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The influence of temperature to a refractive index sensor based on a macro-bending tapered plastic optical fiber

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ABSTRACT

The temperature influence to a refractive index (RI) sensor based on a macro-bending tapered plastic optical fiber (POF) was investigated experimentally. The total temperature dependence loss (TDL_{total}) and total temperature dependence RI deviation (TDR_{total}) were measured at different temperature (10–60 °C) over an RI range of 1.33–1.41. The temperature dependence RI deviation of the sensor itself was obtained by subtracting the temperature dependence RI of measured liquid from TDR_{total}. Therefore, the influence of temperature variation to the sensor was characterized and corrected.

1. Introduction

Refractive index (RI) sensors based on optical fibers are widely applied in biosensor [1] and chemical sensing [2–4] due to their specific advantages, such as immunity to electromagnetic interference, rapid response, compact size and remote sensing capability. A wide range of optical fiber RI sensors have been reported [1–8], and mostly composed of single-mode glass optical fibers (GOFs), which require complex processing of fibers and expensive experimental equipment. Several researchers have investigated the performance of plastic optical fibers (POFs) as an alternative to GOFs. Compared with GOFs, POFs have some unique advantages, such as large diameter, high numerical aperture and low attenuation in the visible region [9]. With special focus on intensity modulation schemes, the POF based RI sensors may be considered as a low cost solution to GOF based RI sensors [10–13]. However, the thermo-optic coefficient (TOC) of the POF is an order of magnitude higher than that of the GOF. Therefore, the temperature influence to the POF RI sensor must be considered. There have been already several reports focused on the temperature dependence of single mode GOF devices [14–17], in which all of theoretical models for the devices are presented, and with good agreement demonstrated between theoretical calculations and experimental results. In the same way, the temperature dependence of a thinned multi-modes POF based RI sensor was studied theoretically and experimentally [18], but the theoretical analytical methods are cumbersome and difficult to operate in the defective (D-type and tapered) fiber based devices. Therefore, an experimental analytical method was presented for the temperature dependence of an RI sensor based on a side-polished macro-bending POF [19].

It is well known that the sensitivity could be enhanced by cascading of bend and tapered POF geometry [20], but to learn the temperature dependence of it would be an important issue for applications. In our recent study, a POF based RI sensing probe with a macro-bending tapered structure was proposed, the RI of the surrounding liquid can be detected by measuring the transmittance or the propagation loss of the sensing probe, and the performance of the sensor can be improved by optimizing the structure parameters. Normally, the RI sensor was operated at a constant temperature. When ambient temperature changes, the variations of the RI of the POF probe and the structure parameters would have influence on the sensor performance. Therefore, the temperature influence to the POF RI sensor was investigated in this paper.

2. Experiment

The schematic of a macro-bending tapered POF (Jiangxi Daishing POF Co., Ltd) sensing probe is illustrated in Fig. 1. The parameters of the POF are shown in Table 1.

An electric soldering iron was used to heat the POF for drawing the POF tapers. If a POF is heated and drawn directly, both the fiber

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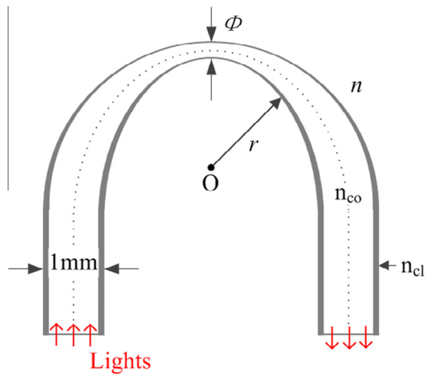

Fig. 1. Schematic of the POF probe with macro-bending and tapered structure, where Φ is the diameter of taper waist, r is the macro-bending curvature radius, n_{co}, n_{cl}, and n are the RIs of the fiber core, fiber cladding and external medium, respectively (Φ = 250 μm, r = 2.0 mm, n_{co} = 1.49 and n_{cl} = 1.41).

Table 1
The parameters of the POF.

	Material	Diameter	RI	Thermo-optic coefficient
Core	PMMA	0.98 mm	1.49	-1.15×10^{-4}/°C
Cladding	Fluorinated polymer	1.00 mm	1.41	-3.50×10^{-4}/°C

core and cladding are tapered proportionally. So, in this way, we obtained a tapered POF with cladding. The tapered POFs became very weak and easy to break for macro-bending process. Therefore, a thermal setting process [12] was used, which made the POF probe more compact and stable for applications.

The schematic of the experimental setup is illustrated in Fig. 2, which is used to measure the transmittance of the POF probe in the glycerin solution at different temperatures. By varying the concentration of glycerin solution, the RIs ranging from 1.33 to 1.43 with step of 0.01 were obtained. They were measured by a commercial Abbe refractometer and described by the following relation,

$$n = 1.33 + 0.13C \tag{1}$$

where C is the volume concentration of the glycerin. The temperatures of the glycerin solution were varied from 10 to 60 °C with step of 10 °C for testing the temperature dependence of the sensor. A semiconductor laser source (TLS001-635, Thorlabs) with a wavelength of 635 nm and launched power of 1 mW was used. A power detector (S120, Thorlabs) with the responsivity of 0.41 A/W at 635 nm and a resolution of 1nW was installed to detect the light signals from the probe. The temperature of the RI liquid is controlled by a digital temperature controller connected to a heater. A digital thermometer was immersed into the RI liquid for the purpose of temperature monitoring. During the experiment, the launched power of the light source was kept constant and the fiber should be fixed by the fiber holders.

3. Results and discussions

The POF probes with the taper waists of 150–600 μm, and with the macro-bending curvature radius of 1.0–3.0 mm were prepared. We found that when the curvature radius and taper waist were 2.0 mm and 250 μm, respectively in the room temperature, the sensing performance was the best in the experiment. In this case, the highest RI sensitivity of the probe reached 937%/RIU in the RI range of 1.33–1.41, and in the range of 1.41–1.43, the sensitivity is equal to 0 because of the existence of the cladding after the tapered process. Obviously, the probe with the macro-bending tapered structure is more sensitive than the one with the only macro-bending structure, or with straight taper, as shown in Fig 3.

When the temperature varies from 20 to 60 °C, the propagation losses of the sensor probe (r = 2.0 mm, Φ = 250 μm) versus the RI of measured liquids are shown in Fig. 4. From the results, it is found that the propagation loss may be varied by not only the RI of measured liquids, but also the environmental temperature.

The propagation loss of the sensor induced by temperature variation from 20 °C is referred to as total temperature dependent loss (TDL_{total}), which is defined as,

$$TDL_{total} = Loss_{T\,^{\circ}C} - Loss_{20\,^{\circ}C} \tag{2}$$

where T is the temperature. The TDL_{total} may be varied by not only the TO effect of the measured liquid, but also the TO effect and thermal expansion (TE) effect of the POF probe itself. Obviously, the TDL_{total} can cause an RI deviation, and we call this deviation as total temperature dependent RI (TDR_{total}). Same as TDL_{total}, the TDR_{total} of the sensor can be divided into two parts: (1) a TDR induced by the TO effect and TE effect of the sensor probe (TDR_{sensor}) and (2) a TDR induced by the TO effect of the measured liquid (TDR_{liquid}). Thus the TDR_{total} can be expressed as follows:

$$TDR_{total} = TDR_{sensor} + TDR_{liquid} \tag{3}$$

Obviously, the key issue is how to separate the wanted TDR_{sensor} of the POF probe from the measured TDR_{total}.

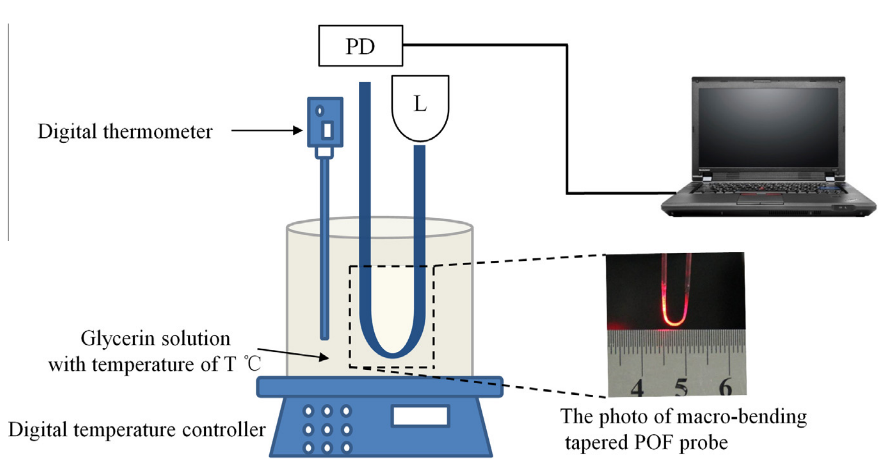

Fig. 2. Schematic of experimental setup. L is laser diode and PD is the photo detector.