

Evanescent Wave Absorption Based Fiber Sensor for Measuring Glucose Solution Concentration

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Abstract. An optical fiber sensor based on evanescent wave absorption designed for measuring glucose solution concentration was proposed. The sensor was made to detect absorbance of various wavelength in the glucose solution. The sensing element was fabricated by side polishing of multimode polymer optical fiber to form a D-shape. The sensing element was immersed in different concentration of glucose solution. As light propagated through the optical fiber, the evanescent wave interacted with the glucose solution. Light was absorbed by the glucose solution. The larger concentration the glucose solution has, the more the evanescent wave was absorbed in particular wavelength. Here in this paper, light absorption as function of glucose concentration was measured as function of wavelength (the color of LED). We have shown that the proposed sensor can demonstrated an increase of light absorption as function of glucose concentration.

Keywords: Evanescent wave, fiber sensor, glucose solution concentration measurement.

1. Introduction

Glucose is a simple types of sugar that can be found in many aspect of life. This substance has molecular formula of $C_6H_{12}O_6$ and can be dissolved in the water because of its polarity. In human and animal body, glucose circulates trough the blood vessel as a blood sugar and the body keeps it up to a certain level for metabolic homeostatis. In food industries, many types of sugar were used to give flavor. We can say that measurement of glucose concentration will accelerate the technology development in industrial aspect and medical research.

For many decades, glucose concentration measurement has been an interesting subject of research. Many methods have been developed utilizing different glucose properties (e.g., those based on chemical reaction and biochemical-sensors). Two examples of the chemical methods used to detect glucose concentration are copper-iodometric glucose and enzyme method. The first method uses copper as a titration for glucose reduction. In the other hand, enzymatic methods were usually combined with biochemical sensors, utilize the change of electrical properties which happens because of the enzyme reacted with the sample. The electrical properties of a compound change whenever a reaction that produce or consumes electron occur. This kind of reaction were often catalyzed by redox enzymes [1].

Other glucose detection method that uses enzyme is ampere-metric glucose sensor based on dehydrogenase enzymes. In this case, glucose is reacted with the dehydrogenase enzymes to produce an electro-active substrate. The produced substance is then detected by the sensor in the form of a current change [2]. Other chemical reaction used to detect glucose is Maillard reaction which detect the product using the change in Fluorescence intensity [3]. In this work, glucose concentration



measurement using evanescence field based optical fiber sensor is proposed. The field will interact with the glucose obeying Beer-Lambert's law [4]. The leak field out of the core can be imagined as tunneling effect on quantum mechanics [5]. In fact, the optical fiber sensor utilizing evanescent wave phenomenon [6] have been widely used for chemical detections with many different modifications [6-12].

2. Material and Methods

Glucose ($C_6H_{12}O_6$) solutions were made with different concentrations (0.1 – 0.6 M). This maximum value of the glucose concentration (0.6 M) was taken by considering that this value corresponded to the refractive index of the polymer optical fiber (POF) used in this experiment. The refractive index of the fiber core is 1.49 and its cladding is 1.42. In order to create an evanescent field based fiber sensor, POF with 0.5 mm in diameter and the length of 8.0 cm was partially polished to the depth of 0.10 mm to form a D-shape.

Figure 1 is the experimental setup used in this experiment. Absorption of light passing through this sensing area was carried out by launching the light (i.e., LED with different color) from one end the fiber and the output light was then detected by a photo detector. Experiments were carried out by covering the sensing area with different glucose concentrations at room temperature.

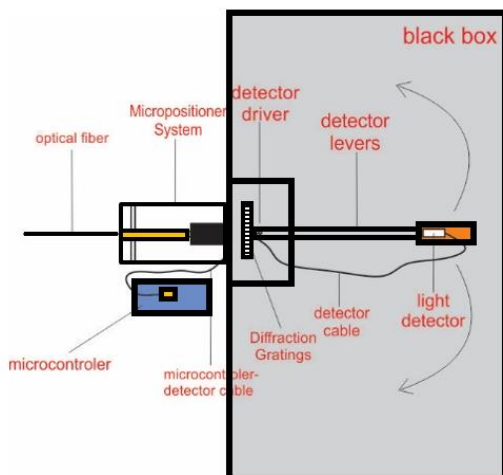


Figure 1. Experimental setup of optical fiber based spectrophotometer used in this experiment

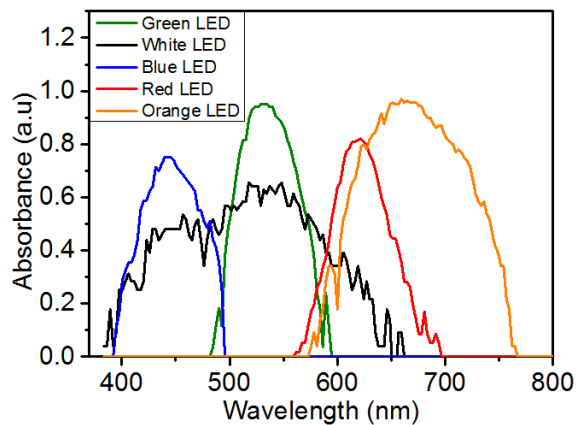


Figure 2: Spectral absorbance from various Light source (for 0.1 M solution).

3. Results and Discussion

Figure 2 shows the output light detected for different color of LED at which the sensing area was covered with 0.1 M glucose. All light spectra as shown were obtained by dividing the output light of glucose covered fiber sensing area by that before being covered. Strong absorption at 626 nm is typical absorption of glucose as has been recorded using UV-VIS-NIR spectrophotometer.

Figure 3 shows the output light from red LED detected by photo-detector as the sensing area was covered by different concentration of glucose. From figure 4, the trend of increase was also observed for other light sources (especially for red and orange LED). Repetition of the experiment showed almost the same results (Figure 5). It is clearly seen that absorption increases (the output voltage decreases) as the glucose concentration increases. This result can be understood from the frame of Maxwell-Boltzmann particles distribution (N_i) over various micro-states or energy levels (ϵ_i) at a temperature T as expressed by equation:

$$N_i = \frac{N \cdot \exp\left(-\frac{\epsilon_i}{kT}\right)}{\sum_j \exp\left(-\frac{\epsilon_j}{kT}\right)} \quad (1)$$

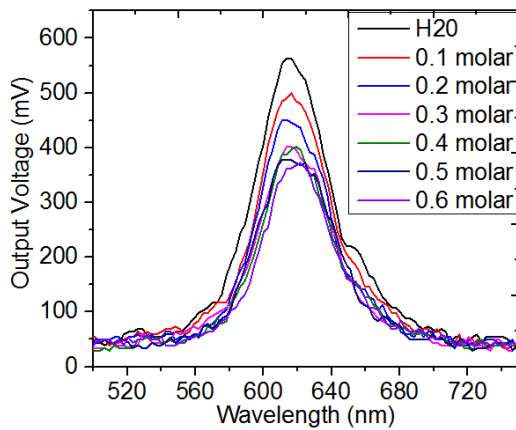


Figure 3: Intensity of light in the wavelength peak of Red LED in various glucose concentration

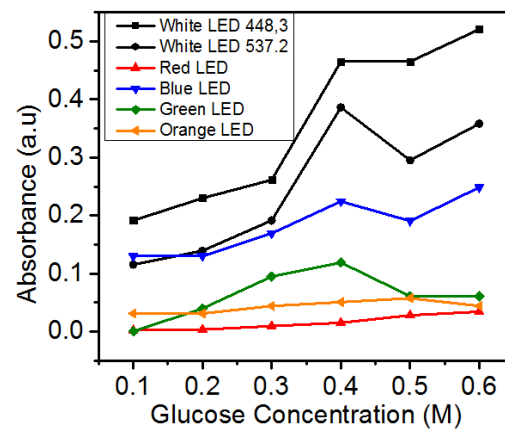


Figure 4: Absorbance as a function of glucose concentration.

where i and j are indices of a single particle micro-states while N and k are the total number of particles in the system and Boltzmann constant, respectively. As the number of particles in the system (N) increases, i.e., glucose concentration increases, the possible number of particles that can absorb a photon energy ε_i in order to be in an energy level ε_i is also increased.

Figure 4 indicates that an increase of glucose concentration results in a linear increase of their refractive index. Taking the relationship between the cladding (glucose covering the D-shape fiber sensor) refractive index (n_{Gl}) and the penetration depth (d_λ) of evanescent field at a wavelength λ as

$$d_\lambda = \frac{\lambda}{2\pi\sqrt{n_c^2 \sin^2 \theta - n_{Gl}^2}} \quad (2)$$

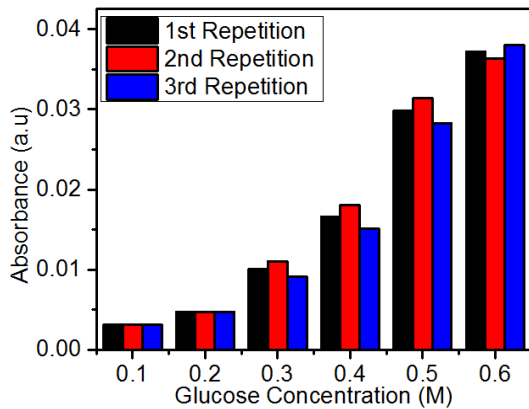


Figure 5: Repeatability of absorbance measurement of light coming out of the fiber as function of glucose concentrations.

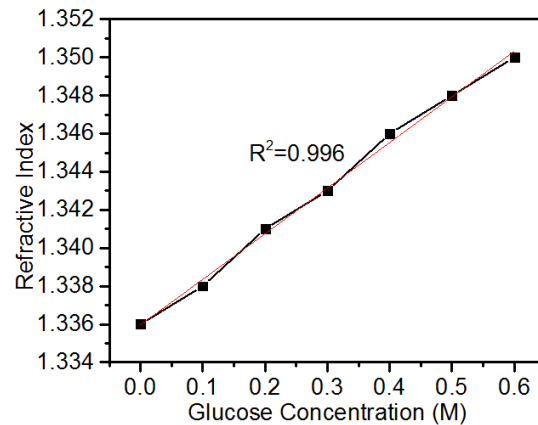


Figure 6: Refractive index of glucose with various concentrations

where θ is incident angle and n_c is refractive index of the core, It can be seen that the increase of the cladding refractive index (glucose concentration) will result in an increase in penetration depth or portion of light travelling in glucose. As absorbance (A) and glucose concentration (c_{Gl}) is related by

$$A = \alpha c \epsilon \quad (2)$$

where α and ϵ are absorption coefficient and molar absorptivity, respectively; it can be seen that the increasing glucose concentration as well as the absorption coefficient will lead to an increase of absorbance. Stated in Beer-Lambert law relationship,

$$I_{t-Gl} = I_{0-Gl} \cdot \exp(-\alpha x) \quad (3)$$

Increasing the absorption coefficient will finally reduce the out-coming light passing through the cladding detected by the photo-detector from I_{0-Gl} to I_{t-Gl} .

4. Conclusion

A fiber sensor based on evanescent field absorption made by side polishing that used to measure glucose concentration have been fabricated and their performance have been demonstrated. The sensor was made by side polishing in such a way that cladding at certain portion of fiber was removed. We have shown that light absorption increased with the increase of glucose concentration measured with different color of LED (wavelength). as function of glucose concentration was measured as function of wavelength (the color of LED). We have shown that the proposed sensor can demonstrated an increase of light absorption as function of glucose concentration.

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