

Laser Biosensor For The Detection of The Human Blood Hemoglobin Concentration

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Abstract--High-sensitivity laser-based sensors have attracted much interesting for their significant applications in biological applications. In this work, the concept of laser-based detector fabricated by using optical fiber for detection of the hemoglobin concentration in the human blood was proposed. The laser biosensor is based on Mach-Zehnder interferometer (MZI) (micro-holes collapsing) which exhibits high sensitivity changing in the hemoglobin concentration of the blood sample. This sensor measures the reduction in the intensity of light from the laser source. By using this sensor, two drops of human blood sample are sufficient to detect the concentration of the hemoglobin. Green laser with wavelength of 532 nm and input power of 12.2 mW has been used. A calibration curve between the absorbance of the green laser by the blood sample and the hemoglobin concentration was obtained to find the hemoglobin concentration for any blood sample which has the refractive index in the range between (1.34117-1.35192). The sensitivity was 20.772 ABS/ (gm/dl) for hemoglobin concentrations in the range of (8.2-13.3) gm/dl.

Keywords—Laser biosensor, Photonic crystal Fiber (PCF), Hemoglobin concentration, Anemia.

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I. Introduction

Bio sensing is a procedure which gets selected information about biological molecular structure. It has been significantly studied and widely utilized in different applications from general healthy and environmental control to homeland safeness and food safety. Based on the Web of Knowledge, a great number of articles about biosensors have been printed each year for the recent years. Though a lot of research activity has been involved in

developing biosensors for make it commercially available [1].

A wide variety of applications used laser in all walks of life as a good tool for high precision measurement. Laser has an important role in biological, communication, material processing, and chemistry applications [2].

Since the invention of the laser, many attempts have been made to apply this instrument in medicine and biology [3]. Although laser has traditionally been used in medicine as therapeutic devices, there has been an interest in using them as diagnostic tools [4]. Laser biosensor components are manufacturing yields less expensive, more precise, and more accurate [5]. Large mode area (LMA) PCF is a type of an optical fiber [6]. The collapsing of air holes of a PCF is another method to making Mach-Zehnder interferometer (MZI); this is a simple technique because it needs only to cleave and splice the fiber [7]. The collapsed region can be controlled by changing the fusion splice parameter. At the point where the air holes are collapsed, there is no cladding part and the PCF does not have a single mode any more. This technique can be formed by splicing PCF between two conventional SMFs. The first collapsed region acts as a splitter. In this region, the air hole is fully collapsed and the core mode beam appreciably diffracts. After the core mode beam propagates a distance of L (the length of the PCF) and reaches the second region of collapsing, the core and clad modes will recombine at the second collapsed region [8] as shown in Fig.1.

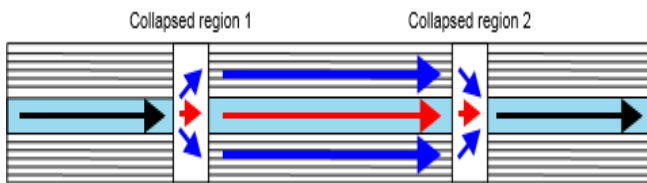


Fig.1 The schematic of In-PCF MZI collapsing regions used to split and recombine the signals [7].

II. Hemoglobin

The Hemoglobin (Hb) concentration in human blood is an important factor to examine the physiological condition. Hemoglobin is the protein that makes blood red, a hemoglobin test detects how much hemoglobin can be found in the blood. With this information anemia (a low hemoglobin level) and polycythemia Vera (a high hemoglobin level) can be diagnosed and monitored. It is also possible to observe imminent postoperative bleedings and autologous re-transfusions. Many diseases are associated with hemoglobin concentration such as anemia and blood viscosity. In men the normal hemoglobin level is 14 to 18 gm/dl. The normal hemoglobin level in women is 12 to 16 gm/dl. [9].

In this work we designed and implemented a simple and possibility integrate laser biosensor for measuring the hemoglobin (Hb) concentration in the human blood sample. This system is based on MZI technique. Different Hb concentrations were detected using green laser with 532 nm wavelength and input power of 12.2 nw. The modulated intensity for the transmitted laser can be observed at the fiber output.

III. Laser source selection

A human blood sample has been put in a quartz cuvette in a spectrophotometer and the absorption spectrum has been obtained. The selection of the laser source wavelength is done according to the absorption spectrum obtained. The wavelength of the laser used should be within the range of the absorption spectrum. At this wavelength the blood sample should absorb enough part of the laser light and make a significant sensing signal.

Different blood samples with different hemoglobin concentration were taken from males and females. The values of Hb concentration [8.2, 10.8, 10.9, 11.9, 12.3 and 13.3] gm/dl have been known by the blood picture examination in a pathological laboratory. The refractive index of each sample been measured using (Abbe-refractometer) for human blood samples with different Hb concentration.

IV. Laser biosensor set-up preparation

The sensor structure is based on Mach-Zander interferometer of which consists of (1.5cm) of a photonic crystal fiber (PCF) (LMA-10) which has a solid core surrounded by four layers of air holes arranged in a hexagonal pattern spliced with a conventional single mode fiber on both sides as shown in Fig.2.

The physical properties are core diameter $10.1 \pm 0.5 \mu\text{m}$, outer cladding diameter $125 \pm 2 \mu\text{m}$ and air hole with a diameter of $3.1 \mu\text{m}$, pitch of $6.6 \mu\text{m}$.

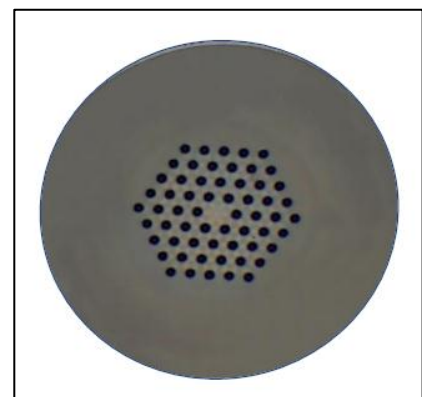


Fig.2 Microscope image of cross section of the LMA-10 PCF used in this work, where the magnification power of the microscope was (20 X).

In general, the PCF splicing with the SMF in both sides is by using mechanical fusion splice, the fusion time and fusion power have been changed, and (by trial and error), the collapse region in this work ($250\text{-}300 \mu\text{m}$) as shown in Fig.3.

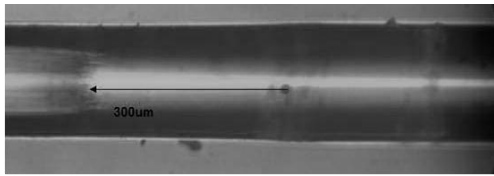


Fig.3 Microscope image of collapse zone splicing between PCF (LMA-10) on the left and SMF on the right, the collapsed length is 300um.

In the first spliced region, the air holes were completely collapsed, the input core mode propagates into the first collapsed region; its mode field diameter is broadened, causing excitation of the core and cladding modes, and then they recombine at the second collapsed region after propagating through a distance of L (the length of the PCF).

The experimental setup is shown in Fig.4. The laser emits the light beam towards the spectrum analyzer passing through the PCFs, in which the blood sample exists above the collapsed regions. The detected signal could be obtained by using an optical spectrum analyzer (OSA) provided by (ocean 2000). The transmission signal is shown on a personal computer.

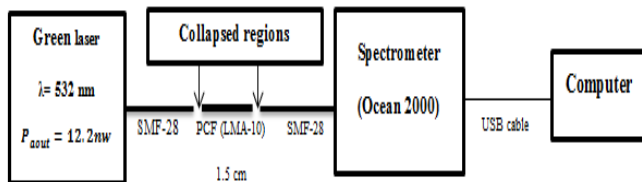


Fig.4 Schematic diagram for experimental set-up of the laser biosensor

V. Results and discussion

The results were taken under laboratory conditions. The room temperature was 25°C and the humidity was very low. It can be seen from Fig.5 that the maximum absorbance of the blood sample is between the wavelengths (505nm-560nm). Thus the green laser with wavelength 532nm has been used as the laser source for this detector. The power of this laser was 12.2nw. The selection of this power is to make sure that there is no chemical or heat effect on the blood sample.

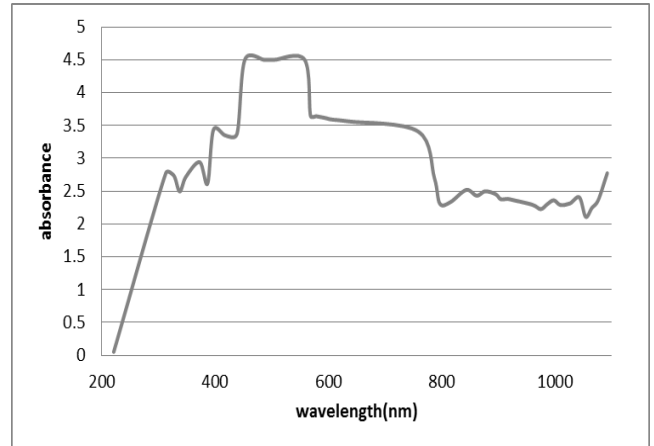


Fig.5 The absorption spectrum of the blood sample using optical spectrophotometer.

The relation between the measured refractive index and the Hb concentration is shown in Fig.6. The refractive index of the blood sample increased directly with the Hb concentration.

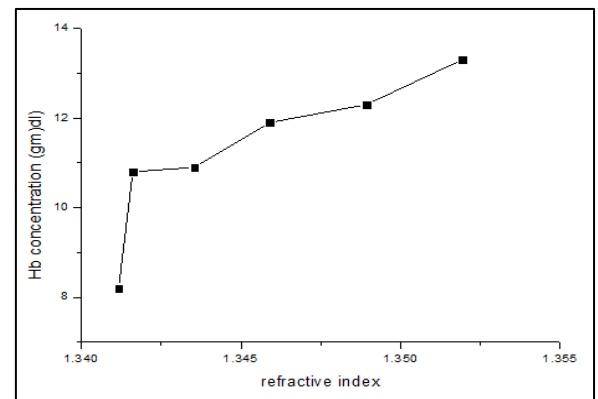


Fig.6 The relation between the measured refractive index and the Hb concentration.

The output transmission spectrum of the green laser with wavelength of 532nm monitored by a spectrometer is shown in Fig.7. The intensity of this spectrum (I_0) was equal to 3161 which has been taken as the reference signal for measuring the absorbance of each blood sample.

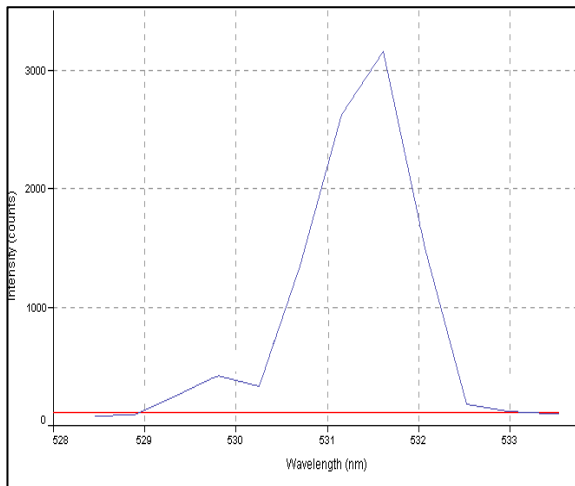


Fig.7 The output spectrum of the green laser 532nm.

Fig.8 shows the output of the transmission spectrum emitted from the sensor for different hemoglobin concentrations of seven blood samples. The output signal shows a sinusoidal variation which is related to the different refractive index of the blood samples.

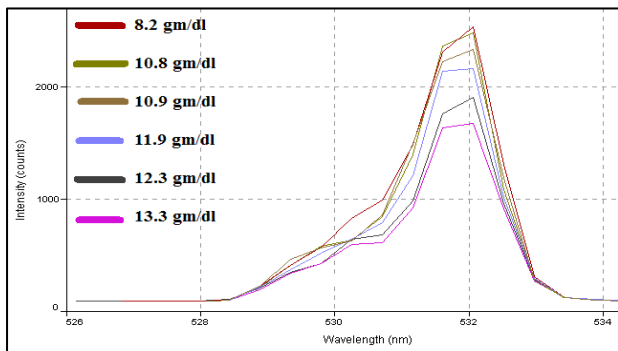


Fig.8. The output spectrum variations with different hemoglobin concentrations.

Table.1 indicates the average values of different parameters after the laser beam passed through different hemoglobin concentrations and the measured refractive indices of different blood samples.

Table1. The values of different parameters of different hemoglobin concentrations.

Sample	Refractive index	Hb concentration (mg/dl)	Maximum transmission intensity (I_0)	normalized absorption ($A = \log(\frac{I_0}{I})$)
1	1.34117	8.2 gm/dl	2531	0.0965
2	1.34161	10.8 gm/dl	2479	0.1055
3	1.34354	10.9 gm/dl	2334	0.1317

4	1.34591	11.9 gm/dl	2159	0.2233
5	1.34893	12.3 gm/dl	1903	0.2203
6	1.35192	13.3 gm/dl	1671	0.2768

The human blood sample with highest hemoglobin concentration has absorbance value larger than the blood sample with the lowest hemoglobin concentration. The increasing of refractive index of the highest hemoglobin concentration compared with refractive index of the lowest hemoglobin concentration made its absorbance larger than the absorbance of the human blood sample with the lowest hemoglobin concentration.

A calibration curve between the absorbance of the green laser by the blood sample and the measured hemoglobin concentration was obtained to find the hemoglobin concentrations of any blood sample, which has the refractive index in the range between [1.33557-1.40716]. The sensitivity was 21.494 ABS/ (gm/dl) for hemoglobin concentrations in the range of [8.2-13.3] gm/dl. This curve is shown in the Fig.9, which has been found by using this sensor.

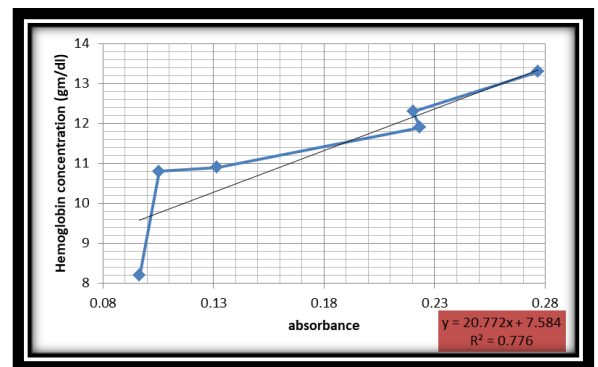


Fig.9 Shows a calibration curve between the hemoglobin concentrations and absorbance of the blood sample

by using 1.5cm LMA-10 PCF length (sensitivity = 20.772 ABS/(gm/dl)).

VI. Conclusions

A compact, robust and simple laser biosensor based on Mach-Zehnder interferometer for

detection of the hemoglobin concentration in human blood was designed. In conclusion the followings been observed:

1. The refractive index of the human blood is increased by increasing the hemoglobin concentration.
2. The variation in the output intensity (normalized absorbance) is increased by increasing the refractive index of blood sample which yields increasing the Hb concentration.
3. By using 1.5 cm PCF length, the sensitivity of Hb concentration sensor in the range of (8.2-13.3) gm/dl is 20.772 ABS/ (gm/dl).

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