Simple Glucose Measurement System Based on Uncladded Fiber Bragg Grating Etched with Nitric Acid

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Abstract. The demand for a non-invasive, fast, and accurate glucose detection for diabetic patients is increasing nowadays. It is predicted that diabetic patient will increase from 415 million people at 2018 to 640 million people at 2050. Glucose is also present in saliva, therefore glucose concentration measurement in saliva can be an alternative way during diabetics monitoring. In this study, we measure 0-60% glucose concentration through optical systems. The optical system consists of an erbium-doped fiber laser, uncladded fiber bragg gratings that have been etched with nitric acid (HNO3), and optical spectrum analyser (OSA). The measured parameter is a Bragg wavelength shift due to changes in glucose solution concentration. The results show that the wavelength shifts to lower value (blue shift) as the glucose concentration increases. The sensitivity obtained from this measurement system is 1.2 pm/% in glucose solution. This result is a preliminary study to detect glucose concentration in saliva based on Fiber Bragg Grating which has advantages for diabetic patients such as simple setup, non-invasive, fast, and low cost.

1. Introduction
It is estimated that the number of adults suffering from diabetes mellitus in the world at 2018 reaches 415 million people [1]. The number of diabetic patients will continue to increase, in 2040 it is predicted that more than 640 million people will suffer from a disease called “the silent killer” [2]. Called as the silent killer because diabetes mellitus can affect all organs of the body and trigger various other diseases such as wounds that difficult to heal, lung infections, and strokes [3].

A method that widely used for early detection and monitoring of diabetes is through measuring glucose levels in the blood. However, in practice, measurement of glucose levels must be done by piercing the patient’s finger several times a day (invasive) which can cause temporary discomfort, bruising, and infection [4]. Beside blood, biomarker containing glucose are saliva [5,6]. Saliva can be easily obtained from patients (non-invasive) and will reduce discomfort during glucose levels checking. Some well-established technologies used in measuring glucose levels in saliva such as Liquid Chromatography - Mass Spectrometry (LC-MS) [7] and UV-VIS Spectrophotometry [8]. Measurements of saliva glucose levels using these two technologies are relatively complex and complicated, therefore they can only be used in the laboratory. Furthermore, the process requires considerable time, expensive reagents, and need highly trained operators. As a result, this technology cannot be used to monitor glucose levels at home and portable.

In terms of measuring glucose levels, optical sensors are superior to electrical sensors because their sensitivity is higher, lighter, and smaller [9]. Fiber Bragg Grating (FBG) has been used as an optical glucose-based sensor and shows high sensitivity, fast response time, and a wide measurement range [10,11]. However, the structure of the FBG that has been used must be in the form of a D-shaped fiber so that it requires complex fabrication and is very prone to broken. In this study, the fabrication and
characterization of uncladded standard FBG was etched by nitric acid solution. The performance of the proposed sensor was analysed in terms of sensitivity and stability. All the experiments were performed in room temperature.

2. **Theory**

The single mode FBG is designed to work in telecommunication wavelengths, where a single wavelength termed by center wavelength or Bragg wavelength is reflected back \[12\]. The center wavelength of the FBG’s reflection band \(\lambda_B\) given in Eq. (1) where \(\Lambda\) is period of the Bragg grating and \(n_{\text{eff}}\) is the effective refractive index. The effective refractive index is the combination of the refractive index of the core and cladding.

\[
\lambda_B = \frac{2 \cdot n_{\text{eff}} \cdot \Lambda_B}{n_{\text{eff}} \cdot \Lambda}
\]

When the cladding was removed and introduced to medium (analytes), the effective index will experience some discrepancy, causing a shift in the reflected wavelength. Due to total internal reflection between the cladding and the surrounding medium, the light could not escape out of the fiber, though is guided back to the core of the fiber. Total internal reflection (TIR) between the cladding and the surrounding produces an evanescent wave that be the basis for the sensing potential of a Fiber Bragg Grating based sensor. The penetration depth \(d_p\) of the evanescent wave at the core-analytes interface is given in Eq. (2)[13].

\[
d_p = \frac{1}{2\pi \left( n_{\text{eff}}^2 \sin^2 \theta - n_{\text{analytes}}^2 \right)^{1/2}} = \frac{\lambda}{2\pi \left( n_{\text{eff}}^2 \sin^2 \theta - n_{\text{analytes}}^2 \right)^{1/2}}
\]

The bragg grating affect the effective index, therefore change penetration depth of the evanescent wave into the surrounding.

3. **Experimental Details**

3.1. **Preparation of Sensing Element**

Standard FBG with 1554 nm central wavelength and reflectivity > 90% purchased from Beijing Samyon Instruments were used as the main part of glucose sensing device. D(+) Glucose anhydrous, deionized water, isopropyl alcohol, and nitric acid purchased from SAP chemicals, Indonesia. The polymer coating of FBG was removed using nitric acid \(\text{(HNO}_3\text{)}\) 65% by immersing the Bragg grating part of the fiber into a glass beaker for 15 minutes until polymer coating look slightly yellowed. It should be noted that extra care must be taken because bragg grating part is very fragile. The FBG was lifted from the acid then FBG cladding removed manually with a fiber stripper. The exposed part over the FBG is cleaned with isopropyl alcohol.

3.2. **Characterization**

The experimental arrangement used for the glucose concentration sensing is shown in Fig 1. Homemade erbium doped fiber laser operated at central wavelength 1550 nm with laser diode (THORLABS, 980 nm) pumping was used for the light source. The ends of the prepared FBG were attached to the light source and Optical Spectrum Analyzer (OSA, Anritsu MS9740A). Light from source was coupled into one end of the prepared FBG and the other end was coupled with an OSA to record the wavelength shift.

![Figure 1. Experimental setup for sugar concentration detection based on Fiber Bragg Grating](image)
During each measurement, petri dish contains 15 ml volume of various glucose concentration that dissolved in deionized water (wt%) is introduced into the FBG-sensing portion and real-time wavelength shift were monitored. Wavelength shift were acquired after 100 s of exposure to each glucose solution [14]. The wavelength shift was recorded for each concentration of glucose in solution. Aqueous samples of glucose with concentration varying from 0% to 60% (prepared in our laboratory) in increments of 10% sugar concentration were used to study the response of sensor toward glucose.

4. Results and Discussion

4.1. Sensing Response

Figure 2. illustrates the wavelength shift of glucose solution at various concentration measured using uncladded FBG after etched with nitric acid. As the glucose concentration increase, the center wavelength starts shifting to the lower wavelength (blue shift). Meanwhile the normal FBG (with cladding) did not show any wavelength shift. At 0% glucose concentration (only deionized water), the center of the wavelength is 1550.0708 nm. Figure 2 (b) shows that the proposed sensor response to glucose concentration is linear in the range 0 - 60% and has a line equation $y = -0.12x + 1550.07$ and the value of $R^2 = 0.99$, $R^2 = 0.99$. Based on this performance, the sensitivity of the proposed sensor can be calculated which is equal to 1.2 pm/% in the measurement range of 0 - 60% glucose concentration.

![Figure 2](image)

**Figure 2.** Result of glucose measurement using the proposed sensor (a) Wavelength spectrum analyzed by Optical Spectrum Analyzer (b) Center wavelength shifted based on different glucose concentration

![Figure 3](image)

**Figure 3.** Plot of glucose refractive index to the transmitted wavelength center of FBG
Shifting the center of the wavelength to a smaller value is caused by changes in the refractive index of various glucose solutions. Based on study done by [6], the higher the concentration of glucose, the greater the refractive index. The refractive index change will change the effective refractive index of the FBG and cause changes in the center of the wavelength as formulated by Eq. (1). The greater the effective refractive index, the bigger the center value of the reflection wavelength and the smaller the value of the transmission wavelength. The plot of the effect of the refractive index of glucose at different concentration provided by using the data in [15] to the shift in the transmitted center wavelength is shown in Figure 3.

4.2. Sensor Stability
The cost of the sensor is decided by manufacturing expenses and its repeated use. The repeated use may decrease the cost per use. The stability of the proposed sensor was tested by measuring response toward glucose of concentration 30% for 4 days. The response of the sensor is shown in Fig. 4. Sensor has shown approximately similar response for 4 days consecutively. The results obtained indicate that the sensor has good stability in measurement.

![Figure 4. Stability curve of proposed sensor measured for 30% sugar concentration](image)

5. Conclusion
In this report, the fabrication and characterization of glucose sensor based etched Fiber Bragg Grating has been presented. The sensor response was studied by exploring the wavelength shift properties at various glucose solution concentration (wt %). The FBG was etched with nitric acid solution, hence providing simple sensor fabrication. The proposed sensor showed good results for both high and low concentrations of sugar and has sensitivity 1.2 pm/% in glucose solution due to refractive index change of glucose solution. The stability of the sensor for 4 days is adequate. This result is a preliminary study to detect glucose concentration in saliva based on Fiber Bragg Grating which has advantages for diabetic patients such as simple setup, non-invasive, fast, and low cost.

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