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High extinction-ratio dual thin-taper fiber interferometer fabricated by arc-discharge and its performance as sensors

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ABSTRACT

We demonstrate an arc discharge fabrication method for a high extinction-ratio (ER) single mode fiber (SMF) based dual thin-taper modal interferometer (MI) and investigate the performance of the MI as thermal and refractive index (RI) sensors. With the optimized discharge parameters of a commercial fusion splicer and a simple mechanical taper setup, the MI with about 24 dB ER could be achieved if fabricating two thin-tapers with 20-μm waist diameter on the common SMF. It can be used as a highly sensitive thermal sensor with a thermal sensitivity of −72.8 pm/°C. However, for the high ER MI, the propagation position of the cladding mode is more close to that of core mode in the MI. Hence, its sensitivity to ambient RI variation is not very high, about 10.299 nm/RIU. If using it for dual parameter measurement, its thermal and RI measurement resolutions are ±1.1 °C and ±0.009, respectively, and are 6.6 and 2.4 times bigger than those of the other fiber sensors.

1. Introduction

Fiber modal interferometers (MI) fabricated on one fiber have attracted much interest due to their inherent advantages of small size, low cost, simple and compact structure. Especially, they have wide applications as fiber filters and sensors [1–12]. As we all know, the primary requirement for the fiber filter is its high extinction ratio (ER). For fiber sensor application, its high ER can improve the measurement accuracy both for wavelength and intensity measurement. Moreover, the high ER filter can be used as quasi-linear filter for low cost intensity-referenced measurement [13].

It should be noted that it is very difficult to fabricate a high ER thin-taper MI on the common single mode fiber (SMF) since its index contrast between the core and cladding is small. Generally, the common thin-taper SMF based MI is below 5 dB due to the unoptimized waist diameter of about 65 μm [10]. A high ER thin-taper MI can be fabricated on the Er–Yb co-doped fiber (EYDF) with 50-μm waist diameter since the fiber has a high index contrast between the cladding and highly phosphorous doped core [11,12]. In addition, generally, there are two heating techniques for fabricating the dual thin-taper MIs, point flame and discharge. Compared to the point flame heating, the discharge heating using a commercial splicer is more easy, robust and repeatable since it can be aultomatically controlled by setting suitable discharge parameters.

In this paper, to the best of our knowledge, we are the first to use arc-discharge method for fabricating high ER SMF based dual thin-taper MI. Compared to the commonly used discharge method, the arc discharge can produce a low level of heating and it is desirable for tapering a fusion splice. By optimizing the discharge parameters of a commercial splicer and designing a simple mechanical taper setup, the MI with about 24-dB ER could be achieved if fabricating two thin-tapers with 20-μm waist diameter on the common SMF. We also investigated its performance as thermal and refractive index (RI) sensors. Experimental results show that it is highly sensitive to temperature variations with a thermal sensitivity of −72.8 pm/°C. However, when it is used as a RI sensor, its sensitivity is not very high since the propagating position of the cladding mode is more close to that of the core mode in the MI. We validated this point theoretically and experimentally. Experimental results show that its RI sensitivity is about 10.299 nm/RIU. If using it as a dual parameter sensor, its thermal and RI resolutions can reach ±1.1 °C and ±0.009, respectively, and are 6.6 and 2.4 times bigger than those in Ref. [10], which is enough to meet the common measurement requirements.

2. Arc-discharge fabrication of the MI

The MI was constructed on a short-length SMF with two adjacent thin-tapers. To introduce the thin-tapers on the fiber, a

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commercial splicer (Fujikura FSM-40S) was applied to produce discharge to heat the fiber. Fig. 1 shows the fabrication process for the thin-taper on the SMF. The left side of the fiber was fixed by the left fiber clip; and the right side of fiber was loosely hold by the right fiber clip and pulled by a weight through a smooth supporting axle. When the arc discharge heating was applied on the central part of the SMF, it was automatically thin-tapered. The tapered fiber transition and waist diameters could be controlled by changing the applied weight via a pulley. By optimizing the parameters of the arc discharge power and the applied weight, a high ER MI could be fabricated.

Fig. 2 shows the typical microscope image of the thin taper. To obtain the MI with a high ER of more than 20 dB, repeat experiments were performed by optimizing the parameters of the arc discharge power arc time and the applied weight. Under the arc discharge power and arc time of 52 bit (default arc power unit: bit) and 200 ms, if applying a weight of 25.7 g, the MI with more than 20-dB ER could be achieved, and the thin-taper has the waist diameter of ~20 μm. Fig. 3(a) shows the typical transmission spectrum of the MI with a length of ~2 cm and a central un-tapered length of ~1.5 cm. As can be seen its ER reaches 24 dB. To determine the number and power distribution of the interference modes, the wavelength spectra in Fig. 3(a) was Fourier transformed to obtain the spatial frequency of the interference fringes, as shown in Fig. 3(b). It is clear a dominated cladding mode is excited, which agrees to our simulation results.

We also investigated the MIs with the same length of ~2 cm and central un-tapered length of ~1.5 cm under waist diameters of 35 and 10 μm, respectively. Fig. 4 shows their typical transmission spectra. The ER of the MI under 10-μm waist diameter reaches 22 dB while that is less than 10 dB under 35-μm waist diameter. Repeatable experimental results show that with the decrease of the waist diameter, the insertion loss becomes bigger accordingly due to the increased mode field diameter (MFD) mismatch between the SMF and tapered fiber. Compared to the MI under 20-μm waist diameter with 24-dB ER, although the ER of the MI under 10-μm waist diameter reaches 22 dB, its insertion loss is too big and the dip loss is as low as −55 dB. Moreover, it has many noise jitters. Hence, the optimized MI with 20-μm waist diameter is the best choice for fiber sensor and filter. Using the special fiber with a high index contrast between the cladding and core may be useful for fabricating lower insertion loss interferometer, but the cost of the specially designed fiber is too expensive.

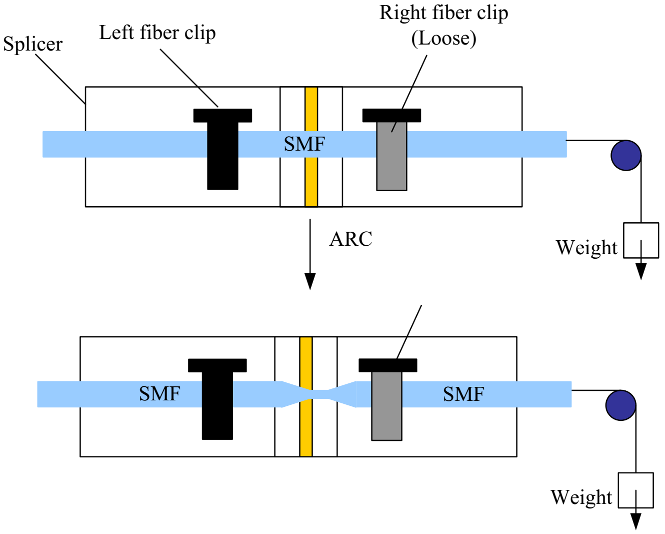

Fig. 1. Fabrication process for the dual thin-taper MI.

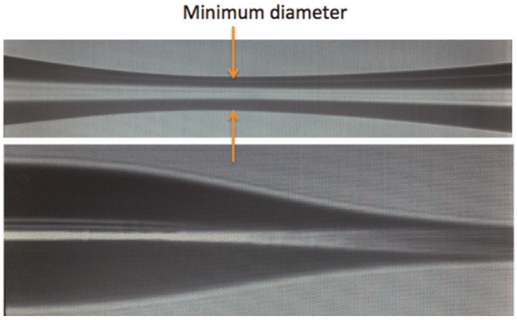

Fig. 2. Typical microscope image of the thin-taper.

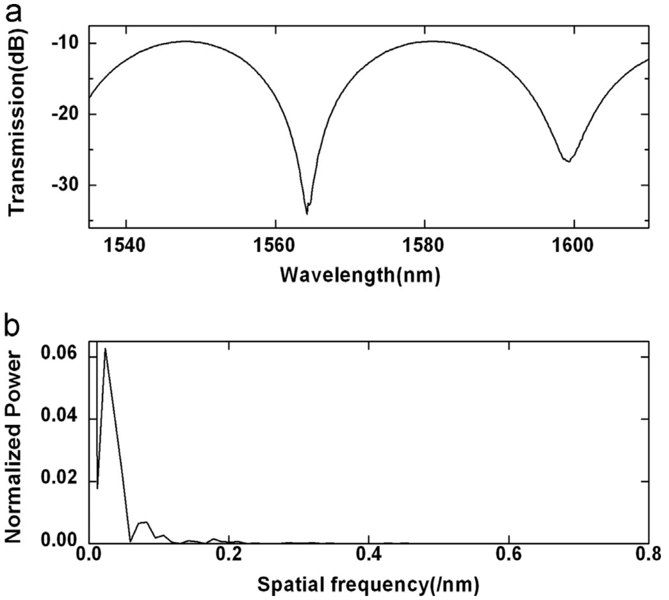

Fig. 3. Transmission spectrum of the MI and its corresponding spatial frequency spectrum.

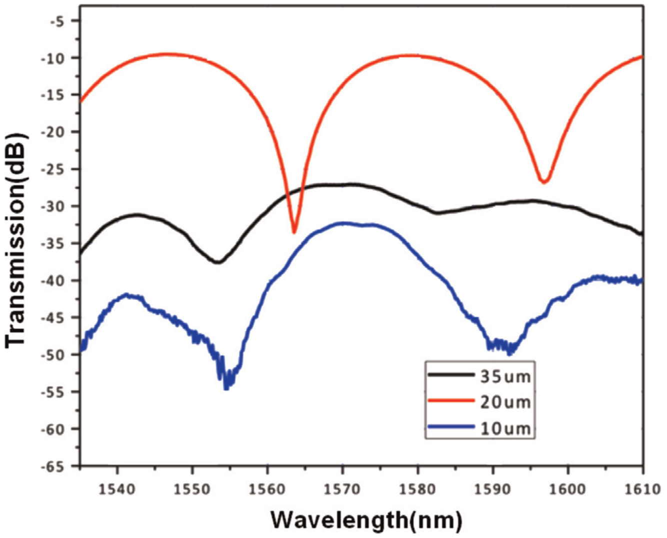

Fig. 4. Transmission spectra of the MI under different taper waist diameter.

3. Interference principle of the MI and its sensing principle

The light propagation in the MI was simulated by using a beam propagation method (BPM). The LP01 mode for the SMF at