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Humidity Responsivity of PMMA Microfiber knot Resonator Coated with ZnO Nanorods

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Abstract

A zinc oxide (ZnO)-coated Polymethyl methacrylate (PMMA) microfiber knot resonator (PMKR) is suggested and displayed for tracking of surrounding atmosphere relative humidity (RH). The PMKR has a knot diameter of 133 μm and was manufactured using direct drawing method utilizing PMMA microfiber 7 μm diameters and 7 mm length respectively. The humidity sensor was developed by coated ZnO onto PMMA microfiber. The output of the humidity sensor was examined on the basis of an increased sensor transmission as the relative humidity level ranges from 50 to 80%. The results displayed an increase in the sensor sensitivity on the PMMA fiber surface with extra ZnO coating. The proposed PMKR coated ZnO has higher output stability compared to uncoated PMKR, making it suitable to be used in sensor application.

Keywords: *Polymethyl methacrylate, Microfiber knot resonator, microfiber sensor, humidity sensor*

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1. INTRODUCTION

Sensor technology based on fiber-optic has historically achieved many developments and keeps going to be largely driven due to reduction of the price of associated components [1], coupled with integrated spatial miniaturized devices [1]. With their tiny size (Hundreds of nanometers in diameter to many other micrometers) [2], accompanied by high-fractional evanescent fields and high flexibilities, making it as a microscale waveguide that has higher sensitivity, faster responses and lower power consumption [2-4] over conventional optical fiber. In addition, light propagate in the microfiber shows low optical loss and high mechanical strength, owed to diameter uniformity and smoothness of atomic-level sidewall of fiber [5,6].

Resonator-type sensor allow light to recirculating at resonant, overlap and couple, thereby effectively increase the optical path thus creating compact, high Q-factor predicted as high as ~10^9 [3,6]. Microfiber loop resonator (MLR) was among configurations that have been reported and attracted much interest to develop them as optical sensor [7,8]. However, it suffers from limited stability since the MLR geometry shape is depend only on electrostatic and Van der Waals forces at joint point of fiber [9]. This mean small environmental change

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such as vibration or heat can break the bond. Therefore, researchers come out with an idea of forming a knot to couple adjacent microfiber called microfiber knot resonator (MKR). This design requires less precision of microfiber alignment, improved stability, and enhanced Q-factor and finesse. Moreover, the Q-factor and spectral properties can be varying by changing the knot radius and wire diameter [10].

Many techniques to produce the sensor-based fiber optic for different sensor purposes have been reported [10,11]. Long period gating and fiber Bragg gratings are inscribed on microfiber where they response to a change in ambient condition as they undergo spectral shift. Alternatively, simpler fabrication of sensor by coating grown material onto the fiber have received much attention for sensing application. In this paper, we demonstrated humidity sensor by using Zinc Oxide (ZnO) as a coating layer. ZnO nanostructure is a bio-safe and sensitive material that change its refractive index, subsequently enhance the guided light in fiber. Apart from coating material, PMMA which is a type of polymer optical fibers (POFs) is used instead of silica fiber due to additional advantages such as greater flexibility, disposability and high resistant to impact and vibrations.

In this experiment, PMMA microfiber knot resonator was demonstrated where ZnO are used as deposited layer onto the PMMA fiber for detecting relative humidity (RH) changes. Their apparent different with and without deposition of ZnO was investigated, in term of output power and sensitivity.

2. METHODOLOGY

In combination with the direct drawing process, a PMMA microfiber was fabricated using a molten PMMA as previously reported [13] (Figure 1). The manufactured 7 µm diameter PMMA has a high surface smoothness and a uniformity of 7 mm fiber length. Due to its large mechanical strength, good dimensional stability, good weather resistance, and natural visibility above the deep ultraviolet field, PMMA has been selected as the polymer wave-guiding material.

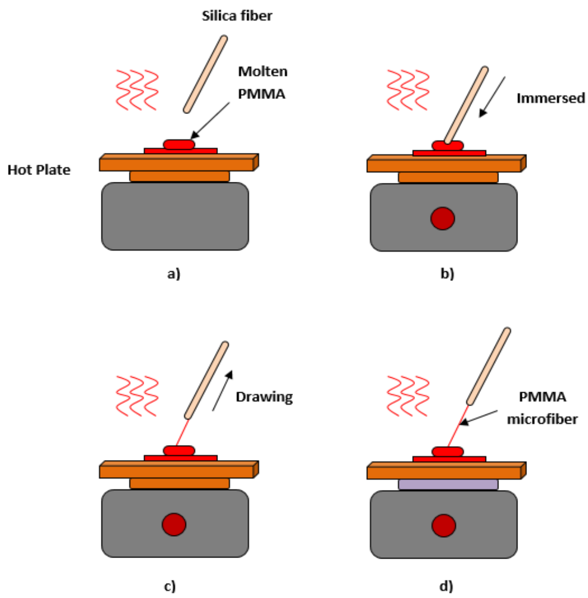

Figure 1. PMMA microfiber fabrication steps

As for the ZnO nanorods, a simple manual dip coating process as previously announced was used to deposit the seed layer onto the fiber to expand the ZnO nanorods [7,8].

ZnO nanorods deposition process on the PMMA microfiber was conducted using the process of sol-gel immersion by suspending the fiber for 2 hours in the rising solution at 30°C. The PMMA microfiber was then defined using the Field Emission Scanning Electron Microscope (FESEM) to investigate coated ZnO nanorod morphology as display in Figure 2.

Figure 2(a) shows an 8000x magnification microscopic image of the PMMA microfiber covered with ZnO nanorods; and Figure 2(b) shows the 5000x

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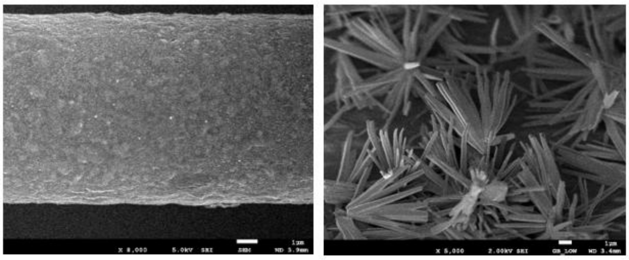
magnification of the ZnO nanorods. Although the ZnO nanorods are distributed dispersively, it can be noted that their diameters and lengths are rather uniform.



(a) (b)

Figure 2. FESEM images of (a) the 8000x magnified image of the PMMA microfiber coated with ZnO nanorods; and (b) the 5000x magnified image of the ZnO nanorods

Figure 3 shows the setup used to measure relative humidity with the manufactured PMMA microfiber covered with ZnO nanorods.

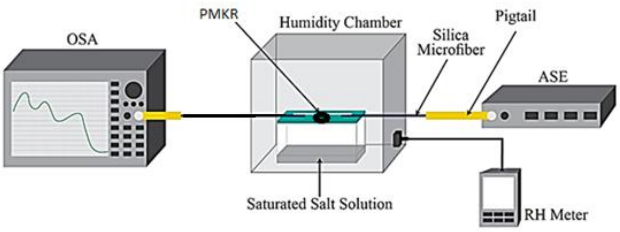


Figure 3. Experimental setup of humidity responsivity of PMKR

The amplified spontaneous emission light (ASE) from the Erbium-doped fiber amplifier (EDFA) was started onto the microfibre probe positioned in a sealed chamber with a saturated salt solution filled plate. Relative humidity depends on the amount of ambient moisture; thus, salt solution has been put in the sealed chamber to represent the different value of relative humidity until the relative equilibrium solution of the salt solution, which is about 80% RH, is reached. The optical spectrum analyzer (OSA) measures the transmitted light and wavelength shift. The performance of the proposed sensor for different relative humidity levels, ranging from 50% RH to 80% RH, was examined in the experiment. The moisture was measured using the temperature-relative humidity meter Omega RH-21C with a 0.1% RH resolution.

3. RESULTS AND DISCUSSIONS

Figure 4 displays 100x magnified microscopic image of 7 µm and 133 µm both of PMKR and knot diameter. The diameter of 133 µm was obtained by the axial tension from pulling force at the two sides of the PMMA fiber. The PMMA microfiber tied into knot structure under an optical microscope using micromanipulation process. Precise alignment easily achieved by naturally overlaps the fiber with itself, thus attribute to high robustness and high stability MKR structure.

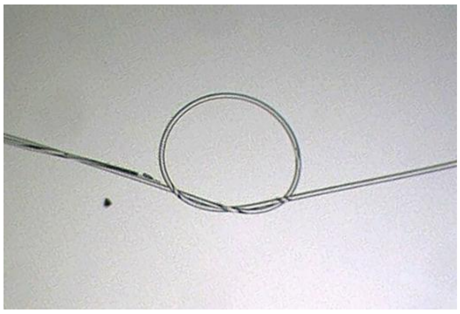


Figure 4. The optical microscopic image of the PMKR.

Figure 5 shows the transmission spectra of microfiber knot with different relative humidity (RH) percentage. Figure 5(a) show the transmission spectra of uncoated PMKR while Figure 5(b) show the transmission spectra for coated PMKR with ZnO. The comb spectra were obtained by using ASE source at the input ports of the PMMA microfiber and an OSA was connected at the output ports. The RH was varied by controlling the saturated salt solution as mentioned previously.

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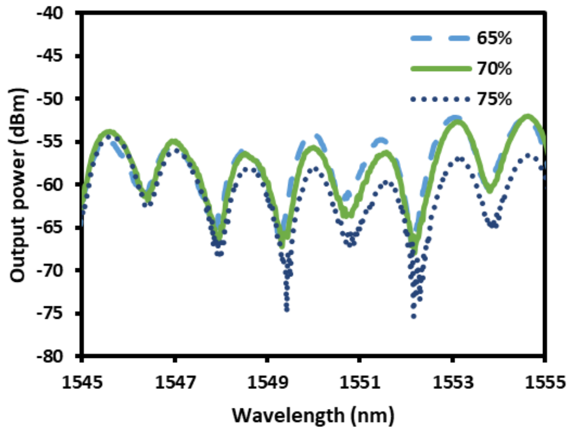
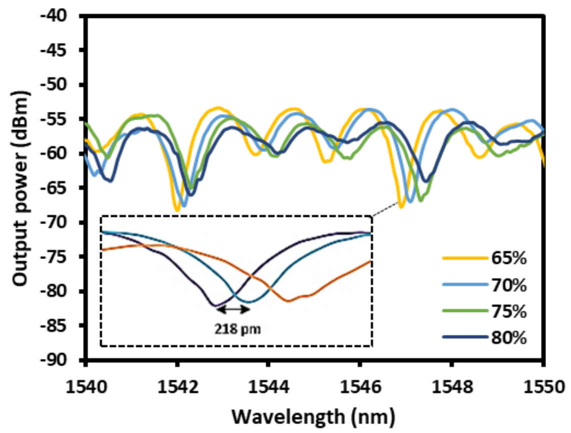


(a)



(b)

Figure 5. Transmission spectrum of the RH-sensor measured with different relative humidity percentage with (a) uncoated PMKR, (b) coated ZnO nanorod on PMKR

The resonant wavelength shift can be seen clearly by plotting the wavelength against RH as in Figure 6. Based on figure 6 for uncoated PMKR, it was observed that as the RH increased, there are slightly shifted of wavelength ranging from 1550.49-1550.86 nm (for the RH-50% to RH-80%), increased by 370 pm. This might cause by polymer microfiber sensitivity toward RH itself. The resonance change in uncoated PMKR can be clarified as improved water adsorption in the molecular state on the PMMA surface as the PMMA had bigger molecular and hydrophilic material. The water retention on the PMMA surface takes place through a physical adsorption process without excluding any possible swelling effect. The water must retain its molecular state and will always remain in either solid liquid or vapor and will only be a charged in the molecular hydrogen bonds [14]. However, as we observed figure 6 for coated microfiber with ZnO, there are significant shift of the resonant wavelength, which is 1055 pm for humidity increases from 50% to 80% [14]. This phenomenon can be described as the ZnO porous matrix traps water molecules on its inner surface, increasing the average composite density of the ZnO. Subsequently the refractive index increased and the resonant wavelength modified. Therefore, the sensor exhibits high sensitivity (437 pm wavelength shifted to 5% change in humidity) as a function of RH for about 1055 pm shift in resonant wavelength for RH range from 50 to 80%. The extinction ratio is approximately 10.0 dBm and 7.0 dBm, respectively before and after the PMKR-coated ZnO. The uncoated and coated PMKR's finesse and Q-factor values as derived from Figure 5(a) are 1985.12 and ~1.82 and Figure 5(b), respectively, are 1247.14 and ~1.47.

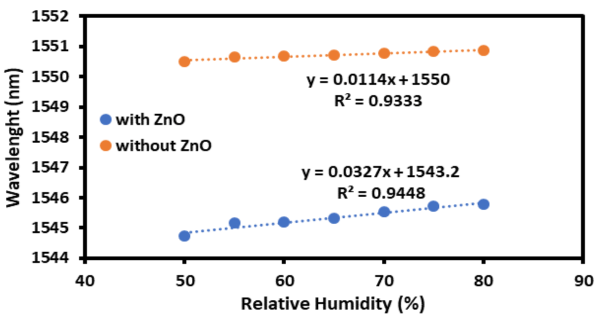


Figure 6. Resonant wavelength shift against relative humidity for PMKR with and without ZnO

Based on figure 6 for uncoated PMKR, it was observed that as the RH increased, there are slightly shifted of wavelength ranging from 1550.49-1550.86 nm (for the

RH-50% to RH-80%), increased by 370 pm. This might cause by polymer microfiber sensitivity toward RH itself. The resonance change in uncoated PMKR can be clarified as the improved water adsorption of the molecular state on the PMMA surface since the PMMA had bigger molecular and hydrophilic material. However, as we observed figure 6 for coated microfiber with ZnO, there are significant shift of the resonant wavelength, which is 1055 pm for humidity increases from 50% to 80%. This phenomenon can be clarified as ZnO's porous matrix traps water molecules on its inner surface, increasing the average composite density of ZnO. Subsequently, the refractive index increased and the resonant wavelength modified. Therefore, the sensor exhibits high sensitivity (437 pm wavelength moved to 5% change in humidity) as a function of RH for about 1055 pm shift in resonant wavelength for RH range from 50 to 80%. The extinction ratio is approximately 10.0 dBm and 7.0 dBm, respectively, before and after PMKR-coated ZnO. The uncoated and coated PMKR's finesse and Q-factor values as derived from Figure 5(a) are 1985.12 and ~1.82 and Figure 5(b), respectively, are 1247.14 and ~1.47.

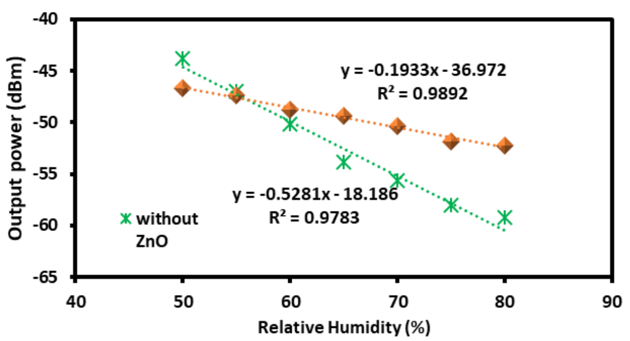


Figure 7. Linear relationship between relative humidity and output power for the uncoated PMKR and coated PMKR

Figure 7 displays the linear function for the uncoated and coated PMKR between temperature and output power. Humidity increases from 50% to 80%, resulting in output power ranging from -43.77 dBm to -59.25 dBm and -43.7 dBm to -59.11 dBm in both for uncoated and coated PMKR. The output power starts to significantly decrease with the rise of humidity level. The transmitted light intensity is observed to be highest with ZnO nanorods coating.

In this experiment, the PMKR that was coated with ZnO showed enhanced properties of a sensor than uncoated PMKR. ZnO exhibit hydrophilicity is recognized as a coated substrate. ZnO is a promising compound in optical transmission, where it easily absorbs water molecules in humid environment. The increase of water absorption by ZnO resulted to the increased of refractive index.

4. CONCLUSION

In summary, using direct drawing technique, we have proved the manufacture of a 7 μm diameter PMMA microfiber. Subsequently, a humidity sensor was created by using sol-gel immersion technique to deposit ZnO nanorods on the microfiber. The execution of the proposed sensor was examined for different levels of relative humidity, ranging from 50% RH to 80% RH. Various RH values are measured by using salt solution to monitor the ambient humidity. Resonant wavelength changes for PMKR with and without ZnO against relative humidity were compared. We observed an increase of sensitivity level, approximately 0.5281 dBm/% for RH range from 50% to 80%. Compared to uncoated PMKR about 0.1933 dBm/% that might cause by polymer microfiber sensitivity toward RH itself. The extinction ratio is approximately 10.0 dBm and 7.0 dBm,

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respectively before and after the PMKR coated ZnO.

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