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PHOTONIC CRYSTAL FIBER BASED DISPLACEMENT SENSOR

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ABSTRACT

The paper presents a study on displacement sensing using a Photonic Crystal Fiber (PCF). A Multimode High Numerical Aperture PCF (MMHNA-200) has been used for the displacement sensing based on intensity modulation technique. The sensitivity of the sensor is 11.6 μW/mm. The sensor performance has been found to be repeatable. The displacement sensor is suitable for usage in high temperature and intense radiation environments.

KEYWORDS: Displacement Sensor, Photonic Crystal Fiber, Sensitivity, Sensor Response.

1. Introduction

Optical fiber sensors have been found to be very useful in a wide variety of applications and have received considerable attention in recent years. Amongst the various types, reflective types of fiber optic displacement sensors find applications in vibration, position, pH, liquid level, glucose concentration measurements due to their simplicity and reliability. Majority of the sensor work is based on either polymethyl methacrylate (PMMA) fibers [1-5] or doped silica fibers.

The PMMA based displacement sensors have limitations due to lower operating temperature range of 80 -100˚C. Doped silica fiber sensors can be used up to a temperature range of 300˚C [6]. Obviously both of these fiber displacement sensors are not suitable for applications in high temperature/intense radiation environments since the fiber probe itself gets affected. The effects of gamma irradiation on doped and pure silica core optical fibers have been reported in the literature [7-10]. It is found that the addition of dopants to the silica matrix increases the number of defects (stress or strain related defects), thus giving rise to absorption by defects in addition to the already existing intrinsic and extrinsic absorptions.

The intense ionizing radiation causes attenuation in the optical fiber thereby corrupting the measurements [11].

In order to resolve this problem, Photonic Crystal Fibers (PCFs) have been studied for use in displacement sensing. In the present study, we have carried out experimental studies of high numerical aperture (HNA) multimode PCFs for displacement sensing. The sensor offers high sensitivity of the order of 11.6 µW/mm making it suitable for precision displacement sensing applications in high temperature/intense radiation environments.

2. PCF Based Displacement Sensor

The basic principle employed in a typical fiber optic displacement sensor is the use of an adjacent pair of fiber optic elements, one to carry light from a remote source to a reflecting surface or target whose displacement is to be measured and the other to receive the light reflected from the object and carry it back to a remote photo sensitive detector. R.O.Cook et. al have presented a detailed study on this type of sensor [1]. Further, fiber optic displacement sensors for different applications have been studied and experimented in the author’s laboratory [2,4,12].

The PCF based displacement sensor is employed exactly in the same way as that of the conventional PMMA fiber based displacement sensor. Multimode high numerical aperture (HNA) PCF has been used which offers the benefits of better launching and light gathering capability, higher signal to noise ratio of the measurement and efficient light guiding. Also because of the high numerical aperture, the transmission loss is minimized to a value that is limited only by the material composition of the silica core. Further, a rare advantage of such an air clad fiber is that no radiation has direct contact with the coating material, thereby reducing chance of any thermo-optical effect [13-14].

3. Experimental Set Up

The experiments were conducted using an adjacent pair of photonic crystal MMHNA-200 fibers. The PCF (procured from Crystal Fibers, Denmark), Aluminum reflector as the target, a microscope objective for focusing the light and Thorlabs Power meter and Photo detector (400 nm to 1100 nm range) have been used. A 3 mW power laser diode operating at 630 nm has been used as the light source for transmission. Micro-meter manipulator has been employed to provide small step displacement (in the range of hundreds of microns) to the target.

Photograph of the multimode high numerical aperture PCF (MMHNA-200) and a cross section of the fiber are shown in Fig. 1 (a) and Fig. 1 (b) respectively.

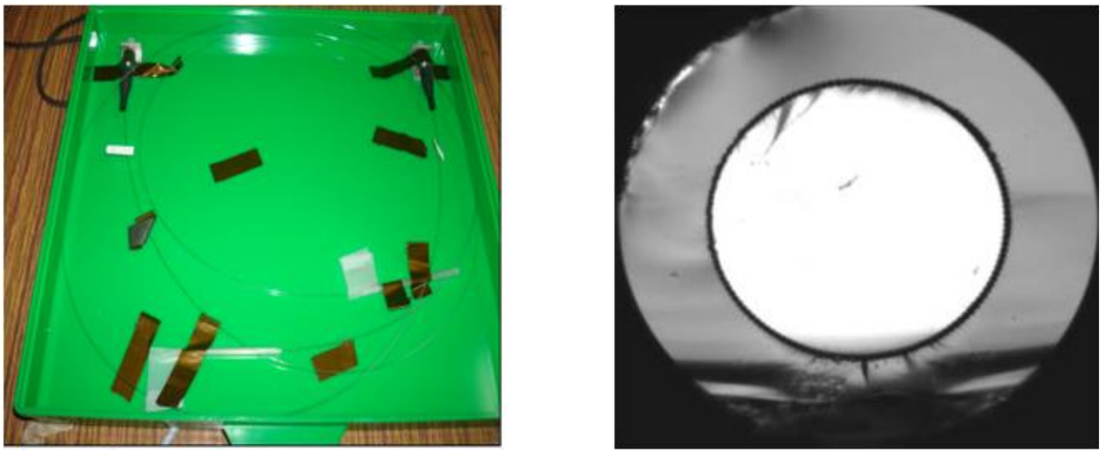

Figure.1. (a) Photograph of MMHNA-200 (b) Cross Section of MMHNA-200

The photograph of the experimental set up is as shown in Fig. 2.

Figure.2. Photograph of Experimental Set Up

The optical power meter (Thorlabs PM-100) was used to measure the power from the output of the receiving PCF. As shown in Fig. 2, the power meter was connected at the output of the sensor. PM-100 displays the power on a graphic LCD readout and has a keypad for various controls. It is provided with large area interchangeable sensor head detector. For our experiment, we have used S120B Silicon sensor which covers the wavelength range of 400 nm to 1100 nm. The power meter has a capability to measure optical power in the range of few pW to 50 mW with a resolution of 1 pW.

4. Results and Discussion

Experiments were performed using two photonic crystal fibers PCF (MMHNA-200), with one as the transmitting fiber and the other as the receiving fiber with an Aluminum foil mounted on a micrometer manipulator platform as the reflector/target. The outputs of power meter were plotted with the corresponding displacements. The sensor response obtained from the experiment is shown in Fig. 3.

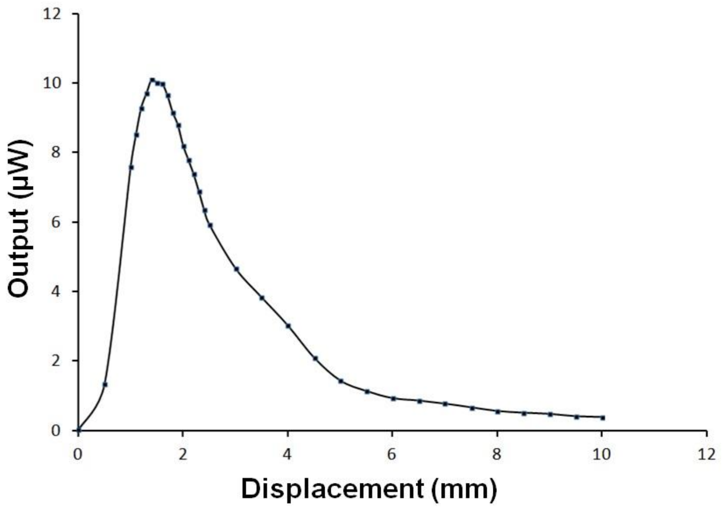

Figure.3. Output vs Displacement Response Using PCF (MM HNA-200)

The sensor response obtained is in agreement with the theoretical displacement response of a typical two-fiber displacement sensor. The front and back slopes are used to determine the corresponding sensitivity. It is observed that the sensitivity is higher for the front slope with lesser linear dynamic range while the sensitivity is lower for the back slope with higher dynamic range. The linear fits to the front and back slopes are shown below in Fig. 4 and Fig.5 respectively.

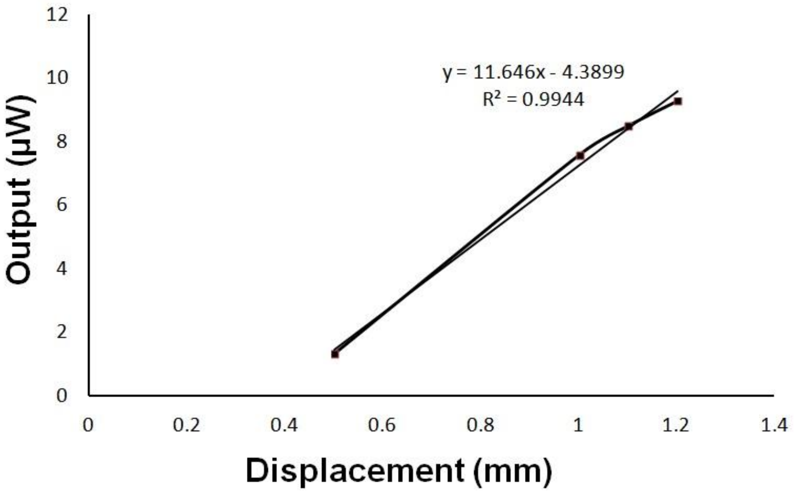

Figure.4. Front Slope of the Sensor Response

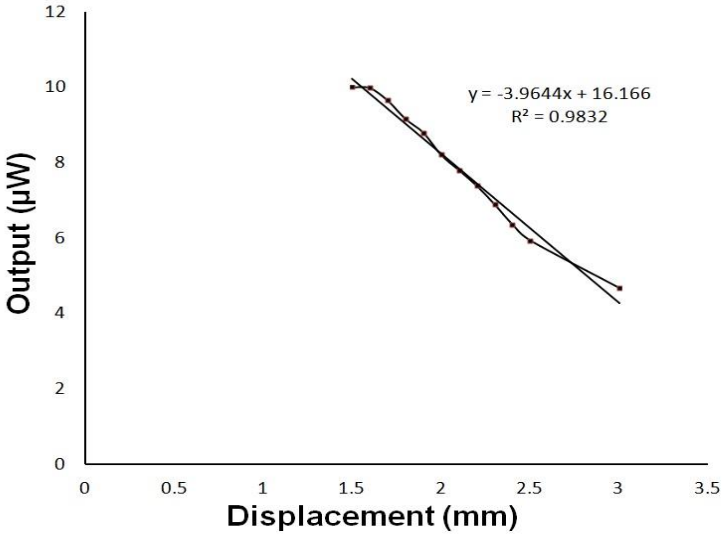

Figure.5. Back Slope of the Sensor Response

The sensor response has been studied for the displacement range of 0 - 10 mm. The front and the back slopes are analyzed separately to find out the corresponding sensitivities. For the front slope of the displacement response curve the sensitivity is 11.64 µW/mm and the linear dynamic range is 0.7 mm. This means for a signal demodulation capability of 1 pW, displacement measurement of 0.1 nm is possible. For the back slope of the displacement response curve the sensitivity is 3.964 µW/mm and the linear dynamic range is 1.5 mm. It is hence indicated that either the front or the back slope can be used for desired sensitivity and dynamic range requirements.

It is found that the displacement response of PCF (MMHNA-200) is in agreement with that of the PMMA fiber sensors and offers good linear response and very good sensitivity. Since the PCF (MMHNA-200) is a high numerical aperture fiber (with NA ≈ 0.64), it offers efficient collection of light from the surfaces under study. As the PCF (MMHNA-200) is made up of pure silica, its melting point (~ 700˚C) is much higher than the melting point of PMMA fiber (~ 80˚C) and hence can be used for high temperature environments. Also the Photonic Crystal Fibers offer resistance to intense radiations and their properties remain unaltered unlike that of the PMMA or doped silica fibers.

Thus, the present Photonic Crystal Fiber (MMHNA-200) based displacement sensor offers tremendous potential to be implemented in harsh conditions like high temperature and intense radiation environment, in addition to all other advantages offered by conventional PMMA or doped silica fiber based sensors.

5. Conclusions

Multimode high numerical aperture photonic crystal fibers have been studied for high precision displacement sensing. The results are matching with conventional PMMA fiber based displacement sensors. Maximum sensitivity of 11.64 μW/mm has been obtained with a resolution of less than 0.1 nm and a linear dynamic range of 1.5 mm.

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