D-shape Fiber Coated with Indium Tin Oxide for Temperature Sensor Application

B Nizamani¹, M I M Abdul Khudus², E Hanafi¹ and S W Harun¹

¹Photonics Engineering Laboratory, Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia.
²Department of Physics, Faculty of Science, University of Malaya 50603 Kuala Lumpur, Malaysia.

E-mail: nizamanibilal@yahoo.com

Abstract. We designed a temperature sensor by using a D-shape fiber coated with indium tin oxide as a sensing probe. D-shape fiber was fabricated out of conventional single mode fiber by a homemade setup using wheel polishing technique. Insertion loss of D-shape fiber was about 3.5 dB. ITO was deposited over the D-shape fiber by electron-beam deposition technique to have precise deposition of 60nm thin film over the D-shape region of fiber to be utilized as a sensor. It is observed that the transmitted power increased with the increase in temperature with a sensitivity of 0.0013 dBm/°C. The proposed sensor also provides a good linearity and stability.

1. Introduction
Temperature sensing has been deployed in many commercial applications over the past few decades such as fire detection, leakage detection, exploration of oil and gas, transmission line monitoring and power cables monitoring. Fiber sensors have recently attracted the researchers due to its predominated ability of being immune to electromagnetic interference. D-shape fibers have been widely used for sensing as they offer benefit of strong evanescent field interaction with metals, semiconductors and metal oxides. Evanescent field interaction varies with the change in surrounding refractive index, thus we coat the evanescent field exposed region of fiber with certain metals, semiconductors or metal oxides. High evanescent field interaction is a vital element for sensing where a good amount of power is needed to interact with the surrounding medium [1].

Indium Tin Oxide (ITO) has transmittance in near-infrared and visible region as high as 90% and electrical resistivity as low as 2x10⁻⁴ Ωcm [2, 3]. It is widely used in variety of applications such as organic light emitting diode (O-LED) [4], liquid crystal lens [5], solar cells [6] and even the sensors such as ammonia gas sensor [7] and humidity sensor [8]. In contrast to other deposition techniques like vapor deposition [9], sputtering [5], electro spinning [10]. ITO was deposited using electron beam deposition technique to have a control over the accuracy in ITO thickness and to get ease in morphology of deposited structure by getting a uniform thickness of ITO thin film over the D-shape fiber.

2. D-shape fiber preparation and deposition of ITO
We prepared a D-shape fiber out of single mode fiber SMF-28 have core diameter of 9 μm and cladding diameter of 125 μm. The preparation was done using a setup similar to [11], where the fiber buffer was removed first, then it was cleaned and placed over the polishing wheel for fabrication. The polishing wheel was covered with a sandpaper of 1000cw grit size for the side polishing of a fiber. Fiber was then...
connected to amplified stimulated emission (ASE) for the light source and Optical power meter (OPM) (Thorlabs: PM100D) for the power measurement during the process, as shown in figure 1. In order to obtain a great evanescent field interaction to be useful as a sensor, we measured insertion loss to be 3.5dB while the diameter of fiber was found to reduce at the D-shape region to 71.11 μm from 125 μm which ensured the fiber was side polished and certain amount of cladding was removed as shown in figure 2.

After the preparation of D-shape fiber, it was taken over the glass slide and placed in the electron-beam deposition chamber for the deposition of ITO over the region of side polished fiber. ITO slot was pre-set to be used for deposition and electron beam was applied on ITO to evaporate and form a 60nm layer over the D-shape region. Figure 3 shows the microscopic image of ITO deposited over the D-shape fiber taken with the help of Medilux-12 microscope. Thus, the 60nm thin film of ITO was deposited over a D-shape fiber for the sensing purpose.

3. Experimental setup
The ITO D-shape fiber was tested for temperature sensor in similar way as of [12] by using a hot plate for temperature measurements. The D-shape fiber coated with ITO was connected to a laser source (ANDO: AQ4321D) at one end and to OPM at other end. Our newly prepared sensor was placed over the hot plate and the multimeter (proskit MT-1860) was connected just beside the sample to have exact
temperature readings over the hot plate. Figure 4 illustrates the experimental setup and sensing mechanism of newly prepared D-shape fiber coated with ITO based on evanescent field interaction from the D-shape fiber which is sensitive to the variation of surrounding refractive index. ITO deposited over the D-shape fiber worked as a temperature change detector over the hot plate.

4. Result and discussions

From the experimental setup in figure 4 the laser source was set to the standard optical communication wavelength of 1550nm. Output power was measured using OPM and a linear increment with increase in temperature was observed in real time. When the temperature was increased from a room temperature of 30 °C to 110 °C, a significant change in output power ensured the sensitivity of our fabricated D-shape fiber. The output power spectrum showed increase in transmittance due to the ITO coating of D-shape fiber. The transmittance trend increased linearly when the temperature raised from 30°C to 110°C, as the output power increased from -5.485 dBm to -5.3688 dBm ensuring the sensitivity to be 0.0013 dBm/ ºC with 99% linearity in results as shown in figure 5. The output power readings showed complete stability of power at 80° C for about 300 seconds which proves that our sensor was stable for a long time as shown in figure 6. With the advantage of using a tunable laser source, wavelength sweep was done from 1549.5 nm to 1550.5 nm and stability with wavelength sweep of 1 nm range from 1549.5 nm to 1550.5 was ensured as shown in figure 7. This experiment was repeated for 3 times and similarity of results was obtained with a standard deviation of 0.05. Table 1 sums up the complete response of our newly fabricated sensor based on D-shape polished fiber coated with ITO. However, the fabricated D-shape fiber without coating of ITO did not respond significantly to the temperature sensing.
Figure 5. Output power change with the change in temperature.

Figure 6. Stability of sensor at 80 °C for 300 seconds at 1550 nm wavelength.

Figure 7. Power stability of sensor at 80 °C in wavelength sweep of 1 nm at the precision of 0.01 nm.

Table 1. Sensing performance parameters of the ITO coated D-shape fiber temperature sensor.

| Parameters       | Values                |
|------------------|-----------------------|
| Linearity        | 99%                   |
| Sensitivity      | 0.0013 dBm/ °C        |
| Standard deviation | 0.05               |

5. Conclusion
By fabricating a D-shape fiber out of a single mode silica fiber and coating it with indium tin oxide, we successfully demonstrated a temperature sensor with a highly stable and linear response to the temperature changes recorded from 30°C to 110°C. Thus this simple temperature sensor can be advantageous for variety of temperature sensing applications in highly electromagnetic environments such as industrial applications and transmission line monitoring in the high electromagnetic radiation conditions.

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