Low-cost fiber-tip Fabry-Perot interferometer and its application for high temperature sensing

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We propose, fabricate, and demonstrate a compact fiber-tip Fabry-Perot interferometer of microcavity for high-temperature sensing. The microcavity which can be used for temperature or pressure sensing is fabricated by using arc discharge at the end of a multimode fiber, which is processed with chemical etching. Advantages of the sensor based on the fiber-tip Fabry-Perot interferometer are small size, easy fabrication, low cost and may have potential applications in space-limited and high-temperature environment.

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In the past three decades, optical fiber sensors have been intensively studied in order to measure various physical and chemical parameters, such as temperature[1,2], curvature[3], strain[4,5] and refractive index[6] due to their advantages such as small size, light weight, high sensitivity, multiplexing capability, immunity to electromagnetic interference, etc. Many kinds of fiber sensors based on interferometers, such as Fabry-Perot interferometers (FPIs)[7–11], Mach-Zehnder interferometers[12] and Michelson interferometers[13], have been reported in recent years. Among them, the FPI sensor is particularly attractive owing to its small cross sensitivity and extremely small form factor. The FPI sensor can be developed by various techniques, such as inserting two pieces of single-mode fiber (SMF) into a capillary tube to form an FPI by the air gap between two air–silica interfaces[7], splicing a short segment of hollow-core fiber between two sections of SMFs[8], and ablating a groove in an SMF using a femtosecond laser[9,10]. However, these techniques need stringent alignment, very well cleaving, or the use of expensive lasers.

In this paper, we demonstrate a novel method to fabricate a low-cost fiber-optic FPI sensor. The manufacturing process of the sensor can be divided into two steps: first, a chemical etching method is used to make a groove in the tip of a multimode fiber (MMF). Second, the etched fiber is put into a fusion splicer and then a microcavity is created in the tip of optical fiber by using arc discharge at the fiber end. The temperature characteristic of the sensor is investigated.

Chemical etching method has been widely used in the field of fiber sensor processing, which has the advantage of low-cost and the ease of operation. The method involves immersion of the fiber end in a solution of hydrofluoric acid (HF) under controlled conditions. As the chemical etching rate of the fiber core of the germanium-doped silica is faster than that of the fiber cladding of the pure silica, it is possible to fabricate a groove in the fiber tip. In addition, by adjusting the acid concentration and immersion time, the scale of the groove can be changed. In this paper, we immerse an MMF with a core diameter of 62.5 mm in a solution of 40% HF for 20 minutes. Owing to the different etching rates, a groove can be obtained in the fiber tip. Fig. 1(a) shows the schematic diagram of chemical etching method. Fig. 1(b) shows image, obtained by the built-in optical microscopy of the fusion splicer, of the fiber after 20 min of chemical etching with HF 40% compared to the fiber without any processing.

Then, the etched fiber is put into an optical fiber fusion splicer. To obtain a sealed microcavity in the fiber tip, the splicing parameters (arc power and arc time) should be adjusted to fulfill the requirement of sealing the fiber tip and avoiding the collapse of groove at the same time. In this work, the discharge current intensity of 5 mA and arc time of 700 ms are adopted for the fusion splicer (Nanjing Jilong Optical Communication Co. Ltd. KL-300T). During the discharge, the temperature reaches the softening point of silica for a short period of time and a sealed microcavity would be created in the fiber tip. In the whole fabrication processing of the sensor, only a single MMF is needed. Fig. 2(a) shows the schematic diagram of arc discharge. Fig. 2(b), which is also obtained by the built-in optical microscopy of the fusion splicer, shows the microcavity in the fiber tip.

As the reflectivity of the silica–air interface is less than 4%, higher-order reflections from these surfaces are negligible[11]. As a result, the sensor can be considered as a two-beam Fabry-Perot interferometer, one is from the end of the MMF, the other is from the surface of the silica wall, as indicated by red line in Fig. 2(b).

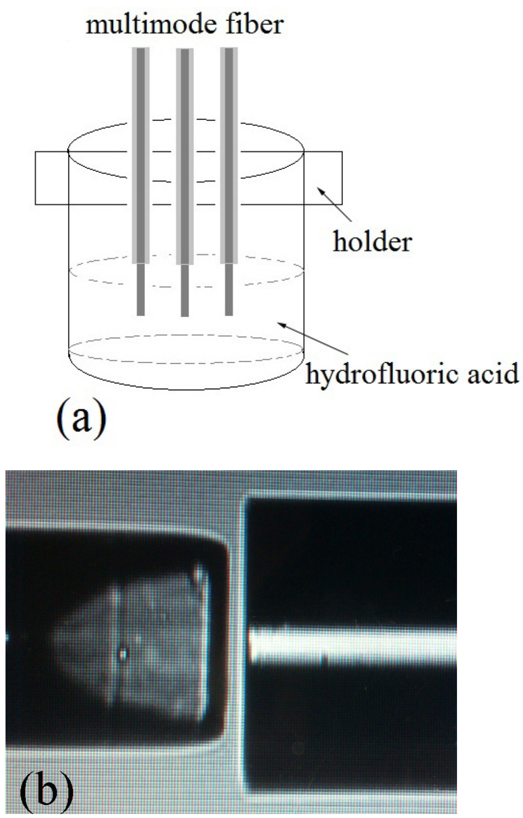

Fig. 1. (a) Schematic diagram of chemical etching method; (b) multimode fiber after 20 min of chemical etching with HF 40% compared to the fiber without any processing.

The temperature-sensing test system for the proposed sensor, shown in Fig. 3, is developed by a broadband optical source with a wavelength range from 1410 to 1640 nm, an optical spectrum analyzer with a resolution of 0.02 nm and an optical coupler to measure the reflective spectral response of the microcavity. The sensor is placed horizontally on a heating furnace with an electronic temperature meter. The heating rate of the furnace is set at 10 °C/min, and the temperature was raised in steps of 250 °C (the first step was set at 220 °C) and maintained for about 30 min at each step to make sure that the temperature in the furnace has stabilized.

Fig. 4(a) shows experimentally measured reflection spectra of the sensor from room temperature to 1000°C. When we focus on the resonant dip, red shift of the reflective spectra is observed. Figure 4(b) shows the experimental relationship between temperature and the resonant dip wavelength. The goodness-of-fit is 0.99864, which indicates the linear relationship between resonant wavelength and temperature. The fitting curve can be expressed as $y = 1551.71 + 0.00189x$, which means the average temperature sensitivity of the sensor is about 1.89 pm/°C.

In conclusion, we fabricate a compact fiber-tip microcavity sensor using the electric arc discharge at the end of an MMF, which is processed by chemical etching. It is demonstrated that the temperature sensitivity of the sensor is about 1.89 pm/°C. The sensors show

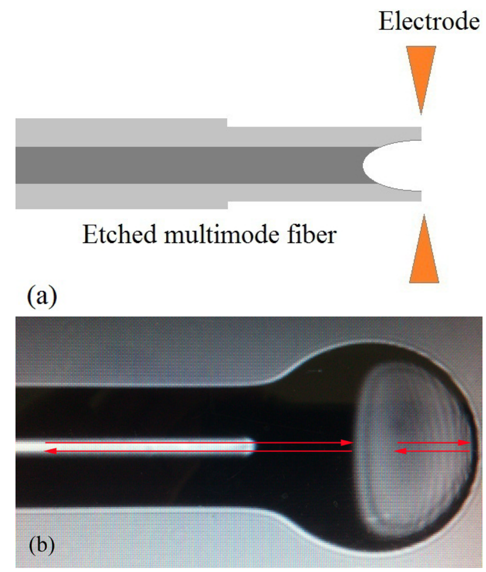

Fig. 2. (a) Schematic diagram of arc discharge; and (b) The obtained micro-cavity in the fiber tip.

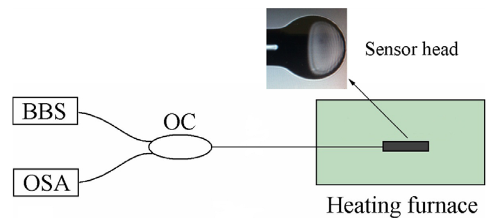

Fig. 3. Experimental setup of the temperature-sensing system.

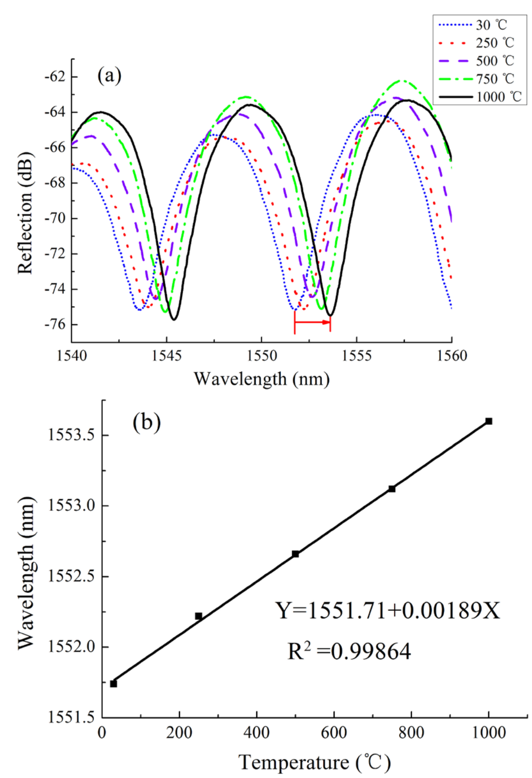

Fig. 4. (a) Reflection spectra of the temperature sensor under different temperatures from 30° C to 1000° C; and (b) relationship between temperature and the resonant dip wavelength.

potential application in space-limited and high-temperature environment. As the microcavity has a thin silica wall, we believe it can be used as a sensitive hydrostatic pressure detector. We are currently working on it.

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