Multimode Fused Coupler Fiber Optic Pressure Sensor

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Abstract. The response of a pressure cell with copper diaphragm of different dimensions for the measurement of pressure using a fused multimode fiber optic coupler is presented. As the pressure varies, the deflection of the diaphragm varies and it modulates the intensity of the reflected light entering into the multimode fused coupler. The sensor is operated in back slope of its characteristic displacement curve and it enabled to sense larger range of pressures. The effect of variation of diameter and thickness of the diaphragm is also studied. The experimental results show that the sensitivity, linearity of the sensor is good and it may finds application in monitoring pressure in industries.

Keywords: Diaphragm, Fiber optic sensor, Multimode fiber coupler.
PACS: 42.81.Pa

INTRODUCTION

In comparison with conventional electro-mechanical sensors fiber optic sensors (FOS) have many advantages such as, immunity to electromagnetic interference, multiplexing capability, high accuracy, easy to fabricate, non-contact, small size and light weight. FOS can measures parameters like temperature, humidity, vibration, displacement and pressure accurately [1]. The accurate measurement of static and dynamic pressure is extremely important in the industry.

Commonly two basic methods are followed for pressure measurement: Phase modulate interferometric method and reflected light intensity modulation method. However interferometric methods are quite complex and cost effective, even though they offer extreme sensitivity. Intensity modulation methods are widely used due to accuracy, simplicity and potentially of low cost [2].

Among pressure sensors, Diaphragm based configurations are suitable for measuring both static and dynamic pressures because of their high sensitivity [3]. Diaphragm based pressure measurement using pair fiber probe were reported but it was difficult to operate the sensor on its backslope of characteristic displacement curve [4]. In this paper an alternative method to overcome the above problem is proposed by introducing a coupler made of multimode plastic fiber that operates on its existed backslope. Here multimode fiber optic probe is preferred because of its better signal coupling ability, large core radius, high numerical aperture as well as ability to receive the maximum reflected light from the reflecting surface. A pressure sensor cell is designed including different thickness of metal diaphragms. The achieved sensitivity of the sensor is comparatively high.

SENSOR WORKING PRINCIPLE

This prototype works on the displacement based reflected light intensity modulation technique. A multimode plastic coupler 50:50 (1×2) with step index fiber of core/cladding diameters 980/1000μm, core refractive index 1.492, cladding refractive index 1.402 and numerical aperture (NA) 0.51 is used. The sensor uses only a single fiber for transmitting and receiving the light from reflecting surface as shown in Figure 1

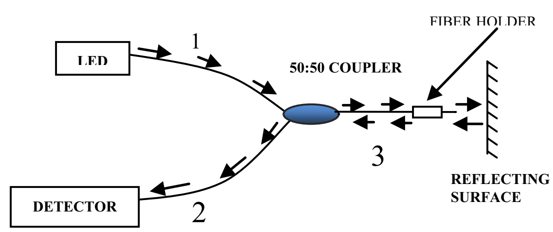

FIGURE 1. Fiber optic displacement sensor.

Figure 2 shows the characteristic displacement curve of the output voltage against gap between fiber tip and reflecting surface. The displacement is measured accurately using a micrometer in steps of 0.005mm over a dynamic range of 3.5mm [5]. The

Optics: Phenomena, Materials, Devices, and Characterization
AIP Conf. Proc. 1391, 450-452 (2011); doi: 10.1063/1.3643576

displacement between fiber tip and reflecting surface plays important role in achieving linearity and accuracy of measurement. When the gap between the fiber tip and the reflecting surface is zero, the fiber receives the maximum light and thus the measured intensity of the reflected light is maximum [6]. The loop region in the Figure 2 is considered as the linear region for pressure sensing. The response curve shows a good linearity within the range 0-1mm with sensitivity 4.3339Volts/mm.

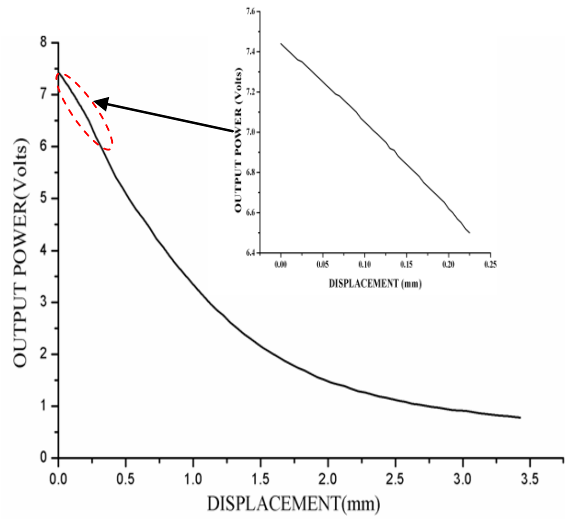

FIGURE 2. The output voltage of the sensor as a function of displacement.

In this sensor only back slope exists because the transmitting and receiving of light occur through the same fiber of the coupler.

EXPERIMENTAL SETUP

The schematic of experimental setup is shown in Figure 3.

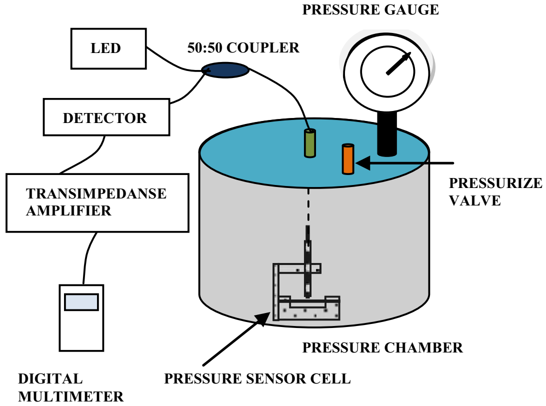

FIGURE 3. Experimental setup of fiber optic pressure sensor.

The pressure cell consists of a LED (IF-E96) with Peak wave length of 660nm, a multimode fiber coupler, a pressure chamber with a pressure gauge (resolution 25mmWC), a pressure sensor cell, a Photodetector (IF-D96), a transimpedance amplifier and a digital multimeter. A compressor is used to pump air into the pressure chamber. As shown in Figure 1, node1 of the coupler is connected to the LED, node3 is used to emit the light on to and receive reflected light from the reflecting surface and node 2 is connected to a detector. A photoconductive transimpedance amplifier is used to convert the detected light intensity into its equivalent voltage and is displayed by a digital multimeter.

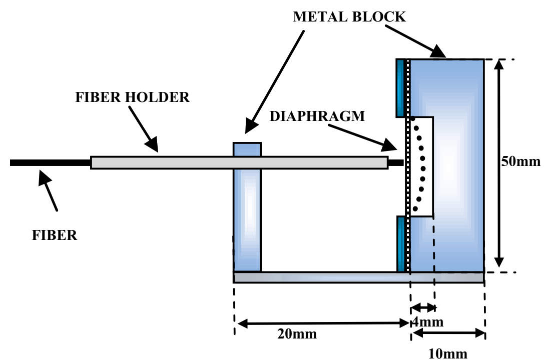

FIGURE 4. Schematic diagram of designed pressure cell.

Figure 4 shows the schematic design of the sensor cell. Fiber and diaphragm holders are made of steel and accurately machined. A diaphragm made of copper foil is tightly mounted on a steel block of 10mm thickness and having 4mm thick cavity. The multimode fiber is held with the help of a fiber holder such that the fiber tip is almost in contact with the copper diaphragm. The experiment was carried out with steel blocks of 25mm and 30mm diameters along with 0.025mm, 0.1324mm thick copper diaphragms. When the pressure $\mathbf{P_2}$ applied on the diaphragm is more than the pressure $\mathbf{P_1}$ in the steel block cavity, the diaphragm deflects from its equilibrium position. The gap between the fiber tip and diaphragm increases and hence the decrease in the output voltage. To maintain constant emitted power from LED a stable regulated power supply is used. The output voltage is calibrated in terms of known applied pressure in steps of 25mmWC. Fiber and diaphragm surfaces are properly polished for more reflectance.

RESULTS AND DISCUSSIONS

Figure 5 shows the results of the pressure sensor for copper diaphragms of 0.025mm and 0.1324mm thickness with 25mm steel block. The linear response region of the sensor with applied pressure for these thicknesses shifted from 125-225mmWC to 325-450mmWC. The sensor provides a very good linearity and measured sensitivity is 0.0004V/mmWC. From the results, as the diaphragm thickness increases the deflection of the diaphragm decreases at the same applied pressure, hence the output voltage increases and vice versa.

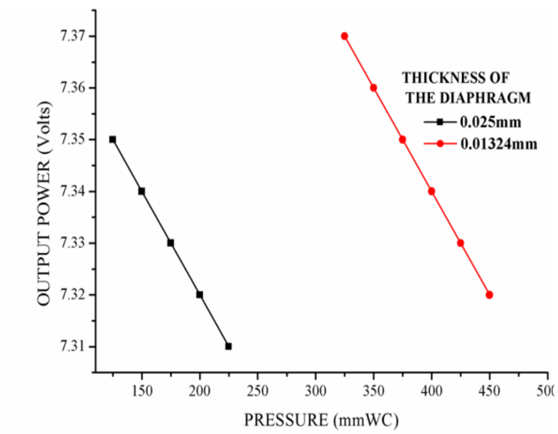

FIGURE 5. The sensor static pressure response at different thicknesses of the diaphragam.

Figure 6 demonstrates the output voltage as a function of pressure with two different steel block diameters 30mm, 25mm and copper diaphragm thickness of 0.1324mm.

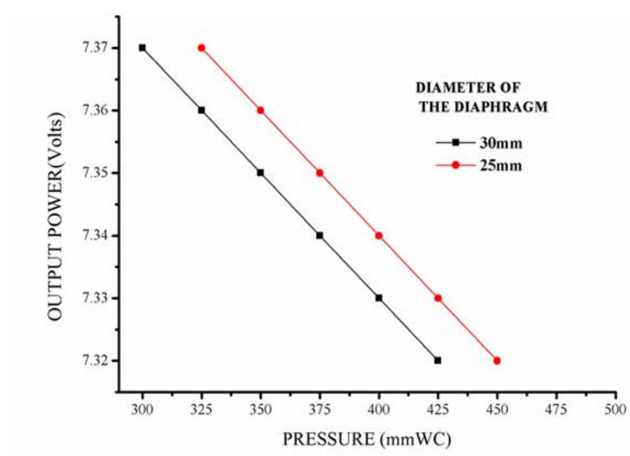

FIGURE 6. The sensor static pressure response at different diameters of the diaphragm

The linear response region of the sensor with applied pressure shifted from 300-425mmWC to 325-450mmWC. In this case the measured sensitivity is 0.0004V/mmWC and shows good linearity. Experimental results reveal that as the effective diameter of the diaphragm decreases the deflection of the diaphragm decreases for the same applied pressure, hence the output voltage increases and vice versa. The parameters of the diaphragm affect the performance of the sensor. The linear response region of the sensor shifted towards the higher pressure region as the diaphragm thickness increases or diameter decreases. The pressure measurement range can be modified simply by replacing a suitable diaphragm for desired application. By increasing the pressure beyond the linear response region of the sensor, the deterioration of the diaphragm takes place and suddenly falls into the region of non linearity. This sensor is easy to fabricate and is of low-cost and is useful for monitoring the pressure.

CONCLUSIONS

A simple, inexpensive and robust diaphragm based fiber optic pressure sensor using a multimode fiber coupler has been demonstrated. Characterization of the relationships among diaphragm thickness, cavity diameter and sensitivity is studied. The increase in thickness or decrease in diameter of the diaphragm produces decrease in deflection of diaphragm for same applied pressure and hence the output voltage increases and vice versa. The sensor shows a good linearity and has a sensitivity of 0.0004V/mmWC.

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