Jurnal Teknologi

Full Paper

DETECTION OF DIFFERENT CONCENTRATIONS OF URIC ACID USING TAPERED SILICA OPTICAL SENSOR COATED WITH ZINC OXIDE (ZnO)

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Article history
Received
10 October 2014
Received in revised form
10 December 2014
Accepted
13 January 2015

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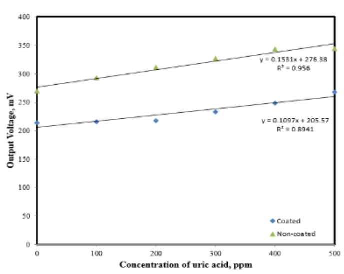
Graphical abstract



Abstract

The working principle of measurement of output power from silica optical sensor for the detection of different concentrations of uric acid is demonstrated. The fabricated sensors used single mode silica optical fibers (SOF) which were tapered using flame brushing technique to achieve a waist diameter of 32 μm and tapering length of 2 mm. The tapered fiber were then coated with ZnO nanostructures using sol–gel immersion method. The concentration of the uric acid is measured in volume parts per million (ppm) for a concentration change from 0 ppm to 500 ppm by tapered SOF coated with ZnO and non-coated sensors. The peak voltage increases linearly for coated and non-coated from 214 mV to 268 mV and 270 mv to 344 mV, respectively. Sensitivity was measured with 0.11 mV/ppm and 0.15 mV/ppm, respectively. In addition, the results show that the linearity of the sensors is 94.56% and 97.78%, respectively. Simple in fabrication and low in cost, this sensor can detect concentration changes of uric acid in a fast and convenient way with high stability and sensitivity. Thus, this sensor will be very promising in chemical and biomedical applications.

Keywords: Optical fiber, uric acid, zinc oxide (ZnO)

Abstrak

Prinsip kerja pengukuran kuasa output dari sensor optik silika untuk mengesan kepekatan asid urik ditunjukkan. Sensor direka digunakan silika mod tunggal gentian optik (SOF) yang tirus dengan menggunakan apiteknik memberus untuk mencapai diameter pinggang daripada 32μm dan panjang 2mm tirus. Serat tirus kemudian disalut dengan nanoZnO menggunakan kaedah rendaman sol-gel. Kepekatan asidurik diukur di bahagian isipadu per juta (ppm) untuk perubahan kepekatan dari 0ppm kepada 500ppm oleh tirus SOF disalut dengan ZnO dan sensor tidak bersalut. Kenaikan voltan puncak linear untuk bersalut dan tidak bersalut dari 214 mV kepada 268 mV dan 270 mv kepada 344 mV, masing-masing. Kepekaan sensor diukur dengan 0.11 mV/ppm dan 0.15 mV/ppm, masing-masing. Di samping itu, keputusan menunjukkan bahawa kelinearan sensor adalah 94,56% dan 97,78%, masing-masing. Mudah dalam fabrikasi dan rendah kos, sensor ini boleh mengesan perubahan kepekatan asid urik dengan cara cepat dan mudah dengan kestabilan tinggi dan sensitiviti. Oleh itu, sensor ini akan menjadi sangat cerah dalam aplikasi kimia dan bio-perubatan.

Kata kunci: seratoptik, asidurik, zinkoksida (ZnO)

1.0 INTRODUCTION

Uric acid is a chemical created when the body breaks down substances called purines [1]. Purines are found in some foods and drinks such as include liver, anchovies, mackerel, dried beans and peas, and beer. Most uric acid dissolves in blood and travels to the kidneys and passes out in urine. If uric acid is produced too much or does not remove enough, it leads to electrochemical oxidation of uric acid have also been developed [6-7].

Recently, the enhancement of optical sensor sensing become a vast interest among the researcher since many devices have been reported to have a ZnO coating as a sensing material to detect biomolecules. ZnO plays an important role in a wide range of applications such as solar cells, piezoelectric element, pharmaceuticals, paints, ceramics, surface acoustic wave element and sensors because it is an n-type semiconductor with wide band gap energy of 3.3 eV and it shows superior optical transparency in the visible region [8]. Apart from these, ZnO has a high isoelectric point of about 9.5, which provide a positively charged substrate for immobilization of enzyme with low isoelectric point and serve as a potential biosensor electrode [9]. However, enhancing the performance of optical sensor is high demand and more research on reducing the cost of coating is carried out in creating a low-*cost sensor*.

In this paper, tapered SOF were coated with ZnO nanostructure solution for sensing uric acid concentration. The ZnO coating on the tapered SOF fiber make changes of the optical characteristics in response to an external biomolecule [10]. The measurement is based on divide of the lightwave signal into constituents to measure the optical power of the wavelengths for different uric acid concentration.

2.0 EXPERIMENTAL

Figure 1 illustrates the fabrication setup for the tapered SOF used in this study, which was produced using flame brushing technique controlled by computer. The desired length of tapered fiber was set in MATLAB program. The refractive index of the core and cladding are 1.4475 and 1.4440 respectively. The tapering of the fiber was done by first placing the single mode SOF between two fiber holders which were fixed onto a translation stage on one end and a fixed stage on the other end. The built in torch flame was fixed at the centre of the SOF before it was pulled slowly at one end to reduce the fiber waist diameter to approximately 32 µm and achieve length of 2 mm. As a precautionary step, the flame should be clean and the burning gas flow should be well controlled. Steps should be taken to reduce any air convection flow that may cause breakage in the fiber during the drawing process. During the tapering process, a broadband amplified spontaneous emission (ASE) light source was launched into the SOF to monitor its loss and spectral response using an optical spectrum analyzer (OSA) at the output end of the SOF. After the taper was made, the profile of the taper was measured and observed using a microscope.

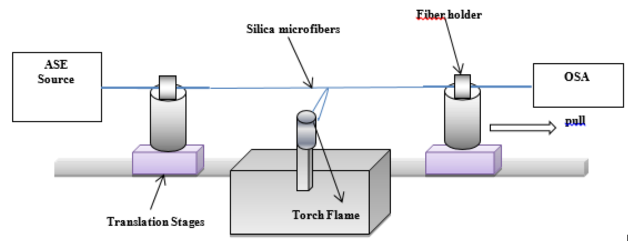


Figure 1 Schematic diagram of the tapering process of the SOF using flame brushing technique

These tapered SOF were then coated with ZnO nanostructures using sol-gel method. The ZnO solution was prepared using zinc acetate dehydrate ($Zn(CH_3COO)_2{\cdot}2H_2O$) as a precursor dissolved in isopropanol with molarity of 0.025 M. The solution was stirred at 60°C for 2 h in ambient to yield a clear and homogenous solution. Then, the solution was cooled down to room temperature for the coating process. The coating process of the tapered SOF was manually immersed into the solutions for 24 h. Figure 2 shows the microscope images of SOF with original fiber in Figure 2(a), tapered SOF in Figure 2(b) and tapered SOF coated with ZnO in Figure 2(c) which have a cladding diameter of 432 µm before tapering and 32 µm after tapering.

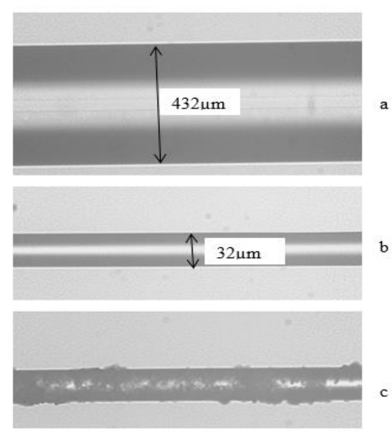


Figure 2 Shows the microscope images of SOF with (a) original fiber, (b) tapered SOF and (c) tapered SOF coated with ZnO

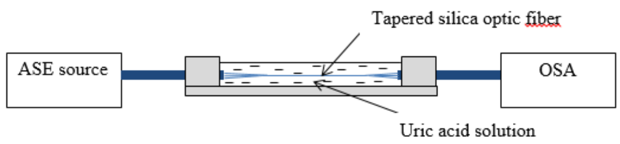


Figure 3 The experimental setup for the proposed sensor to detect different concentrations of uric acid using a tapered SOF coated with ZnO nanostructures

Figure 3 shows the experimental setup for the proposed sensor to detect different concentrations of uric acid using the fabricated tapered SOF with ZnO nanostructures which is same as monitoring of fiber loss during tapering process. In this experiment, the proposed SOF sensor was investigated for various uric acid concentrations. The tapered region of SOF was fully immersed in a container which was filled with uric acid. One end of SOF was connected to ASE light source operating in the 1550 nm region while the other end was connected to OSA to observe and measure output power versus wavelength. As light source from ASE was injected into the SOF sensor, the tapered region sensed the uric acid concentration based on the propagating of wave power along the fiber.

3.0 RESULTS AND DISCUSSION

Figure 4 shows the variation of the transmitted light from the tapered SOF coated with ZnO nanostructures against the concentration of uric acid solution and Figure 5 shows the refractive index of the uric acid solution which measured by using METTLER Toledo RE40D refractometer) against the uric acid concentration. As the concentration of uric acid increases from 0 ppm to 500 ppm, the refractive index of the solution also increases from 1.33251 to 1.3330. As can be seen, OSA was used to measure the output power passed through the SOF sensor by dividing the lightwave signal into constituents which corresponds to the transmitted light intensity linearly, increases as the concentration of uric acid solution increases. It is initiated that the sensitivity of tapered SOF coated with ZnO is 0.11 mV/ppm with a slope linearity of more than 94.56 % and limit of detection of 0.20 ppm. Then, the sensitivity of tapered SOF without ZnO is 0.15 mV/ppm with a slope linearity of more than 97.78 % and limit of detection of 0.20 ppm.

Chemical substance is a form of matter that has constant chemical composition and characteristic properties. Type of chemical substance can be classified as electrolytes and non-electrolytes depending on the dissociation of their ions in solutions [10]. Uric acid is electrolyte that containing free ions to make the solution electrically conductive. The tapered SOF coated with ZnO reacts with uric acid due to strong electrostatic reaction and response with the increasing concentration. However the ZnO nanostructure could significantly enhance the sensing of the sensor that is immersed in solutions of higher concentration. These results show that the proposed sensor is applicable and beneficial for the detection of biomolecular concentration such as uric acid because the sensor has an ability to provide real time measurement.

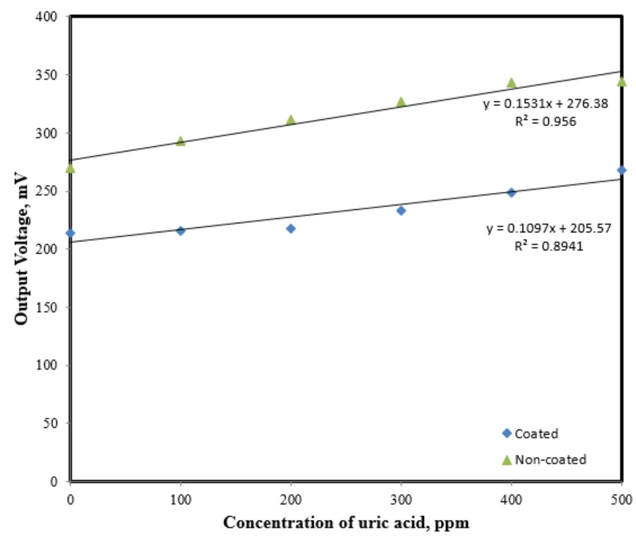


Figure 4 Output voltage against uric acid concentrations for the fabricated tapered SOF coated with ZnO and non-coated

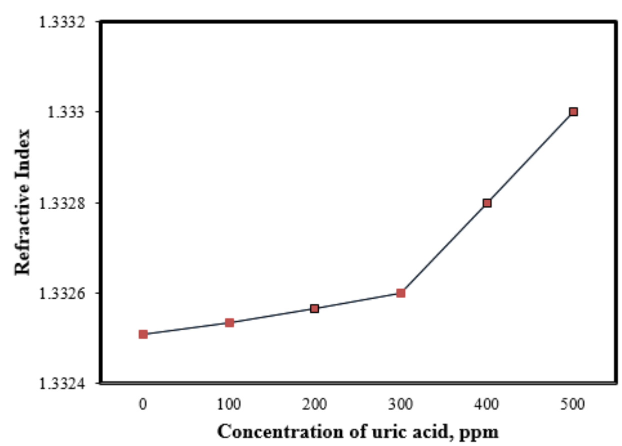


Figure 5 The measured refractive index at different concentrations of uric acid

The performance of the proposed sensor is summarized in Tables 1. Overall, the sensor is considered to be sufficiently stable with standard deviations of 9.32 % for tapered SOF coated with ZnO and 9.31% for non-coated tested on uric acid with different concentration as being recorded. These results show that the proposed sensor coated with ZnO nanostructures is suitable and indicated better performance in measuring uric acid concentration in real time due to high sensitivity compared to non-coated fiber. Although the SOF non-coated sensor produced high output voltage but the sensor is not able to have high sensitivity.

The whole system is setup by connecting the PI camera module to the CSI port on the Raspberry PI board via ribbon cable while the LCD screen is connected to the board via HDMI cable. The wireless keyboard and mouse is connected to the board using wireless USB adapter. This is only needed when manipulation of code is required. The power is supplied to the board by connecting a micro USB to USB cable to a wall socket USB adapter or power bank.

Table 1 The performances of the fabricated uric acid detection sensor

Performances	Coated	Non-coated
Sensitivity (mV/ppm)	0.11	0.15
Linearity (%)	94.56	97.78
Standard deviation (%)	9.32	9.31
Limit of detection (ppm)	0.20	0.20

4.0 CONCLUSION

Simple in fabrication and low in cost, the sensor is proposed and demonstrated using a tapered SOF coated with ZnO for measurement of different concentrations of uric acid in de-ionized water. The tapered SOF was fabricated by using flame brushing method to achieve a waist diameter of 32 µm and tapering length of 2 mm. Then, the tapered SOF was coated with ZnO nanostructures using sol–gel immersion method for 24 h. As the solution concentration of the uric acid varies from 0 ppm to 500 ppm, the output voltage of the sensor using tapered SOF coated with ZnO nanostructure increases linearly with better sensitivity of 0.11 mV/ppm and a linearity of more than 94.56% and limit of detection of 0.2 ppm. The tapered SOF coated with ZnO and non-coated SOF interacts with uric acid due to strong electrostatic interaction and response with the increasing concentration. However the ZnO nanostructure could significantly enhance the sensitivity of the sensor that is immersed in solutions of higher concentration.

Acknowledgement

This work was supported by the grant UM.C/625/1/HIR/MOHE/SCI/29 from the University of Malaya

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