Research Article

Relative Humidity Sensor Based on Microfiber Loop Resonator

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A novel relative humidity (RH) sensor based on a microfiber loop resonator (MLR) is proposed and experimentally demonstrated. As refractive index of the microfiber in the MLR is modified by environmental humidity, resonant wavelength of the MLR changes with RH level. By detecting this wavelength shift, RH measurement is realized with a linear response sensitivity of 1.8 pm/% RH. The obvious advantage of this technique over others is that no coating of humidity-sensitive material is required.

1. Introduction

Optical fiber-based relative humidity (RH) sensors have been widely studied due to their advantages such as feasibility of long-distance sensing, real-time monitoring, and immunity to electromagnetic interference. Various techniques including tapered optical fiber, heterocore optical fiber, and fiber grating have been reported previously [1–4]. Most of them contain a certain kind of RH-sensitive materials to be coated out of the fiber surface. But it brings some disadvantages, such as increasing manufacturing difficulty and reducing the measurement speed.

Recently, micro/nanofibers (MNFs), drawn from standard optical fibers have attracted a lot of attention. Due to their subwavelength diameter, MNFs leave a large fraction of the guided field outside the fiber as evanescent waves. So silica optical MNFs are promising to develop kinds of micro- and nanophotonic components and devices [5–13]. In this work, we proposed and experimentally demonstrated a novel coating-free RH fiber sensor by using a microfiber loop resonator (MLR). The microfiber is only several micrometers in diameter and there is no additional humidity-sensitive material coated on the fiber surface. The proposed sensor is therefore compact in size, fast in response, and low in cost.

2. Sensor Configuration

Figure 1 shows the schematic diagram of the proposed sensor. The microfiber was drawn from a standard telecom single-mode fiber (SMF-28, Corning Inc.) using a fusion splicer

(Fujikura ARC Master FSM-100P). Under the special function mode a two-step fiber-tapering program was created. In step 1, the discharge current was set as SP-45 bit and the diameter of the fiber was then tapered from 125 μm to about 7 μm . In step 2, the discharge current was set as SP-220 bit to increase length of the 7 μm fiber region to 6 mm.

Controlling the shape of the microfiber with two translation stages under an optical microscope, we managed to coil the microfiber into a self-touching loop. The parallel alignment of the adjacent microfiber segments were achieved with the help of the surface attraction forces (Van der Waals and electrostatic), which kept both the microfiber segments together (as shown in Figure 1), apparently overcoming the elastic force that would tend to straighten out the microfiber. The two ends of the microfiber connected to the single mode fiber were used as input and output ports, respectively. We used a broadband light source (BBS) as the input source and an optical spectrum analyzer (OSA) to measure the transmission spectrum of the so-formed MLR, as shown in Figure 2. Relative humidity-sensing experiment was carried out by placing the MLR in a sealed chamber that contains two stages to fix microfiber.

3. Experimental Results and Discussion

After tuning the extinction ratio of the resonance spectrum by carefully adjusting the coupling region of the ring resonator, we obtained the spectral transmission curve as shown in Figure 3. In order to reduce the influence of vibration

FIGURE 1: Schematic diagram of the microfiber loop resonator.

FIGURE 2: The relative humidity measurement system. BBS: broadband light source: OSA, optical spectral analyzer.

FIGURE 3: Measured transmission spectrum of the MLR.

FIGURE 4: Transmission spectra of the MLR under various RH levels.

caused by air-flow, we used a water vapor generator to change the relative humidity in the testing chamber. And the relative humidity in the chamber was monitored by using a hygrothermograph. Humidity was turned in the range between 51% RH and 78% RH under fixed temperature of 21.9°C. Without dry air pumping into the chamber to decrease the relative humidity, we had to start the test under the lab relative humidity around 50% RH.

When humidity level was changed, transmission spectrum of the MLR was recorded by using the OSA. Figure 4 shows several of measured spectra under different RH levels. It can be seen that resonant wavelengths of the MLR red-shifted together with an increase in intensity and a slight reduction in extinction ratio when the level of relative humidity increased. Figure 5 shows the linearity between humidity and resonant wavelength shift and the square

regression coefficient (R^2) is 0.9901. We can find that the response is in a linear relationship and the achieved sensitivity is 1.8 pm/% RH. Figure 6 shows the relationship between RH and extinction ratio/intensity of resonant wavelength A. The extinction ratio of resonant wavelength A reduced from 3.7 dB to 2.1 dB, the achieved sensitivity is -0.064 dB/% RH, and the square regression coefficient (R^2) is 0.9864. Alternatively, the intensity increased from -21.3 dBm to -18.5 dBm, achieved sensitivity is 0.095 dBm/% RH, and the square regression coefficient (R^2) is 0.9895. An increase in intensity and a slight reduction in extinction ratio may be caused by aggregation of water molecules and formation of clusters on the MLR [11, 13].

FIGURE 5: Relationship between RH and resonant wavelength A.

FIGURE 6: Relationship between RH and extinction ratio/intensity of resonant wavelength A.

The response of the MLR to humidity can be explained as follows. The porous matrix of the silicon trapped water molecules on its interior surface. These trapped water molecules increased the average density of the silicon and resulted in an increase of the refractive index [11]. Finally, resonant wavelengths of the MLR shifted with RH level as a result of the refractive index change. The MLR is also sensitive to temperature and sensitivity of 0.043 dB/°C has been reported [14]. We plan to use another MLR that have the same parameter to monitor the influence of the temperature. Further study involving temperature compensation technique for the proposed MLR sensor is in process. Although the sensitivity of this MLR-based humidity sensor is relatively low, it can be improved by further reducing diameter of the microfiber and the obvious advantage is that the sensing element is formed by bare microfiber, no additional materials coated on its surface. It also provides potentials of fast response, low cost, and compact size.

4. Conclusions

A RH sensor based on an MLR without coating of any humidity sensitive material has been proposed and experimentally demonstrated. Experimental results show that linear

response with sensitivity of 1.8 pm/% RH has been achieved. Although the sensitivity is relatively low, the proposed MLR-based RH sensor shows potentials of compact size, fast response, and low cost.

Conflict of Interests

The authors of this paper do not have a direct financial relation with the commercial identities mentioned herein.

Acknowledgments

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