Sensitivity and Selectivity of an Ozone Sensor for the UV Spectrum

Michael David, *Student Member* IEEE, Tay Ching En Marcus, Maslina Yaacob, Mohd Rashidi Salim, Mohd Haniff Ibrahim, Sevia Mahdaliza Idrus, Asrul IzamAzmi, and Nor Hafizah Ngajikin

***Abstract*— The use of optical retro-reflectors in improving the sensitivity of an optical sensor base on optical absorption spectroscopy for the measurement of ozone gas to increase optical path length is presented in this article. Two optical retro-reflectors were employed in the design of a 20cm absorption gas cell. Our analysis shows that, in the 20cm gas cell we can achieve a sensitivity value of 0.0681ppm. However these sensitivity values are dependent on the optical density of the sensor. In addition the 20 cm gas cell has a better potential for a faster sensor response time. Also, at 253.7nm, ozone can be detected with minimal interference in the presence of CO_2 and SO_2.**

***Index Terms* — Monitoring, Optical path length, Optical recto-reflectors, Ozone, Selectivity, Sensitivity.**

I. Introduction

INCREASINGLY, more research activities have been devoted towards the sensing and monitoring of gases that constitute hazard to the wellbeing of humanity [1]. Ozone, though a toxic gas has a wide range of industrial applications; however, exposure to unsafe level of ozone is associated with inherent health dangers such as allergy, - asthma, breathing difficulty, inflammations, premature ageing of the lungs, and irritations in the human body; and as a bye product of the drying process in a printing press it can result to cancer and heart and blood related diseases, [2, 3, 4, 5, 6].

The monitoring of ozone using optical absorption spectroscopy has been in use and is widely accepted [7]. Ozone has peak absorption at 253.7nm and 603nm [8]. The working principle of gas cells of the optical gas sensor is based on Beer Lamberts law which states that if radiation of intensity I_0 is directed at an analyte of path length L, radiation of intensity I_t leaves the analyte [9]. It mathematically stated as:

$$I_0(\lambda) = I_t(\lambda)10^{\varepsilon(t,p,\lambda)LC} \quad [10, 11] \qquad (1)$$

Where,

- ε = the decadic molar absorption coefficient of the sample being measured
- c = the concentration of the sample.

By increasing ε and/or L the absorption sensor can be very sensitive [10].

Michael David (corresponding author. email: mdavid2@live.utm.my), Tay Ching En Marcus, Maslina Yaacob, Mohd Rashidi Salim, Mohd Haniff Ibrahim, Sevia Mahdaliza Idrus, Asrul IzamAzmi, and Nor Hafizah Ngajikin, are all currently with Lightwave Communication Research Group, Infocomm Research Alliance, Faculty of Electrical Engineering, Universiti Teknologi Malaysia.

II. Problem Statement

Ozone sensing has become increasingly important because of ozone application in many industrial processes, its concentration variations and the health hazards associated with the exposure to unsafe quantity of ozone gas. Ozone sensing with spectroscopic methods witness a great revolution with the advent of fiber optics; however sensor sensitivity, selectivity and response time has remain trio challenges. In recent times retro reflectors has been employed to increase path length of light which in turn increases sensitivity and yet there is still the need to improve on the measured sensitivity and sensor response time.

III. Methodology

The Sensitivity *(S_s)* of a Sensor is the smallest amount of analyte concentration which it is built to measure that it can measure.

Referring to (1), we make C the subject of the equation as shown below:

$$C = \left(\frac{1}{\varepsilon(t,p,\lambda)L}\right) \log_{10}\left(\frac{I_0}{I_t}\right)$$

$$C = \left(\frac{1}{\varepsilon(t,p,\lambda)L}\right) D$$

Where D is the optical density

$$C = \left(\frac{D}{\varepsilon(t,p,\lambda)L}\right) \qquad (2)$$

From (2),

Increasing the value of $\varepsilon(t,p,\lambda)$; and/or
Increasing the value of L;
Reduces the value of C and these results in the increase of Sensor sensitivity (S_s).

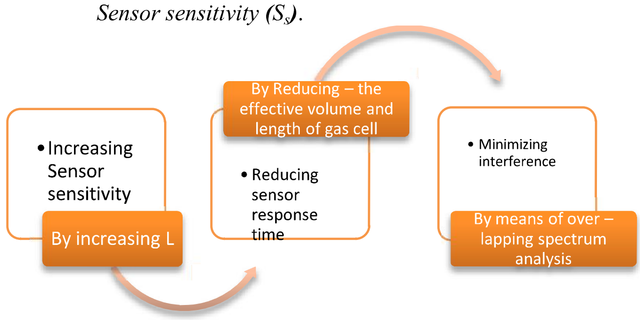

Fig. 1: Research Methodology

Selectivity (S_L) of a sensor is its ability to discern a certain gas from others [12]. The overlapping spectrum comparison method for interference study is adopted for this study [13]. Spectrums for O_3, CO_2 and SO_2 obtained from MPI-Mainz-UV-VIS Spectral Atlas of Gaseous Molecules [13] are compared at room temperature.

The response time of a sensor is a function of the velocity or rate of diffusion of gas, density of gas, length and volume of gas cell, operating temperature and pressure and other related factors. Hence the reasons for reducing the length of gas cell from 40cm to 30cm and to 20cm [14].

IV. NEW SENSOR DESIGN

Our proposed sensor design is based purely on the light propagation principle in an optical retro-reflector. An optical retro-reflector has three internal surfaces; light incident at 90° is reflected by the three surfaces and reflected light returns parallel to the incident light [15]. Our gas cell aligns two retro-reflectors. The complete experimental set up is illustrated in fig. 2.

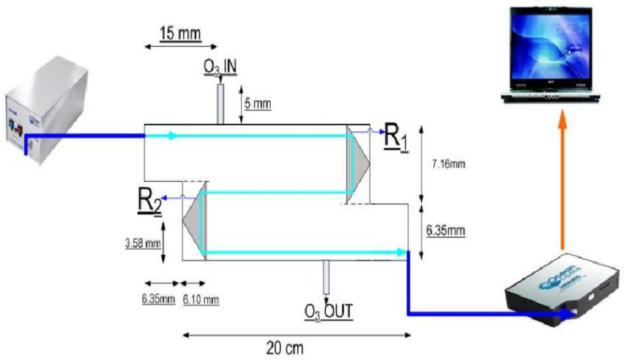

Fig. 2: Proposed ozone gas cell with two optical recto-reflectors

V. ANALYTICAL RESULTS

In the analysis below, Fig.3 is when the optical densities of-

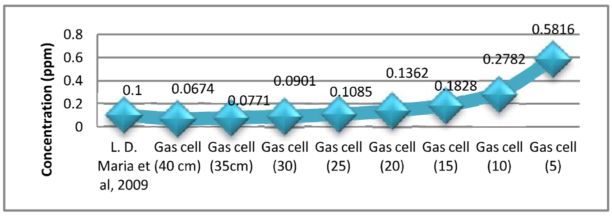

Fig. 3: Analyte concentrations with equal values of optical densities.

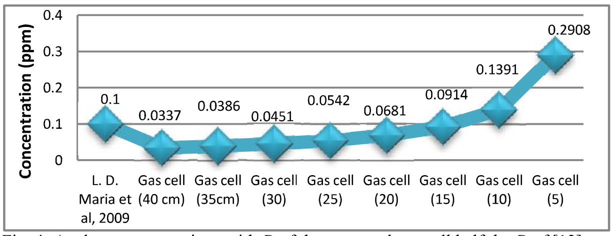

Fig. 4: Analyte concentrations with *D* of the proposed gas cell half the *D* of [12].

- our proposed gas cell and that of [16] are both equal. Fig. 4 and Fig. 5 are when the optical density of our proposed gas cell is half and twice the value of that of [16] respectively.

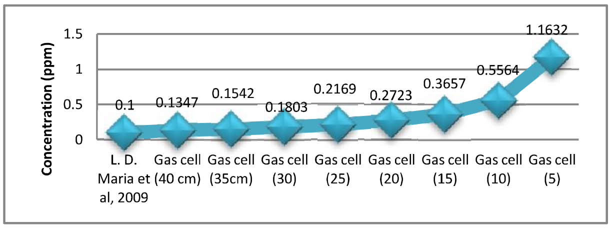

Fig. 5: Analyte concentrations with *D* of the proposed gas cell twice the *D* of [12].

VI. CONCLUSION

Using N-numbers of optical retro-reflectors the optical path length of an optical gas sensor can be greatly increased thus increasing sensitivity. With two retro-reflectors in a 20cm gas cell as compared with one retro-reflector in a 40cm gas cell, sensitivity of a gas sensor can be increased to 0.0681ppm. However this depends on the optical density of the sensor. The 20 cm gas cell has the potential for faster sensor response time. 235 nm is suggested to enhance selective ozone masurements at the UV spectrum.

REFERENCES

[1] Y. Han, T. Liang, X. Yang, X. Ren, and Y. Yin, "Research on Optical Air Chamber of Infrared Gas Sensor," *Proceedings - 2010 1st International Conference on Pervasive Computing, Signal Processing and Applications, PCSPA* 2010, Pp 33-36.

[2] G. Yu, J. Lin, and F. Qian, "Measurement of Ozone in the Printing Process," Advanced *Materials Research* Vol. 380, pp 201-204, 2012.

[3] M. Degner, N. Damaschke, H. Ewald, S. O'Keeffe, and E. Lewis, "UV LED-based fiber coupled optical sensor for detection of ozone in the ppm and ppb range," *Proceedings of IEEE Sensors, 2009* pp. 95-99.

[4] Air Quality Guidelines for Europe. WHO Regional Publications, European Series, Second Edition, No. 91. 2000. http://www.euro.who.int/__data/assets/pdf_file/0005/74732/E71922.pdf. pp 181, 182.

[5] E. Hawe, G. Dooly, P. Chambers, C. Fitzpatrick, and E. Lewis, "Gas detection using an Integrating Sphere as a Multipass Absorption Cell," *Proceedings of SPIE – Proceedings of SPIE - The International Society for Optical Engineering, v 6379, 2006*, Photonic Applications for Aerospace, Transportation, and Harsh Environments.

[6] M. A. Gondal, A. Dastageer, & Z. H. Yamani, "Laser-induced photo acoustic detection of ozone at 266 nm using resonant cells of different configuration," *Journal of Environmental Science and Health - Part A Toxic/Hazardous Substances and Environmental Engineering*, v 44, n 13, p 1457-1464. October, 2009.

[7] M. Köhring, U. Willer, S. Böttger, A. Pohlkötter, and W. Schade, "Fiber-Coupled Ozone Sensor Based on Tuning Fork-Enhanced Interferometric Photoacoustic Spectroscopy," *IEEE Journal of Selected Topics in Quantum Electronics*, Vol. 18, No. 5,pp 1566- 1572. January, 2012.

[8] S. O'Keeffe, C. Fitzpatrick, E. Lewis, "An optical fibre based ultra violet and visible absorption spectroscopy system for ozone concentration monitoring," *Sensors and Actuators B: Chemical* Volume 125, Issue 2, Pages 372–378. August, 2007.

[9] R.C. Denney, Dictionary of spectroscopy, 2nd ed. Willey, 1982, p.119-20.

[10] S. W. Otto, "Introduction," *Fibre Optic Chemical Sensors and Biosensors*, Volume I. CRC Press Boca Raton Ann Arbor Boston London.1991.

[11] G. Dufour, A. Valentin, A. Henry, D. Hurtmans, and C. Camy-Peyret, "Concentration and Measurements of Ozone in the 1200 – 300 ppbv range: an Intercomparison between the BNM Ultraviolet Standard and Infrared Methods," *Spectrochimica Acta - Part A: Molecular and Biomolecular Spectroscopy*, v 60, n 14, pp 3345-3352. December, 2004.

[12] G. Li and S. Kawi. MCM-41 Modified Sno2 Gas Sensors: Sensitivity and Selectivity Properties. Sensors and Actuators B 59 (1999) 1 – 8

[13] Hannelore Keller-Rudek, Geert K. Moortgat, *MPI-Mainz-UV-VIS Spectral Atlas of Gaseous Molecules*, www.atmosphere.mpg.de/spectral-atlas-mainz

[14] K. Teranishi, Y. Shimada, N. Shimomura, and H. Itoh, "Investigation of Ozone Concentration Measurement by Visible Photo Absorption Method," *Ozone: Science & Engineering: The Journal of the International Ozone Association*, 35:3, 229-239, March, 2013.

[15] J. Liu, and R. M. A. Azzam, "Polarization properties of corner-cube retroreflectors: theory and experiment," Applied *Optics*, Vol. 36, Issue 7, pp. 1553-1559. March, 1997.

[16] L. D. Maria, and G. Rizzi, "Ozone Sensor for Application in Medium Voltage Switchboard," *Journal of Sensors* vol. 2009, Article ID 608714, 5 pages, 2009. doi:10.1155/2009/608714.