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Effect of Microfiber Diameters on Micro-sphere Resonator Based Humidity Sensor

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***Abstract*—In this paper, the effect of microfibers diameter on the micro-sphere resonators (MSR) ability to detect relative humidity changes is analyzed. Microspheres show whispering gallery mode (WGM) characteristics when light is properly coupled into them. The interaction between that coupled light and the surroundings can be used for sensing applications. Three different diameters of microfiber were used to couple light into the MSR, 5 µm, 8 µm and 10 µm. The MSR with the sphere diameter of 200 µm was categorized by its quality factor and spectrum transmission modes. Then, the structure was used as a humidity sensor. The transmission modes of the MSR were compared at three different tapering sizes. Each of these structures was tested as a humidity sensor in the relative humidity range 50-90%. In addition, sensitivity, and linearity of the three proposed sensors were calculated. According to the compared results, the 5 µm microfiber has a much better sensitivity than the 8 µm and 10 µm microfiber when using the MSR.**

***Index Terms*—Humidity sensors, microfiber, microsphere resonator, whispering gallery mode.**

I. Introduction

RECENTLY, the optical micro-resonator (OMR) has received considerable attention due to their wide applications as sensors. By supporting the whispering gallery mode (WGM), OMRs have gained a potential towards application in optical microsystems and miniaturization attention [1, 2]. The micro-bubble, micro-bottle and micro-disc representing several geometries of the OMR allow coupling the lowest volume mode with the high-quality factor (Q-factor) value [3-9].

The process is completed by having a total internal reflection between the formation of WGMs and the microcavity surrounding the medium. These micro-resonators are considered as 2-D resonators while confining the mode in equatorial planes and allowed spectral properties defined by their diameters. OMRs supporting WGMs have been investigated to incorporate cylindrical shaped structures. For example, optical filaments and OMRs framed on strands are appraised for their way of confining light, easy handling and useful applications [10, 11].

Another example includes the micro-sphere resonator (MSR) that has increased considerable attention because of its capability to support 3-D light confinement of the WGM through a combination of the WG-bouncing ball and WG-ring principle [12, 13]. The area of the WGM confinement model can be defined with two distinctive MSR turning points corresponding to the regional field enhancement. The efficiency of the add/drop function can be increased owing to the presence of distinctive turning points in MSRs [14]. MSRs can generate complex spectra transmitted with high degenerated resonances, which is different with other micro-resonator structures [15]. This is possible owing to multiple overlapping MSR radii that allow bringing up the resonance spectra and trap the light close to the MSR surface [16].

In this paper, we study the effect of size of microfiber coupled with MSRs fabricated by the “soften-and-compress” method [17] on the sensing performance of MSR humidity sensors. The MSR formed with technique known as “soften-and-compress” on SMF-28 silica fiber using tapering machine. The size of the MSRs were varied by varying the number of plasma arcs applied to MSR. The microfiber was firstly fabricated and then coupled to a microsphere of 200 µm diameter before being employed for humidity sensing in a range of 50% - 90%. The position The size of the MSRs were varied by varying the number of plasma arcs applied to MSR. The tapered bare fiber characteristic is firstly defined by employed with MSR, 200 µm before being employed for humidity range of 50% - 90% with three different size of MSR. The position of MSR were in the middle area of taper microfiber where the distance is always touch each other respectively. Analysis of the performance of MSRs coupled difference size tapered exposed the potential of MSR with difference size tapered bare fiber in humidity sensing.

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II. EXPERIMENTAL ARRANGMENT

At first, the microsphere or MSR was fabricated at the tip of a standard single mode-fiber (SMF) by using a fiber fusion splicer machine (Furukawa Electric Fitel S178A). In this work, a cleaved tip of the SMF is placed in one arm of the manually controlled fusion splicer and a series of arcs were then applied. The plasma arcs heated and partially melted the fiber tip to form a spherical shape due to surface tension. The diameter of microsphere formed can be controlled by the number of arcs applied on the fiber tip. Fig 1 (a) shows the fabricated of MSR with 10 times arc. It has a stem and microsphere diameter of 125 µm and 200 µm, respectively. To allow for coupling of light to and from the microsphere, a microfiber was fabricated using a customized flame brushing technique. Fig. 1(b) shows the microsphere, which was placed directly on the microfiber to allow efficient coupling of light in or out of the MSR. 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 microsphere.

If absorption of light in the silica microsphere is minimal and scattering losses at the boundary of the microsphere are very low, then the photons can circulate on their orbit several thousand times before exiting the microsphere by loss mechanism. This long lifetime of the confined photons is associated to a long optical path length because of the resonant nature of the phenomenon. When a water molecule is brought in contact with the confined circulating light, the interaction will be resonantly reinforced. A frequency shift of the resonances occurs when the radius and/or the refractive index of the sphere change; as the water molecules aggregate at the surface, it interacts with the evanescent part of the WGM field inducing a change in the Q-factor or a shift in the wavelength.

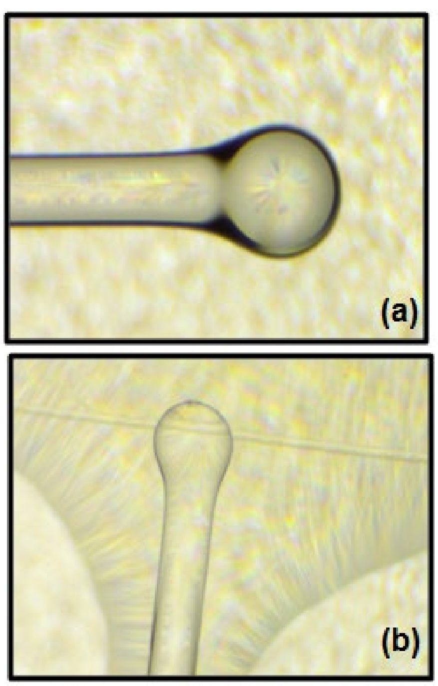

Fig. 1: (a) The microsphere resonator (MSR) element, (b) MSR placed on top of microfiber

Fig. 2 shows the schematic diagram of the humidity sensor using a MSR as sensor probe. Tunable laser source (TLS) was used to provide the light to the MSR structure via a microfiber. The output of the MSR were detected using an optical power meter (OPM, THORLABS PM100D). The MSR structure was placed in a controlled chamber with constant pressure 1 atm and constant temperature 25°C. The humidity inside the chamber was controlled by saturated salts (hydroxide Sodium) and silica gel pellets. Then, the relative humidity was recorded by a humidity/temperature meter (Hygrometer RS 1365, Sensitivity: 1%). The humidity inside the chamber was varied from 50-90% RH and the output power of the sensing media was continuously recorded. The OPM also connected to the computer, so that it easier to show the result and generate the graph.

The experiment was then repeated for different sizes of optical microfiber. For the second part of the experiment, each MSR with different microfiber size is tested for humidity sensing using the controlled chamber. The humidity sensing experimental setup is constructed, then connected as illustrated in the schematic depicted in Fig. 2. The MSR is placed inside the chamber. The tune-able laser source (ANDO AQ4321D) injected the light beam into one of the microfiber ends while the second one is connected to the optical power meter (THORLABS PM100D) for measuring the output power and detecting the transmission mode.

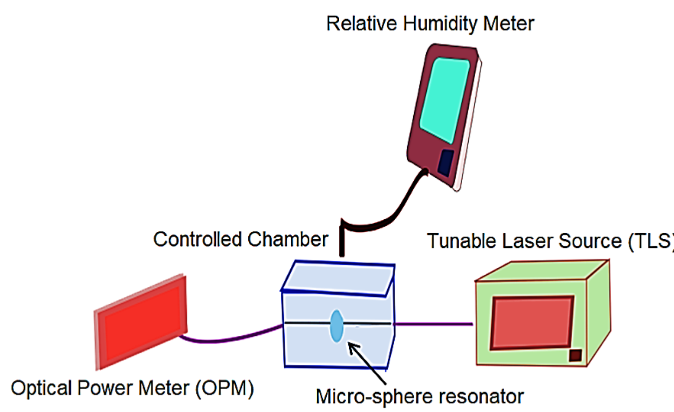

Fig. 2: Experimental Setup for Humidity

III. RESULTS AND DISCUSSION

The MSR need to be tested its capability such as Q-factor which indicate the characterizes resonator's bandwidth relative to its center frequency or the measure of the damping of resonator modes. A light source of tuneable laser source (TLS) with operating wavelength in range of 1520 nm to 1620 nm and average output power of 1 dB has been launched into the microfiber with diameter of 10 µm, 8 µm, and 5 µm that coupled MSR. The laser adjusted wavelength is between 1520 nm to 1525 nm with wavelength interval of 0.001 nm. The transmitted power is collected by using an optical power meter. From the fig.3 below, the Q-factor for MSR is that coupled with the respective sizes of microfiber diameter are 5.07 x 10^5, 7.614 x 10^5 , and 3.803 x 10^5 respectively. The quality factor (Q-factor) of the MSR is equals to Δλ/λ. λ is the resonance wavelength. The value of Q-factor depends on the micro-fiber diameter, it increases when the used micro-fiber diameter decreases [18].

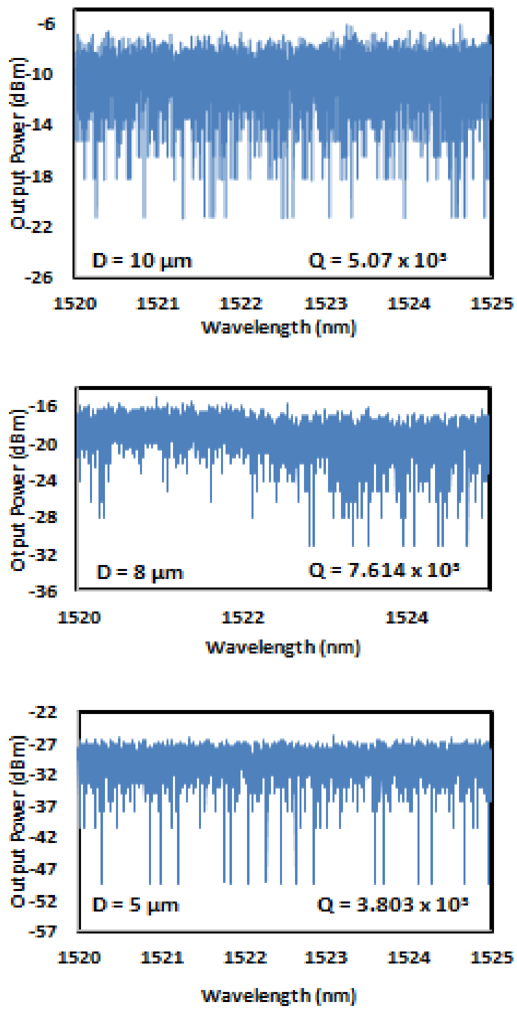

Fig. 3 : WGM transmission modes of MSR with different waist diameter of the optical microfiber

The real time response of the MSR is for the humidity range 50% to 90%. the recorded values are taken in a step of 5 % of the humidity as shown in Fig.4. Depending on the obtained results it was realized that the output power decreases with the increase of the humidity the fiber is exposed to. The MSR coupled with the 5 µm of microfiber values is shown to highest linearity equal to and sensitivity. The output power reduced value is caused by the reduction in transmission due to increased level of humidity of the MSR. The reduction of the transmission is caused by the added scattering losses made by water particles that absorb part of the power changing the refractive index of the micro fiber and resulting in increased sensitivity [19, 20].

Every RH experiment of the MSR is repeated three times for every fiber diameter. All the recorded fiber outputs are illustrated in Fig. 5. The average of the three test conducted for each tapering size is plotted in Fig. 5.

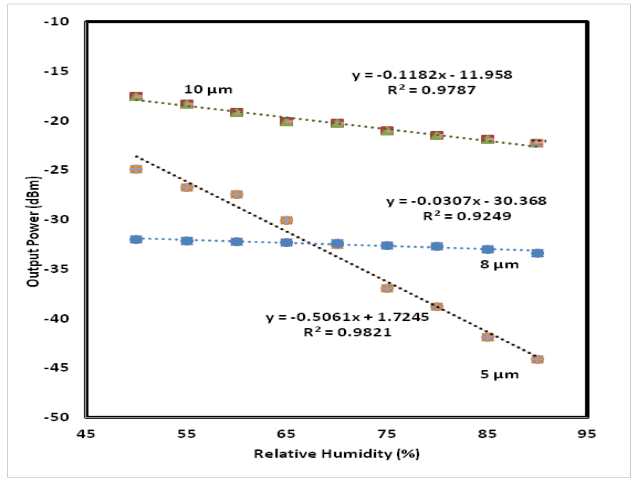

Fig. 4: The MSR response towards the humidity sensing

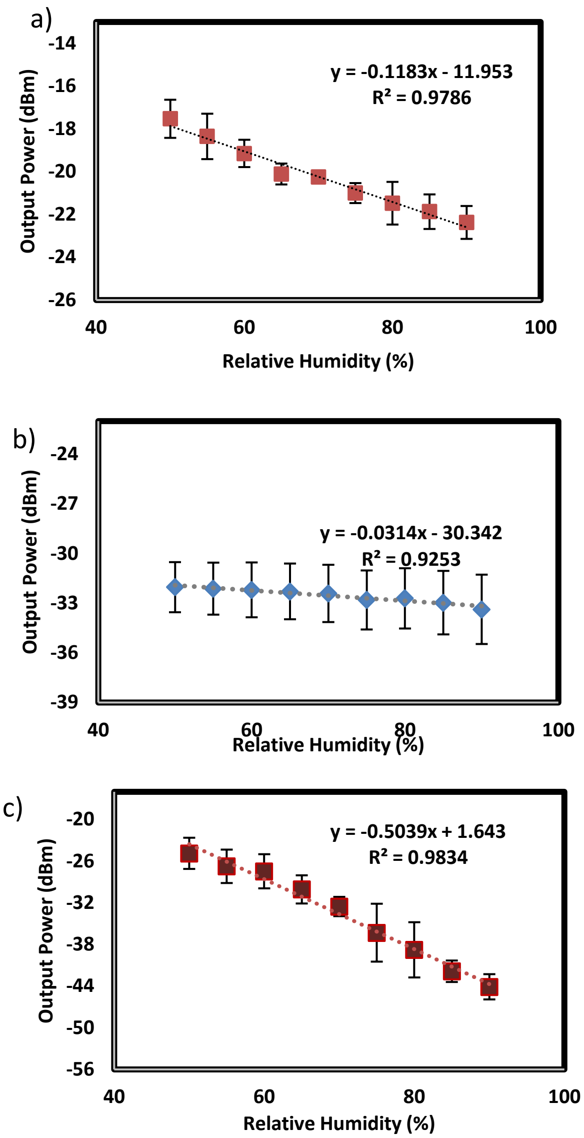

Fig. 5: The MSR RH sensing repeatability that couple with microfiber with (a) 10 µm diameter (b) 8 µm diameter (c) 5 µm diameter.

From the Fig. 5, the MSR RH sensing repeatability that couple with microfiber with different sizes of diameter can be summarize into Table 1. The sensitivity and linearity of 5 µm diameter microfiber (Sensitivity (dB/%RH) = 0.5039 , Linearity (%) = 99.16%) was the highest among the other diameter. While the 10 µm the sensitivity (dB/%RH) = 0.1183, while the linearity (%) = 98.92% and 8 µm the sensitivity (dB/%RH) = 0.0314 while the linearity (%) = 96.16%. The measurement shows that the smallest diameter has the better performance. Smaller tapering diameters means more light coupled into the resonator. Smaller tapering diameters have stronger evanescent fields that gets easily coupled into the resonator increasing the interaction between the light and the surroundings of the sensor.

TABLE I
SENSING PERFORMANCE OF HUMIDITY SENSING

Microfiber diameter (μm)	**10 μm**	**8 μm**	**5 μm**
Sensitivity (dBm//%)	0.1183	0.0314	0.5039
Linearity (%)	98.92	96.19	99.17

IV. CONCLUSION

This paper presented the performance of MSR based humidity sensor using three microfibres with different diameters. A method known as 'soften-and-compressed' was applied to a silica fibre that created a bulge area at the end of fiber called the micro-sphere resonator (MSR) with the stem diameter of 125 µm, and ball diameter of 200 µm. The MSR was then excited through the three microfibres with the diameters of 5 µm, 8 µm and 10 µm via a tuneable laser source. Then, those structures were characterized by shifting the wavelength of the TLS from 1520 nm to 1525 nm with the wavelength interval of 0.001 nm. The comparison between the three different diameters of the microfibre was reported based on two parameters: linearity and sensitivity. According to the results, the 5 µm microfibre is more efficient against the others. The 5 µm waist diameter of the microfiber has the best performance against the others. This is because it has the smallest diameter so that the evanescent field can easily go out of the microfiber and then couple with the microsphere resonator. This simple humidity sensor can offer wide range of applications such as in green house automatic control system and in extremely humid environments.

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