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Fabrication and Characterization of NO_2 Gas Sensor Based On One Dimensional Photonic Crystal for Measurement of Air Pollution Index

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Abstract- We have fabricated the corresponding photonic crystal (PC) structure by means of electron beam evaporation in a sample chamber at a pressure of 10^{-3}Pa with BK-7 glass substrate at temperatures of 573K. This PC device is applied as a sensor to detect the concentration of NO_2 gas dissolved in specific reagent Griess Saltzmann. From spectroscopic measurement it is found that the absorption spectral of the NO_2 gas to be in the range of light source wavelength 500-550 nm. Based on this fact, we set up the PCs to admit a photonic pass band (PPB) at a wavelength of 550 nm. To enhance the performance, the device is designed to work on the basis of both absorption and PPB variation phenomena. The experimental results show that the response of the device correlates linearly with the concentration of dissolved NO_2 gas and exhibits high sensitivity with coefficient determination of 99%. This sensor is potential to apply in an air pollution index measurement system
Keyword: air pollution, NO_2 gas, photonic crystals, photonic pass band, reagent.

I. INTRODUCTION

Air pollution is the term used to describe any harmful gases in the air we breathe. Pollution can be emitted from natural sources such as volcanoes, but humans are responsible for much of the pollution in our atmosphere [1]. Ambient air pollution consists of a highly variable, complex mixture of different substances, which may occur in the gas, liquid or solid phase. Several hundred different components have been found in the troposphere, many of them potentially harmful to human health and the environment [2]. There are seven pollutant in the atmosphere where is influence for human health, such as sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), hydrocarbon (HC), particulate matter (PM) and total suspended particulate (TSP). Nevertheless, the systematic review focused on NO_2 gas. Nitrogen dioxide (NO_2) is a reddish-brown, highly reactive gas that is present in all urban air. NO_2 is a strong oxidizing agent that reacts in the air to form corrosive nitric acid, as well as toxic organic nitrates. NO_2 is a stable gas with anesthetic characteristics. The typical ambient concentration of NO_2 is much below the threshold concentration for a biological effect. NO_2 can be derived from oxidation with N content in the fuel and air oxidation with N due to heat. NO_2 are toxic, especially to the lungs. At typical ambient concentrations, NO_2 has not been proven to be related to lung disease. At higher concentrations it can irritate the lungs, cause bronchitis and pneumonia, and lower resistance to respiratory infections. Continued or frequent exposure to high levels of NO_2 can cause pulmonary edema. Inflammation of the lungs can occur 5 to 72 hours after exposure to elevated NO_2 levels. In concentrations of NO_2 gas upon 100 ppm most of animals will die [3].

The Government of the Republic of Indonesia has issued Ambient Air Quality Standard (BMUA) in the Government regulations on the Control of Air Pollution (PP No. 41 of 1999). Values of BMUA are provided for some measuring averaging time. For example, to averaging time of 1 hour, the quality standard NO_2 is 400 μg/Nm^3. This value will be compared with the average value of measurements NO_2 gas for 1 hour [3]. Table 1 shows the value of quality standard NO_2 gas at several averaging time.

Value of BMUA can be basic to determine the Air Pollutant Standards Index (ISPU). Air pollutant standards index (ISPU) is a number that does not have a unit that describes the condition of ambient air quality in specific locations and times based on the impact on human health, aesthetic values and other living things (PP No. 41 of 1999). Table 2 shows the effect ISPU of NO_2 gas and Table 3 is the limit ISPU of NO_2 gas.

TABLE 1
AMBIENT AIR QUALITY STANDARD OF NO_2

Averaging time	Value of quality standard
1 hour	400 μg/Nm^3
24 hour	150 μg/Nm^3
1 year	100 μg/Nm^3

TABLE 2
THE EFFECT AIR POLLUTANT STANDARS INDEX OF NO_2 GAS

Category	Range	NO_2

Good	0 - 50	Bit smelly
Medium	51 - 100	Smelling
Unhealthy	101 - 199	Smelly and lose color. Increased vascular reactivity of patients with asthma
Very unhealthy	200 - 299	Increased sensitivity of patients with asthma bronchitis
Dangerous	>300	Dangerous level for all exposed populations

Decree of the Chairman of Environmental Impact Control Agency
No. 107 of 1997 Date of 21 November 1997

TABLE 3
LIMIT AIR POLLUTANT STANDARS INDEX OF NO_2 GAS IN SI UNITS

ISPU	1 hour NO_2 ($\mu g/Nm^3$)
50	-2
100	-2
200	1130
300	2260
400	3000
500	3750

Decree of the Chairman of Environmental Impact Control Agency
No. 107 of 1997 Date of 21 November 1997
Note: 1. at temperatures of 298K and at a pressure of 10^{-3}Pa
2. There is no index that can be reported at low concentrations with short-term exposure

Many types of measurement systems have been available to detect pollutants in ambient air; one of them is with the development of photonic crystal sensor. The review is carried out numerical studies of one-dimensional photonic crystal with two defects that indicate that the position of photonic pass band (PPB) in the photonic band gap (PBG) can be varied by changing the refractive index and thickness of the geometry on both defects. Both defects are referred to as regulators and receptors, each of which shows typical properties. The effect of changes in the regulator cause changes in frequency or wavelength that is transmitted by electromagnetic waves that pass through the photonic crystal. The effect of changes in the receptor results a change in transmittance values. The application of one-dimensional photonic crystal sensor with two defects for gas detection applied to pass through the phenomenon of photonic pass band (PPB) with changes in the refractive index of the material on the second defect as a pollutant gas sample, where the variation of the refractive index on the second defect layer responsibility to changes in transmittance [4]

One-dimensional of photonic crystal's design shown in Fig. 1. The number of cells lining in the left of D_1, between D_1 and D_2, and D_2 on the right, consecutive is given by M, L, and N. The design was made with the configuration M = 4, N = 6 and L = 2. In the first cell defect, the high index layer has twice the thickness of the other layers with the low index layer left unchanged, while in the second cell defects separated by 4 unit cells, the first layer is a void to be filled with the sample

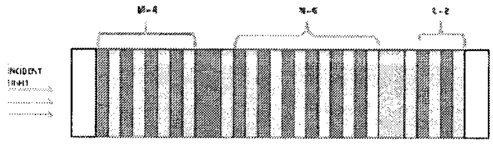


Fig 1. One-dimensional of photonic crystals design.

solution. Parameter values were as follows: $n_0 = 1$ (air), $n_s = 1.57$ (BK-7), $n_1 = 2.1$ (OS-5), $n_2 = 1.38$ (MgF_2) and satisfy the condition optical thickness of quarter wave stack: $n_1 d_1 = n_2 d_2 = \lambda_0/4$, where the operating wavelength λ_0 provided by 550 nm. Three defect selected cell is identical, with the $d_{d1} = d_{d2} = d_{d3} = \lambda_0/2$ [5].

This research will be developed fabrication and characterization of NO_2 gas sensor based on one-dimensional photonic crystal for measurement of air pollution index. Application of the sensor one-dimensional photonic crystal with two defects for the detection of NO_2 gas is applied through the phenomenon of PPB variation with changes in the refractive index of the material on the second defect as a NO_2 gas sample, where the variation of the refractive index at the second defect layer allows the change of transmittance response [6].

II. METHODOLOGY

A. Fabrication of photonic crystal

Photonic crystal substrate made of standard glass material known as BK-7 is a glass material *borosillicate crown* with a refractive index of 1.52 with light transmission range 300 nm to 2.0 µm. The substrates were cleaned are placed in a special dome for the multilayer coating. Then, dome inserted into a vacuum chamber in which coating material has been prepared for the fabrication of photonic crystal. Fabrication of photonic crystal was performed by the method of electron beam evaporation at a pressure of 10^{-3} Pa and the temperature of 573K. Coating process conducted in two phases. First, the coating 22 layer of the layer-1 to layer-22 before a second defect in accordance with the design of photonic crystal coatings that have been studied and simulated by numerical analysis. In this first process includes the first defect is located in the ninth layer. This process is implemented on a substrate-1 as a BK-7 glass. Secondly, the coating 5 layer from layer-28 to layer-24, whereas the layer-23 is a void to place a reagent solution to be analyzed. This process is implemented on a substrate-2 is also a BK-7 glass. After that, carried out checks USPM photonic crystals by using a spectrophotometer (Fig. 2).

B. Gas Sampling

Each chamber is filled with a reagent solution of Saltzmann Griess for 10 ml. This procedure was performed for absorbing NO_2 from ambient air (Fig. 3). Data is collected for 1 hour with a flow rate of 0.4 L/min.

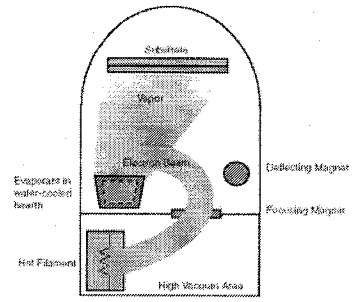
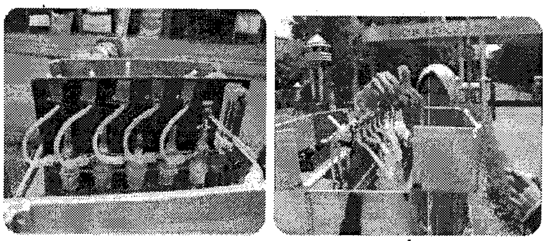


Fig 2. Fabrication photonic crystal used by electron beam evaporation.



a b

Fig 3. a. Air sampler, b. setting and treatment for air sampling activity.

C. Chemical analysis

This procedure is used to measure concentration of absorbed NO_2 gas from ambient. Stage of chemical analysis consists by making calibration standard solution NO_2 and absorbance measurements of each solution using a spectrophotometer at a wavelength of 550 nm. Stages chemical analysis shown in Fig. 4.

D. Spectrometry analysis

Characterization performed using the method of UV-VIS Spectrophotometer Ocean Optics USB 4000 to measure the transmittance photonic crystals sensor with a refractive index defect at the receptor. Fig. 5 shown a schematic implementation of the characterization sample on the defect

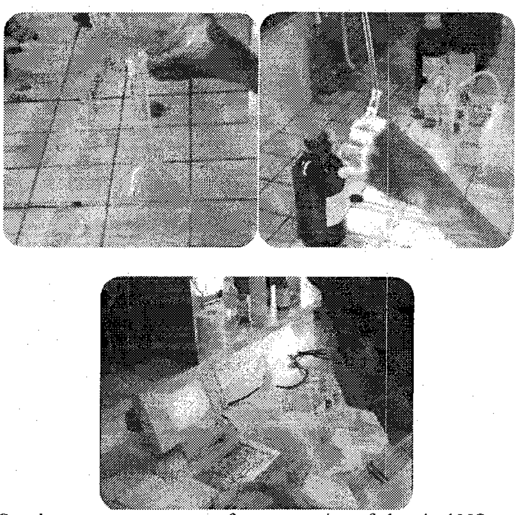


Fig 4. Step by step measurement of concentration of absorbed NO_2 gas from ambient.

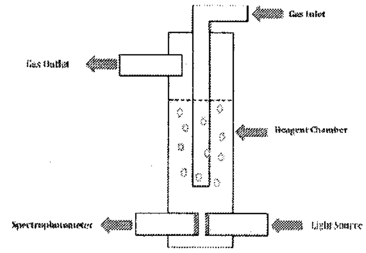


Fig 5. Illustration of reagent chamber that used to characterize PC, reagent and sensing test of PC sensor.

using reagent solution that has reacted with NO_2. This procedure is used to analyze photonic crystal response spectra, absorption spectra of NO_2 gas, and sensing test of PC sensor to detect concentration NO_2 in reagent solution

III. Result and Discussion

Based on the results of UV-VIS spectroscopic measurements indicated that the maximum absorbance spectrum of NO_2 in Griess saltzmann reagent located at a wavelength of 500-550 nm. So that, we made photonic crystals with photonic band pass (PPB) which correspond to this wavelength. Design of PC sensor based on maximum absorbance spectra of NO_2 gas that absorbed by Griess Saltzmann reagent to combine Beer Lambert's Law and PPB phenomena (Fig. 6). Fabrication of photonic crystal using electron beam evaporation method produced photonic crystal with PPB wavelength at 533 nm. This result has deviation up to 3% from design of 550 nm (Fig. 7).

Fig. 8 shows variation of PPB spectra that response to several of concentration of absorbed NO_2 gas. The results of spectroscopic measurements showed increased concentrations of NO_2 caused in an increase transmittance. The linear correlation indicates that the photonic crystal sensor is able to respond various changes in increasing concentrations of absorbed NO_2 gas. Plot of correlation of PPB peak and concentration of the reagent shown by Fig. 9. This result has been validated by PPLH-IPB using chemical analysis. Comparison of calculations and measurement results could be described by solid square and circle notation in Fig. 9.

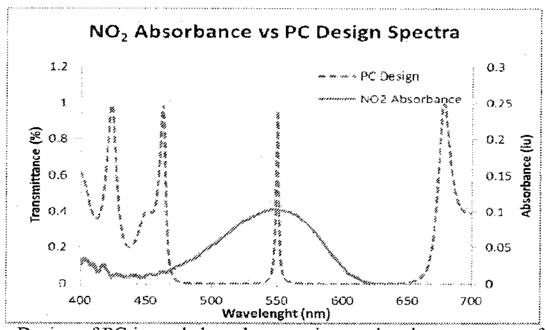


Fig 6. Design of PC is made based on maximum absorbance spectra of NO_2 gas that absorbed by Griess Saltzmann.

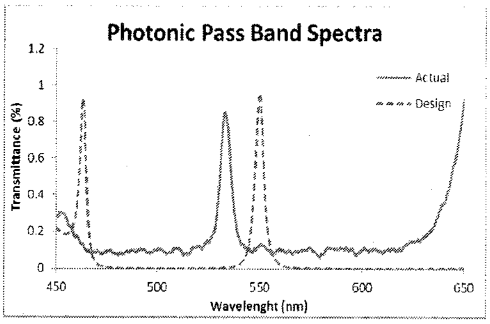


Fig 7. Comparation PPB spectra of design and actual fabricated PC. Actual PC has 3% deviation from the design.

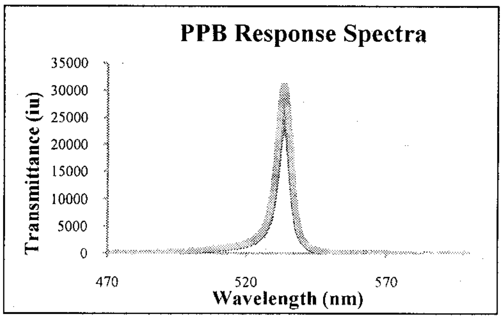


Fig 8. Variation of PPB spectra in various concentration of absorped NO_2 gas.

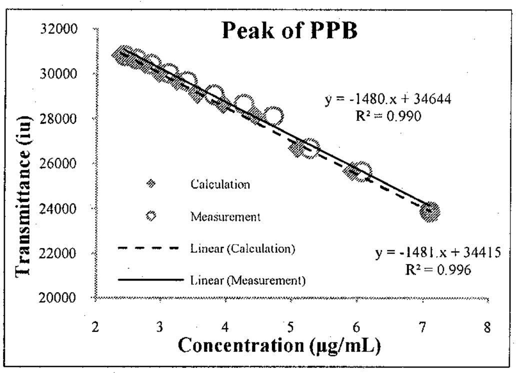


Fig 9. Linear Regression of PPB peak in various concentration of absorped NO_2 gas. The result shows coeffecient determination of 99%.

IV. Conclusion

There is a correlation between elevated concentrations of pollutant NO_2 gases with a transmittance. Photonic crystal sensor is a response to changes in concentration of NO_2 gas. The application of photonic crystal is potential for measurement of NO_2 gas from ambient with coefficient determination up to 99%.

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