Microbottle-Resonator Ethanol Liquid Sensor

M A M Johari1,2, A H Rosol1, N A Baharuddin1, M I M A Khudus3, M H Jali1,4, Maslinda M S1, S S Jaapar5,6, S W Harun1.
1 Department of Electrical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia.
2 Faculty of Engineering Technology, Universiti Teknikal Malaysia Melaka, 76100 Melaka, Malaysia
3 Department of Physics, Faculty of Science, University of Malaya, 50603 Kuala Lumpur, Malaysia
4 Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, 76100 Melaka, Malaysia
5 School of Data Sciences, Perdana University
6 Adnuri SMA Research Center Sdn.Bhd
Email: swharun@um.edu.my

Abstract. This investigation studies the use microbottle resonator (MBR) as ethanol liquid sensor. This resonator made-up from silica fiber SMF28 using process recognized as “soften-and-compress” to form bottle structure with a diaphragm diameter $D_b = 170\mu m$, stem diameter of $D_s = 125\mu m$ and bottle length $L_b = 180\mu m$. The MBR characterized by via 3μm tapered microfiber and bright to have $>10^4$ for the quality factor value (Q-factor). The MBR was formerly used as ethanol liquid sensor for the range between 10% to 100% and compared with non-MBR microfiber for wide-ranging performance. The MBR sensor was initiate to have a sensitivity $0.1756 \text{ dB/%ppm}$ with linearity 99.28% and standard deviation of 3.355 dB, which was exceptional compare to the non-MBR microfiber in all limitation measured.

1. Introduction
Optical microresonator (OMR) has established significant reputation due to widespread ability in sensors, laser and also for some plasmonic devices [1-9]. The OMR has been designed in perceptible structure such as micropillar, microring also microdisc and it was expressively work at some definite wavelength by internal reflection in continuous resonant [10-18]. The concept of this reflection was primarily exposed by Lord Rayleigh in the dome of St. Paul’s cathedral in London which is acknowledged as whispering gallery modes (WGM) [19]. Lord Rayleigh revealed that along the dome length at some specific point, the sound could be hear obviously. The sound wave was then so-called as whispering gallery modes. The idea of the sound along the dome dimension was then interpreted in the optical micro resonator with the alike construction, which produce alike resonance structures for WGM. The WGM which functioned on resonator, was then revealed having numerous advantages including in fabrication, minimal losses and able to produce high quality factor (Q-factor) based on resonator classification [20, 21]. One of WGM resonator geometry apprehended interest recently due to competence on having high Q-factor. It was known as micro-bottle resonator (MBR); designed in micro size from silica-based fiber [21, 22]. Due to these advantages including high sensitivity, high accuracy
lesser losses, the MBR has been used in various sensing purposes, including humidity and formaldehyde sensing [23-27].

In this paper, we explore the capability of MBR for ethanol liquid sensor. The performance of MBR as an ethanol liquid sensor was compared with non-MBR microfiber. The MBR was molded from standard silica fiber SMF28 using the technique known as “soften-and-compress.” For characterization of the MBR, 3μm microfiber was used together with optical power meter and tuneable laser source. The MBR was employed for ethanol liquid in a range of 10% - 100% ppm and compared with non-MBR microfiber for complete sensing performance.

2. Micro-bottle Resonator Fabrication and Characterization

The optical micro-resonator was formed using silica fiber SFM28 using the method known as “soften-and-compress” [28]. A manual splicing machine (Furukawa Electric Fitel S178A) was used to fix the silica fiber position. The heat from the splicing machine was applied on the middle area and the fiber was compressed inwards from both sides. This procedure allowed the creation of a bugle on the silica fiber and the bugle size was determined by the number of arcs employed [22]. The resonator in bottle structure is defined by three parameters: the bottle diameter $D_b$, the stem diameter $D_s$, and the bottle length $L_b$, as shown in Figure 1. The bare microfiber with a diameter of 3μm was made up from SMF28 silica fiber using the “flame brushing” procedure [29].

![Figure 1](image_url)

Figure 1. The MBR fabricated from SMF28 with $L_b = 180 \mu m$, $D_b = 170 \mu m$ and $D_s = 125 \mu m$

For the characterization of the MBR, a tuneable laser source (ANDO AQ4321D) was used to supply a range of wavelengths and optical power to the microfiber (THORLABS S145C) for collection of the final output. This tuneable laser source (TLS) was able to supply wavelengths in the range of 1520 nm to 1620 nm, which is suitable for the MBR characterization. The wavelength from the TLS was adjusted from 1550 nm to 1575 nm (with 0.001 nm interval) and launched into the MBR over the tapered microfiber with 3μm waist diameter. Figure 2 denoted the transmission spectral of the MBR with numerous sharp resonant peaks [30]. The graph displayed the insertion loss roughly at -17dBm and it was possibly enhanced by monitoring a gap in the coupling between the MBR and tapered microfiber [31]. The Q-factor used to determine the quality of the resonant peak of the MBR and define as $\Delta\lambda/\lambda$ where $\lambda$ is the resonant wavelength and is recorded to be $1.534 \times 10^7$ which is less than the earlier work [32]. The is owed to the tapered microfiber size and the size of the MBR and gives a huge influence in the Q-factor.
3. Ethanol Liquid with Different Percentage of Concentration Preparation Process

Ethanol is a simple alcohol which can be produced synthetically from petroleum by-product or naturally from plant fermentation. It appears as colourless liquid organic solvent and possess hydroxyl (OH) group moieties, two single bonded carbon atoms with five hydrogen atoms in its molecular structure [33, 34].

Ethanol solvent is particularly important chemicals in research, medicine, industrial as well as the most critical ingredient in food and beverage in our daily lives [33, 35, 36] highlights the considerable amount of ethanol percentage should be presence in the food and beverage industry as it is crucial to maintain the quality and safety of products. This is due to the fact that ethanol is suffered from alcohol intoxication which may cause anxiolytic effect, short term memory loss, locomotor suppression, motor incoordination and the loss of righting reflex or narcosis to the consumer [33]. On the other hand, in ASEAN country such as Malaysia, Thailand and Singapore the halal products are allow to have a little of ethanol content (0.5-1%), while Brunei, United Kingdom and Canada ethanol is not allowed [37].

Due to these phenomena, variable methods have been used in detecting ethanol such as Fourier Transform Infrared Spectrometer (FTIR), chromatography and raman spectrophotometer. Unfortunately, the drawback of this method is time consuming and require large sample [38]. To overcome this limitation, researchers have developed optical ethanol sensor which is able to detect the concentration of ethanol in rapid and accurate method for the on-site ethanol detection [36, 38].

4. Experiment Setup for The MBR Ethanol Liquid Sensing

An experiment setup of the MBR ethanol liquid sensor shown in Figure 3. The microfiber and the MBR are positioned on the stage with an ethanol liquid located under the stage. The MBR is situated between the microfiber and ethanol liquid. This is to certify the MBR able to couple with the microfiber and touch the ethanol in the same time. The setup was seal inside the compartment at ambient room temperature of 250°C at atmospheric pressure 1.0 atm. One end of fiber connected to TLS while another end is connected to OPM. The ethanol liquid was then changeable from 10% to 100% concentrations. The TLS wavelength is 1560 nm and the output power recorded at different ethanol concentrations. Both performances are compared to define the best ethanol liquid sensing.
Figure 3. The MBR in between ethanol liquid and tapered microfiber of 3μm. The tuneable laser source and optical power meter connected to the end of fiber.

5. The MBR and Bare Microfiber Performance as Ethanol Liquid Sensor

The averaged output power (dBm) of the MBR and non-MBR microfiber at different concentrations of ethanol display in Figure 4. Usually, the output power increased once the level of concentration rises. The outcomes of the sensor performance showed in Table 1 wherever sensitivity, linearity and standard deviation used as parameters. The performance of the MBR is so much surpass than non-MBR microfiber for all parameter. Truly, the sensitivity of the MBR is 0.07 dB/%ppm then non-MBR microfiber (0.1756 dB/% as compare to 0.1049 dB/%). The linearity of the MBR is 99.28%, better than non-MBR microfiber where is only 83.01%. All these outcomes showed the MBR is outperforms the non-MBR microfiber as per ethanol liquid sensor. Throughout spectral transmission, the light experienced multiple rotation on the MBR where is each circular were increase the adsorption, consequently increase the sensitivity [39, 40].

Figure 4. The output power value for MBR and bare microfiber varies with percentage of ethanol concentrations.
Table 1. Analysis of MBR and bare microfiber performance in ethanol liquid sensing activity.

| Parameters                  | Non-MBR Microfiber | With MBR Microfiber |
|-----------------------------|--------------------|---------------------|
| Linearity (%)               | 83.01%             | 99.28%              |
| Sensitivity (dB/%ppm)       | 0.1049             | 0.1756              |
| Standard deviation (dBm)    | 5.827              | 3.355               |
| Linear Range (% ppm)        | 10 - 100           | 10 - 100            |

6. Conclusion
We have examined the performance of MBR ethanol liquid sensors. The “soften-and-compress” procedure was used to structure the MBR with bottle diameter of $D_b=170 \mu m$, stem diameter of $D_s=125 \mu m$ and bottle length of $L_b=180 \mu m$. A silica microfiber by a waist diameter of 3 μm was applied to launch a light from a TLS to the MBR. The TLS wavelength range remained set to 1550.00 nm and 1575.00 nm with an intermission of 0.001 nm for the measurement. A Q-factor of $>10^5$ was documented for the MBR. Following, the performance of the MBR ethanol liquid sensor were examine and compare with non-MBR microfiber. The sensitivity, linearity and standard deviation would be being documented to evaluate the performance of the MBR sensor. The linearity of the MBR are $>90\%$ which is show that the MBR are performed so well than non-MBR microfiber is only $<90\%$. However, the MBR showed batter sensitivity as compared to non-MBR microfiber, whose highest sensitivity 0.1756dB/%RH. standard deviation for non-MBR microfiber is much higher then the MBR which less accuracy for non-MBR microfiber as ethanol liquid sensor.

Acknowledgement
The authors would like to acknowledge University of Malaya and Ministry of Education, Malaysia, Fakulti Teknologi Kejuruteraan Elektrik dan Electronik, Universiti Teknikal Malaysia Melaka and the University of Malaya for their financial support.

References
[1] Chiasera A, Dumeige Y, Feron P, Ferrari M, Jestin Y, Nunzi Conti G, Pelli S, Soria S and Righini G C 2010 Spherical whispering-gallery-mode microresonators Laser & Photonics Reviews 4 457-82
[2] Matsko A, Savchenkov A, Strekalov D, Ilchenko V and Maleki L 2005 Review of applications of whispering-gallery mode resonators in photonics and nonlinear optics IPN Progress Report 42 1-51
[3] Berini P 2009 Long-range surface plasmon polaritons Advances in optics and photonics 1 484-588
[4] Berini P, Charbonneau R and Lahoud N 2007 Long-range surface plasmons on ultrathin membranes Nano letters 7 1376-80
[5] Bykov V and Silichev O 1995 Laser Resonators, Cambridge Intl Science Publ
[6] Rosol A H A, Rahman H A, Ismail E I, Irawati N, Jusoh Z, Latiff A A and Harun S W 2017 Cadmium Selenide Polymer Microfiber Saturable Absorber for Q-Switched Fiber Laser Applications Chinese Phys. Lett 34 094202
[7] Rosol A, Latiff A, Khudus M A and Harun S J I J o P 2019 Nanosecond pulses generation with rose gold nanoparticles saturable absorber 1-5
[8] Rosol A H A, Rahman H A, Ismail E I, Jusoh Z, Latiff A A and Harun S W J C O L 2017 Mode-locked fiber laser with a manganese-doped cadmium selenide saturable absorber 15 071405
[9] Rosol A H A, Rahman H A, Ismail E I, Irawati N, Jusoh Z, Latiff A A and Harun S W J C P L 2017 Cadmium selenide polymer microfiber saturable absorber for Q-switched fiber laser applications 34 094202
[10] Little B E, Chu S T, Haus H A, Foresi J and Laine J-P 1997 Microring resonator channel dropping filters Journal of lightwave technology 15 998-1005
[11] Absil P P 2000 Microring resonators for wavelength division multiplexing and integrated photonics applications
[12] Kokubun Y 2005 Wavelength selective integrated device by vertically coupled microring resonator filter Photonics Based on Wavelength Integration and Manipulation IPAP Books 2 303-16
[13] Armani D, Kippenberg T, Spillane S and Vahala K 2003 Ultra-high-Q toroid microcavity on a chip Nature 421 925
[14] Armani D, Min B, Martin A and Vahala K J 2004 Electrical thermo-optic tuning of ultrahigh-Q microring resonators Applied physics letters 85 5439-41
[15] Gérard J, Sermage B, Gayral B, Legrand B, Costard E and Thierry-Mieg V 1998 Enhanced spontaneous emission by quantum boxes in a monolithic optical microcavity Physical review letters 81 1110
[16] Sarma J and Shore K 1985 Electromagnetic theory for optical disc resonators IEE Proceedings J (Optoelectronics) 132 325-30
[17] Srinivasan K, Barclay P E, Painter O, Chen J, Cho A Y and Gmachl C 2003 Experimental demonstration of a high quality factor photonic crystal microcavity Applied Physics Letters 83 1915-7
[18] Lee P-T, Lu T-W, Tsai F-M and Lu T-C 2006 Investigation of whispering gallery mode dependence on cavity geometry of quasiperiodic photonic crystal microcavity lasers Applied physics letters 89 231111
[19] Rayleigh L 1910 CXII. The problem of the whispering gallery The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science 20 1001-4
[20] Lee P-T, Lu T-W, Fan J-H and Tsai F-M 2007 High quality factor microcavity lasers realized by circular photonic crystal with isotropic photonic band gap effect Applied physics letters 90 151125
[21] Bianucci P 2016 Optical microbottle resonators for sensing Sensors 16 1841
[22] Murugan G S, Wilkinson J S and Zervas M N 2009 Selective excitation of whispering gallery modes in a novel bottle microresonator Optics express 17 11916-25
[23] Johari M A M, Khudus M I M A, Jali M H B, Al Noman A and Harun S W 2019 WHISPERING GALLERY MODES ON OPTICAL MICRO-BOTTLE RESONATOR FOR HUMIDITY SENSOR APPLICATION Optik
[24] Johari M, Khudus M A, Al Noman A, Jali M, Yusof H, Harun S and Yasin M 2019 Microbottle resonator formaldehyde sensor. In: Journal of Physics: Conference Series: IOP Publishing) p 012021
[25] Johari M, Al Noman A, Khudus M A, Jali M, Yusof H, Harun S and Yasin M 2018 Microbottle resonator for formaldehyde liquid sensing Optik 173 180-4
[26] Johari M A M, Khudus M I M A, Jali M H B, Al Noman A and Harun S W 2018 EFFECT OF SIZE ON SINGLE AND DOUBLE OPTICAL MICROBOTTLE RESONATOR HUMIDITY SENSORS Sensors and Actuators A: Physical
[27] Matsko A B and Ilchenko V S 2006 Optical resonators with whispering gallery modes I: basics IEEE J. Sel. Top. Quantum Electron 12 3
[28] Murugan G S, Petrovich M, Jung Y, Wilkinson J and Zervas M 2011 Hollow-bottle optical microresonators Optics express 19 20773-84
[29] Lim K, Harun S, Arof H and Ahmad H 2012 Selected Topics on Optical Fiber Technology:
[30] Nasir M N M, Murugan G S and Zervas M N 2016 Broadly tunable solid microbottle resonator. In: Photonics Conference (IPC), 2016 IEEE: IEEE) pp 759-60
[31] Cai M, Painter O and Vahala K J 2000 Observation of critical coupling in a fiber taper to a silica-microsphere whispering-gallery mode system Physical review letters 85 74
[32] Nasir M N M, Murugan G S and Zervas M N 2016 Spectral cleaning and output modal transformations in whispering-gallery-mode microresonators JOSA B 33 1963-70
[33] Pauzi N, Man S, Nawawi M S A M and Abu-Hussin M F B 2019 Ethanol standard in halal dietary product among Southeast Asian halal governing bodies Trends in Food Science & Technology
[34] Alzeer J and Hadeed K A 2016 Ethanol and its Halal status in food industries Trends in Food Science & Technology 58 14-20
[35] Gorgus E, Hittinger M and Schrenk D 2016 Estimates of ethanol exposure in children from food not labeled as alcohol-containing Journal of analytical toxicology 40 537-42
[36] Nguyen N L T, Baek S H, Akbar Z A, Jang S-Y, Ha S, Park J P and Park T J 2018 Rapid Determination of Ethyl Alcohol in Alcoholic Beverages Using a Fluorescent Nanofiber Film BioChip Journal 12 240-8
[37] Jamaludin M, Hashim D, Rahman R, Ramli M, Majid M, Othman R and Amin A 2016 Determination of permissible alcohol and vinegar in Shariah and scientific perspectives International Food Research Journal 23
[38] Mulijani S, Iswantini D, Wicaksono R and Notriawan D 2018 Optical Sensor based Chemical Modification as a Porous Cellulose Acetate Film and Its Application for Ethanol Sensor. In: IOP Conference Series: Materials Science and Engineering: IOP Publishing) p 012014
[39] Arregui F J, Liu Y, Matias I R and Claus R O 1999 Optical fiber humidity sensor using a nano Fabry–Perot cavity formed by the ionic self-assembly method Sensors and Actuators B: Chemical 59 54-9
[40] Batumalay M, Harun S W, Irawati N, Ahmad H and Arof H 2015 A study of relative humidity fiber-optic sensors IEEE Sensors Journal 15 1945-50