A Study of Optical Micro-bottle Resonator Humidity Sensor

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Abstract. This experiment reports the fabrication of the optical Micro-bottle Resonator (MBR) as a relative humidity (RH) sensor. The MBR is fabricated via the “soften-and-compress” method to create the bottle-shaped with diameter $D_b = 175 \, \mu m$. The MBR is then optically excited using a $8 \, \mu m$ microfiber and was found to have a Q Factor of $> 10^5$. The MBR was then employed as a humidity sensor with the RH level percentage range between 40% to 100% and the performance is compared with a non MBR microfiber. The MBR sensor was found to have a sensitivity of $0.2973 \, \text{dBm}/\%$, linearity $>90\%$ and is superior to the bare microfiber in all measured parameters. The MBR humidity sensor was also found to have good repeatability and stability over a period of 60 seconds compare to bare microfiber.

1. Introduction

Recently, the micro-resonator (MR) has received lot of attention due to their wide applications. By supporting the whispering gallery mode (WGM), OMRs have gained a potential towards application in optical microsystems and miniaturization attention [1,2]. They’re usually associated with circular-path resonant cavities like micro-sphere, micro-ring and micro-disc geometry and these resonators can support whispering gallery mode (WGM) operation by providing continuous internal reflection at specified resonant wavelengths [3-12]. A WGM can be represented as an optical beam transmitted solely at the micro-resonator surface due to grazing-angle total internal reflection, according to the geometrical optical principle [13]. When light is evanescently coupled into the micro-resonator via a microfiber, the transmission spectrum shows a very tiny resonance dip with a full width half maximum (FWHM) on a level of pm. Optical sensing is one of the many applications for the optical WGM device [14-15].

Relative humidity (RH) sensors based on optical fiber have been extensively explored for various important application such as agriculture and in medical field [16]. RH sensors previously have been described using a variety of approach including tapered fiber, fiber grating, coupler microfiber, interferometer fiber and resonator based humidity sensor [16]. In this studies, we study the characteristics of micro-bottle resonator (MBR) coupled with microfiber with size $8 \, \mu m$ on the
sensing performance. The MBR formed with technique known as “soften-and-compress” on SMF-28 silica fiber using manual splicer machine while microfiber was fabricating by tapering machine. Thinner microfibers may improve light coupling to WGM resonators because the fiber was physically in contact with them. The position of MBR were in the middle area of taper microfiber where the distance is always touch each other respectively. They were then used to measure humidity in a range 40% to 100%. Analysis of the performance of MBR coupled tapered exposed the potential of MBR with tapered bare fiber in humidity sensing.

2. Experiment Setup
MBR that are using in this study were made with the so called “soften-and-compress” method [2] using a splicer machine (Furukawa Electric Fitel S178A) as shown in Figure 1. In a mode manual splicer machine, placed some length of SMF-28 fiber and clamped on both sides and a small center part is heated under a plasma arc. This clamped fiber was compressed inward in the direction of the plasma arc, forming bottle like structure.

![Figure 1. A splicer machine used to form micro-bottle resonator](image1)

The size is determined by the arc number during the fabrication process. Figure 2 shows microscopic image of the of MBR resonator whereas with 10 time’s arc. The size a MBR is defined by diameter stem, Ds and the bottle diameter, Db. MBR in this work has stem, Ds and bottle diameter, Db of 125 μm and 175 μm, as shown in Figure 2.

![Figure 2. The micro-bottle resonator (MBR)](image2)

To allow for coupling of light to and from the MBR, a microfiber was fabricated using a customized flame brushing technique with 8 μm tapering waist. Figure 3 shows the MBR, which was placed directly on the microfiber to allow efficient coupling of light in or out of the MBR. This is attributed to the evanescent field of a phase-matched microfiber can be easily aligned to be overlap with the evanescent field of a WGM from the MBR.
Figure 3. Tapered microfiber and MBR

Figure 4 shows the schematic diagram of the experiment humidity sensor uses an MBR as sensor. Tunable laser source (TLS) (ANDO AQ4321D) is a source the light to the MBR structure via a microfiber and the output of the MBR was detected using an optical power meter (OPM) (THORLABS PM100D). The MBR structure was placed in a control chamber, which percentage humidity level varies from 40%-100% and the humidity controlled by saturated salts solution inside the chamber. Then, the relative humidity was recorded by a humidity meter (Hygrometer RS 1365, Sensitivity: 1%) and sensing media’s output power of the sensing was continually measured. The OPM was also connected to the computer, making it easier to display the result and generate the graph.

Figure 4. Humidity sensor experimental setup

3. Result and Discussion
The MBR was first characterized using TLS together with an OPM and the TLS, which its operations in the wavelength range between 1520 nm and 1620 nm and average output power of 1 dB has been launched into the microfiber coupled MBR. OPM was used to measure the output power of a laser that adjusted wavelength between from 1520.2 nm to 1520.3 nm with a wavelength interval of 0.001 nm. From the Figure 5 below, the Q factor for MBR is that coupled with microfiber is $7.6013 \times 10^5$ dBm. The Q-factor loss can be influenced by altering the position or spacing between MBR with tapered microfiber. The insertion loss of MBR is roughly 27.5 dBm to 31 dBm. The MBR's Q-factor, defined as $\Delta \lambda / \lambda$ where $\lambda$ is the resonant wavelength. This is thought to be due to the microfiber, which contributes significantly to the entire micro-bottle ensemble’s insertion loss.
For bare microfiber and MBR, the fluctuation of transmitted light against relative humidity was examined. Figure 6 depicts the fluctuation of transmitted light in bare microfiber and MBR on tapered microfiber as a function of relative humidity. As the relative humidity rises from 40% to 100%, the intensity of the transmitted light through the bare micro-fiber and MBR on the tapered fiber increases. Table 1 summarizes the performance characteristics of raw microfiber and MBR. The MBR coupled with microfiber is shown much better than bare microfiber. The sensitivity of the bare microfiber is 0.152 dB/%, 38.99 % of a slope linearity and 20.197 % of a limit of detection, whereas the sensitivity of the tapered microfiber and MBR is 0.2973 dB/%, 97.80% of a slope linearity and 19.132 % of limit of detection. The analysis discovered that the MBR has a substantially higher humidity sensing efficacy than bare microfiber. One of the cause is surface absorption in the resonator’s transmitting insertion loss, which increases as humidity levels. Despite the fact that losses in the resonator were observed as a result of light circulation inside the resonators, power loss with each circle pathway considerably increased the sensitivity.
Table 1. SENSING PERFORMANCE OF HUMIDITY SENSING.

| Parameters                    | Bare microfiber | MBR     |
|-------------------------------|-----------------|---------|
| Linearity (%)                 | 38.99%          | 97.80%  |
| Sensitivity (dBm/%RH)         | 0.1546          | 0.2973  |
| Standard deviation (dBm)      | 3.00            | 4.46    |
| Linear Range Humidity (%)     | 40-100          | 40 - 100|
| Limit of detection            | 20.197          | 19.132  |

Every RH experiment was repeated three times for MBR and bare microfiber to determine the setup's reproducibility. Figure 7 shows that the results were similar for MBR and bare microfiber, with MBR sensitivity values of more than 0.25 dB/% and bare microfiber sensitivity value of less than 0.2 dB/%, respectively %. As a result, when compared to the bare microfiber, the MBR functioned far better as a humidity sensor.

Figure 7. The MBR RH sensing repeatability performance of (a) bare microfiber and (b) MBR

4. Conclusion

This paper presented the performance of MBR based humidity sensor using micro-fiber. A micro-bottle resonator (MBR) has a stem and bottle diameter of 125 μm and 175 μm, respectively. MBR was made using a ‘soften-and-compressed’ method was applied to a silica microfiber which formed bulge area at the center of fiber. The MBR was then excited through the microfibers with the diameters of 8 μm via a TLS. With increase the RH level from 40% to 100%, the MBR was employed as a humidity sensor. The MBR RH sensor was observed to have a sensitivity of 0.2973 dB/%, linearity >90% and showed relatively good repeatability and stability. This simple humidity sensor can offer wide range of applications such as in green house automatic control system and in extremely humid environments.
References

[1] K.J. Vahala, Optical microcavities, *Nature* 424 (6950) (2003) 839.

[2] A.B. Matsko, V.S. Ilchenko, Optical resonators with whispering gallery modes I: basics, *IEEE J. Sel. Top. Quantum Electron* 12 (3) (2006) 3.

[3] Sumetsky, M., Dulashko, Y., & Windeler, R. (2010). Optical microbubble resonator. *Optics Letters*, 35(7), 898-900.

[4] Chiasera, A., et al., *Spherical whispering-gallery-mode microresonators*. Laser & Photonics Reviews, 2010. 4(3): p. 457-482.

[5] Murugan, G.S., J.S. Wilkinson, and M.N. Zervas, Selective excitation of whispering gallery modes in a novel bottle microresonators. Optica express, 2009. 17(14): p. 11916-11925.

[6] Little, B.E., et al., *Microring resonator channel dropping filters*. Journal of lightwave technology, 1997. 15(6): p. 998-1005.

[7] Absil, P.P., *Microring resonators for wavelength division multiplexing and integrated photonics applications*. 2000.

[8] Kokubun, Y., *Wavelength selective integrated device by vertically coupled microring resonator filter*. Photonics Based on Wavelength Integration and Manipulation IPAP Books, 2005. 2: p. 303-316.

[9] Armani, D., et al., *Ultra-high-Q toroid microcavity on a chip*. Nature, 2003. 421(6926): p. 925.

[10] Armani, D., et al., *Electrical thermo-optic tuning of ultrahigh-Q microtoroid resonators*. Applied physics letters, 2004. 85(22): p. 5439-5441.

[11] Gérard, J., et al., *Enhanced spontaneous emission by quantum boxes in a monolithic optical microcavity*. Physical review letters, 1998. 81(5): p. 1110.

[12] Sarma, J. and K. Shore, *Electromagnetic theory for optical disc resonators*. IEE Proceedings J (Optoelectronics), 1985. 132(6): p. 325-330.

[13] Sumetsky, M., & Fini, J. (2011). Surface nanoscale axial photonics. *Optics express*, 19(27), 26470-26485.

[14] Marcotili, E.A.J., *“Bends in optical dielectric waveguides”*, Bell System Techn. J. 48, 2103-2132 (1969).

[15] Braginsky, V.B., Gorodetsky, M.L., and Ilchenko, V.S. *Quality-factor and nonlinear properties of optical whispering-gallery modes*. Phys. Lett. A 137, 393-396 (1989).

[16] Lee, P.-T., et al., *High quality factor microcavity lasers realized by circular photonic crystal with isotropic photonic band gap effect*. Applied physics letters, 2007. 90(15): p. 151125.

[17] Bianucci, P., *Optical microbottle resonators for sensing*. Sensors, 2016. 16(11): p. 1841.

[18] Y. Peng, Y. Zhao, M.Q. Chen, F.Xia, *Research advances in microfiber humidity sensors*. Small 14 (29) (2018) 1-20

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