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Fiber Optic Displacement Sensor for Measuring Cholesterol Concentration

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Abstract: A simple design of a cholesterol concentration detection is proposed and demonstrated using a fiber optic displacement sensor based on an intensity modulation technique. The proposed sensor uses a bundled plastic optical fiber (POF) as a probe in conjunction with a flat mirror as a target. It is obtained that the peak voltage reduces with increasing cholesterol concentration. The sensor is capable of measuring the cholesterol concentration ranging from 0 to 300 ppm in a distilled water with a measured sensitivity of 0.01 mV/ppm, a linearity of more than 99.62 % and a resolution of 3.9188 ppm. The proposed sensor also shows a high degree of stability and good repeatability. The simplicity of design, accuracy, flexible dynamic range, and the low cost of fabrication are favorable attributes of the sensor and beneficial for real-field applications.

Keywords: Fiber optic sensors, Flat mirror, Cholesterol solution.

1. Introduction

Cholesterol is partly a fat content contained in cells made by low density lipoproteins, high density lipoproteins, total cholesterol and triglycerides. Cholesterol is present in the bloodstream and body cells needed for the formation of cell walls. Excessive concentration of cholesterol in the blood, can cause various diseases, where normal cholesterol should be below 200 mg/dl. Excessive cholesterol in the body settles in the blood vessels and will cause atherosclerosis in which the arteries narrow or harden. Cholesterol is a compound that has a nucleus of four cyclopentano - phenanthrene. In blood plasma, 30 % of the cholesterols are partially bound to lipoproteins that can increase their solubility in blood. As much as 70 % of the blood cholesterols are in the form of cholesterol esters [1]. Cholesterol is not soluble in water but can be extracted from tissues with chloroform, ether, and benzene. Fig. 1 shows the cholesterol includes a steroidal compound with the formula $C_{27}H_{45}OH$.

Many techniques have been proposed and reported by researchers to detect and measure the cholesterol concentrations. For instant, the fluorometric detection was proposed based on β-cyclodextrin functionalized carbon quantum [2].

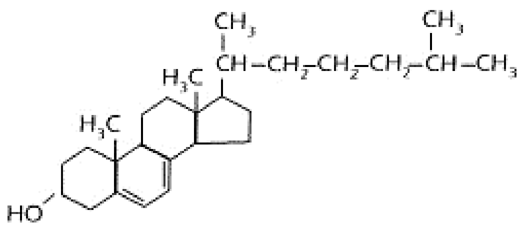

Fig. 1. The compound of cholesterol.

Cholesterol detection can also be done by using magnetite [3], and cobalt (II) chloride [4] as a platform material and electrocatalyst, respectively. Electrochemical sensors was also proposed based on molecular film molding on carbon nanoparticles modified electrodes for the determination of cholesterol [5]. These proposed methods have several deficiencies in terms of performance and thus they require further optimizations to improve their sensitivity, linear range and detection limit.

Previously, many optical sensors have been proposed and demonstrated to determine the concentration of a liquid solution using various types of optical fiber probes such as optical fiber bundle [6], optical fiber taper [7], and fiber optic coupler [8]. Fiber optic displacement sensors were also demonstrated to determine the concentration of solution [9] as well as to investigate the material salinity [10-11] due to their many advantages such as simple instrument designs, low prices, and high sensitivity measurements. In this paper, we demonstrate a new fiber optic displacement sensor for detecting cholesterol concentration based on a flat mirror target. This fiber optic sensor employs a He-Ne laser operating at wavelength of 632.5 nm as a light source and a bundled plastic optical fiber (POF) as a probe. The sensor operates based on an intensity modulation.

2. Experimental Setup

The schematic diagram of the experimental set-up for the cholesterol concentration measurement is shown in Fig. 2. The device is based on optical fiber displacement sensor, which consists of a fibre optic transmitter, fibre optic probe, position micrometer, flat mirror, a silicon photodiode detector, digital voltmeter, and PC. A He-Ne laser source operating at wavelength of 632.5 nm with the maximum power of 5 mW is used a transmitter. The fibre optic probe consists of two plastic PMMA (polymethyl methacrylate) fibres of length 40 cm, diameter 1 mm, numerical aperture 0.5, core refractive index 1.492 and cladding refractive index 1.402. It has many advantages such as light weight, small size, EMI immunity, geometrical versatility and ease of multiplexing and demultiplexing. The bending losses are minimized by putting both fibres in close contact, thus forming an equal radius of curvature.

Detection of this cholesterol concentration is based intensity modulated extrinsic sensor. The fiber optic probe is immersed into the measuring liquid. The static displacement of the fibre optic probe is achieved by mounting it on a micro displacement meter, which is rigidly attached to a vibration free table. A He-Ne laser beam is coupled into the transmitting fiber of the probe before it is launched into a flat mirror as a target, which was place inside a test liquid solution. 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 signal from the detector is converted to voltage and is measured by a voltmeter.

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 4 mm in a step of 50 µm. The measurements are carried out for cholesterol solution with concentrations of 50 ppm, 100 ppm, 150 ppm, 200 ppm, 250 ppm, 300 ppm in a distilled water. During the experiment, the temperature is kept constant at 25 °C, and the error due to the temperature variation is negligible.

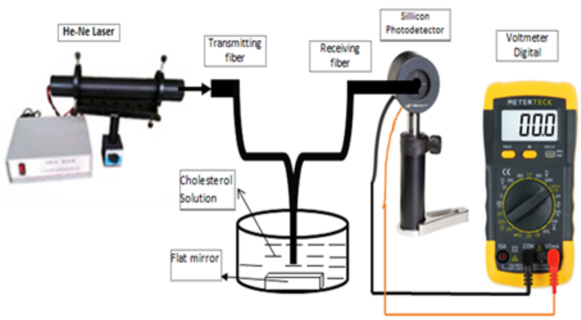

Fig. 2. Experimental setup for the proposed fiber optic displacement sensor with a flat mirror as a target.

3. Results and Discussions

At first we investigate the variation of the output voltage with the displacement of the fibre optic probe from the reflecting target. Fig. 3 shows the displacement curves at various cholesterol concentrations. They exhibit a peak with a steep front slope while the back slope follows an almost inverse square law relationship. At small distances, the light cone does not reach the receiving fibre and thus the measured signal is minimal. When the displacement is increased, the size of the reflected cone of light at the plane of fibers increases and starts overlapping with the core of the receiving fiber leading to a small output. Further increase in the displacement leads to large overlapping which results in increase in output. 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 the increase the cone size.

As shown in Fig. 3, the maximum sensor output voltage obtained is dependent on the cholesterol concentrations. Without the cholesterol in the distilled water, we obtain the maximum voltage at 203.2 mV. The peak voltage reduces as the cholesterol concentration reduces. This is attributed to the refractive index of the solution which increases with the cholesterol concentration. The increase of refractive index reduces the size of the light cone at the probe, which in turn reduces the amount of light that can be collected by the receiving fiber. Fig. 4 shows the result of refractive index measurement, which was obtained at various cholesterol solutions using a refractometer. The result indicates a direct correlation relationship between refractive index values with cholesterol concentrations.

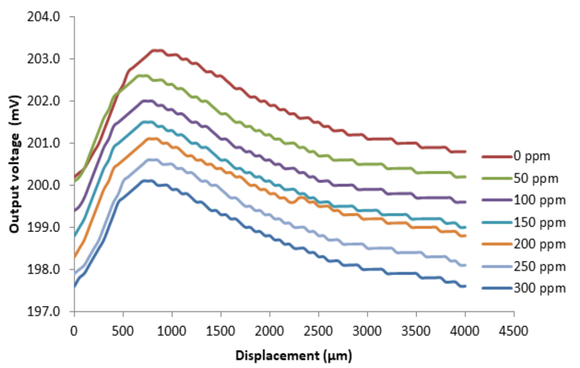

Fig. 3. Output voltage against displacement for various concentrations of cholesterol.

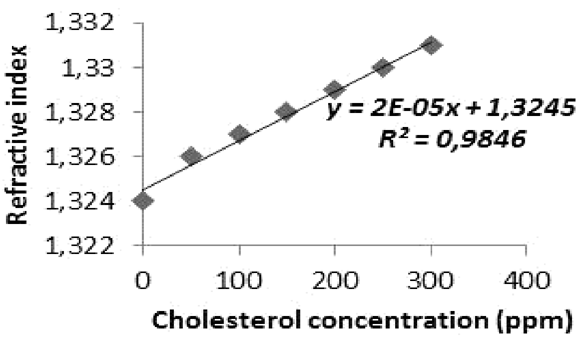

Fig. 4. Refractive index against the cholesterol concentrations.

Fig. 5 shows the variation of peak voltage with increasing cholesterol concentration in distilled water. In the present investigation, it is found that the peak voltage reduces linearly with the cholesterol concentration. The sensing sensitivity is obtained at 0.01 mV/ppm with linearity of 99.62 %. The stability of measurement is also investigated by measuring the maximum voltage within 450 s for each cholesterol concentration increment from 0 ppm to 300 ppm. The result is shown in Fig. 6, which indicates the measurement result in the proposed sensor is stable with the standard deviation of about 0.039188 mV. From the experimental results it can be concluded that as the cholesterol concentration increases, the refractive index also increases proportionally. This in turn reduces the signals received in the receiving fiber due to the reduced size of the light cone between the target and probe. The performance of the cholesterol sensor is summarized in Table 1. The sensor can measure the cholesterol with resolution of 3.9188 ppm and the results are repeatable as measured and investigated in this setup. The result obtained for the cholesterol measurement is also comparable with the previous results obtained by theoretical analysis [12-13]. This finding may be quite useful for chemical, biomedical, pharmaceutical and process control sensing applications.

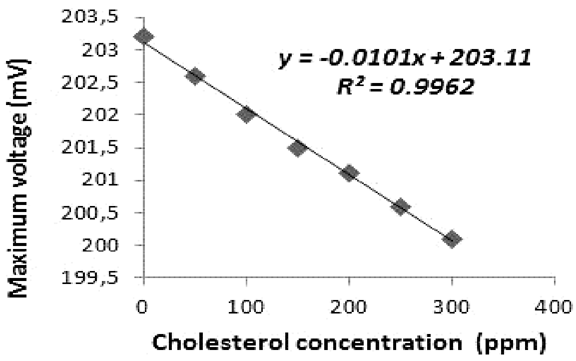

Fig. 5. Maximum voltage versus concentration of cholesterol.

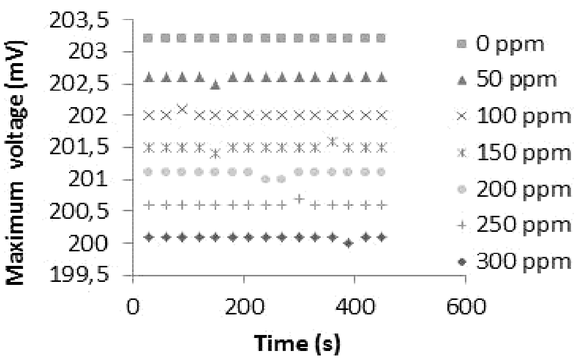

Fig. 6. Sensor stability test results within 450 s.

Table 1. Performance of the proposed cholesterol sensor.

Parameter	Value
Sensitivity	0.01 (mV/ppm)
Linearity	> 99 (%)
Linear range	0 – 300 (ppm)
Resolution	3.9188 (ppm)
Standard Deviation	0.039188 (mV)

4. Conclusion

A simple intensity modulated displacement sensor is demonstrated as a device to detect cholesterol 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 reduces linearly with the cholesterol concentration. The proposed sensor has a measured sensitivity of 0.01 mV/ppm with a linearity of more than 99.62 % and a resolution of 3.9188 ppm. This finding may be quite useful for biomedical applications.

References

[1]. Budiyanto Moh, Suhariningsih, Moh Yasin, Cholesterol Detection Using Optical Fiber Sensor Based On Intensity Modulation, *Journal of Physics: Conference Series*, Vol. 853, No. 012008, 2017, pp. 1-5.

[2]. Qian Sun, Siying Fang, Yafen Fang, Zhaosheng Qian, Hui Feng, Fluorometric detection of cholesterol based onβ-cyclodextrin functionalized carbon quantum dots via competitive host-guest recognition, *Journal Talanta*, Vol. 167, 2017, pp. 513-519.

[3]. J. Jaime, G. Rangel, A. Muñoz-Bonilla, P. Herrastia, Magnetite as a platform material in the detection of glucose, ethanol and cholesterol, *Sensors and Actuators B: Chemical*, Vol. 238, 2017, pp. 693-701.

[4]. Alisa N. Kozitsina, Andrei V. Okhokhonin, Anatoly I. Matern, Amperometric detection of cholesterol using cobalt (II) chloride as an electrocatalyst in aprotic media, *Electroanalytical Chemistry*, Vol. 772, 2016, pp. 89–95.

[5]. Jian Ji, Zhihui Zhou, Xiaolian Zhao, Jiadi Sun, Xiulan Sun, Electrochemical sensor based on molecularly imprintedfilm at Au nanoparticles-carbon nanotubes modified electrode for determination of cholesterol, *Biosensors and Bioelectronics*, Vol. 66, 2014, pp. 590–595.

[6]. Faria J. B., Modeling The Branched Optical Fiber Bundle Displacement Sensor Using a Quasi-Gaussian Beam Approach, *Microwave and Optical Technology Letters*, Vol. 25 No. 2, 2000, pp. 138-141.

[7]. Yasin M., H. Ahmad, K. Thambiratnam, A. A. Jasim, S. W. Phang, S. W. Harun, Design of Multimode Tapered Fibre Sensor for Glucose Detection, *Optoelectronics and Advanced Materials*, Vol. 7, No. 5-6, 2013, pp. 371–376.

[8]. Samian, A. H. Zaidan, Moh. Yasin, Detection of Rhodamine B levels in destilled water based on displacement sensor using fiber coupler and concave mirror, *Journal of Optoelectronics and Advanced Materials*, Vol. 18, No. 11-12, 2016, pp 988–992.

[9]. Rahman H. A., S. W. Harun, Saidin N., M. Yasin, H. Ahmad, Fiber Optic Displacement Sensor for Temperature Measurement, *IEEE Sensors Journal*, Vol. 12, No. 5, 2012, pp. 1361–1364.

[10]. Yasin M., Y. G. Yhun Yhuwana, M. Khasanah, H. Arof, N. Irawati, S. W. Harun, Intensity based optical fiber sensors for calcium detection, *Optoelectronics and Advanced Materials – Rapid Communications*, Vol. 9, No. 9-10, 2015, pp. 1185-1189.

[11]. M. Yasin, S. W. Harun, Kusminarto, Karyono, Warsono, A. H. Zaidan, H. Ahmad, Study of bundled fiber based displacement sensors using theoretical model and fitting function approaches, *Journal of Optoelectronics and Advanced Materials*, Vol. 11, No. 3, 2009, p. 302–307.

[12]. Hida N., N. Bidin, M. Abdullah, M. Yasin, Fiber Optic Displacement Sensor for Honey Purity Detection in Distilled Water, *Optoelectronics and Advanced Materials*, Vol. 7, No. 7-8, 2013, pp. 565-568.

[13]. Rahman H. A., S. W. Harun, M. Yasin, H. Ahmad, Fiber Optic Salinity Sensor Using Fiber Optic Displacement Measurement with Flat and Concave Mirror, *IEEE Journal of Selected Topics in Quantum Electronics*, Vol. 18, No. 5, 2012, pp. 1529–1533.