Low-Cost Temperature Sensing Using D-Shaped Optical Fiber

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***Abstract*—A low-cost temperature sensor using D-shaped optical fiber with 1.7m long, highly concentrated erbium-doped fiber as the gain medium, has been experimentally demonstrated. The D-shaped optical fiber was polished using a 5V DC motorized mechanical wheel and interacted with surrounding temperature varying from room temperature to 70°C. Due to the temperature changes, the wavelength shifted to a longer region. This sensor has a sensitivity and linearity of 8.6 x 10-3 dBm/% and 94%, respectively. By using a simple fiber ring laser cavity, a sensitive and stable temperature sensor was successfully achieved.**

***Index Terms*—Temperature sensing; D-shaped optical fiber**

I. INTRODUCTION

Optical fiber sensors are characterized as novel sensing devices. Optical fiber sensor technology has been reported in [1] along with its working theory [2]. Optical fiber sensors can gain remote measurements in conditions that are either dangerous, suffering from severe electromagnetic interference or where storage and weight are limited. These sensors have the potential to measure a wide range of parameters and as such been investigated as refractive index sensor, pressure sensor, magnetic field sensor and temperature sensor.

Nowadays, temperature measurement of functional structures within the nanometric range is one of the biggest challenges in temperature sensing. This is due to insufficient spatial resolution of conventional techniques such as the thermocouple, which has a spatial resolution of approximately 100μm [3]. Thus, several approaches have been extensively studied including utilizing high sensitivity fiber like the Fabry-Perot interferometer [4] and fiber Bragg grating [5]. Nonetheless, the interferometer tends to be bulky in size and rather expensive. Furthermore, despite being efficient and simple to implement [6], fiber Bragg grating requires an additional technique to support the Bragg shifts by temperature. Recently, Hongjuan et al. demonstrated fiber optic sensors for measuring temperature in seawater using microfiber knot resonator, but the fiber mechanical strength of the sensing element is low since the microfiber waist has been reduced within a few of micrometers.

D-shaped optical fibers have recently been suggested as a sensing element given that part of the cladding is removed using the side-polishing method. The cross section of this fiber is useful to access the evanescent field of the guided mode. Such excellent properties make the D-shaped optical fiber an ideal candidate for temperature sensing. In this work, we demonstrate a D-shaped optical fiber for temperature sensing applications. The D-shaped optical fiber enables the evanescent field to respond with temperature on a hotplate which provides sufficient strength to withstand the high temperature.

II. EXPERIMENT

A. D-Shaped Optical Fiber Preparation

The D-shaped optical fiber sensor is fabricated by directly polishing and removing a portion of its cladding from a single mode optical fiber (SMF-28) using a mechanical wheel (5V DC motor) wrapped with abrasive paper (800 grit sandpaper) to access the evanescent wave as illustrated in Fig. 1. Before being paired with fiber holders, the single mode fiber is stripped in advance. Then, the fiber cladding is polished for few hours until a 5-dB insertion loss is measured by an optical power meter (OPM). Once an insertion loss of 5-dB is achieved, the 800-grit sandpaper is replaced with 1000-grit fine sandpaper to reduce the roughness of the polished surface region. In previous works, the preparation of the fiber begins with groove fabrication followed with chemically etched. However, it required simple manufacturing process and experimentation for our D-shaped optical fiber which reduces costs.

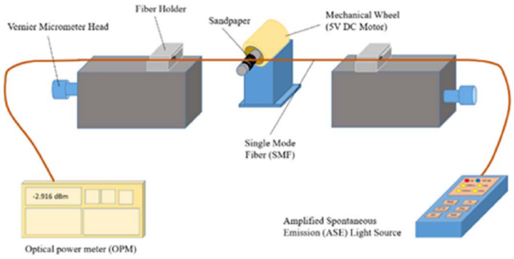

Fig. 1. Schematic diagram of D-shaped optical fiber preparation.

B. Fiber Ring Laser Configuration

The fabricated D-shaped optical fiber sensor is employed in a fiber ring laser configuration and placed on the hotplate (MSH-20D). The hotplate temperature is increased linearly starting from room temperature to 30°C, 40°C, 50°C, 60°C and 70°C. The schematic diagram of the fiber ring laser

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configuration is illustrated in Fig. 2. The D-shaped optical fiber sensor is added into the cavity as a sensing element following a 95/5 fiber coupler. In order to monitor two simultaneous measurements, the 5% output is monitored using an OPM and an optical spectrum analyzer (OSA, YOKOGAWA AQ6370C). The proposed optical fiber sensor configuration is not only simple, it also archives high sensitivity, anti-interference and is compact in size.

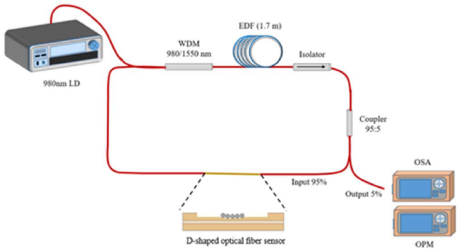

Fig. 2. Schematic diagram of fiber ring laser: LD (laser diode), WDM (wavelength division multiplexer), EDF (erbium-doped fiber), ISO (isolator), SMF (single mode fiber), coupler 95:5 and D-shaped optical fiber sensor.

III. RESULTS AND DISCUSSIONS

Fig. 3 displays the average temperature range of the emitted light from the D-shaped optical fiber. The hotplate temperature increased from 30°C to 70°C, resulting in a 6.79dBm to 6.62dBm output signals. With the increase of the hotplate temperature, the output signal begins to decrease significantly. The sensor sensitivity is found to be 8.6×10^{-3} dBm/% while the sensor linearity is obtained from the R2 value of 94% as depicted in the graph. Since the cladding diameter of the D-shaped optical fiber has been reduced and exposed, the refractive index of the surrounding medium acted as a passive cladding, which affected in terms of the amount of power loss through the polished region. The index of the surrounding medium increased when the polished fiber was placed on the hotplate at different temperatures as the reaction rates increased due to the disproportionately large increase in the number of high-energy collisions.

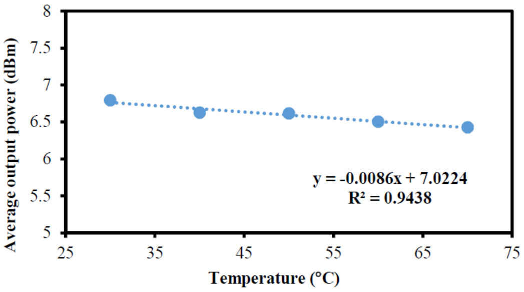

Fig. 3. Linear function between average output power versus temperature.

During the experiment, the output spectrum was monitored using an OSA while the sensor was in contact with the hotplate. The spectral response of the D-shaped optical fiber at different temperatures is shown in Fig. 4. It is observed that the peak wavelength exhibits shifting to longer wavelengths from 1557.8nm to 1561.8nm as the temperature increases, where 50°C shows the longest shift. These reactions can conclude that there are significant wavelength changes. Referring to the peak wavelength of this figure, it is easy to determine that the D-shaped optical fiber experienced a wavelength change as the temperature rises from 30°C to 70°C, which is due to the higher D-shaped optical fiber attenuation with each temperature increase of the hotplate.

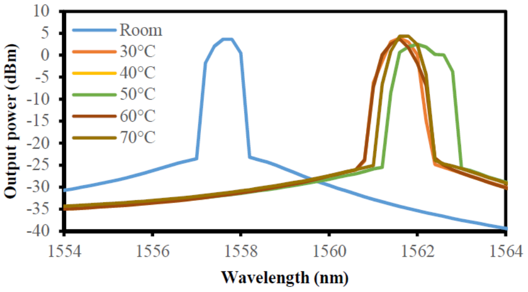

Fig. 4. Transmission spectra of D-shaped optical fiber at different.

IV. CONCLUSIONS

In summary, at a threshold pump power of 149.1mW, a stable temperature sensing has been successfully demonstrated using a D-shaped optical fiber in the C-band region. Based on the results, the polished single-mode fiber is able to detect the changes in temperature of a hotplate. The wavelength is observed to shift to longer regions and power is significantly dropped with increasing temperature.

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