OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 16, No. 9-10, September-October 2022, p. 414 - 418

Comparative study on single and double optical microbottle resonator for ethanol gas sensor

MD ASHADI MD JOHARI[1], MOHD HAFIZ BIN JALI[2], HAZIEZOL HELMI BIN MOHD YUSOF[3], AMINAH BINTI AHMAD[1], A. R. MUHAMMAD[4], MUHAMMAD IMRAN MUSTAFA ABDUL KHUDUS[5], SULAIMAN WADI HARUN[6]

[1]*Faculty of Electrical and Electronic Engineering Technology, Universiti Teknikal Malaysia Melaka, 76100 Melaka, Malaysia*
[2]*Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, 76100 Melaka, Malaysia*
[3]*Faculty of Electronic and Computer Engineering, Universiti Teknikal Malaysia Melaka, 76100 Melaka, Malaysia*
[4]*Institute of Microengineering and Nanoelectronics (IMEN), Universiti Kebangsaan Malaysia (UKM) Bangi, 43600, Selangor, Malaysia*
[5]*Department of Physics, Faculty of Science, University of Malaya, 50603 Kuala Lumpur, Malaysia*
[6]*Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia*

This experimental paper studied the effect of a single and double optical microbottle resonator's effect on ethanol gas sensors. The MBR is formed in two different sizes by the “soften-and-compress” technique from silica fiber SMF28. The characterization procedure for both single and double MBR can have Q-factor > 10^5 with insertion loss value between -18 dBm until -20 dBm. The MBR then experienced ethanol gas sensing with sensitivity, linearity, stability and repeatability performance defined by transmitted power value and wavelength shift results. Ethanol gas is used from 10% to 100% ppm on every procedure. Single MBR-B, which is slightly bigger than single MBR-A, manage to have excellent performance after all. The size of MBR influenced the sensor to be better in a sense. However, double MBR shows more exquisite performance than single MBR, where numbers of MBR affect the sensor performance after all.

(Received April 19, 2022; accepted October 5, 2022)

Keywords: Optical Microresonator, Microbottle Resonator, Ethanol

1. Introduction

Recently, optical fiber technology has captured high demand in several research fields such as communication engineering, sensor, optical laser, and plasmonic devices [1-3]. However, optical microresonator (OMR), a new sub-class of optical fiber, is lately involved in optical fiber sensors [4]. The OMR is then operated by manipulating whispering gallery modes (WGMs), enhancing the resonator's performance as a sensor [5]. Several OMR with different structures has been invented, such as microring,microdisc, microball and microloop for several numbers of application [6, 7]. The effect of WGMs on the OMR was seriously being investigated through assembly procedure, quality factor, and intrinsic losses, leading to virtuous performance outcomes [8]. However, this paper explored the WGMs of OMR for gas sensors. The OMR shape introduced in this paper was known as a microbottle resonator similar to the bottle structure, and believe it may receive, unlike WGMs manipulative as sensor [9, 10]. The WGMs worked by circulating across the MBR outer surface and turned the resonator sensitive toward surrounding changes which practical use as a sensor [5, 11, 12]. The MBR may produce a free-spectral range, which is then used to calculate the quality factor and determine the quality of this sub-OMR as woks as sensor [13]. Ethanol is an organic chemical component generally found as a simple alcohol form [14]. It was written with the chemical formula of C_2H_6O, which is typically used in several medical applications like antiseptic or antidote and used in engine technology as a fuel [15]. Ethanol is colourless, slightly similar to wine, flammable, and always known as a volatile solvent [16]. Ethanol is produced by the chemical interaction of yeasts with sugars, known as the petrochemical process [17]. Ethanol has consistently been recognized as a suitable chemical solvent and continuously synthesises organic compounds [18]. Therefore, it would be the best sensing material that couraged the MBR to perform as well as the sensor.

2. Characterisation of single and double MBR

The technique used to form bottle structure known as “soften-and-compress” where utilized an electrical (Furukawa Electric Fitel S178A) arc from the splicer machine to heat the middle focused area on fiber [19] [20]. The fiber was compressed inward by the fiber holder during the heating process, allowing the heated area to bump and form the bottle look [19, 21]. The numbers of electrical arcs applied determined the size of the MBR, which guided by three parameters as bottle diameter D_b, bottle stem diameter D_s and also bottle length L_b, as showed in Fig. 1 and Table 1. Three different MBR condition are prepared based on the size and the numbers of MBR, as showed in Fig. 2. The MBRs performance determined by characterized procedure which crucially coupling with taper microfiber. The taper microfiber is formed by 'flame-brushing' technique.

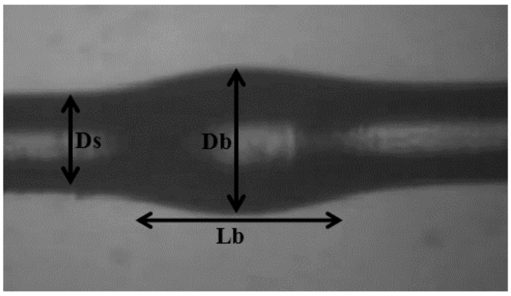

Fig. 1. Size of MBR determined by bottle diameter D_b, bottle stem diameter D_s and bottle length L_b

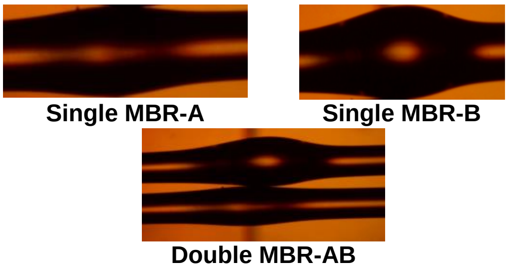

Fig. 2. Single MBR-A, single MBR-B and double MBR-AB

The coupling MBRs with taper microfiber is then connected to a tunable laser source (ANDOAQ4321D) and optical power meter (THORLABS S145C). This tunable laser source (TLS) supplied a range of wavelengths 1551.0 nm to 1552.2 nm and the optical power meter (OPM) is then used to record the final transmitted spectral. The Q-factor and FSR results of the single and double MBR calculated from the transmitted spectral to ensure the sensor's suitabilities of the resonator.

Table 1. The MBRs size based on three parameters

Micro-bottle Resonator	Neck-To-Neck Length L_b	Bottle Diameter D_b	Stem Diameter D_s
MBR-A	$200\mu m$	$170\mu m$	$125\mu m$
MBR-B	$194\mu m$	$190\mu m$	$125\mu m$

Fig. 3 shows three transmitted spectral power signals using Q-factor values by three different MBRs conditions. The insertion loss of these graphs may differ due to the coupling gap between the MBRs and the taper microfiber. Additionally, free-space modes and overlapping of partial numbers lead to changes of insertion loss. The Single MBR-A can experience -18.5 dBm, slightly higher than Single MBR-B of -20 dBm. However, the insertion loss decreased to -22 dBm when Double MBR-AB was applied, lower than the previous. The size and numbers of MBRs used may influence insertion loss and numbers of resonance depth overall.

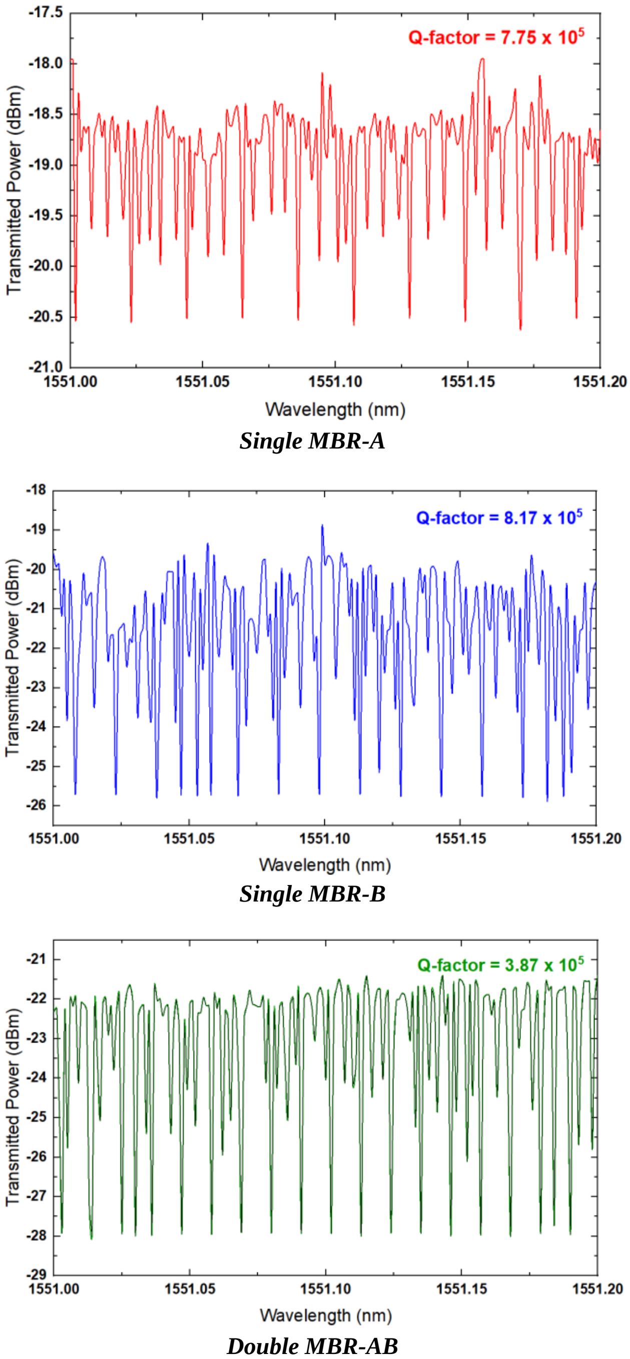

Fig. 3. Single and double MBR with different Q-factor values, numbers of resonating depth and insertion loss (color online)

The equation estimation defines the Q-factor and Lorentzian fitting, which can have $> 10^5$ for all MBRs, similar with previous. The equation estimation is determined by calculating the value of $\lambda/\Delta\lambda$ with λ marked as the frequency resonant. Fig. 3 showed that the Single MBR-B managed to have the highest Q-factor value than MBRs, due to the size bigger than others with $8.17\ x\ 10^5$.

3. Single and double MBR as ethanol gas sensor

Fig. 4 shows the experimental arrangement where the setup placed inside a sealed chamber. The cross-section of the MBRs experiences the sensing mechanism while the WGMs are deployed over the resonator. The sealed chamber is used to control the circulation of the ethanol gas, and the ethanol gas used is from 10% ppm to 100% ppm. The temperature level keeps changing due to different ethanol gas used during the process [22]. Every gas percentage produced a separate graph and repeated three times and remained 60 minutes for each repetition, preventing random error during data collection for all MBRs. The single MBR-A used input signal 1551.107 nm, single MBR-B is 1551.038 nm, and double MBR-AB is 1551.030 nm.

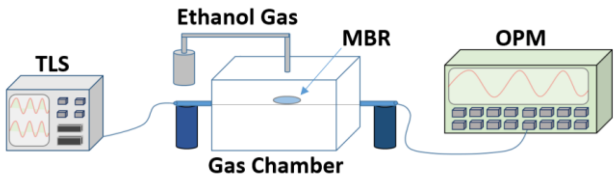

Fig. 4. The experiment setup for MBR ethanol gas sensor

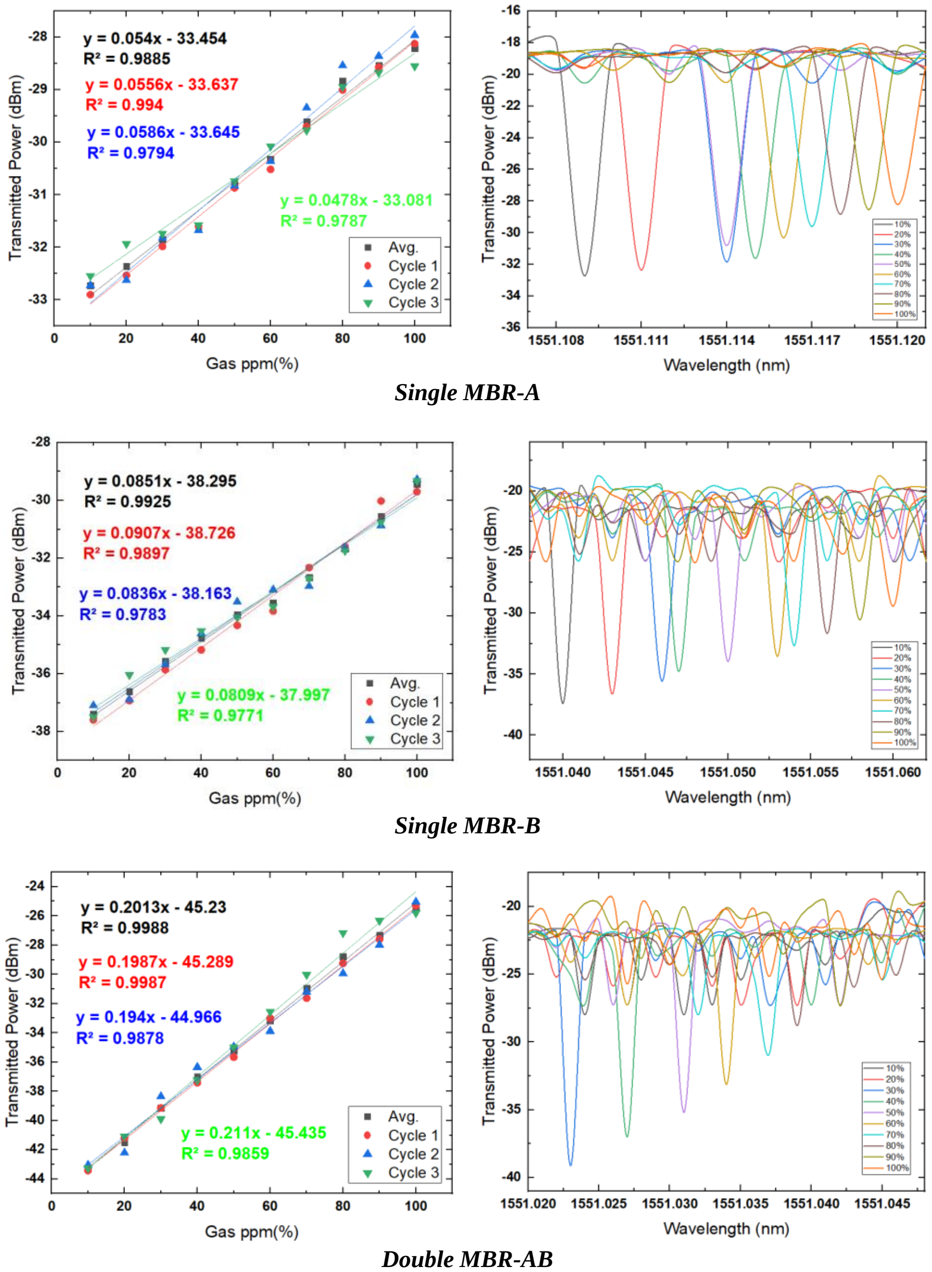

Fig. 5. Sensor performance analysis for single and double MBR ethanol gas sensor

The performance of the MBRs ethanol gas sensor determined by sensitivity, linearity, stability, and repeatability, which evaluated from the transmitted spectral and wavelength shift as Fig. 5. The transmitted spectral graph showed increases in power value for each gas used while the wavelength shifted to the right due to the increasing value of gas percentage. The Single MBR-A received sensitivity 0.054 dB/% ppm with 99.42% linearity and wavelength shifted from 1551.109 nm to 1551.120 nm with a small interval of 0.011 nm.

The Single MBR-B manage to have a sensitivity value of 0.0851 dB/%ppm with a linearity of 99.62%, which is slightly higher than MBR-A. The wavelength shifting happened in 0.02 nm interval from 1551.040 nm to 1551.060 nm. Due to the size, the MBR-B performed a suitable sensing mechanism towards ethanol gas sensing. However, the combination of single MBRs, named double MBR-AB, served well as a gas sensor with 0.2013 dB/%ppm of sensitivity and 99.93% linearity, which was higher than the bunch. The size and numbers of MBR influences performed as a sensor. Fig. 6 is the sensitivity and linearity value recorded from the shifting of the wavelength. This double MBR-AB had a higher sensitivity of 0.3 pm/%ppm with 99.6% linearity. These analyses demonstrated that a bigger size is better to be used as a sensor, and double MBR may perform better than a single MBR.

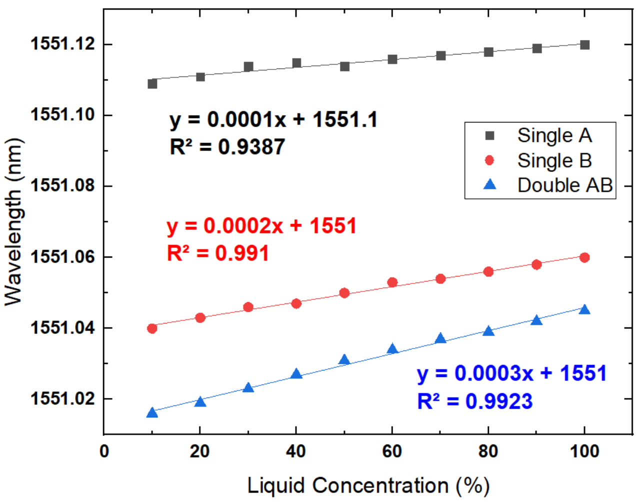

Fig. 6. Sensor performance analysis from wavelength shift data (color online)

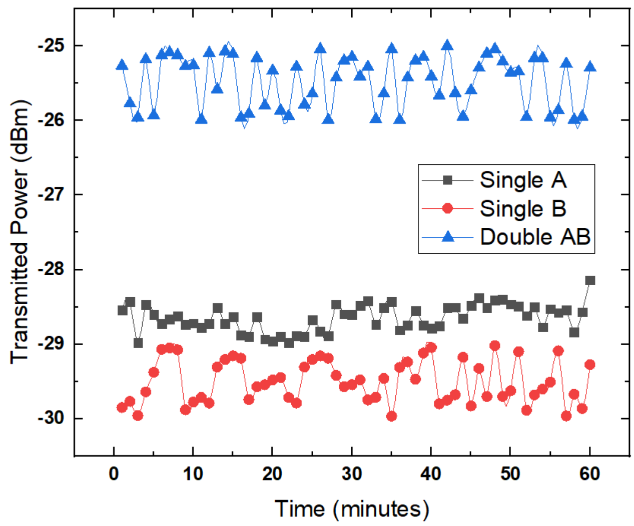

Fig. 7. The stability results (color online)

The stability performance of single and double MBR sensors as shown in Fig. 7, experienced 60 minutes stability test. However, the chart only presented 100% ppm ethanol gas represents where the MBRs showed a tremendous stability test with the power value remaining close to each reading along 60 minute periods. All results recorded in Table 2.

Table 2. Performance of single and double MBRs

From Transmitted Power			
MBRs	**Single-A**	**Single-B**	**Double-AB**
Sensitivity (dB/%ppm)	0.0540	0.0851	0.2013
Linearity (%)	99.42	99.62	99.93
From Wavelength Shift			
MBRs	**Single-A**	**Single-B**	**Double-AB**
Sensitivity (pm/%ppm)	0.1	0.2	0.3
Linearity (%)	96.8	99.5	99.6

4. Conclusions

This experimental paper inspected the presentation of single and double MBR as ethanol gas sensors. The resonators were designed by a method known as “soften-and-compress” from SMF-28 silica fiber. The MBRs characterization for Q-factor value via microfiber with $2\mu m$ diameter. The single and double MBRs managed to have a Q-factor of $> 10^5$ where the most significant size contributes the enormous value of the Q-factor. The single and double MBRs then applied as an ethanol gas sensor where 10% to 100% ppm gas was used as a sensing medium. Via transmitted spectral and wavelength shift, the single MBR-B, the biggest resonator, performed well as ethanol gas sensor. However, the performance the double MBR-AB was used as a gas sensor showed tremendous performance after all. Here, the size and resonator numbers may influence the resonator performed as a gas sensor.

Acknowledgements

The authors would like to acknowledge Fakulti Teknologi Kejuruteraan Elektrik dan Elektronik Universiti Teknikal Malaysia Melaka, Fakulti Kejuruteraan Elektrik Universiti Teknikal Malaysia Melaka, Fakulti Kejuruteraan Elektronik dan Komputer Universiti Teknikal Malaysia Melaka, Faculty of Engineering, University of Malaya and UTeM Short Grant [PJP/2021/FTKEE/S01824] for their financial support.

References

[1] M. H. Jali, H. R. A. Rahim, M. A. M. Johari, U. U. M. Ali, S. H. Johari, H. Mohamed, S. W. Harun, M. Yasin, Optics & Laser Technology **139**, 106853 (2021).

[2] H. H. M. Yusof, M. H. Jali, M. A. M. Johari, K. Dimyati, S. W. Harun, M. Khasanah, M. Yasin, IEEE Photonics Journal **11**(1), 1 (2019).

[3] A. Ahmad, X. S. Cheng, M. C. Paul, A. Dhar, S. Das, H. Ahmad, S. W. Harun, Microwave and Optical Technology Letters **61**(6), 1651 (2019).

[4] L. Wu, H. Wang, Q. Yang, Q. X. Ji, B. Shen, C. Bao, M. Gao, K. Vahala, Optics Letters **45**(18), 5129 (2020).

[5] G. S. Murugan, J. S. Wilkinson, M. N. Zervas, Optics Letters **35**(11), 1893 (2010).

[6] M. Jali, H. R. A. Rahim, H. H. M. Yusof, M. A. M. Johari, S. Thokchom, S. W. Harun, Journal of Physics: Conference Series, IOP Publishing **1371**(1), 012005 (2019).

[7] M. M. Sharif, M. A. M. Johari, A. Al Noman, M. A. Khudus, S. W. Harun, Sensors and Actuators A: Physical **304**, 111828 (2020).

[8] A. Matsko, A. A. Savchenkov, D. Strekalov, V. S. Ilchenko, L. Maleki, IPN Progress Report **42**(162), 1 (2005).

[9] M. A. M. Johari, A. Al Noman, M. A. Khudus, M. H. Jali, H. H. M. Yusof, S. W. Harun, M. Yasin, Optik **173**, 180 (2018).

[10] M. H. Jali, H. R. A. Rahim, S. S. Hamid, M. A. M. Johari, H. H. M. Yusof, S. Thokchom, S. W. Harun, M. Khasanah, M. Yasin, Optik **196**, 163174 (2019).

[11] M. A. M. Johari, M. H. B. Jali, H. H. M. Yusof, H. R. B. A. Rahim, A. B. Ahmad, M. I. M. A. Khudus, S. W. Harun, Optics & Laser Technology **143**, 107379 (2021).

[12] Md Ashadi Md Johari, Mohd Hafiz Bin Jali, Haziezol Helmi Bin Mohd Yusof, Hazli Rafis Bin Abdul Rahim, Aminah Binti Ahmad, Muhammad Imran Mustafa Abdul Khudus, Sulaiman Wadi Harun, Optoelectron. Adv. Mat. **15**, 427 (2021).

[13] M. A. M. Johari, M. P. Pour, A. Al Noman, M. I. M. A. Khudus, M. H. B. Jali, M. S. Maslinda, U. U. M. Ali, S. W. Harun, Microwave and Optical Technology Letters **62**(3), 993 (2020).

[14] C. G. Steinmetz, P. Xie, H. Weiner, T. D. Hurley, Structure **5**(5), 701 (1997).

[15] K. Sadakane, T. Ichinose, International Journal of Medical Sciences **12**(2), 116 (2015).

[16] W. R. Roderick, W. G. Brown, Journal of the American Chemical Society **79**(19), 5196 (1957).

[17] H. Sreenath, T. Jeffries, Bioresource Technology **72**(3), 253 (2000).

[18] R. Hoogenboom, H. M. Thijs, D. Wouters, S. Hoeppener, U. S. Schubert, Soft Matter. **4**(1), 103 (2008).

[19] M. A. M. Johari, M. A. Khudus, A. Al Noman, M. H. Jali, H. H. M. Yusof, S. W. Harun, M. Yasin, Journal of Physics: Conference Series, IOP Publishing **1151**(1), 012021 (2019).

[20] M. A. M. Johari, M. I. M. A. Khudus, M. H. B. Jali, M. S. Maslinda, U. U. M. Ali, S. W. Harun, A. H. Zaidan, R. Apsari, M. Yasin, Sensing and Bio-Sensing Research **25**, 100292 (2019).

[21] M. A. M. Johari, M. I. M. A. Khudus, M. H. B. Jali, A. Al Noman, S. W. Harun, Sensors and Actuators A: Physical **284**, 286 (2018).

[22] L. Wang, Y. Kang, X. Liu, S. Zhang, W. Huang, S. Wang, Sensors and Actuators B: Chemical **162**(1), 237 (2012).

*Corresponding author: ashadi@utem.edu.my