Acoustic Fiber Sensors by Fabry-Perot Interferometer technology

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Abstract. A diaphragm-based Fabry-Perot interferometry (FPI) fiber optic sensor that uses a super luminescent emitting diode (SLED) source was designed and tested for on-line detection of the acoustic waves. The single-mode fiber (SMF) and a diaphragm used as sensors. SMF captured in a glass tube to form an extrinsic Fabry–Perot interferometer (FPI). Investigation fallouts show that this optical fiber acoustic-optics sensor is suitable and efficient for sensing acoustic signals by the vibrated diaphragm and the advantage fiber has a high bandwidth and sensitivity.

Keywords. Fiber Optics Sensors, Fiber Optics-tip sensors, Fabry-Perot fiber optics sensors, Acoustic Sensors.

1. Introduction
Optical fiber sensors (OFS) can be useful in measuring a varied numbers of physical factors, like as stress, pressures, temperature, and other measures via record the variations in optical spectrum of light intensity, polarization of light, the phase, or its wavelength that are produced by these factors in the optical fiber (OF) [1]. An OF sensor has founded to demonstrate to stay smart tools to measure many parameters of chemical and physical factors as sensors require numerous normal benefits. These benefits make the OF sensors are excellent options for partial discharge (PD) result, besides that, the OF has tiny size, normally on the order of the OF diameter is 100μm; it makes this system small in size and weight [2]. Furthermore, the long-range transmission of the OF permits to transducer elements; via factors measuring can be long-range away from the control unit station [3].

Optical fiber acoustic sensors (OFASs) have proved to be useful in many applications. Early OFASs to detected acoustic signal stood founded often OF interferometer technique like as all-optical fiber Mach–Zehnder and Michelson. The FPI had been employed for a transducer application for a past time [4]. This meddling is produced by light waves consecutively that returned between the dual parallel reflection plates. They are OFASs capable of wavelength transfer encodes information into a signal intensity qualifies great sensitive and the sensors own fast speed. With the progress of fiber optical technology and FPI theory can procedure a novel kind of OFS with many characteristic benefits. The last updates have enabled FPIs to be conveniently at the end face of the fiber. The so-called Fiber-tip FPI sensor combines the best advantages of both optical fiber and FPI sensors [5], as well as the high sensitivity, easy manufacturing and low in the cost.

Additional recently, optical fiber extrinsic Fabry–Perot interferometry (EFPI) devices must be below improvement to detected acoustic-signal [6]. EFPI devices are manufactured by a tiny element sensing
known as a Fabry–Perot crater designed via dual parallel reflecting plates. The PD devices are built on an FPI that includes a diaphragm and the end surface of SMF. The shaking of the membrane produced from PD created acoustic wave’s runs the interferometer in the signal own a linear range of its meddling borders. However, the PD measured structure does agonize from basis control variation produced by back reflection, first quadrature-point (Q-point) balance for the reason that of construction acceptance, functional point sense produced via perpendicular force in oil’s transformer, and point’s temperature. Though the multi-wavelength interrogation demodulation [7].

In this work, a new construction technique to develop tip optical fiber sensors (TOFS) by film thickness have ranging about nanometers was suggested. The projected fiber-tip FPI consumes a tiny size and great sensitivity, which creates it a faultless applicant for health requests, as like as non-invasive pressure quantity and test of ultrasonic.

2. Design Tip optical fiber Sensors
Several fabrication techniques for TOFS using different materials for the film, for example, polymer [8], Pyrex [9], silica [5] and graphene [6] need is established. Utmost of them are mounted on a film of silica that is gotten via joining OF extra segment to the end fiber face and then cleaved by cutting [10].

Optical fiber-tip pressure sensors have involved an unlimited contract of motivating consideration newly [11]. These sensors are regularly synthetic by round film through a micrometer of depth instruction. An improvement of a good-rendering, thin-film construction is vital in success these instruments. Thus, the linear deviation of a thin film is necessary for these sensors of pressure transducer. For the sake of boosting sensitivity, thickness of film should be thin to increase the deflection responsivity. The thin film could also outcome in lower resonant frequencies. To achieve a smooth response in the concerned range of frequency, the measured frequency’s superior limit should be greatly inferior to the minimum resonant frequency of the device. Furthermore, Frequency responsivity of the device can be greatly affected by the diaphragm dimension. So, a recommended action to be taken is to examine the relevance between the film parameters (radius, thickness, and material properties) and device presentation (sensitive and response for frequency).

3. The response of Thin Film
Some common method for testing thin films variable properties is the weight deflection technique [12]. By using this method, the refraction of a deferred film is measured below the useful compression. The circle shape is discussed in the following part. For the held curved figure film on the tip of the fiber optics, it can be averted below a consistent pressure P. As presented in Figure1. The deflection center of the curved film Y is a function of P assumed by [13, 14]:

\[ \Delta L = \frac{3(1-v^2)P.a^4}{16Eh^3} \]

Where are: \( \Delta L \) = bend of the film, \( h \) = thickness of the film, \( P \) = pressure, \( a \) = the span of the diaphragm, \( E \) = Young’s Modulus and \( v \) = Poisson’s Ratio.

![Diagram of Thin Film Response](image)
Once a purpose is pushed or embraced, to a postponement or reduction in a path for useful load, it makes a reduction or postponement in the pathway vertical to practical load. The $v$ is the ratio between these two amounts. Utmost materials have $v$ standards alternating between (0.0 - 0.536). Silver has a $v$ of (0.36737). Equation (1) is binding only the refraction of the thickness film width, the width of the film and the diameters. Aimed at any particular an OF tip device, it includes fixed pressure amount variety which is resolute by the thickness and radius of the film, young’s modulus and $v$ of the materials. Extreme determinate $P$ with direct reaction was considered by [14, 15]:

$$P < \frac{16\epsilon h^3}{5(1-v^2)a^4}$$

The sensitivity of thin Film Pressure ($\delta$), definite via the relation of the bend to the applied pressure, is individual of greatest significant performance factors of a pressure device. Aimed at rotund formed film, the assumed sensitivity is defined as shown [11, 14]:

$$\delta = \frac{3(1-v^2)}{16\epsilon h^3} a^4$$

4. Methodology
Numerous element sensors have been manufacturing whichever by synthesis connecting with borosilicate dust or using epoxy of SM optical fiber, a ferrule silica glass, a pipe from glass, and a tiny diaphragm, such as presented in Figure 2. Synthesis connection ensures the benefit of temperature factor then weakness problematic air-gap controller and likely loss to brooding coverings. Connection by epoxy is humbler also additional simply manageable then takes an upper sensitivity to temperature. The entire fabrication procedure of the projected Optical fiber-tip device comprises steps, containing (1) developing the optics hollow; (2) fixing the silver film; and (3) connection film to crater. Figure 2 is illustrated their methods.

5. Experimental
These extrinsic fiber sensors usually use single-mode fiber; to split the light source is into dual fibers by equivalent intensity by OF 3-dB coupler. SM optical fiber, mentioned by way of detecting part, is showing the acoustic indication and the other, denoted to such as the orientation part, and is protected since the influence of the sound wave. Either the transmissions FPI of the beam of laser are transmitting in the dual parts. They are reassembled to produce meddling signals controlled by sound waves.

OF sound sensor is explained in figure 3. The scheme contains of an element sensor, a super luminescent emitting diode (SLED), a bandpass filter (wavelength 630 nm, bandwidth 10 nm), a little...
of noise, wide-ranging band receiver of optical, and SM fibers connecting the element sensor to the optical detection device.

Receiver signal unit: This block performs the absolute or relative measurement of the received optical power. The electronics pre-amplifier part is a little noise, great gain, a trans-impedance amp that is considered to afford a through a digital display of the current produced from a photodetector; the amp can display the optical power. For detectors that want an opposite bias, the item can apply a chosen bias in sequence through the photodetector, shown in figure 4.

The laser from a 632-nm great power SLED is throwing an isolator and transmits alongside OF to the element device using bandpass optics filter and a 3-dB coupler. A 632-nm optics isolator was introduced next SLED to condense optics response to source of light, also an optical band-pass filter is narrowed range in a confident variety. In addition, the principal out-in OF and the tinny diaphragm are fused composed in cylinder-shaped fused silica pipe to procedure an FPI element sensor. The lunched light is partly reflection R1 by end surface of central OF. The residue of light transmits through air gap to the inside diaphragm surface, wherever it is after once more partly reflected R2. The etalon that is made by the two surfaces of the diaphragm should be carefully handled in the earlier PD sensor system.

Figure 3 shows the mechanism of loading the sound signal which is produced from the signal generation and transmitting it to the speaker. Then the speaker becomes a source of the sound wave, the wave sound creates pressure waves in the air gap between the speaker and the tip optical fiber optics sensors. To recording signal input and output using two channels from Oscilloscope, the frequencies are
range from 40Hz to 800Hz. Usually, to test response and effective TOFS, put it near speaker in path pressure sound waves. TOFS has transferred wave sound to laser fringes in FPI. So that, the FPI between tee sensor film and face fiber optics that is become as etalon. In addition; the multiple reflections in the optics pars, which is consists of an optical detector and an electronics amplification circuit. The aim is measured sensitivity and response of the TOFS.

6. Results and Discussion

Figure 5 expressions the association among the radius and sensitivity with a thickness range of (100, 200, 300, 400) μm for silver slide. The high sensitive is depended on the thickness and radius of the film. As soon as the thickness is set, the sensitivity boosts with increasing diameter of film. The sensitivity is perfect variable in thick film 100 μm.

![Figure 5](image1.png)

Figure 5. Sensitivity versus radius under a thickness of (100, 200, 300, 400) μm (silver film).

Figure 6 illustrations the relationship between the sensitivity and thickness after used thin film from silver through a radius of about (20, 60, 120, 200) μm. The high sensitive depends on the thickness and diameters of film. Once the radius is set, the sensitivity boosts with decreasing film thickness. The sensitivity is a strong variable in a radius of 200 μm.

![Figure 6](image2.png)

Figure 6. Sensitivity versus thickness under a radius of (20, 60, 120, 200) μm (silver film).

The film response of frequency is too a significant reflection concerning the design of the sensor, especially as soon as the designed sensors for acoustic quantity. To complete the linearity of responses device toward useful pressure, frequency signal should be minor than the lowermost frequency resonant of construction diaphragm.
In figure 7; illustrated the frequencies bigger than 40Hz, the sensing response of TOFS and effect are clear in range frequencies from (80Hz - 210Hz). Also, show figure 8; that frequencies from (210Hz - 800Hz) are so small affected and not a good response of TOFS. The results expression the TOFS to a natural frequency of the materials speaker and the sound generating parts.

Figure 7. Input signal and the output signal from the optical tip sensor at frequencies ranging from 40 Hz to 210 Hz.
Figure 8. Input signal and the output signal from the optical tip sensor at frequencies ranging from 250 Hz to 8000 Hz.
7. Conclusion
In summary, a diaphragm-based optical fiber Fabry–Perot sensor system has been developed for the detection of weak acoustic waves. Developments in visibility fringe and sensitivities of the sensor, which uses a low-coherence light source, have been achieved by the introduction of a bandpass optical filter to decrease the spectral width of the interrogating light. The test result ensures the feasibility of using the OF devices for finding sound waves. Compared with conventional acoustic sensors, the TOFS has the advantages of a nonelectrical conducting, immunity to electromagnetic interference, chemical inertness, small size, and the capability for multiple-point monitoring. Further improvement in performance may be obtainable by the use of tunable optical bandpass filters.

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