Fiber optic displacement sensor for measurement of glucose concentration in distilled water

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A simple intensity modulated displacement sensor is proposed and demonstrated 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 and its position increases linearly with the concentration due to the increased of the refractive index of the liquid. The measured sensitivities are obtained at around 0.0103 mV/(%) and 0.0229 mm/(%) for the peak voltage and position changes respectively. The stability, high sensitivity and simplicity of the sensor make it suitable for chemical, pharmaceutical, biomedical and process control sensing applications.

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1. Introduction

Fiber optic technology offers the possibility for developing of a variety of sensors for a wide range of applications [1–4]. A vast range of properties 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, the needs for ever more sensitive and reliable sensors are required to measure a large range of physical, chemical and biomedical quantities. 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. There are also certain reports on the study by non-invasive sensors using polarimetric method to measure the glucose concentration of the aqueous humour of the human eye in vivo [6]. M. Yokota et al. [7] have measured glucose concentration with a resolution of 0.01 g/dl using fiber Faraday rotator as the polarization modulator and or the polarization compensator.

Glucose control is of vital importance in diabetic patients, and therefore a glucose sensor is an integral part of an artificial pancreas with can controlled the insulin release. 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 bundled fiber optic probe and a silicon detector. A yellow 594 nm light from He-Ne laser is launched into the fiber and directed to a region where the light interacts with the glucose liquid. This interaction results in a modulation of optical intensity and modulated light is collected by the another optical fiber and measured by a detection system. The probe has been optimized and successfully experimented for sensing the variation of concentration of glucose in distilled water.

2. Experimental setup

The schematic experimental set-up for sensing the variation of concentration of glucose liquid solutions is shown in Fig. 1. The set-up consists of a fiber optic transmitter, fiber optic probe, reflective flat mirror, photodiode, lock-in amplifier and a computer. The fiber optic probe consists of two 2m long PMMA (polymethyl methacrylate) which consists of one transmitting core of 1 mm in diameter and 16 receiving cores of 0.25 mm in diameter, numerical aperture 0.5, core refractive index 1.492 and cladding refractive index 1.402. The light from a He-Ne laser (λ=594 nm) is coupled into a transmitting fiber and is emitted at the end of the bundle fiber to the flat mirror. The reflected light is then collected by the receiving fiber and transmitted to the photodiode. The laser provides an average output power 3.0mW, beam diameter 0.75mm and beam divergence 0.92 mRads. The photodiode (818 SL, Newport) is a high speed photodiode detector housed in a "connector-less" style plastic fiber optic package. Optical response of silicon detector extends from 400 to 1100 nm, making it compatible with a wide range of visible. This includes 594 nm visible yellow He-Ne laser used for optimum transmission in PMMA plastic optic fiber.

The displacement of the fiber optic probe is achieved by mounting it on a piezoelectric-meter, which is rigidly attached to a vibration free table. The fiber optic probe is immersed into the measuring liquid (solutions of glucose in distilled water). Light from the fiber optic transmitter (peak wavelength at 594 nm) is coupled into the transmitting fiber. The signal from the receiving fiber is measured by moving the probe away from the zero point, where the reflective surface and the probe are in close contact. The light source is modulated externally by a chopper with a frequency of 200 Hz and is used in conjunction with lock-in amplifier to reduce the dc drift and the interference of ambient stray light. The signal from the detector is converted to voltage and is measured by a lock-in amplifier (SR 510, Stanford Research System). The fiber optic probe is first immersed in distilled water; the output intensity is measured by changing the position of the fiber optic probe from 0 to 10 mm in a step of 50 μm. The measurements are 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 distilled water. During the experiment, the error due to this temperature variation is negligible [8] and the temperature is kept constant at 25°C.

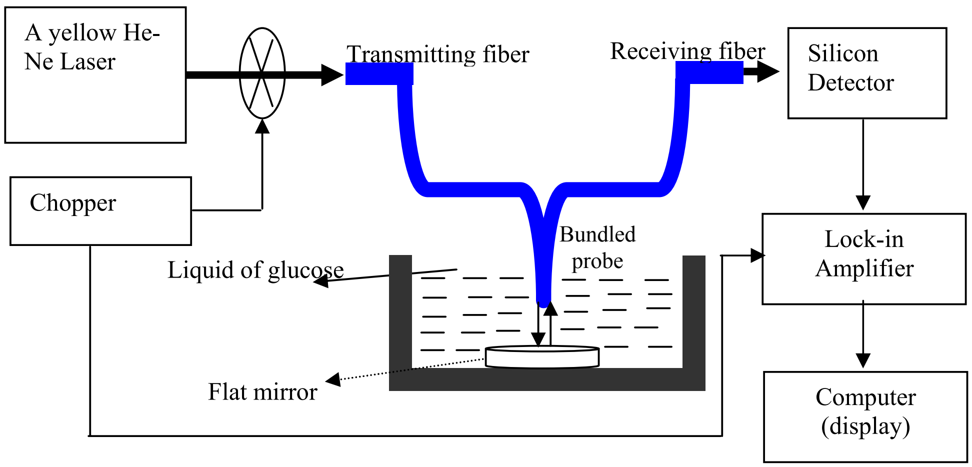

Fig. 1. Schematic experimental setup for sensing the variation of glucose concentration.

3. Results and discussion

Fig. 2 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. The displacement curves exhibit a maximum with a steep front slope while the back slope follows an almost inverse square law relationship. The signal is zero at small distances, because the light cone does not reach the receiving fiber. When the displacement is increased, the size of the reflected cone of light at the plane of the fibers increases and starts overlapping with the core of the receiving fiber leading to a small detected output. Further increase in the displacement leads to large overlapping resulting in rapid increase in the output and reaches a maximum. The output after reaching the maximum starts decreasing for larger displacements due to large increase in the size of the light cone as the power density decreases with increase in the size of the cone of light. The shift in the peak of the curve in Fig. 2 denotes enhanced mode coupling with the receiving fiber with respect to the increase in concentration. It is seen that when the concentration increases, the peak voltage value increases and moving forwards the left. 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 angles of the two fibers. The performance of the sensor is summarized as given in Table 1. As shown in the table, front and back slopes sensitivity and linear range are observed to be random for different glucose concentration.

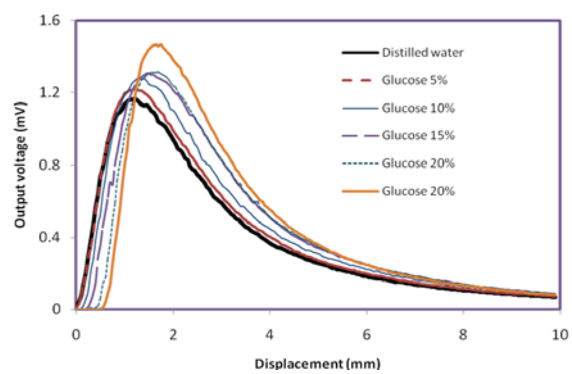

Fig. 2. The output voltage as function of the displacement at various glucose concentrations in distilled water.

Fig. 3 shows the variation of peak voltage and its position with increasing concentration of glucose. In the present investigation, it is found that the peak voltage is increases linearly with the glucose concentration at a rate of 0.0103mV/(%), this is far the case when the glucose concentration is varied from 0 to 25%. The peak voltage position also increases linearly with concentration as shown in Fig. 3. From the experimental results it can be concluded that as the glucose concentration increases, the refractive index also increases proportionally. This in turn increases the signals received in the receiving fiber due to the reduced acceptance angle cone. The glucose concentration fiber optic has a measured error of less than 0.6% and the results are repeatable as measured and investigated in this setup. This finding may be quite useful for chemical, pharmaceutical, biomedical and process control sensing applications.

Table 1. The performance of the fiber optic displacement as glucose sensor fiber optic sensor.

Glucose (%)	Position of peak voltage (mm)	Peak voltage (mV)	Front slope		Back slope	
			Sensitivity (mV/mm)	Linear range (mm)	Sensitivity (mV/mm)	Linear range (mm)
0	1.20	1.167	1.57	0.60 (0.1-0.7)	0,34	2.1 (1.5-3.6)
5	1.20	1.223	1.53	0.7 (0.1-0.8)	0.35	2.15 (1.45-3.6)
10	1.30	1.283	1.60	0.7 (0.2-0.9)	0.34	2.2 (1.8-4.0)
15	1.45	1.305	1.46	0.8 (0.3-1.3)	0.35	2.2 (2.1-4.3)
20	1.65	1.315	1.65	0.75 (0.5-1.25)	0.35	2.45 (1.90-4.35)
25	1.70	1.467	1.86	0.8 (0.6-1.4)	0.42	2.1 (2.1-4.2)

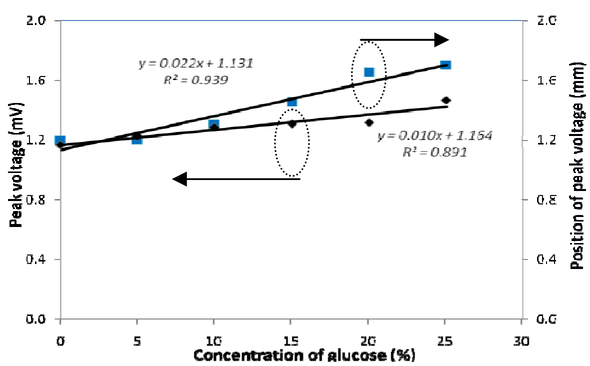

Fig. 3. Variations of peak voltage and its position with increased concentration of glucose in distilled water.

4. Conclusions

A simple intensity modulated displacement sensor is demonstrated as a device to detect glucose concentration in distilled water. The displacement curves exhibit a maximum with a steep front slope while the back slope follows an almost inverse square law relationship in this sensor. The experimental results show that the peak voltage or light intensity and its position are increases linearly with the glucose concentration. The sensitivity is measured to be around 0.0103mV/(%) when the glucose concentration is varied from 0 to 25%. This finding may be quite useful for many applications especially in biomedical sensor such as detecting sugar concentration in bottled drinks.

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