



DEVELOPMENT OF PLASMONIC SENSOR FOR DETECTION OF TOXIC MATERIALS

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ABSTRACT

The plasmonic sensor has been developed for the detection of toxic materials in solution form. This system consists of a light source that is connected to a fiber optic duplex system with two arms. The first arm transmits light from the light source beam to the sample and the second arm sent the reflected light from the sample to the spectrophotometer. The sensing process was done in the sensor chamber made from Teflon with a sliding sample drawer is used to place the sample or known as sensing material. OOIBase32 was used to analyze the recorded spectrum from the spectrophotometer. In this study, the testing of the plasmonic sensor was carried out using targeted analyte namely boric acids with deionized water that is set as a reference medium. Two gold nanoparticles shapes which are gold nanosphericals and gold nanoplates were used as sensing materials. As a result, it was found that the plasmonic sensors with the gold nanoparticles as their sensing materials are sensitive toward the presence of targeted analyte. The sensing parameters are based on changing of their resonance peak position and its intensity.

Keywords: plasmonic sensor, gold nanoparticles, localized surface plasmon resonance.

INTRODUCTION

Localized surface plasmon resonance (LSPR) is a resonance phenomenon of free electron waves in a metal nanostructure such as gold, silver and lead which has smaller sizes than light wavelength (Sannomiya & Vörös, 2011). The LSPR has a unique characteristics that gain interest among scientist and researchers in various field such as catalytic, solar cell, Surface-Enhanced Raman Spectroscopy (SERS) and sensor. In sensor application, the implementation of LSPR is very broad because of its sensitivity to dielectric and refractive index of surrounding medium. The LSPR-based sensor also known as plasmonic sensor that has been operated based on the changing of optical characteristics of metal nanostructures in analyte either liquid or gaseous form. The reference medium for LSPR-based liquid usually deionized (DI) water while LSPR-based gaseous is inert gaseous such as nitrogen. The advantage of this sensor is the detection of analyte can be done without changing their chemical properties (Chau *et al.* 2006; Swalen *et al.* 1980).

Thus far, there are many researches that have been done using plasmonic sensor. For example, the detection of formilin liquid using gold nanospherical as its sensing material by (Nengsih *et al.* 2012). Nengsih *et al.* has developed the plasmonic sensor using gold nanospherical as its sensing material. Other than that, in medical field, the plasmonic sensor has been used to detect the biological marker for Alzheimer (Haes *et al.* 2005; Yang *et al.* 2014) and cancer cell (Ma *et al.* 2014). There are also researches on plasmonic sensor using air as a medium for example the research done by Kreno (Kreno *et al.* 2010). The sensor has been developed to detect a

toxic gaseous namely carbon monoxide (CO) and sulfur hexafluoride (SF₆).

This paper reports a development of plasmonic sensor to detect toxic materials. The toxic material that has been investigated in this study is boric acid. Boric acid is poisonous and declared as unsafe to be used as preservatives and additives in foods by FAO/WHO Expert Committee (Litovitz *et al.* 1988). However, it is used by small scale producers in food processing to control freshness and enhance colour, texture and flavor (See *et al.* 2010). In this study, the fabrication of plasmonic sensor and all the components used will be discussed. The models of sensing materials to be used in the sensor system will also be proposed.

DEVELOPMENT OF PLASMONIC SENSOR

Setup of plasmonic sensor

An optical sensor system that implementing plasmonic theorem has been developed. This sensor can be used for the detection of toxic materials in solution. The system setup is made of few components as shown in Figure-1. This system consists of a light source that is connected to a fiber optic duplex system. This optical fiber has two arms. The first arm transmits light from the light source beam to the sample and the second arm sent the reflected light from the sample to the spectrophotometer. A typical sensor chamber has been designed to accommodate the sensing system. All of these components have been placed on anti-vibration table. The details for each components in this system will be explained in the next section.

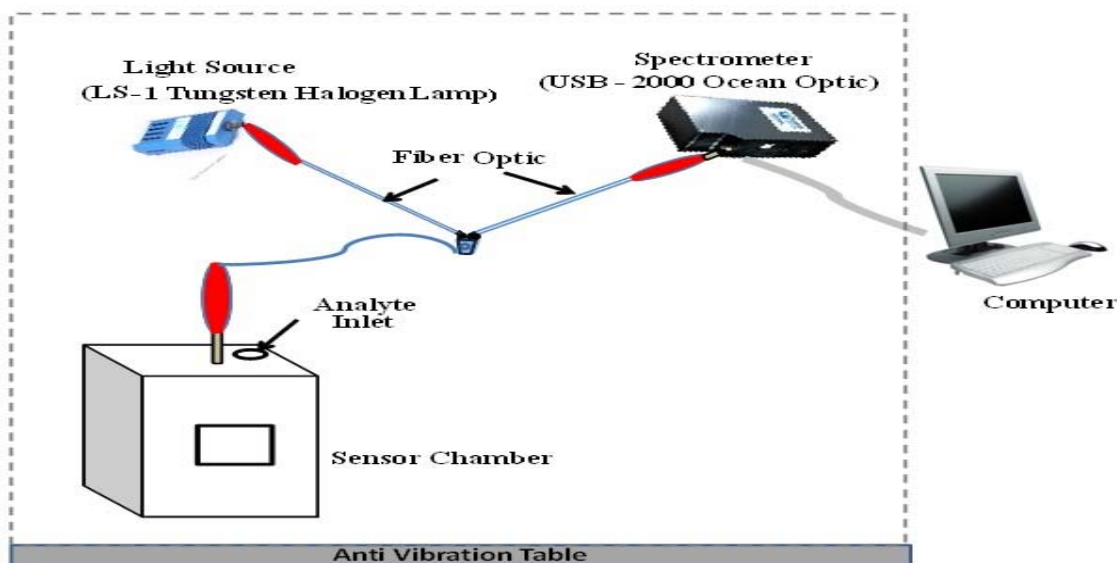


Figure-1. Setup of plasmonic sensor.

The following describes the function of each components in this sensor system:

a) Light source

Light source is a device that provides electromagnetic radiation visible light to excite the resonance properties of metal nanoparticles such as gold. In this sensor system, the light source is made of tungsten lamp; LS-1 Halogen Tungsten model from Ocean Optics, USA. This lamp will emit visible light and near infrared radiation with wavelength in the range of 360 nm - 2500 nm. The lamp has an output power of 6.5 W and the time required for the stable condition is about 10 minutes.

b) Duplex fiber optical probe system

Duplex fiber optical system acts as a light channel from the light source to the sample inside the sensor chamber and subsequently sent the reflected light by the sample to spectrophotometer. In this system, R400 model - Angle - Vis from Ocean Optics, USA is used as the fiber optical probe system. It is made of pure silica core with a diameter of $400 \mu\text{m} \pm 8 \mu\text{m}$ and able to transmit electromagnetic wavelength from 400 nm to 2500 nm. This optical fiber consists of two parts arm; the end of the first arm is connected to the light source while the end of the second arm is connected to the spectrophotometer. These two ends meet at a probe in the duplex fiber optical system. This probe is placed perpendicular to the sample inside the sensor chamber. There are two channels in the probe where the first channel will emit the incident light to the sample and the second channel in the probe will collect the reflected light reflected from the sample and sent to a spectrophotometer as explained previously. The red rubber rods are used as connector at the end of each fiber optics. The process is shown in Figure-2.

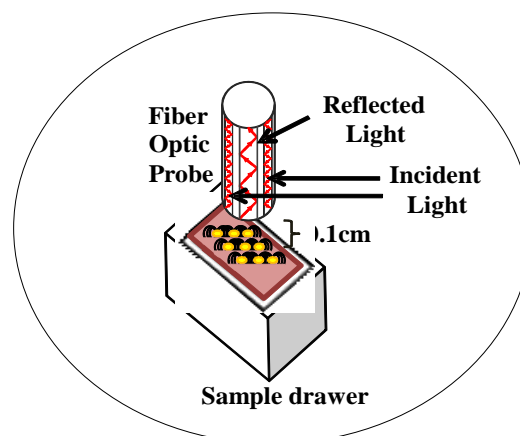


Figure-2. The optical probe in the duplex fiber optical system.

c) Sensor chamber

The main component in an optical sensor system is sensor chamber. In this study, the chamber is made from Teflon material with the dimension of 3.5 cm x 3 cm x 6 cm. The chamber has been designed as a box with a sliding drawer to facilitate the process of replacing the sample substrate. The sensor chamber is placed on a square block of transparent thermoplastic materials named Perspex as a base foundation. The sample substrate will be placed on a reflector mirror inside the drawer during the experiment. The drawer dimension is 1.5 cm x 2.2 cm x 0.8 cm. The reflector mirror is used to reflect all the emitted lights towards the sample sensor. The upper sensor chamber is drilled to create hole to accommodate fiber optical system probe. This fiber optical probe is then placed vertically in the hole of sensor chamber. The distance between the probe tip and the sample substrate is



0.1 cm. During the experiment, the sample drawer will be filled with air or liquid i.e.; deionized water and targeted analyte. Figure-3 illustrates the designed sensor chamber.

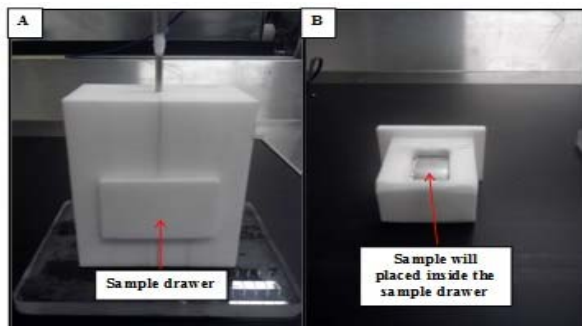


Figure-3. The design of sensor chamber (A) Sensor chamber (B) Sample drawer.

d) Spectrophotometer

Spectrophotometer acts as a recorder of reflected light spectrum by the sample that has been passed through fiber optical system. In the optical sensor system, HR 2000 supplied by Ocean Optics, USA was used as the spectrophotometer model. It is capable of detecting light of wavelength in the range from 200 nm to 1100 nm with an optical resolution of 0.035 - 6.8 nm FWHM. The spectrophotometer system consists of 2-MHz analog-to-digital converter (ADC), electronic pre-program, 2048 element of CCD Camera - linear detector arrays charge coupling device from Sony ILX511 model and high-speed USB port. The data recorded by the spectrophotometer will be sent to the computer via the USB port.

e) Data analysis software

A personal computer is the last component in the optical sensor system that includes a commercial data software to analyse data obtained from the spectrophotometer. The software is OOIBase32. The software allows there are three types of measurement modes namely absorption, reflection and transmission. In this study, the absorption mode was chosen as the measurement mode.

SENSOR OPERATION

The sensor operation starts with warming up process to ensure stability in the measurement, light and spectrophotometer. All the components were switched on for an hour before sensing process is carried out. During this period, the targeted analyte will be prepared with deionized water chosen as a solvent. The OOIBase32 was set to absorption mode, and thus the reflected light from the sample been collected by the optical fiber probe will be converted directly into optical absorbance readings.

Before starting the sensing process, the reading of the light spectrum for a blank quartz substrate was recorded and will be used as a baseline. This procedure is to ensure the effects of absorption by the substrate are removed before the actual measurement using actual sample is taken. The measurement on the sample will be

done in three mediums; air, deionized water and targeted analyte. In liquid medium, the bottom of the probe is set to be immersed in the solution. Total optimal solution for each sensing process is 1.3 mL to enable the probe to dip. Once the sensor system has achieved its stability especially from surrounding noise, the spectrum readings will be recorded.

TESTING AND RESULTS

The sensor system was tested using different sensing materials such as gold nanospherical and gold nanoplates. In this study, the targeted analyte chosen was a toxic materials in a food preparation namely boric acids. The results are shown in Figure-4.

The optical response of gold nanosphericals toward boric acid shows the LSPR spectra of gold nanosphericals. This is achieved when the sample was first immersed in the deionized (DI) water and followed by in 1 mM boric acid solution as depicted in Figure-4 A (i). It was observed that a single peak that is associated with transverse SPR (*t*-SPR) (B. Sepúlveda et. al, 2009 and Marlia et. al, 2012) emerges and it presents for each testing medium; DI and boric acid. The peak position of the spectrum in water is 545 nm and right-shifted by 1 nm in the presence boric acid. The FESEM image for gold nanospherical as shown in Figure-4 A (ii).

Meanwhile, the result of testing using gold nanoplates is shown in Figure-4 B (i). It can be seen that for this testing, there are two resonance peaks occur at 545 nm and 712 nm. The first peak is assigned as transverse SPR (*t*-SPR) and the second peak is assigned as longitudinal SPR (*l*-SPR) (Umar et. al, 2009 and Marlia et. al, 2014). Similar to gold nanosphericals, two changes in the spectra were recorded which are; resonance peak position and intensity when the sample is put in different medium; deionized water and 1 mM boric acids. The FESEM image of gold nanoplates is shown in Figure-4 B (ii).

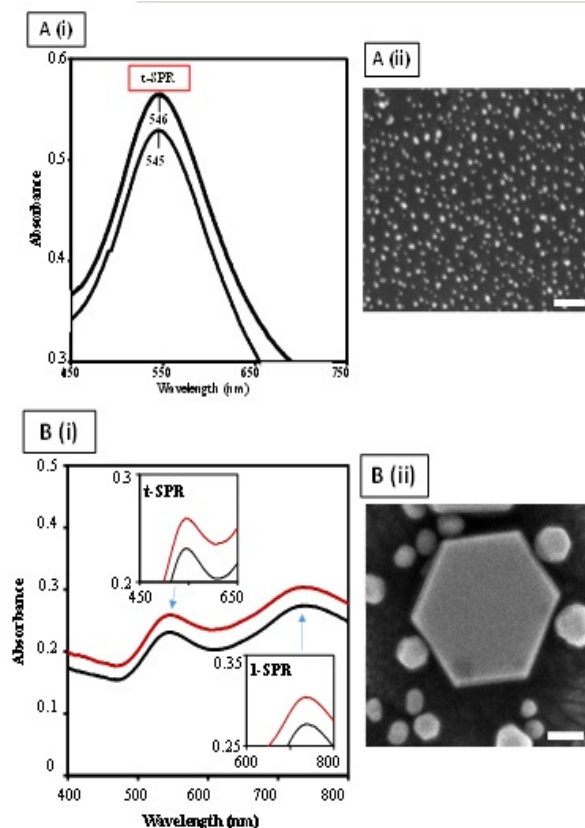


Figure-4. The spectra of gold nanoparticles in 2 different medium; lower line -deionized (DI) water and upper line - 10 mM boric acid. The sensing materials used are (A) gold nanosphericals and (B) gold nanoplates. Scale bar for FESEM images : 100 nm.

The resonance peaks can be related to the shapes of the gold nanoparticles. The higher the number of edge of gold nanoparticles, the higher the number of peaks that presents the number of sensing parameters (Petrayeva & Krull 2011 and Tréguer-Delapierre *et al.* 2008).

Hence, it was found that the plasmonic sensor with the gold nanoparticles as sensing material is sensitive toward the presence of targeted analyte with resonance peak position and its intensity are measured as sensing parameters.

CONCLUSIONS

In this study, the plasmonic sensor was successfully developed for toxic materials detection. The sensing parameters are based on changing of their resonance peak position and its intensity.

For future work, the researcher should control the fabrication of sensing materials to produce a sharp and accurate peak position as well as intensity so that the sensitivity of this plasmonic sensor can be increased.

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