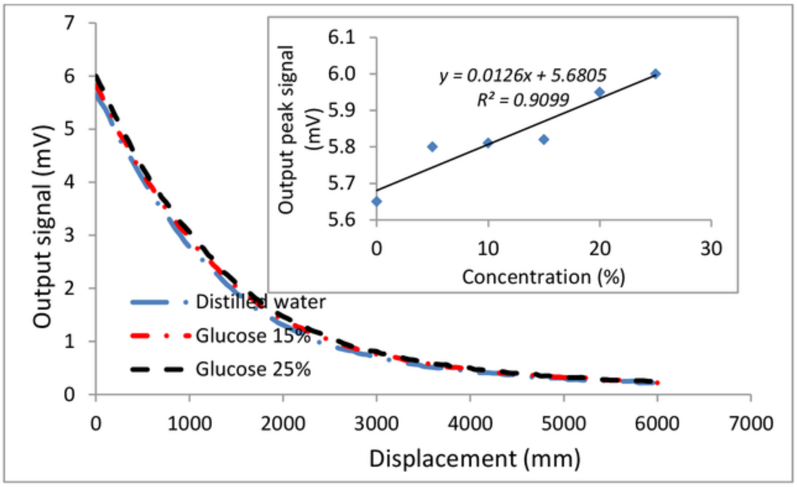

Fig. 3. The output signal as function of the displacement at various glucose solutions. Inset shows the output peak signal versus glucose concentration

Table 1. The performance of FODS for the glucose detection

Parameter	Value
Sensitivity (mV/%)	0.012
Linearity (%)	More than 95
Stability (mV)	0.016-0.030
Resolution (%)	2.5

The performance of the proposed glucose sensor is also investigated based on the slope analysis of the displacement curves. The slope of the displacement curve within the range from 2350 nm to 3000 nm is measured for various glucose concentrations and the result is presented in Fig 4. It is found that the slope increases linearly with the glucose concentration at a rate of 0.0035 mV/(%)^2. This shows that the peak voltage based analysis is more sensitive than slope based analysis. The resolution is obtained at around 2.5% with the peak voltage measurement approach.

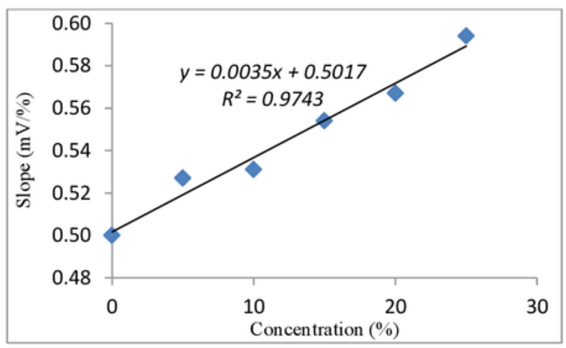

Fig. 4. The slope of displacement curve against the glucose concentration

4. Conclusion

A simple intensity modulated displacement sensor using fused coupler is proposed and investigated for sensing the concentration of glucose in distilled water. For a concentration change of glucose from 0 to 25% in distilled water, the peak light intensity increases linearly with the concentration due to the increased of the refractive index of the liquid. The measured sensitivity and resolution are at around 0.012 mV/(%) and 2.5%, respectively. The stability, high sensitivity and simplicity of the sensor make it suitable for chemical, pharmaceutical, biomedical and process control sensing applications.

Acknowledgement

The authors like to express their thanks to Indonesian Directorate General of Higher Education (*DGHE or DIKTI*) through Desentralisasi Research Grant Airlangga University (2014-2015). The authors thank to Prof. Noriah Abidin (Head of Laser Research Group, Universiti Teknologi Malaysia, Malaysia) and Prof. Sulaiman W. Harun (PRC, Univ. of Malaya, Kuala Lumpur, Malaysia) for many discussions and collaboration.

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