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حسگر رطوبت نسبی مبتنی بر فیبر نوری باریک شده با پوشش ژل سیلیکا

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چکیده- با بهره‌گیری از ساختار فیبر نوری چند مُد باریک شده، حسگر فیبر نوری برای تشخیص درصد رطوبت محیط ساخته و مشخصه یابی شده‌است. در این ساختار از ژل سیلیکا به عنوان لایه‌ی حسگر استفاده شده‌است. دراین مقاله، ضمن نشان دادن اثر قابل ملاحظه‌ی حضور لایه‌ی ژل سیلیکا روی ناحیه‌ی باریک شده‌ی فیبر بر روی حساسیت حسگر نشان می‌دهیم تغییرات رطوبت به صورت تغییرات توان در طیف عبوری ظاهر میشود. به عبارت دیگر، با افزایش رطوبت توان خروجی از فیبر کاهش می‌یابد. به‌علاوه، نشان می‌دهیم با کاهش ضخامت قطر میانی، حساسیت حسگر افزایش می‌یابد. نتایج تجربی نشان می‌دهد، بهترین حساسیت از حسگری با قطر ناحیه میانی چهار میکرومتر پوشیده شده با ژل سیلیکا بدست می‌آید و در ناحیه خطی این حساسیت برابر 0.39 dB/%RH است.

کلید واژه- حسگر رطوبت، حسگر فیبر نوری، فیبر نوری باریک‌شده.

Relative Humidity Sensor Based on Tapered Optical Fiber Coated with Silica-Gel

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Abstract- We have fabricated and characterized a relative humidity (RH) sensor, by tapering the mid-region of a piece of multimode-fiber (MMF) and coating it with a layer of silica-gel as the sensing layer. The experimental results show that the device sensitivity depends on the presence of silica-gel layer. The sensor response to the fluctuations of relative humidity in the environment is determined through measuring the changing in fiber transmission power. The experimental results also show that the device sensitivity increases as the diameter of the fiber, in the tapered region, decreases down to a certain size. The same results show that the highest linear sensitivity of 0.39 dB/%RH can be achieved for a tapered region of the MMF with 4-µm waist diameter coated with silica gel.

Keywords: humidity sensor, optical fiber sensor, tapered optical fiber.

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1. Introduction

Optical fiber sensors have been studied for their potential in sensing and received significant attention in the past decades. Some of the advantages these devices enjoy as compared to the conventional sensors are immunity to electromagnetic fields, long-distance operation, real-time monitoring, and compact size. Numerous researches have been devoted to the development of optical fiber sensors for use in chemical- and bio-sensing. Among various applications, relative humidity (RH) sensors are used in the industrial field, food processing, human breath detection, and environment monitoring [1].

Many researchers have focused on developing and improving the humidity sensors, using the single-mode side-polished multimode-single-mode (SSPMS) fibers coated with gelatin [2], silica-gel coated microfiber coupler humidity and temperature sensor [3], humidity sensor for monitoring human breath based on etched single-mode coated with MoS_2 layer [4]. Some researchers have shown that a tapered multimode fiber (TMMF) can be used as a refractive index (RI) sensors, whose sensitivity increases as the tapered region diameter decreases. Nonetheless, they have demonstrated that there is a trade-off between the sensitivity, measurement range, and the sensor mechanical stability [5]. Some others have also used a TMMFs for sensing humidity, coating the tapered region with polyvinyl alcohol [6].

In this paper, we fabricate and characterize humidity sensors by coating the tapered regions of the prepared TMMFs with layers of silica-gel. Note that recent studies have demonstrated that silica-gel is sensitive to humidity and is transparent to the optical signal [3]. We have studied the effect of the diameter of the waist of the tapered region on the resulting sensitivity.

2. Sensor Fabrication

The aim of this work is to fabricate inexpensive and reliable RH sensors. Hence, we have chosen the TMMF as the sensor foundation and the silica-gel as a sensing layer. Figure 1 illustrates a schematic of a fabricated sensor in which the tapered region of a TMMF is coated by a layer of silica-gel.

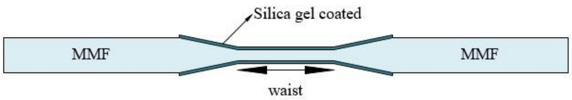

Fig. 1: Schematic of a TMMF coated with silica-gel

For preparing the required TMMFs, we used the well-known microheater brushing technique [5]. In this technique, a 1-m long multimode fiber (MMF) is passed through a microheater and pulled in the opposite directions, by two linear motorized stages from both sides. The results show an adiabatic taper MMF due to the small angle of the transition region.

Then, we employed the sol-gel technique by labor constitution [7] to synthesize the silica-gel solution, required for uniformly coating the surface of the tapered region of each TMMF (see Fig. 1). The thickness of the coating layer can be increased, by repeating the coating process. For synthesizing a silica-gel solution with suitable viscosity, we mixed 20 ml of tetraethylorthosilicate (TEOS) with 10 ml of ethanol in a beaker, using a magnetic stirrer for 20 minutes at room temperature. Then we added 3 ml of H_2SO_4 (0.1 mol/L) to the solution and stirred it for 150 minutes.

Next, for coating the tapered region of each TMMF, we passed it through a drop of silica-gel for four times. Then, for dying the silica-gel coats, we hanged the silica-gel coated TMMFs by a plastic holder in the air at room temperature for 3 days. Figure 2 shows a microscope image of a fabricated sensor.

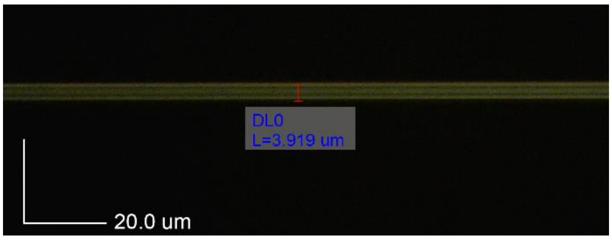

Fig. 2: Microscope image of a sensor

3. Results and Discussion

We used a fiber fusion splicer, a broadband light source (BBS) and an optical spectrum analyzer

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(OSA) to characterize the sensor. The sensor was placed into a chamber of ~2 L volume with two inputs. One of the chamber inputs was connected to a humidifier and the other to an argon gas cylinder. The sensor was connected to the BBS and OSA. During the Characterization, we used the SHT20 sensor to indicate the RH percentage (RH%) and the chamber temperature. The chamber temperature was set to 26 °C. Figure 3 shows a schematic of the characterization setup.

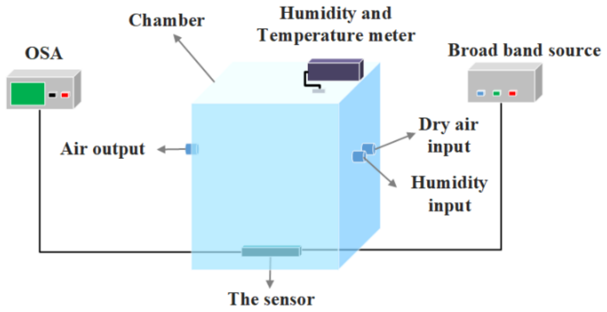

Fig. 3: Schematic of the characterization setup.

Figure 4 shows the transmission spectra through the sensor with l = 9 mm and d 4 μm for different RH%, measured in the first communication window (820≤λ≤880 nm). Here, l is the length of the tapered region and d is the waist diameter.

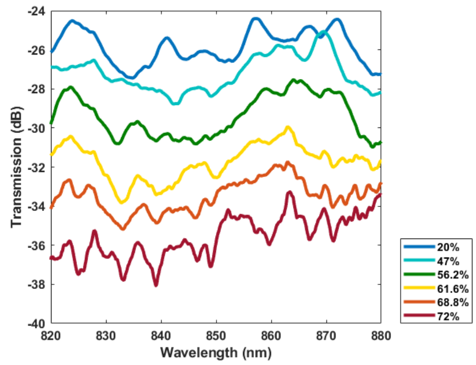

Fig. 4: Transmission spectra through the sensor with l = 9 mm and d 4 μm for different RH%

The sensor response to the fluctuations of the RH% is represented by variation in the power transmission through it. We calculate the average of the sensor transmission on the interval 820≤λ≤880 nm. To emphasize the effect of the silica gel coating on the sensor performance, we have compared the power loss through two TMMF sensors with the same dimensions (i.e., l= 9 mm and d=4 μm), but one without coating and the coated four times with silica gel. The solid circles in Fig. 5 represent the response of the sensor with no coating and solid squares show a similar response measured for the one coated four times with silica gel. As this comparison illustrates, the influence of the silica gel coating on the sensor functionality is significant. This phenomenon can be explained by the fact that water molecules diffuse into the silica gel coat where they are absorbed [3]. This absorption increases the coating layer effective refractive index nonlinearly, increasing the transmission loss through the sensor accordingly.

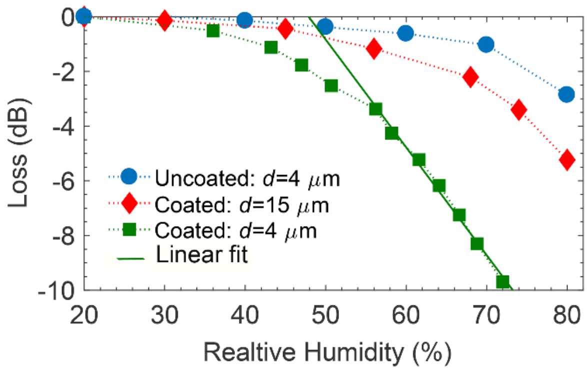

Fig. 5: Comparison of the sensor response for an uncoated TMMF (circles) with those of similar TMMFs coated with silica gel (diamonds: $l \approx 8$ mm, $d \approx 15$ μm). The lengths and diameters of the waist regions of both sensors were $l \approx 9$ mm and $d \approx 4$ μm.

Next, we have investigated the effect of the tapered region waist dimensions on the sensor response. The solid diamonds in Fig. 5 show the response of a TMMF sensor with a thicker and shorter tapered region (i.e., $d \approx 15$ μm, and l =8 mm) that is also coated with silica gel for four times. A comparison of the latter sensor's response with the one represented by the solid squares reveals that the coated sensor with a thinner waist region is more sensitive to the environment humidity. However, its detection range drops from 80% to 72%. This result shows the trade-off between the sensitivity and detection range. Hence, there is a trade-off between the sensitivity and the sensing range. This can be attributed to an effectively larger volume of the silica gel coating the waist of the tapered region of the corresponding sensor. Nonetheless, this

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significantly higher sensitivity is achieved at the expense of a large decrease in the fiber output power level. Moreover, as can be observed form the solid squares in Fig. 5, the response of this particular sensor in the range of RH ≥55% varies almost linearly. This behavior is demonstrated by the solid linear line fitted into the data in that region. The slope of the loss response ($\mathbb{S} \equiv d(\text{loss})/d(\text{RH}\%)$) determines the sensor sensitivity. According to this definition, the sensitivity of the TMMF sensor with a thinner waist in the linear region is $\mathbb{S} \cong -0.39$ dB/RH%.

Finally, to evaluate the sensor response time (τ_{res}) and recovery time (τ_{rec}), we have measured the power loss versus time, when the chamber humidity is changed from 40% to 60%. Figure 6 illustrates this characteristic of the sensor with the l =9 mm and d=4 µm. From this figure, one can see $\tau_{res}\approx$ 10 s and $\tau_{rec}\approx$ 8 s.

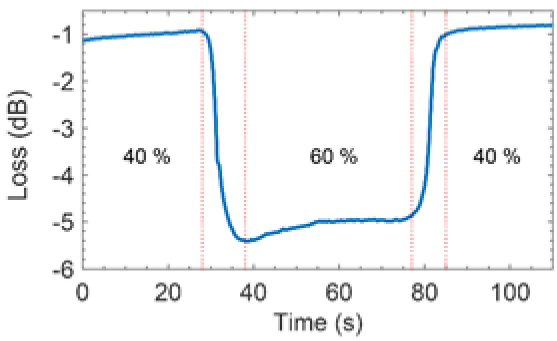

Fig. 6: Time characteristic for the sensor with the l =9 mm and d=4 µm

Table I compares the characteristics of our sensor with those of others'.

Table I. Comparison of this work with others.

Structure	Sensitivity	τ_{res} (s)	τ_{rec} (s)	Ref.
TMMF	0.39 dB/RH%	10	8	This work
SSPMS	0.14 dB/%RH	1	-	[2]
Etch-fiber	—	0.066	2.395	[4]
TMMF	1.994 µW/%RH	2	-	[6]

Conclusion

We have fabricated and characterized a humidity sensor based on a TMMF whose tapered region is coated by a layer of silica-gel. We have demonstrated the effect of the size of the waist diameter of the tapered region on the device sensitivity. The experimental results have shown that the sensitivity in the linear region for the sensor with l=9 mm and d= 4 µm equals $\mathbb{S}\approx$0.39 dB/RH%.

Acknowledgments

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References

[1] M.-J. Yin, B. Gu, Q.-F. An, C. Yang, Y. L. Guan, and K.-T. Yong, "Recent development of fiber-optic chemical sensors and biosensors: Mechanisms, materials, micro/nano-fabrications and applications," *Coordination Chemistry Reviews*, vol. 376, pp. 348-392, 2018.

[2] X. Wang, G. Farrell, E. Lewis, K. Tian, L. Yuan, and P. Wang, "A humidity sensor based on a singlemode-side polished multimode–singlemode optical fibre structure coated with gelatin," *Journal of Lightwave Technology*, vol. 35, no. 18, pp. 4087-4094, 2017.

[3] L. Sun *et al.*, "Investigation of humidity and temperature response of a silica gel coated microfiber coupler," *IEEE photonics journal*, vol. 8, no. 6, pp. 1-7, 2016.

[4] B. Du *et al.*, "MoS2-based all-fiber humidity sensor for monitoring human breath with fast response and recovery," *Sensors and Actuators B: Chemical*, vol. 251, pp. 180-184, 2017.

[5] D. Liu *et al.*, "High sensitivity refractive index sensor based on a tapered small core single-mode fiber structure," *Optics Letters*, vol. 40, no. 17, pp. 4166-4169, 2015.

[6] T. Li, X. Dong, C. C. Chan, C.-L. Zhao, and P. Zu, "Humidity sensor based on a multimode-fiber taper coated with polyvinyl alcohol interacting with a fiber Bragg grating," *IEEE Sensors Journal*, vol. 12, no. 6, pp. 2205-2208, 2011.

[7] A. K. Mallik, G. Farrell, D. Liu, V. Kavungal, Q. Wu, and Y. Semenova, "Silica gel coated spherical micro resonator for ultra-high sensitivity detection of ammonia gas concentration in air," *Scientific reports*, vol. 8, no. 1, p. 1620, 2018.

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