Sensitivity investigation of optical fiber sensors based on Fabry–Pérot interferometry using MoS_2 and GO membrane for detection of acoustic waves

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Abstract- In this paper, an optical fiber sensor (OFS) based on extrinsic Fabry–Pérot (F-P) interferometry (EFPI) is reported for acoustic waves detection. The sensor diaphragm is made of disulfide molybdenum (MoS_2) and graphene oxide (GO) nanosheets. These diaphragms are placed in the end face of single-mode fiber (SMF) optics. Due to the lower Young's modulus of the MoS_2 rather than GO, the fabricated sensor benefits high sensitivity to detect acoustic waves. The results show that the sensitivity of the MoS_2-based sensor, ~18.50 rad/Pa, is more than the GO-based sensor (~15.52 rad/Pa).

Keywords: Optical fiber acoustic sensor; Fabry–Pérot interferometry; MoS_2; Graphene oxide

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1. Introduction

Nowadays, there is a need to fabricate more accurate, smaller and more capable sensors. The enhancement of the sensitivity, efficiency and accuracy of these sensors requires the discovery of new materials and tools. Optical fibers are interesting support for measuring various parameters, including chemical, biological and physical parameters. The advantages of OFSs benefit small-sized, high sensitivity, remote sensing, immunity against electromagnetic interference (EMI), passive fabrication and applicability in multiplexing. The OFSs based on a micro-cavity EFPI are widely used to measure pressure and acoustic waves. The fabrication of EFPI acoustic OFS with high sensitivity is still an important issue. This goal achieves by modifying the diaphragm material such as two-dimensional (2D) materials [1, 2]. The various 2D materials increase the sensitivity, frequency response and selectivity performance of the OFSs. MoS_2 layers with a direct bandgap create a great deal of interest in the research community. Furthermore, single or few-layer GO is an oxidized form of graphene that has recently been used as a promising material in OFS [3, 4]. The used materials for EFPI sensors diaphragm have been included fused silica, silicon, graphene, polymer, etc. diaphragms [5]. Moradi et al. reported the EFPI acoustic OFS using an air cavity/MoS_2 diaphragm with 18.8 rad/Pa sensitivity [1]. A PVC cavity/GO diaphragm was used to fabricate the EFPI acoustic OFS with 685 mV/Pa sensitivity ranging from 0.1 to 10 kHz [3]. Here, we have investigated the sensitivity, wide bandwidth and frequency response of EFPI sensors based on air cavity and MoS_2 and GO diaphragms to detecting acoustic waves.

2. Theory

In general, the optical fiber EFPI sensor consists of an SMF, an air cavity with length l, a circular sleeve and a sensitive diaphragm for acoustic waves with thickness t, effective diameter 2r, as shown in Figure 1(a). The source incident light propagates along with the fiber to the sensor head after launching a fiber circulator. The sensor head is a low-finesse F-P interferometer formed by the fiber end face and a reflecting diaphragm. A portion of the incident light ~4% (Fresnel reflection) is reflected at the end of the fiber and returns straight back to the fiber. The residual light propagates through the air gap to the inner surface of the diaphragm. Then, the reflected light is re-coupled into the fiber and interferes with the first reflected light. The F-P cavity formed between the optical fiber end face (reflector R_1) and the inner surface of the diaphragm (reflector R_2). The reflected light intensity recorded by photodetector via the F-P cavity according to the principle of multi-beam interference can be mathematized as [6]:

$$I_r(\lambda) = \frac{R_1 + R_2 - 2\sqrt{R_1R_2}\cos\Phi}{1 + R_1R_2 - 2\sqrt{R_1R_2}\cos\Phi} I_i(\lambda) \tag{1}$$

where I_i, I_r and λ are incident light intensity, reflected light intensity, the central wavelength of the incident light, respectively. The phase shift per round trip, ϕ, is given by:

$$\Phi = \frac{4\pi l}{\lambda} \tag{2}$$

where l is the F-P cavity length which is modulated by the pressure of acoustic wave (p) on the diaphragm. The cavity length of the EFPI will be changed when the pressure arising from acoustic waves is applied to the sensor head. Thus, the sensitivity (η) is equal to the change of cavity length per unit of pressure that can be expressed as [7]:

$$\eta = \frac{dl}{dp} = \frac{3(1-\nu^2)r^4}{16Et^3} \tag{3}$$

where υ, E, r and t are Poisson's ratio, Young's modulus, the effective radius of the diaphragm and thickness of the diaphragm, respectively.

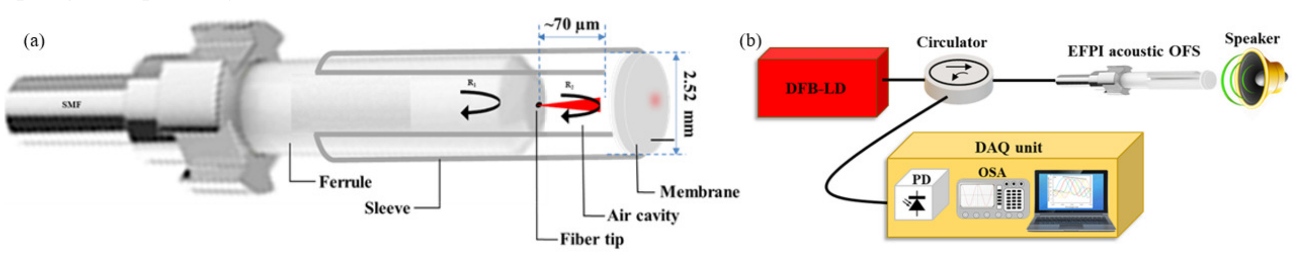

Figure 1. (a) Schematic of EFPI acoustic OFS using MoS_2 and GO diaphragms. The optical fiber is an SMF with 9 and 125 µm diameter core and cladding, respectively. (b) Schematic diagram of the optical fiber FPEI experimental setup for acoustic waves measurement.

3. Experiment

Figure 1(b) illustrates the experimental setup of the EFPI acoustic OFS to detect acoustic waves. The sensor configuration includes a light source, a photodiode, a fiber circulator, and a sensor head. The 8mW distributed feedback laser diode (DFB-

LD) with 5kHz narrow linewidth (NKT Photonics) at 1550 nm is launched into the EFPI using an optical circulator. The laser beam propagates into the EFPI sensor. The variation of acoustic wave pressure arising from the speaker deforms the diaphragms. Subsequently, the length of the air cavity and reflected intensity are deviated by acoustic wave pressure. According to the interferometric demodulation mechanism, the demodulated signals are detected due to the alteration of reflected intensity. An InGaAs PIN photodetector (PD, 1811-FC New Focus) and a data acquisition (DAQ) unit record reflected light from the EFPI acoustic OFS through the fiber circulator as a function of intensity versus time.

4. Results and Discussion

As shown in Figure 1(a), an EFPI acoustic OFS is typically fabricated by manufacturing a microstructure at the fiber end. The change in the diameter, thickness and material of the diaphragm can be modified by the sensitivity, frequency response and dynamic range of the sensor [8]. The sensor head is an F-P cavity including MoS_2 and GO membranes with 500 nm thickness as diaphragms made of by spin coating method. Figure 2 shows the amplitude-frequency spectra recorded by EFPI acoustic OFS based on MoS_2 and GO diaphragms at 8 Hz, 20 Hz, 40 Hz and 100 Hz frequencies. The outputs of the MoS_2-based sensor are higher than the outputs of the GO-based sensor.

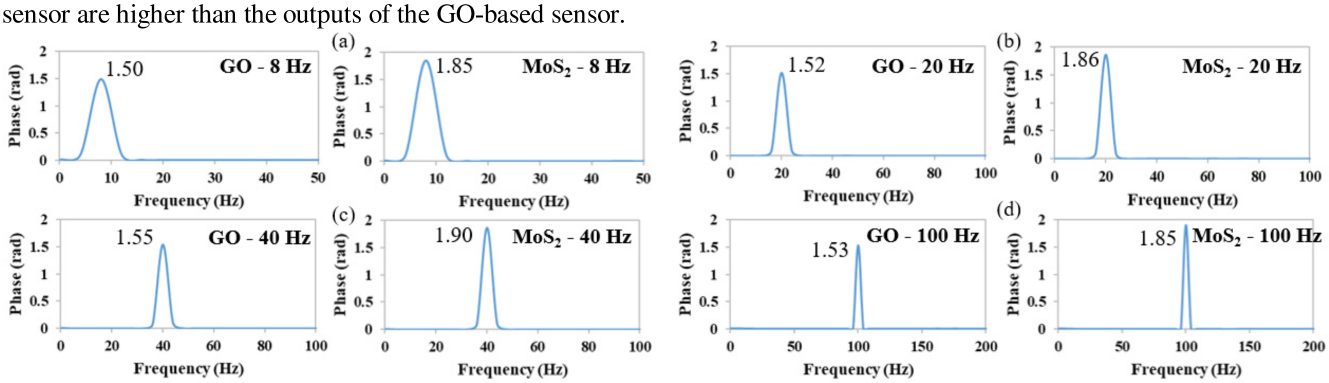

Figure 2. The sensor's output of EFPI acoustic OFSs at frequency of (a) 8 Hz, (b) 20 Hz, (c) 40 Hz and (d) 100 Hz for MoS_2 and GO diaphragms at 100 mPa pressure.

Figure 3 depicts the sensor sensitivity for MoS_2 and GO diaphragms at 100 mPa pressure that are obtained 18.50 and 15.52 rad/Pa, respectively. Hence, the MoS_2 diaphragm exhibits more sensitivity and better frequency response than the GO diaphragm according to the low Young's modulus of MoS_2. Regarding Equation 3, the sensitivity is inversely related to Young's modulus.

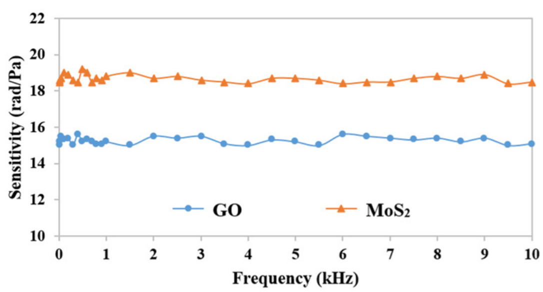

Figure 3. The sensitivity of EFPI acoustic OFSs based on MoS_2 and GO diaphragms in terms of rad/Pa at 100 mPa pressure.

5. Conclusion

Here, the EFPI acoustic OFS based on MoS_2 and GO diaphragms is introduced to detect acoustic waves. The sensitivity of the two types of diaphragms is investigated. The results emphasize that the sensitivity of the optical fiber EFPI sensors with MoS_2 diaphragm are ~20% better than those using the GO diaphragm. Furthermore, the sensor operates in the frequency ranging from 8 Hz to 10 kHz at 100 mPa.

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