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Investigation of refractive index sensors based on side-polished plastic optical fibers

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ABSTRACT

A side-polished plastic optical fiber (POF) was proposed for liquid's refractive index (RI) measurement. The POF was polished into an arc shape on the surface of the fiber for increasing its RI sensitivity. The experiment shows that the straight side-polished POFs are not sensitive enough as the RI probes. After the straight side-polished POFs were bent into the U-shaped probes, the sensitivities were markedly increased. By changing the structural parameters, the RI sensing performance of the U-shaped probe was optimized, a sensitivity of 864%/RIU with a resolution of 3.3×10^{-4}/RIU in the RI range of 1.33–1.44 was obtained. In addition, the characteristic of the temperature dependence of the sensor was presented. The sensor is a low cost solution for RI sensing applications which has the features of simple structure, compact size, and intensity modulation at visible wavelength.

1. Introduction

Refractive index (RI) measurement is widely applied in many areas, such as medicine and biochemistry. Optical fiber based RI sensors have the advantages of immunity to electromagnetic interference, compact size, high sensitivity and fast response [1,2]. Recently, POFs based RI sensors have attracted a lot of attention [3–10]. Compared with glass counterparts, the POF RI sensors have some unique advantages, such as easy fabrication and operation, working in the visible region and less prone to flexural damage. Generally, the POFs based sensors are more suitable for intensity modulation schemes due to their multimode characteristic. With special focus on low cost solutions, the RI sensors based on POF can be considered as a valuable alternative to traditional technology.

The POFs should be locally modified to enhance the sensitivity in some ways, such as tapering [3–6], making a hole [7,8], side-polishing [9], chemical etching [11], insertion imperfections [12,13] and so on. Compared with other configurations, the side-polished POF is easy to implement, and the fiber core is easy to expose to the environment for improving the sensing performance. Ning Jing et al. [9] reported a macro-bending side-polished POF for RI sensing, which presented a good RI sensing performance, but the flat region polished on the macro-bending POF is limited in area. In this work we tried a different way to modify the POFs for improving the RI sensitivity. The POF was polished to an arc shape on the surface of the fiber, and then bent into a U-shaped probe. The RI sensing performance of the probe was improved experimentally by optimizing the structural parameters, and the temperature dependence for the RI sensing performance was presented.

2. Preparation of the POF probe

The POF we used was commercial available step-index POF (Jiangxi Dashing POF Co., Ltd). The core material of the POF is PMMA with diameter of 980 μm, RI of 1.49 and thermo-optic (TO) coefficient of -1.15×10^{-4}/°C, while the cladding material is a fluorinated polymer with thickness of 10 μm, a lower RI of 1.41 and TO coefficient of -3.50×10^{-4}/°C. The schematic diagram of side-polished structure on POF was shown in Fig. 1, the side-polished area can be described as an arc of a circle with the polished length L and polished depth d. The principle of operation is based on the propagation loss and evanescent wave introduced by the side-polished structure on straight or macro-bending fiber, and modulated by the environmental RI. Therefore, the RI can be detected by measuring the changes of transmittance of the light propagating in the probe.

The side-polishing procedure is easy to implement due to the soft materials of POFs. This procedure included two steps, the rough polishing and fine grinding. A rough abrasive paper was used at first to obtain the desired geometry of the sensor probe, and a

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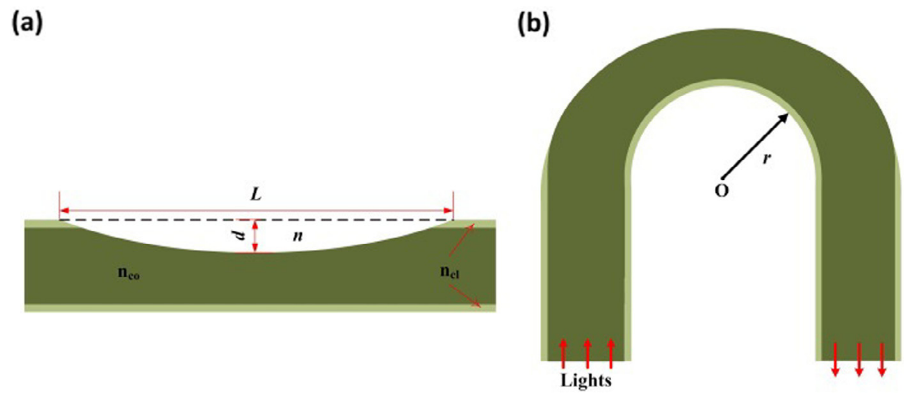

Fig. 1. The schematic diagram of the side-polished POF. (a) The straight side-polished POF, where n_{co}, n_{cl}, and n are the RIs of the fiber core, cladding and environment, respectively. The outline of side-polished region is an arc of a circle with the chord length *L*, curvature radius *b* and polished depth *d*, and the relationship of them is described as $b^2 = (b - d)^2 + L^2/4$. (b) The macro-bending side-polished POF, where *r* is the curvature radius.

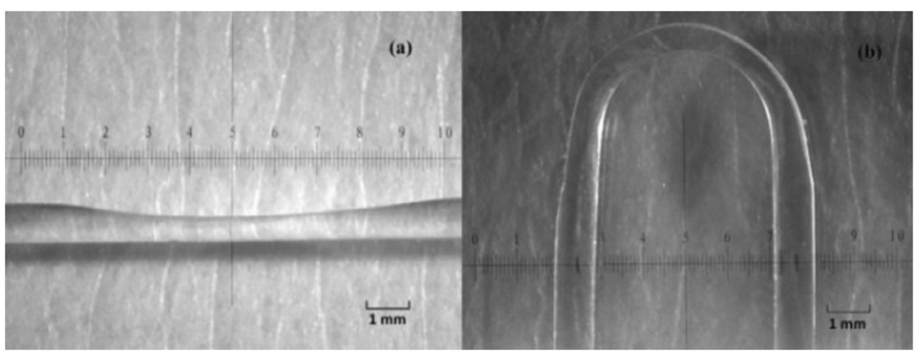

Fig. 2. The microscope images of the straight (a) and macro-bending (U shaped) (b) side-polished POFs.

thinner grind paper was used for the fine grinding step in order to get a smooth polished surface. During the side-polishing process the POF was fixed by the clamps. After the side-polishing process, the polished geometric parameters were measured by a microscope. For easy to test the RIs of liquids, the side-polished POFs were bent to macro-bending (U-shaped) probes, and the side-polished region located in the outer side of the macro-bending POF. In this process, a thermal setting method was used which made the probe more compact and stable for applications. The side-polished POF was bent around a heated metal rod, and the macro-bending radius of the probe could be altered by using the metal rods with different radii. The images of the straight and macro-bending side-polished POFs were shown in Fig. 2.

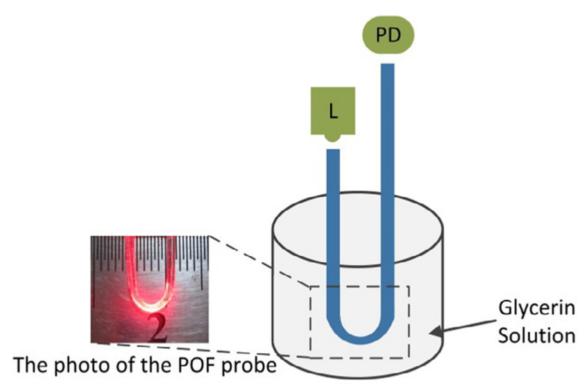

Fig. 3. Schematic of the experimental setup. L is the laser diode and PD is the photo detector.

3. Experiments and discussions

Fig. 3 shows the schematic of the experimental setup, which is used for measuring the transmitted light of the POF probe in the glycerin solution. A laser diode (TLS001-635, Thorlabs) was used to generate a laser beam with the wavelength of 635 nm. The launched power of the light source was 1 mW. A photo detector (S120, Thorlabs) with the responsivity of 0.41 A/W at 635 nm and a resolution of 1nW was used to detect the light signals. By varying the concentration of glycerin solution, the liquids with an RI step of 0.01, ranges from 1.33 to 1.44 were obtained. The RIs were measured by an Abbe refractometer and described by the relation of $n = 1.33 + 0.13C$, where *C* is the volume concentration of the glycerin at 20 °C. Ten sets of measured results were recorded for each measurement for the calibrating procedure. After each of the measurement, the sensing probe was washed by the alcohol and deionized water, then dried for reuse. The experiment was performed at a constant temperature (20 °C) to avoid the influence of the temperature.

The RI sensing performances for the straight probes with the polished length of 10 mm and depth of 100–500 μm were investigated as shown in Fig. 4. The average values and the measurement errors at each measurement point are given. The errors are mainly generated from the fluctuation of light source and the detector noises, and given as three times the relative standard deviation. Experiment results showed that for the probes with the polished depth of 100 and 200 μm, the changes of the transmittance with the RI variation were submerged by the light source fluctuations, and for those with depth of 300, 400 and 500 μm, the transmit-