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A new method of fabricating Fabry-Pérot type optical fiber temperature sensor using an external silicon microsphere

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Abstract

A new optical fiber temperature sensor based on in-line silicon microsphere cavity Fabry–Pérot interferometer (FPI) was demonstrated for sensitive and high temperature applications. The estimated thermal sensitivity ~80pm/℃ was five times higher than those of the current FPIs based on silica fiber within the temperature range up to 700°C.

1. Introduction

Optical fiber Fabry–Pérot interferometer (FPI) is one of the most commonly used interferometers [1-2]. Because of their simple structures, small sizes, and immunity to electromagnetic interference, FPI based sensors have been widely employed for the detection of physical and chemical parameters such as temperature, strain, refractive index, and gas concentration, etc. [3]. However, most cavities of the temperature sensors were generally made from air or silica which exhibited 2.1 pm/℃ and 14 pm/℃ temperature sensitivity, respectively, limited by their thermal-optic coefficients [4, 6].

Recently silicon core fibers (SCFs) have attracted increasing attention due to their unique features and new applications [5]. One example is for temperature sensing application because the thermal expansion and the thermo-optical coefficients of silicon are larger than those of silica. A silicon cavity based fiber FPI for temperature sensing have been reported [3, 6], where a small section of SCF was first spliced with a SMF and then heated with electric arc to form a single silicon microsphere or two silicon/silica reflection planes. Since the silicon cavity was embedded in silica, such enclosed structure might have its own limitations because of non-direct contact with external environments.

In this work, we report a novel method to fabricate a silicon microsphere cavity Fabry–Pérot type optical fiber temperature sensor, which allows direct contact with external environments. First, we used arc discharges to produce a series of silicon microspheres. Secondly, a portion of the fiber's cladding was removed to expose the silicon microspheres. Thirdly, a silicon microsphere was put in a hollow core fiber (HCF) spliced with a single mode fiber (SMF). Finally, the fabricated fiber temperature sensor was placed in a heated zone for testing.

2. Experimental Results

A SCF of 50mm long was fabricated by the drawing method [7] to make silicon microspheres. The SCF was moving across the region where the electric arc discharged sequentially. With proper control of parameters, the silicon core could be melted and a series of relatively uniform silicon microspheres (20~25μm in diameter) could be formed as shown in Fig. 1. The silicon microspheres were released from the silica cladding by etching away silica using hydrofluoric acid, and the obtained microspheres are shown in the inset of Fig. 1. The measured surface roughness using laser confocal microscope (VK-9700, Japan Keyence) was about 20 nm.

Most of the HCF spliced to the SMF was cleaved out to remain a small section. We then utilized a silica fiber taper to manipulate the silicon microsphere into the HCF. With Van der Waals force between silicon microsphere and silica fiber taper, a silicon microsphere with diameter of ~25 μm could be moved and placed at the junction between SMF and HCF as shown in Fig. 2 to finalize the construction of a temperature sensor.

A tunable laser (LUNA, Phoenix 1400) was used as scanning light source for measurement. The reflected light was measured by using the built-in power detector of the laser source. An isolator was used to avoid the damage to the laser diode by back reflection. Both scanning and data acquisition were controlled by a desktop computer. For temperature characterization, the sensor was put in a temperature controlled furnace. The measured spectra for the temperature ranging from 30℃ to 110℃ are shown in Fig. 3(a). When the temperature increased, the spectrum shifted to a longer wavelength. The extinction ratio of the interference fringe was about 12 dB. FSR was about 13.4nm, which matched the cavity length of silicon microsphere. Fig. 3(b) shows that the sensor has a high temperature sensitivity of about 80 pm/°C ranging from 30℃ to 350℃, and the sensor could be operated up to 700℃.

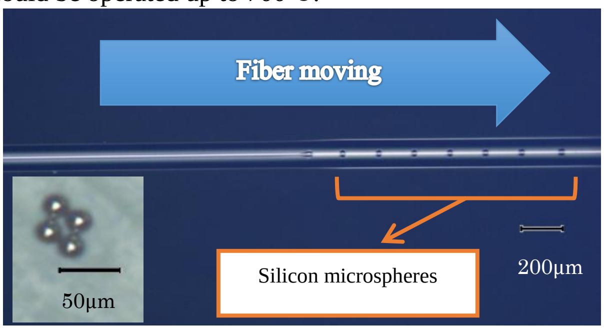

Fig. 1 Microscope image showing silicon microspheres are formed sequentially. The inset shows silicon microspheres without silica cladding.

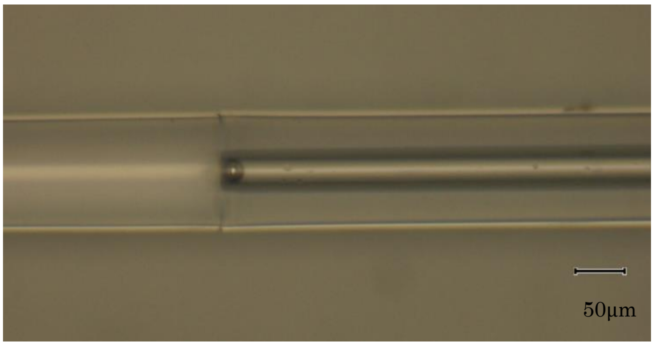

Fig. 2 A silicon microsphere is moved and placed at the junction between HCF and SMF to form a sensor.

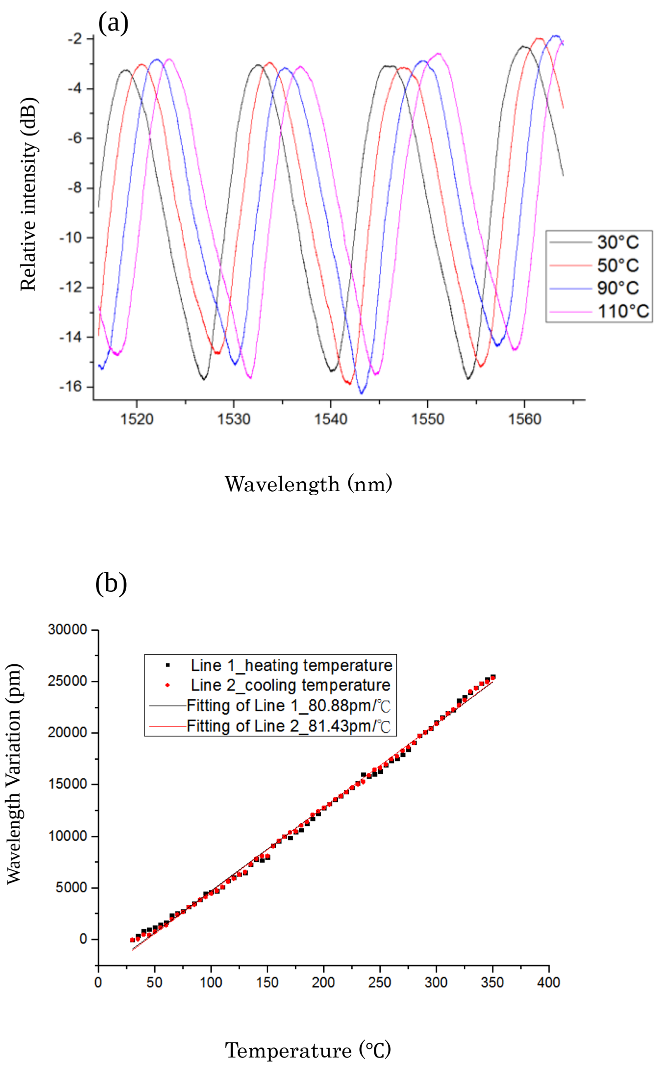

Fig. 3 (a) Reflection spectra of the FPI fiber sensor measured at various temperatures. (b) Temperature versus wave length variation: the black line is for the heating process, and the red for the cooling.

Summary

We heated a SCF to produce silicon microspheres sequentially by arc discharges, and a silicon microsphere thus obtained was put in a HCF spliced with a SMF to form a temperature fiber sensor. The measured thermal sensitivity was ~80pm/℃ for temperature range up to 700°C. With its open cavity structure such an in-line optical fiber sensor may find other sensing applications because of its ability of direct interaction with external environments.

Acknowledgements

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