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# In-line photonic microcells based on the elliptical microfibers for refractive index sensors applications

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## ABSTRACT

We report the fabrication of in-line photonic microcells (PMCs) by encapsulating tapered elliptical microfibers (MFs) inside glass tubes. The encapsulation does not change the optical property of the MF but protects the elliptical MF from external disturbance and contamination and makes the micro-laboratory robust. Such micro-laboratory can be easily integrated into standard fiber-optic circuits with low loss, making the elliptical MF-based devices more practical for real-world applications. Evanescent field sensing is realized by fabricating micro-channel on the PMC for ingress/egress of sample liquids/gas. Based on the encapsulated elliptical MF PMCs, we demonstrated RI sensitivity of 2024 nm per refractive index unit (nm/RIU) in gaseous environment and 21231 nm/RIU in water.

Keywords: in line, photonic microcells, elliptical microfibers, refractive index sensing

## 1. INTRODUCTION

Microfiber (MF) photonic devices have attracted considerable attention recently. Various MF-based devices such as microfiber resonators and add/drop filters [1-3], supercontinnum sources [4], refractometric sensors, and photoacoustic gas detectors [5,6] have been reported. Many of these devices take advantage of the large external evanescent field of MFs and exploit the strong interaction between the evanescent field and surrounding media, which form the basis for a range of chemical, biological and environmental sensors. However, the optical performance of the MFs degrades quickly due to light scattering from dust particles and cracks induced by water vapor, and an increasing unrecoverable optical loss was observed over time if they are left in open air [7,8]. Moreover, the MFs are fragile and not easy to handle, which hinders practical applications of these fibers.

In this paper, we report a simple and low cost method for fabricating encapsulated MF photonic microcells (PMCs). The MFs are fabricated by bi-tapering a conventional single mode fiber (SMF) and suspended along the center area of a capillary tube. The MFs are kept straight within the capillary while their SMF pigtails are glued to the two ends of the capillary. The encapsulation does not change the optical property of the MF but the capillary tube protects the MF from external disturbance and contamination. Side holes are made on the capillary wall and act as ingress/egress channels for sample liquids or gases. We demonstrated refractive index (RI) sensors by incorporating an encapsulated elliptical microfiber PMC into a fiber-optic Sagnac loop interferometer (SLI) and achieved RI sensitivity of 2024 nm per RI unit (RIU) in gaseous environment and 21231 nm/RIU in water.

## 2. ENCAPSULATED ELLIPTICAL MF PMCS AND REFRACTIVE INDEX SENSORS

The elliptical MF was taper-drawn from a commercial SMF-28 fiber. The fiber was firstly “cut” by use of a femtosecond IR laser to remove parts of the cladding on both sides of the fiber, and the cut region was then tapered down to a MF with an approximately elliptical shape. The detailed process for fabricating elliptical MF tapers has been described in a previous paper [9,10]. The elliptical MF was then encapsulated inside a silica capillary. Before the start of tapering, the cut SMF was spliced into a (SLI) [10] and the evolution of loss and birefringence of the MF were monitored continuously by observing the transmission spectrum of the interferometer.

Before performing pressure and RI measurements, the influence of temperature on the transmission spectrum was firstly studied. By placing the encapsulated elliptical MF PMC into a digitally controlled oven, the output spectrum of the SLI was recorded when the temperature was varied from 25 to 100 °C in steps of 25 °C. The two 400 μm-diameter holes were kept open so that the pressure inside the capillary is maintained at atmospheric pressure. Figure 4(a) shows the spectrums at 25 and 100 °C, and the wavelength of the dip around 1558 nm as function of temperature is shown in Fig. 1. The effect of temperature is very small (~7.72 pm/°C), which similar with result of the naked elliptical MF temperature measurement, and is believed due mainly to the thermal-expansion of silica [10].

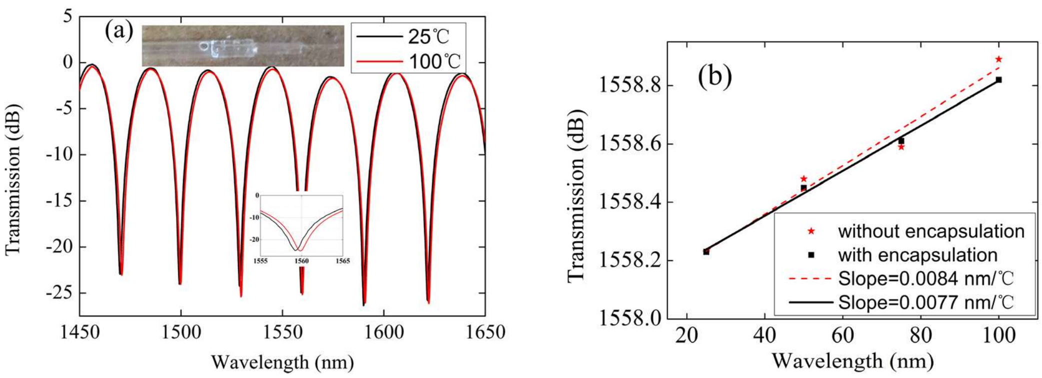


Fig. 1(a) Output spectrums of a fiber Sagnac interferometer incorporating an encapsulated elliptical microfiber at two different temperatures (i.e., 25 and 100 °C); (b) Dip wavelength around 1558 nm as a function of temperature for the elliptical MF with (black solid line) and without (red dash line) encapsulation.

The encapsulated elliptical microfiber sample was then used to measure the refractive index of a gas mixture. The encapsulated sample was placed inside a gas chamber. The inlet and outlet of the chamber were kept open to make sure that the pressure in the chamber is stable and at atmospheric pressure. Standard hydrogen and nitrogen gases were mixed with different proportions by varying the flow rate of the gases, which were controlled by two digital mass flow controllers (MFCs). The gas mixture was then guided into the gas chamber within which the encapsulated microfiber sample is placed. For a small gas chamber, the gas concentration within the gas chamber and the capillary reaches steady state within seconds, and the refractive index of the gas mixture may be calculated by using [11]

$$n_m = v_{H_2} n_{H_2} + v_{N_2} n_{N_2} \quad (1)$$

where $n_m$ is the refractive index of the gas mixture, and $n_i$ and $v_i$ are respectively the refractive indexes and the fraction of the gas component *i* ($i=H_2$ or $N_2$).

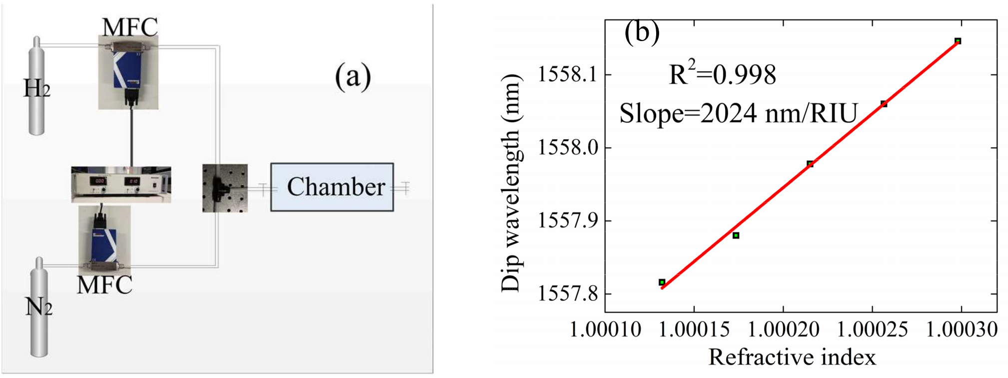


Fig. 2(a) Setup for producing gas mixtures with different refractive indexes. MFC: mass flow controller. (b) Dip wavelength as a function of refractive index. Inset: spectrums for five different gas mixtures.

The experimental process is as follows: firstly, the hydrogen gas was switched off and the nitrogen gas with a flow rate of 150 sccm (standard cubic centimeter per minute) was continually injected into the chamber, the spectrum was recorded when it became stable, which means that the nitrogen gas had completely filled the chamber; the flow rate of hydrogen gas was then set to 50, 150 and 450 sccm, the evolution of spectrums were recorded; the flow of nitrogen gas was set to 0 sccm and only the hydrogen gas was injected into the chamber, the spectrum was recorded when the chamber was fully filled with hydrogen. The five recorded spectrums correspond respectively to ($v_i$, $v_i$) = (1,0), (3/4,1/4), (1/2, 1/2), (1/4, 3/4) and (0,1). Figure 2(b) shows the dip wavelength around 1558 nm as a function of RI of the gas mixture, and the detailed spectrums for the five gas mixtures are shown in the inset of Fig. 2(b). The dip wavelength shifts to the longer wavelength with increasing refractive index and the slope coefficient or sensitivity is 2024 nm/RIU.

In order to explore the refractive index response of the PMCs in liquid environment, one hole on the capillary wall was immersed into water while the other hole left open to atmosphere, the section between the two side-holes was filled with water in a few second via capillary effect, as shown in the inset Fig. 3(a). The transmission spectrum of Sagnac interferometer for varying water temperature is shown in Fig. 3. The interference dip around 1548 nm shifted about 70 nm for temperature from 25 to 50 °C. This shift is due primarily to the thermal coefficient of water RI (~$-1\times10^{-4}$/°C) and, as demonstrated in Fig. 3 the temperature sensitivity of the SLI with microfiber in air is ~0.008 nm/°C and may be neglected in this experiment. By use of the look-up table in [12], the temperature changes can be converted into refractive index change and the dip wavelength as function of water RI is plotted in Fig. 3(b). The RI sensitivity is ~21231 nm/RIU, which agrees with the experimental results without encapsulation [10]. The PMCs does not change the optical properties of MFs and could be used to exploit the evanescent field liquid sensing.

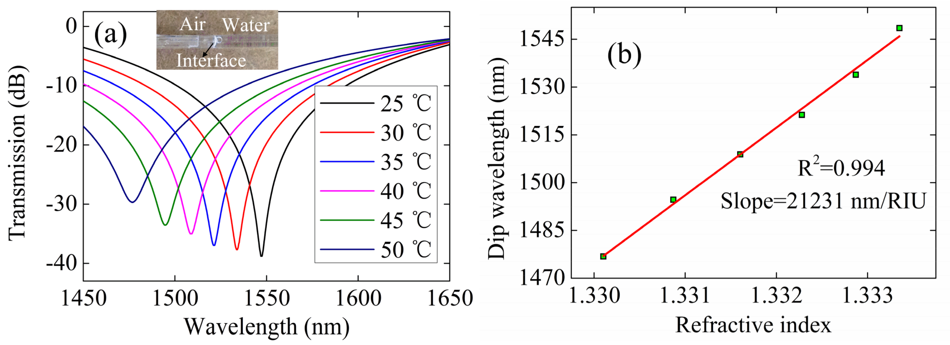


Fig. 3(a) Measured transmission spectrums when temperature is varied from 25 to 50 °C, inset: the region around hole at the end of the capillarity. (b) Wavelength of the dip around 1548 nm as function of temperature.

## 3. CONCLUSION

We have demonstrated a simple, effective method for fabricating in-line photonic microcells with a tapered micro/nanometer-sized elliptical core encapsulated within a capillary tube. With an encapsulated elliptical microfiber PMC spliced into a Sagnac interferometer, we demonstrated gas RI sensors with pRI sensitivity of 2024 nm/RIU at RI ≈ 1. With the same PMC, and liquid RI sensors with sensitivity of 21231 nm/RIU at RI ≈ 1.33.

## ACKNOWLEDGEMENT


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