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A DIAPHRAGM BASED LOW-COST FIBER OPTIC PRESSURE SENSOR

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ABSTRACT: *This article presents a low cost fiber optic pressure sensor using metal diaphragm. The sensor works on the principle of fiber optic proximity sensor. As the pressure varies, the deflection of the diaphragm varies and it modulates the intensity of light reflecting from the diaphragm. The performance of the sensor is studied for different diameters and thicknesses of the diaphragm.* © 2012 Wiley Periodicals, Inc. Microwave Opt Technol Lett 54:2229–2231, 2012; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.27093

Key words: *pressure; diaphragm; fiber optic sensor; multimode fiber coupler; sensitivity*

1. INTRODUCTION

The accurate measurement of static and dynamic pressure is extremely important in the industry. Compared with conventional electromechanical sensors, fiber optic sensors have many advantages like immune to EMI, small size, lightweight, high sensitivity, and large bandwidth, high reliability, suitable for hazard environment and anti corrosion [1]. The mechanisms of fiber optic pressure senor may be classified into four categories which are based on intensity modulation, phase modulation, wavelength modulation, and polarization modulation [2–5]. The intensity modulation sensor has lesser accuracy, but longer dynamic range and simple design; moreover it can be made with lower cost and gives measurements that is easy to interpret. However remaining categories are quite complex and cost effective, even though they offer extreme sensitivity. Among the intensity modulated sensors diaphragm based configurations are suitable for measuring both static and dynamic pressure [6, 7].

In this study, a simple designed fiber optic pressure sensor based on light intensity modulation is presented. A multimode fused fiber coupler made of poly methyl methacrylate is used to transmit and receive the reflected light from the reflecting surface of the diaphragm. The effect of change in physical parameter (thickness and diameter) of the diaphragm on pressure sensing range and sensitivity are studied. The design of the pressure sensor cell with diaphragm also demonstrated.

2. SENSOR WORKING PRINCIPLE

The sensor cell works on the modulation of reflected light intensity by the deflection of diaphragm. The modulated light intensity is a function of the axial displacement of the diaphragm surface from the fiber tip. A multimode plastic fiber optic coupler is used to transmit onto and receive light from the reflecting surface. The sensor cell utilizes a thin copper foil as diaphragm for pressure sensing and act as reflector. The light from a light source (LED) enters into arm 1 of 3-dB multimode fiber coupler (1 × 2) and incident on the reflecting surface through arm 3.The reflected light is launched back into the same fiber before a portion of the light routed into a detector using the coupler shown in Figure 1.

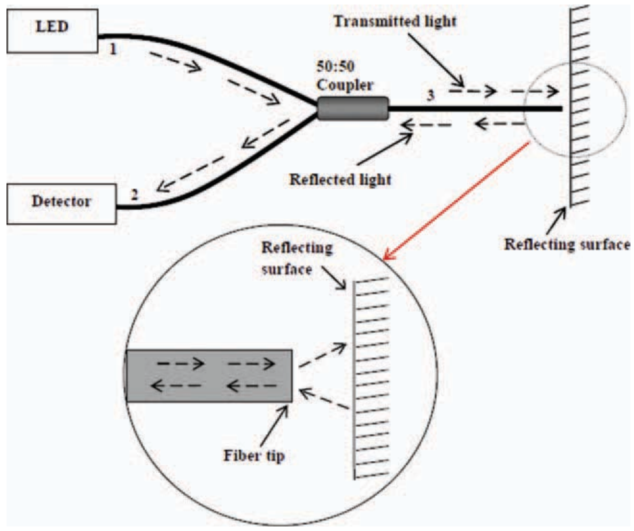

Figure 1 Fiber optic proximity sensor principle. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

The intensity of reflected light depends on how far the reflecting surface is from the fiber tip. Theoretical analysis gives the distance and reflected power varies in accordance with inverse square law [8] which can be simplified as

$$\frac{P_r}{P_t} = \frac{d^2}{(2x\tan\theta)^2} \tag{1}$$

where P_r, P_t, d, x, and θ are the reflected power, output power, core diameter, axial displacement and fiber's acceptance angle respectively. As the applied pressure increases, the gap between the diaphragm and the fiber tip increases, which results a change in reflected light intensity, is a measure of applied pressure.

2.1. Calibration of the Sensor

To calibrate the sensor, a translational micro meter (Newport, M-462 Series) is used to displace the reflector from the fiber tip over a span of 3.5 mm in successive steps of 5 μm and the corresponding output power is measured by the photo-detector. When the gap between fiber tip and reflector is near to zero, the fiber receives maximum light and decreases with increasing the gap. A graph is plotted with the recorded data which shows only back slope because of the transmitting and receiving light pass through the same fiber. Figure 2 shows the reflected light intensity in terms of volts against the corresponding displacement. The region of 0–0.5 mm shown in Figure 2 is considered for pressure sensing. A good linearity of 99.8% with −4.15 mV/μm sensitivity is observed within the range (0–0.5mm).

3. EXPERIMENTAL SETUP

The schematic of experimental setup is shown in Figure 3. Light from the LED (IF-E96) of peak wavelength 660 nm is coupled through a passive and bidirectional multimode fiber coupler (IF-562) into the pressure sensor cell. A regulated power supply is

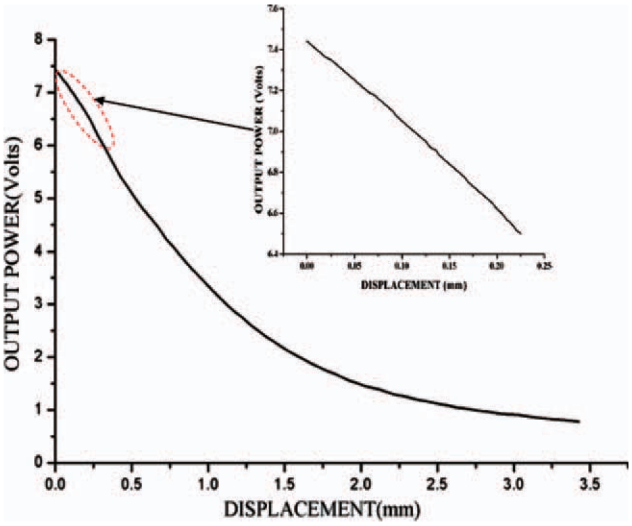

Figure 2 The response of the sensor against the displacement. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

used to bias the LED for constant emission of light. A diaphragm made of thin copper foil is air tight fixed to the pressure sensor cell to act as a sensing element for pressure measurement.

The sensor cell is installed into an air tight pressure chamber (inner diameter 10 cm, height 11.5 cm, and thickness 5 mm) as shown in Figure 3. A compressed air cylinder is used to pressurize the pressure chamber. Pressure inside the chamber is monitored using a pressure gauge (resolution 25 mmWC) and controlled with a relief valve. The applied pressure modulates the reflected light intensity and is converted into its equivalent voltage signal by a transimpedance amplifier. The output voltage is measured using a digital multimeter.

Schematic side view of the pressure sensor cell is shown in Figure 4. To hold the fiber and the diaphragm, separate steel mounts are designed and accurately machined. The arm 3 of the coupler is mounted with the help of fiber holder such that the fiber tip is very close to the copper diaphragm. Diaphragm is

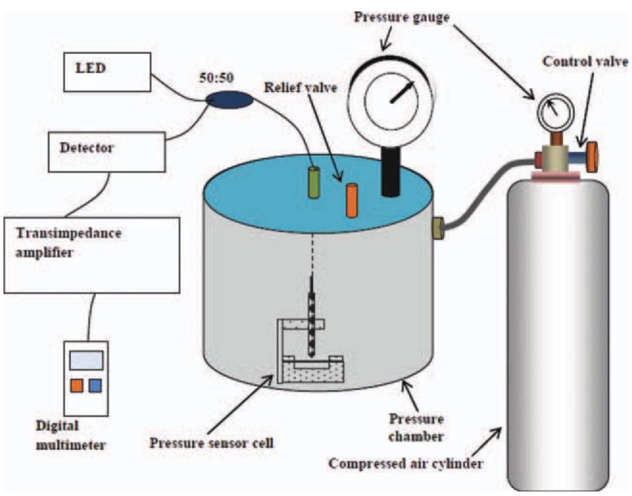

Figure 3 Schematic sketch of the experimental setup. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

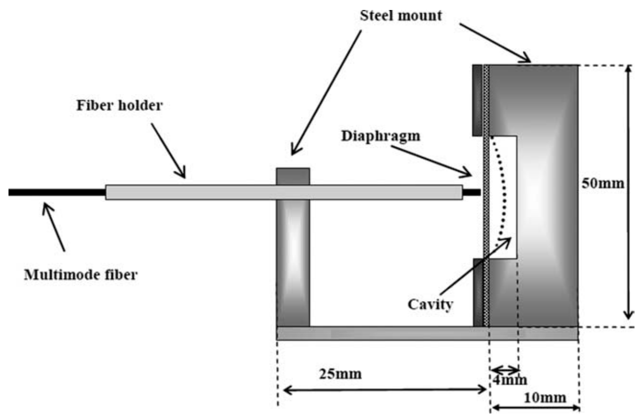

Figure 4 Side view of the designed pressure sensor cell

tightly fixed on the steel mount of 10-mm thickness having 4-mm depth of circular cavity. The pressure measurement is carried out using copper diaphragms of different thickness (0.025 and 0.1324 mm) and diameters (25 and 30 mm).

4. RESULTS AND DISCUSSION

The response of the sensor against applied pressure is as shown in Figure 5. The output voltage is calibrated with applied pressure in steps of 25 mmWC using a commercial pressure gauge. The copper diaphragm of 25 mm diameter of two different thicknesses 0.025 and 0.1324 mm are used for pressure sensing. The measured pressure sensitivity of the sensor with this thickness is −0.3885 mV/mmWC and −0.3828 mV/mmWC, respectively. The results show that output voltage is linearly decreases with increase in pressure and the linear range of pressure measurement is increased from 100–225 mmWC to 300–450 mmWC by increase in thickness of the diaphragm from 0.025 to 0.1324 mm, respectively.

The result obtained using the copper diaphragm of thickness 0.1324 mm of two different diameters 25 and 30 mm is illustrated in Figure 6 and measured pressure sensitivity of the sensor is −0.3828 mV/mmWC and −0.3894 mV/mmWC, respectively.

The linear range of pressure measurement is increased from 300–425 mmWC to 325–475 mmWC by decreasing diameter from 30 to 25 mm, respectively. The point observed from the results that the linear range of pressure measurement can be

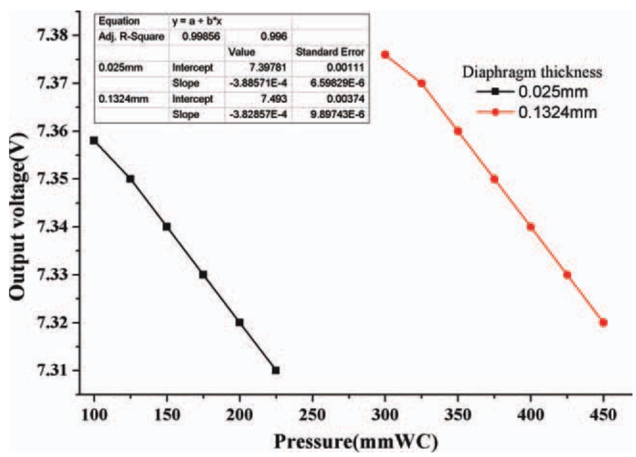

Figure 5 The pressure response of the sensor with two different thicknesses of the diaphragm. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

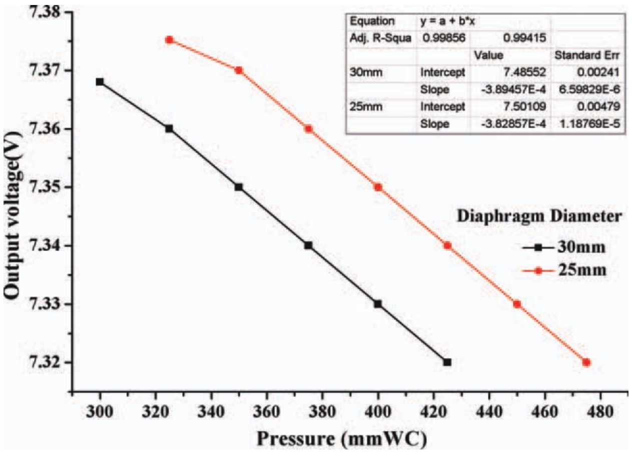

Figure 6 The pressure response of the sensor with two different diameters of the diaphragm. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

shifted to higher value by increasing thickness or decreasing diameter of the diaphragm, respectively.

5. CONCLUSION

A diaphragm based fiber optic pressure sensor is demonstrated. The effect of diameter and thickness of the diaphragm on pressure sensing is investigated. Experimental results reveal that the pressure measurement range and sensitivity can be determined by replacing with suitable diameter and thickness of the diaphragm for desired application. The usage of plastic optical fiber and simple design of pressure sensor cell makes the sensor low cost and may be useful for low pressure sensing in industrial applications.

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A NOVEL BUTTERFLY-SHAPED MULTILAYER BACKWARD MICROSTRIP HYBRID COUPLER FOR ULTRAWIDEBAND APPLICATIONS

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ABSTRACT: *In this letter, the numerical analysis and design of aperture-coupled backward microstrip hybrid coupler for ultrawideband (UWB) multilayer microwave circuits are introduced. The proposed coupler is composed of two microstrip patches located on two stacked substrate layers. This coupler uses a broadside coupling via a rectangular-shaped slot in the common ground plane (mid-layer). To achieve broadband characteristics for UWB operation, butterfly-shaped patches are used. The numerically simulated results using two simulation programs with two different numerical techniques show that the proposed coupler have good insertion losses (both through S_{21} and coupled S_{31}) variation (less than ±2 dB) and high return loss S_{11} (greater than 14 dB) with acceptable isolation S_{41} (about 14 dB) over most of the 3.1–10.6-GHz frequency band. A 3dB/90°-backward hybrid coupler prototype is fabricated and then tested experimentally using Agilent E8364B PNA Network Analyzer. Experimental results agree well with the simulated ones.* © 2012 Wiley Periodicals, Inc. Microwave Opt Technol Lett 54:2231–2237, 2012; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.27092

Key words: *ultrawideband*; *microwave devices*; *multilayer circuits*; *microstrip printed circuit board*; *hybrid couplers*

1. INTRODUCTION

Hybrid couplers are considered fundamental and important passive microwave devices that can be widely used in many microwave integrated circuit applications such as in balanced mixers, modulators, and beamforming networks. A hybrid coupler is defined as a four-port network [1]. It can be used as a divider/combiner to divide or combine signals with an appropriate desired phase. Some conventional and well-known 90°-directional couplers, such as branched-line, coupled-line, and Lange coupler, are often used in different microwave circuits. Those types of couplers have shown narrow-bandwidth operation performance. For broadband wireless communication applications, such as ultrawideband (UWB) systems, there are some requirements to design broadband and efficient hybrid couplers. Couplers should have high performance, low cost, and compact size.

There are many different techniques to design broadband directional couplers [2–6]. A technique has been introduced by Ref. 4 using coupled lines with a slotted ground plane underneath them, but it has been found that the spacing requirements between those lines are very small to achieve the desired coupling and hence the coupler become hard to manufacture. Moreover, there are some serious limitations that affect the overall performance of those kinds of structures. Another approach [6] has been used to improve the performance of the conventional branch-line coupler by using microstrip electromagnetic bandgap element and to reduce its size. In addition, a broadside coupling approach has been proposed to avoid problems of spacing limitations between lines in coupled-line couplers [2, 3, 5]. This