Photoacoustic Microscopy Based on Polydimethylsiloxane Thin Film
Fabry-Perot Optical Interferometer

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ABSTRACT

We present a photoacoustic microscopy (PAM) system based on a Fabry-Perot Interferometer (FPI) consisting of a transparent Polydimethylsiloxane (PDMS) thin film. Most of the PAM systems have limitations with the system alignment because the ultrasound transducers for detection are not transparent. Therefore, the excitation laser source should avoid the opaque transducer to illuminate the sample, which makes the system difficult to build up. Especially, the system volume is highly limited to be compact. In our experiment, to solve these difficulties, a FPI based on the PDMS film has been implemented and applied to measure the acoustic wave signal. The system uses a FPI as an acoustic wave detector instead of a conventional ultrasound transducer. A tunable laser was used to choose the quadrature-point at which the signal has the highly sensitive and linear response to the acoustic wave. Also a 20Hz pulsed Nd:YAG laser was used to generate acoustic waves from a sample. When the acoustic waves arrive at the PDMS film, one of the surfaces of the film is modulated at the detecting point, which gives the tuned FPI interference signal. From the signal arriving time, the depth location of the sample is calculated. As a primary experiment using the PDMS thin film as an ultrasound transducer, a couple of narrow black friction tapes located in a water container were used as the samples. This proposed imaging method can be used in various applications for the detection and measurement of acoustic waves.

Keywords: Photoacoustic microscopy, Fabry-Perot interferometer, thin film, PDMS

1. INTRODUCTION

In these modern times, we have various high resolution imaging systems such as optical coherence tomography and microscopy\textsuperscript{1}, confocal microscopy\textsuperscript{2}, and etc. These commercial imaging systems provide high resolutions, but with limited imaging depths into biological tissues. This is because the light coming from the sample is easily scattered and absorbed within the tissues. Recently, photoacoustic (PA) imaging and detection studies have been in the spotlight to overcome this limitation. In a PA imaging system, generally, acoustic waves are generated within a sample after absorbing a short pulse laser and the acoustic waves are detected by an ultrasound transducer. Also, it is capable of providing laser absorption contrast, which is useful for estimation of blood oxygen saturation and it can give the images of optical contrast of a sample\textsuperscript{3,4}.

Generally, a precision experiment, such as optical microscopy imaging, requires extremely careful and systematic alignment. In a conventional photoacoustic microscopy (PAM) system, an ultrasound transducer is generally used to detect acoustic waves. However, the excitation short laser pulse should go around the opaque transducer since the ultrasound transducer is non-transparent. Therefore, a PAM system cannot be easily implemented in a compact size. For these reasons, some of the research groups have set to research using other ultrasound detection methods\textsuperscript{5,6,7}.

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In this study, we present a PAM imaging system implemented by using the Fabry-Perot Interferometer (FPI) consisting of a transparent polydimethylsiloxane (PDMS) transducer—a thin film—that is 84 μm thick, attached on a glass plate. Both surfaces of the PDMS film were reflection coated in able to obtain high FPI contrast. For the imaging experiment, a sample is immersed in a water tank and the film side of the FPI transducer is placed to touch the surface of the water. To test the performance of the implemented PAM system, two stripes of a black tape immersed in water tank were used as a sample.

2. OPERATION PRINCIPLE AND EXPERIMENT METHOD

2.1 Fabry-Perot optical interferometer as an ultrasound transducer

Figure 1 (a) describes a FPI ultrasound detector. The detector consists of a thin PDMS film attached to a glass plate. The PDMS film placed on the coverglass surface were dichroic coated and the other side was covered by gold thin film for obtain high reflection. Therefore, the fringe contrast and sharpness of the interference are decided by the reflectivity of the PDMS film surfaces. When the acoustic waves generated from the sample arrive the PDMS surface, the thickness of PDMS, \( l \), is temporally modulated. As a result of the modulation in the PDMS thickness, the optical interference intensity is changed. Figure 1 (b) shows an interferometer transfer function (ITF), in which the phase bias \( \Phi_0 \) is set halfway between a maximum point and the nearby minimum point of ITF. An incident acoustic wave modulates the thickness \( l \) of the film, the location of the phase point \( \Phi \) is shifted. The phase shift \( d\Phi \) induces the intensity modulation \( dI_R \) through the ITF. Therefore, the amplitude of the incident acoustic wave is able to be measured by monitoring the incident change of FPI. Of course, to get a high sensitivity of the acoustic wave detection, the phase bias \( \Phi_0 \) should be set at a high slope of the ITF. The highest slope point can be obtained by taking derivative of the ITF and choosing the maximum point, which gives the so-called quadrature-point (Q-point). In our experiment, the wavelength of the laser for FPI detection was adjusted at the Q-point by using a tunable laser.

![Figure 1. (a) Schematic of the home-made FPI ultrasound detector. The incident light is reflected from the front and back surfaces of the PDMS film and make interference to each other. This optical interference is modulated by the acoustic waves generated within the sample. To get a high interference contrast, the film was reflection coated. (b) Simulation of FPI intensity-phase transfer function. The optical output intensity \( I_R \) of the interferometer varies as a function of the phase difference \( \Phi \).](image)

2.2 Reflection coating on PDMS film

In our experiment, both surfaces of the PDMS film attached to reflection coated plates. To get high contrast interference of the FPI transducer, one side of the PDMS film placed on the cover glasses which is evaporated dichroic filter. To make dichroic mirror one side of the cover glasses, we used Electron-Beam evaporation method. Then the other side of the film was covered with gold coating film. To avoid multiple reflections from the cover glasses, we put an wedge prism on the top of the cover glasses. The space between the prism and the cover glasses was filled with index matching oil. In general,
the conventional FPI systems consists of two accurately flat plates, semi-coated on their inner surfaces. When light is incident on the interferometer, a part of the light is reflected and the others are transmitted between two plates and make multiple interference. As a result of the multiple interference, the sharpness of interference fringes is decided by the reflectivity of the inner surface of FPI. Figure 2 shows the configuration of our FPI transducer.

**EXPERIMENT METHOD**

The schematic of the experimental system is shown Figure 3. The system primarily consisted of an excitation arm and a detection arm. To generate acoustic waves within a sample, a pulsed Nd:YAG laser (532 nm, 20 Hz, Quantel) was used. The beam from the excitation laser was focused by an objective lens (LMO-20X, Optics for Research) to the sample. Then, the acoustic waves generated within the sample were propagated to the FPI transducer, modulating the surface of the film. To detect the acoustic waves, a tunable laser (TSL-200, Santec) was used, whose wavelength was adjusted to the Q-point of the FPI. To amplify the detection laser source, EDFA (LXI-2000, LUXPERT) was used. Then the amplified laser source was illuminated through an objective lens (10X, Olympus) to the FPI transducer. The interference signal of the FPI was measured by a photodector (1817, New FOCUS), and it was converted to an image using a LabVIEW program.

Figure 3. Schematic of the PAM system implemented with a FPI transducer (inset: photography of the FPI transducer)
3. RESULTS

3.1 Interferometer transfer function (ITF) and high-Q point

To detect the most phase-sensitive and linear response to the acoustic wave signal, the wavelength of the detection laser source was adjusted so that the phase bias could be located at halfway between the ITF maximum and minimum. Figure 4 shows a part of the FPI interferometer transfer function (ITF) of a thickness of 84 \( \mu \)m PDMS sensing film. The reflection spectrum of the sensing film was measured with an optical spectrum analyzer (86142B, Agilent) and a broadband light source (FLS-2300B, EXFO), which was plotted in a linear scale.

![ITF spectrum of the 84 \( \mu \)m PDMS sensing film.](image)

With the measured ITF spectrum, it is possible to calculate the thickness of the PDMS film from

\[
\Delta \lambda = \frac{\lambda^2}{2n(l \cos \theta)}
\]

Where, \( \Delta \lambda \) is the free spectral range of ITF and \( \lambda \) is the operating wavelength, \( n \) is the refractive index of PDMS (\( n = 1.4 \)), \( l \) is the thickness of the film, and \( \theta \) is the incident angle of the detection laser beam, respectively. In our experiment, the laser source illuminated the FPI detector perpendicularly, so the incident angle is close to 0 degrees. With this equation, from the ITF of Figure 4, the thickness of the PDMS film is calculated as 86 \( \mu \)m, which is well matched with the design thickness of 84 \( \mu \)m.

We tuned the detection wavelength to the highest derivative value of measured ITF to get high sensitive and linear response. Considering our equipments specification, we set it around 1551.5 nm. Had been processing the experiment, the wavelength a little bit tuned.

3.2 Dichroic mirror coating

To make a highly sensitive FPI as an ultrasound transducer, we fabricated a dichroic mirror on a surface of the PDMS film and measured the reflection spectrum. As can be seen in Figure 5, the dichroic mirror shows better than 80% reflectivity over a couple of hundred nanometers. Considering the wavelength range of the detection laser, around 1550 nm, we can say that the dichroic mirror has a suitable reflectivity for the detection. The other surface of the PDMS film was coated with a gold film as shown in figure 2 for getting high reflection also.
3.3 Line scan image of stripes of black friction tape

The purpose of photoacoustic imaging is recognizing the distribution of objects within a sample, which can generate acoustic waves. To evaluate the performance of our photoacoustic system, two narrow black friction tapes were placed within a water container. The excitation laser pulse was illuminated from the bottom of the container, and the home-made FPI transducer was placed 15 mm above the tapes. Each stripe width and thickness of the tapes had around 235 \( \mu \text{m} \) and 140 \( \mu \text{m} \), respectively. The sample scanning was made in the direction perpendicular to the stripes, with 10 \( \mu \text{m} \) scanning steps and a total 1 mm scan length. Figure 6 (a) shows that, the acoustic waves were detected around 10.5 \( \mu \text{s} \) after illuminating the excitation laser; the excitation laser signal was not shown in the figure. Considering that the speed of sound in water is approximately 1,484 m/s, the time delay of 10.5 \( \mu \text{s} \) gives around 15.6 mm, which is well matched with the FPI transducer separation of 15 mm. The result of the detection signal was shown in figure 6 (b). In figure 6 (b) after 600 \( \mu \text{m} \) scanning, we can see that the intensity of acoustic signal is decreased a little bit and the time delay is increased; it is due to the fact that the second black friction tape was unintentionally angled toward the bottom of the water container.

![Figure 6](image-url)
4. CONCLUSION

We have presented the feasibility of photoacoustic imaging with the PAM (photoacoustic microscopy) system that is implemented with a PDMS (Polydimethylsiloxane) thin film FPI (Fabry-Perot Interferometer) transducer. A transparent thin film of PDMS (84 um thickness) attached on a glass plate was used as the acoustic transducer. The FPI interference between the beams reflected from both surfaces of the film was detected with a detection laser of around 1550 nm wavelength. The thickness modulation of the PDMS film induced by the acoustic wave gave appreciable variation in the reflection intensity of the FPI. To get a high sensitivity of the optical transducer, dichroic mirror and gold coatings were made on both surfaces of the PDMS film. A line scan image of the implemented PAM system shows that PDMS thin film has worked well as the optical FPI transducer for detecting photoacoustic signals. Two stripes of narrow black friction tape, buried in a water container, could be successfully identified. In a depth of 15 mm, the width and thickness of the stripe, about 235 \( \mu \)m and 140 \( \mu \)m, respectively, was measured almost the same with the designed one.

5. REFERENCES


