Study of Frequency Response Characteristics in Microphone Used by Optical Sensor

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In this paper, in order to analyze property of frequency response in microphone using optical sensor, acousto-optic sensor system has been implemented. The capacitance microphone and fiber-optic transmission path type fiber-optic microphone (FOM) have weaknesses in directivity, size, weight, and price. However suggested optical microphone can be constituted by cheap devices, so it has many benefits like small size, light weight, high directivity, etc. Head part of optical microphone which is suggested in this paper is movable back and forth by sound pressure with the attached reflection plate. Operating point has also been determined by measuring the response characteristics. The choosing the point, which has maximum linearity and sensitivity has changing the distance between optical head and vibrating plate. We measured the output of the O/E transformed signal of the optical microphone while frequency of sound signal is changed using sound measurement /analysis program, "Smaart Live" and "USBPre", which are based on PC, and compared the result from an existing capacitance microphone. The measured optical microphone showed almost similar output characteristics as those of the compared condenser microphone, and its bandwidth performance was about 4 kHz at up to 3 dB.

Keywords : Optical sensor, Microphone, Acousto-optic sensor, Transducer

1. INTRODUCTION

Since cheap optical devices are available due to the dramatic progress of semiconductor industry and optical technology, many high quality products are developed with competitive price Among them, the research about optical microphone has been vigorously conducted to complement defects of capacitance microphone like size, weight, price, directivity, etc[1-7]. Since condenser microphone needs expensive preamplifier and power amplifier to modify the sound by the small fluctuation of capacitance, thus it is expensive[3]. Moreover, optical microphone using optical fiber is completely not interfered by surrounding electromagnetic field or radioactive ray, it has excellent sensitivity to sound pressure. Since it uses optical transfer communication using optical fiber, long-range signal detection and transfer are possible, thus it is effective for detection of sound signal[8]. However, light source and detector and circulator are expensive, the price of microphone is relatively high. In other hand, if only cheap light source and detector is used without using optical fiber, small form factor microphone of low price can be producted.

Optical microphone which is based on optical transform technology changing sound signal to optical signal can be divided into three categories, amplitude modulation, phase modulation, polarization modulation due to the method of optical transform. Because phase modulation and polarization modulation can measure the small signal, we can make high-sensitive microphone, but, they are easily affected by surrounding environments such as impulse, vibration, temperature, etc[9-12]. Thus amplitude modulation which is structurally simple, unaffected by surrounding environments, stable has been researched vigorously in a sense of practicality.

This study manufactured an optical microphone using a low-priced optical sensor by applying the light intensity modulation method and tested the characteristics. Furthermore, this study confirmed its applicability as an actual microphone by measuring the optical coupling efficiency and frequency against the dynamic displacement for the acoustic pressure of the manufactured optical microphone.

2. STRUCTURE OF OPTICAL-MICROPHONE AND ITS MECHANISM

2.1 Structure of proposed optical microphone

In this paper, we implement optical head with cheap light source and detector. vibrating plate of optical microphone is a form of that reflection plate is attached at center. It can move to the direction of external inputted sound wave, proportionally to the acoustic-pressure. Since sensitivity of condenser microphone is proportional to the area movement of vibrating plate, vibrating plate should be large and the movement of the whole plate should be uniform, but only the movement of the center part which reflects the light is needed to be considered, we can construct small form factor microphone, and cheap optical device is available through the development of the optical technology, so production of high-quality is possible with competitive price.

Light from the source is delivered to the vibrating plate with attached reflection plate, vibration of the vibrating plate by sound pressure is received by the measuring turning optical signal from the reflection plate through photo-detector. This is the form of optical-head. In this paper, by changing the distance between light source and vibrating plate, we conduct an experiment of the optical coherence, and we choose the angle and position with the maximized linearity and sensitivity as the operating point. And by using the sound measurement/analysis program, Smaart Live and Oscilloscope, Spectrum analyzer based on PC, we examine the characteristic of frequency respond of optical microphone while the frequency of sound signal input is changing.

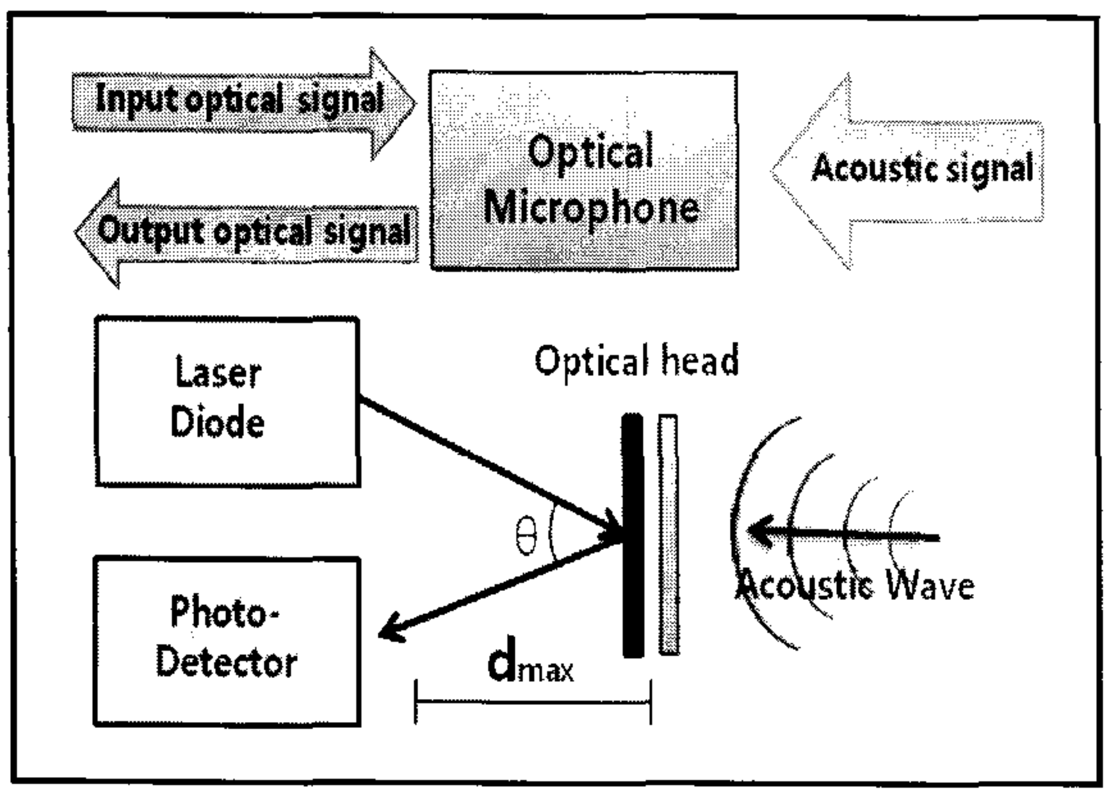


Fig. 1. Schematic configuration of the proposed microphone.

The structure of the optical microphone proposed in this paper is illustrated. The optical head of the optical microphone is constituted by light source, detector, and vibrating(reflecting) plate. At first, the light source is made by He-Ne Laser(5 mW) with the wavelength 632.8 nm. Detector transformed the optical signal to electric signal by using optical sensor Measurement equipment are Oscilloscope (4CH, 600 MHz), Spectrum analyzer (30 Hz ~26.5 GHz), GPIB (National instruments), USBPre (TASCAM US-144), Smaart Live(SIA, Smaart Live v5.0), Speaker (8 ohm, 300 W), amplifier (2 x 300 W /4 ohm), CD player etc.

The vibrating plate moves freely back and forth, a reflection plate does vibrating motion as same as a vibrating plate, it reflected the light from the light source, and delivered the light to photo-detector.

2.2 Mechanism of proposed optical microphone.

Mechanism of proposed optical microphone is as follows: LD(Laser Diode) and PD(Photo Detector), and vibrating plate(reflection plate) make 74.5 ° angle to each other. Light is coming from the LD, and light is reflected on vibrating(reflection) plate, light is entered to PD, optical signal is transformed the electric signal.

When sound wave which is produced by both Smaart Live and speaker is incident to backside, vibrating plate moves back and forth in the direction of sound wave.

Due to the magnitude of sound signal, the distance between light source, detector, and vibrating plate changes, so the magnitude of coherenced optical power is proportional to the sound pressure. Namely, if sound pressure becomes large, then the movement of the vibrating plate, so the amplitude modulation of optical signal increases. Proposed devices transformed the sound signal into optical signal, and it consequently plays a role of optical microphone. Specially, to play the sound signal input, it must have nice linearity and sensitivity of the characteristic of optical signal modulation due to sound pressure. For this, we use Oscilloscope, Spectrum analyzer, and see the shape of the sound signal wave, and frequency characteristic.

And by using Smaart Live, we analyzed the sound signal. Moreover we compared and analyzed the how much the proposed optical microphone and commercial capacitance microphone are capable of that they can collect the sound signal.

2.3 Results and discussion

In Fig. 2, the experimental setup for measuring the performance of the proposed optical microphone, which is constituted by light source and detector, vibrating plate is illustrated. We configurate that the angle of the beam is properly modified in light source and detector of optical head. A vibrating plate is necessary to consider only the movement of the center, which reflects the light, so the we attached the small reflection plate at the center.

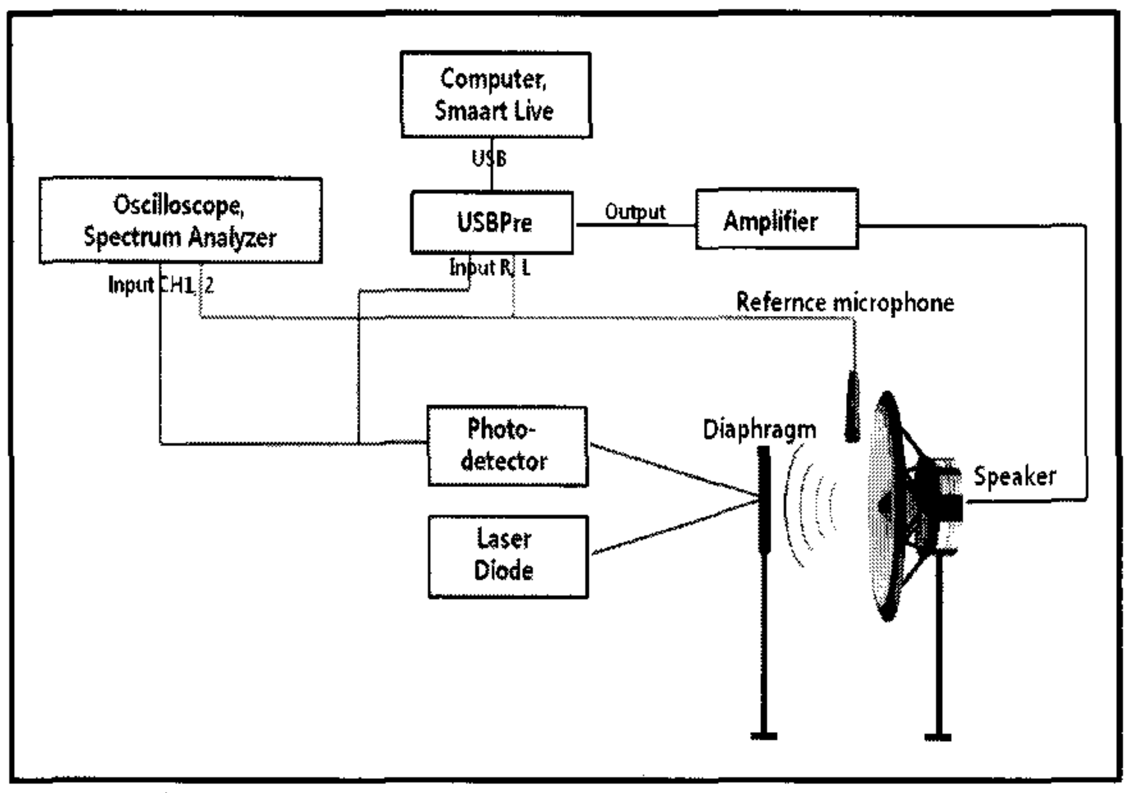


Fig. 2. Experimental setup of the proposed microphone.

To determine the operating point which represents the best distance between optical head and the vibrating plate, as we changes uniformly the distance between two devices, we measure the coupling efficiency of optical power which is received from the reflection at the reflecting plate of the vibrating plate.

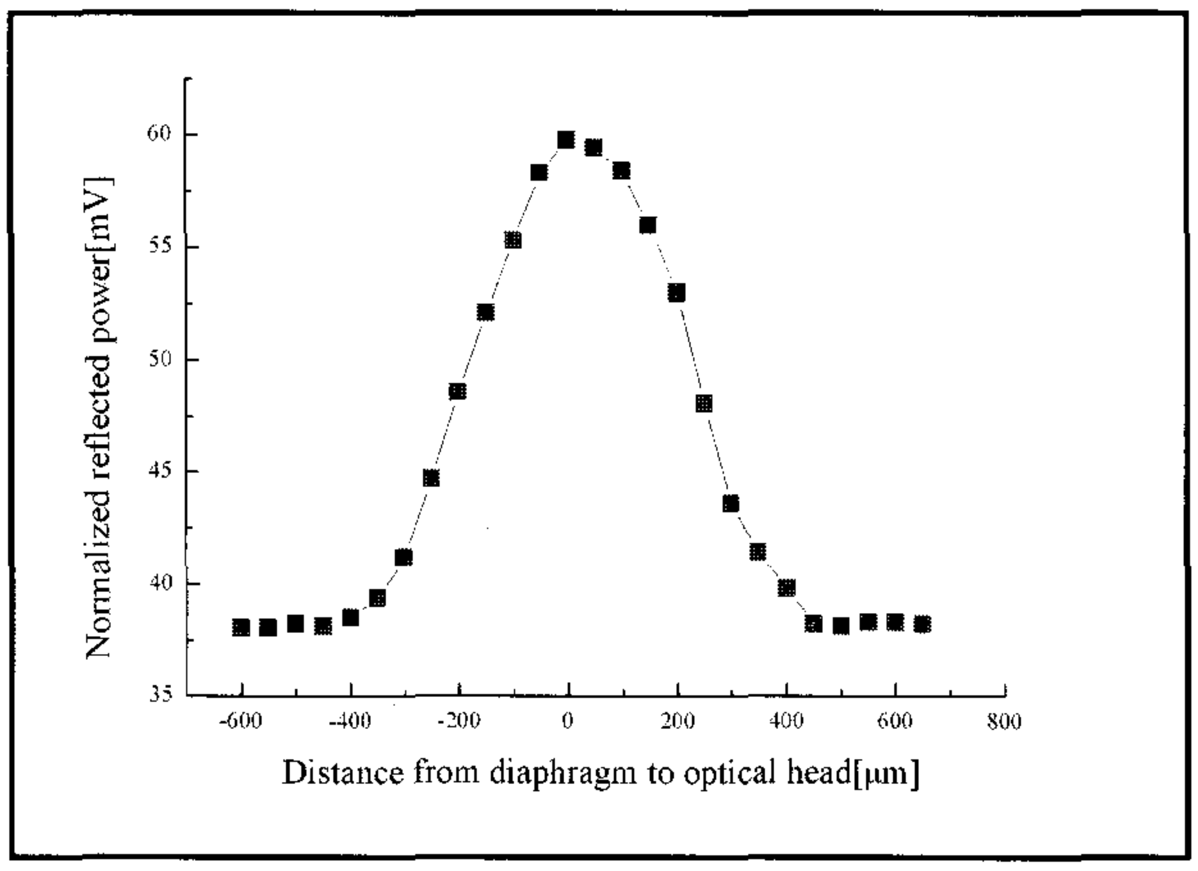


Fig. 3. Static optical coupling efficiency as a function of the distance from the optical head to the reflective diaphragm.

In Fig. 3, the result of the optical coupling efficiency with the distance between optical head and the vibrating plate is represented, from the measurement. As the distance between light source, detector and vibrating plate are close, the optical coupling efficiency becomes better, but since there are problems such as the arrangement of optical axis and the size of the LD, so basically we arranged them which are separated by 4 mm distance to each other. This coupling efficiency is set to be 4 mm as standard, by moving back and forth by 50 μm, we measured the optical coupling efficiency due to vibration. Namely, when the light is reflected at the

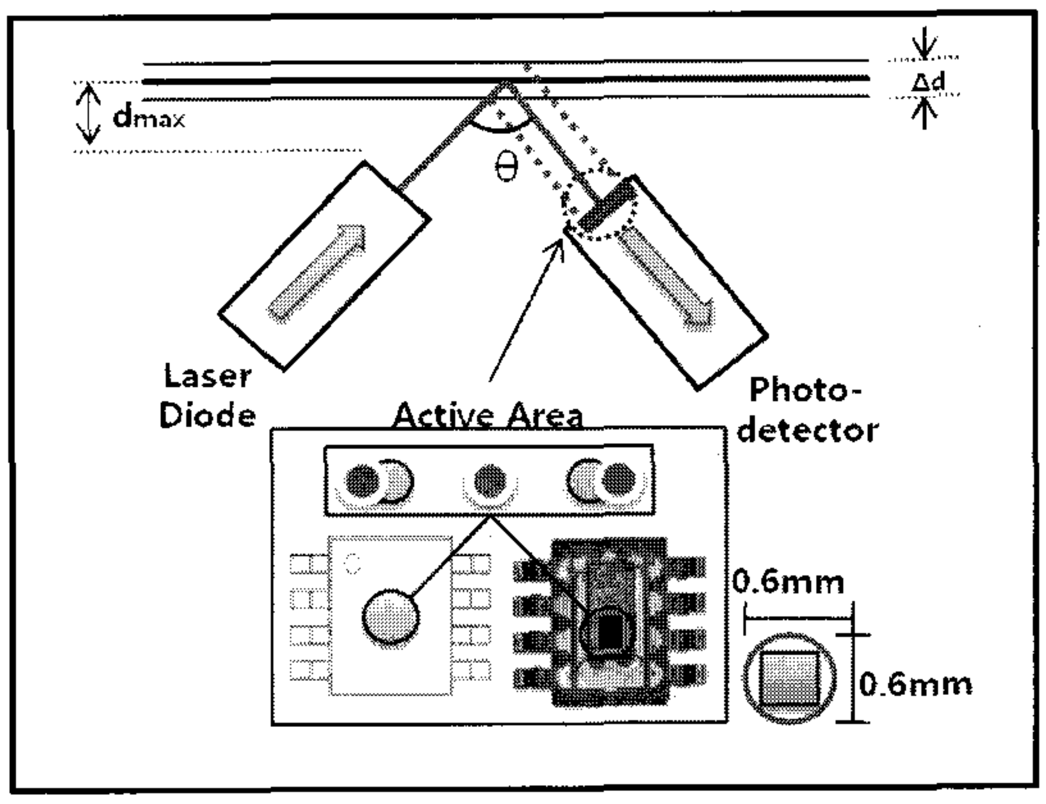


Fig. 4. Analysis of optical microphone structure for operating point.

reflecting plate of the vibrating plate and they enter into active area of the detector completely, the maximum optical efficiency is appeared. By sound pressure, if we have variation at the vibrating plate, the optical coupling efficiency decreases because the beam is incident to the place where are apart from the center of the detector.

As you see in Fig. 4, if we set the angle between the light source and detector as, if the vibrating plate moved by △d, the light which is started from light source, and reflected at mirror, entered into detector is moved by 2△d • tan/2 • cos/2 from initial state. If we assume that the beam from the light source has the intensity distribution of the Gaussian function, the intensity distribution at the z, in the direction of the beam advance is given by equation (1)[13].

$$I(\rho,z)=I_0\left[\frac{W_0}{W(z)}\right]^2\exp\left[\frac{2\rho^2}{W^2(z)}\right]$$

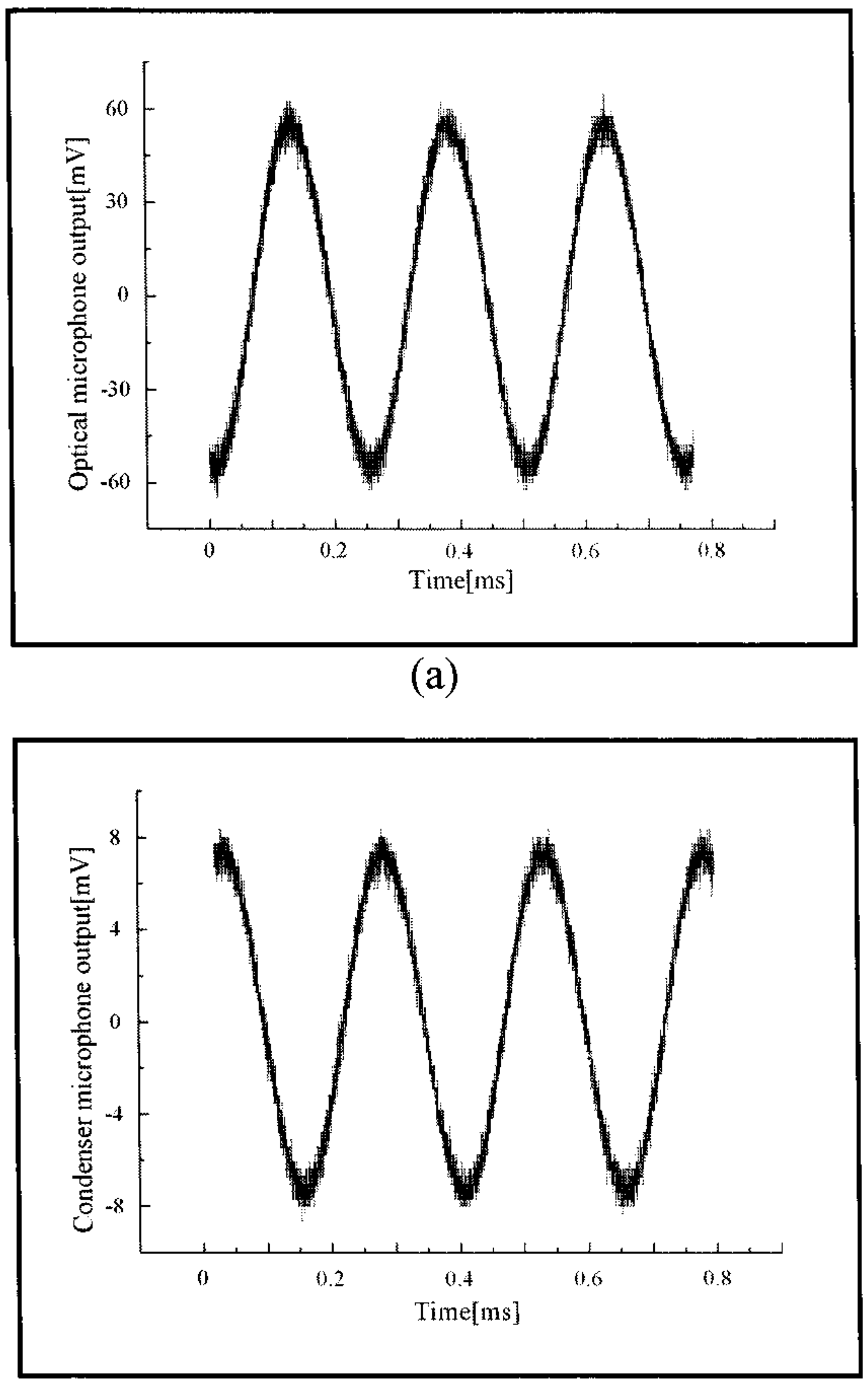
$$W(z)=W_0\left[1+\left(\frac{z}{z_0}\right)^2\right],\ W_0=\left(\frac{\lambda z_0}{\pi}\right)^{\frac{1}{2}},\ \theta\approx\frac{\lambda}{\pi W_0} \qquad (1)$$

Here, I_0 and W_0 represent the intensity and the radius of the beam at the z=0 from the light source. And is Rayleigh region, z_0 is the beam's divergence angle, λ is wavelength of light source(632.8 nm).

From the measurement, we obtained the d_{max} which is the position in that we can get the maximum power, and as you see in Fig. 4. we choose the operating point by the determining the point at the detector such that the brightest light from the light source is incident to the center of the detector.

We determine the 4 mm, 74.5 ° as the acting point of the optical microphone, which has the maximum optical coupling efficiency of linearity and sensitivity.

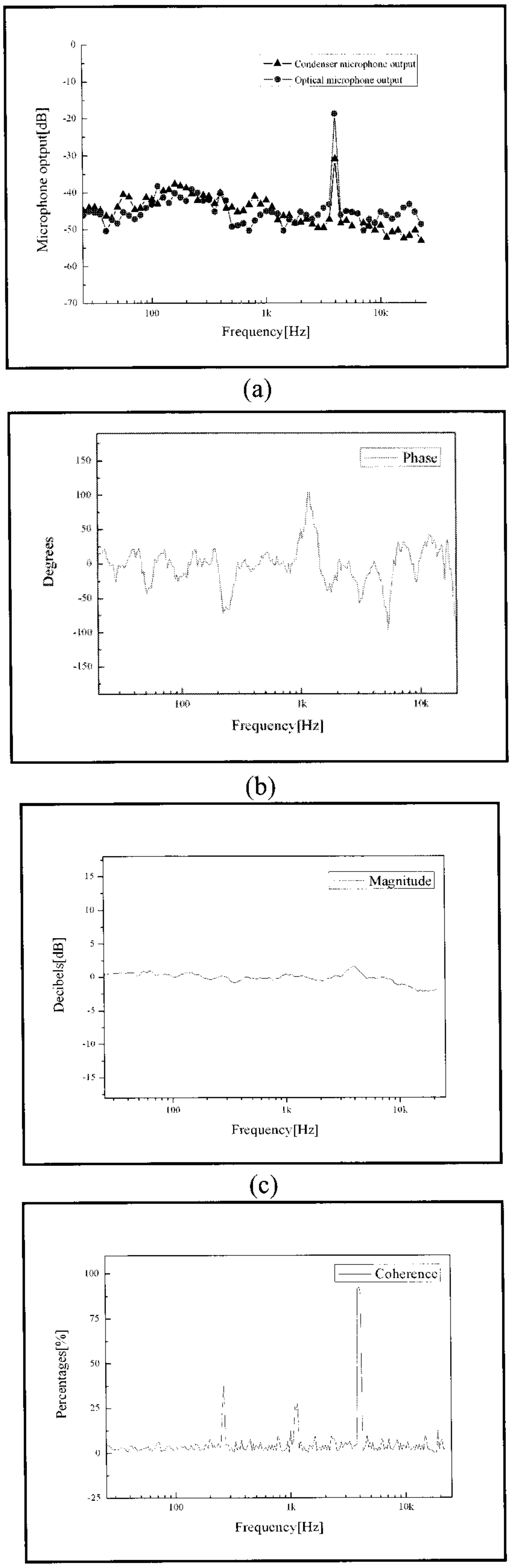
We send the sound signal which is produced from Smaart Live, USBPre, speaker to implemented optical



(a)

(b)

Fig. 5. 4 kHz audio signal oscilloscope analysis. (a) Optical microphone, (b) Reference condenser microphone.



(a)

(b)

(c)

(d)

Fig. 6. 4 kHz audio signal Smaat Live analysis. (a) Real Time Analysis(RTA), (b) Phase, (c) Magnitude, (d) Coherence.

microphone and measure the characteristics of frequency respond. To test the performance of optical microphone, it was compared with commercialized condenser microphones.

Figure 5(a), (b) are the data, which was measured from the output signal of optical microphone and comparison condenser at 4 kHz.

According to Fig. 5(a), (b) it can be found that comparison condenser microphone is almost same as proposed optical microphone and it is possible to get the output without any distortion.

Figure 6(a) shows that the audio signal of comparison condenser microphone is nearly same as the audio signal of optical microphone by comparing with each other by RTA(Real Time Analysis). During an experiment , there were some fine noises. They were produced due to the connection state of equipments.

Figure 6(b)-(d) indicates that one signal was used as a standard signal by Loop-Back, another signal is the analyzed data by comparing the audio signal from optical microphone with the standard signal.

Figure 6(b) shows characteristic and Fig. 6(c) shows Magnitude. Magnitude indicates the frequency response characteristic. Fig. 6(d) shows coherence, which is the standard of trust about transmission and return signal.

In Fig. 6(b) brilliant Phase characteristic was shown at 4 kHz and also, we can find out that frequency response characteristic(magnitude) in Fig. 6(c) is almost same as its original signal.

Coherence in Fig. 6(d) indicates 90 % of correction and the audio signal at 4 kHz is being sincerely regenerated.

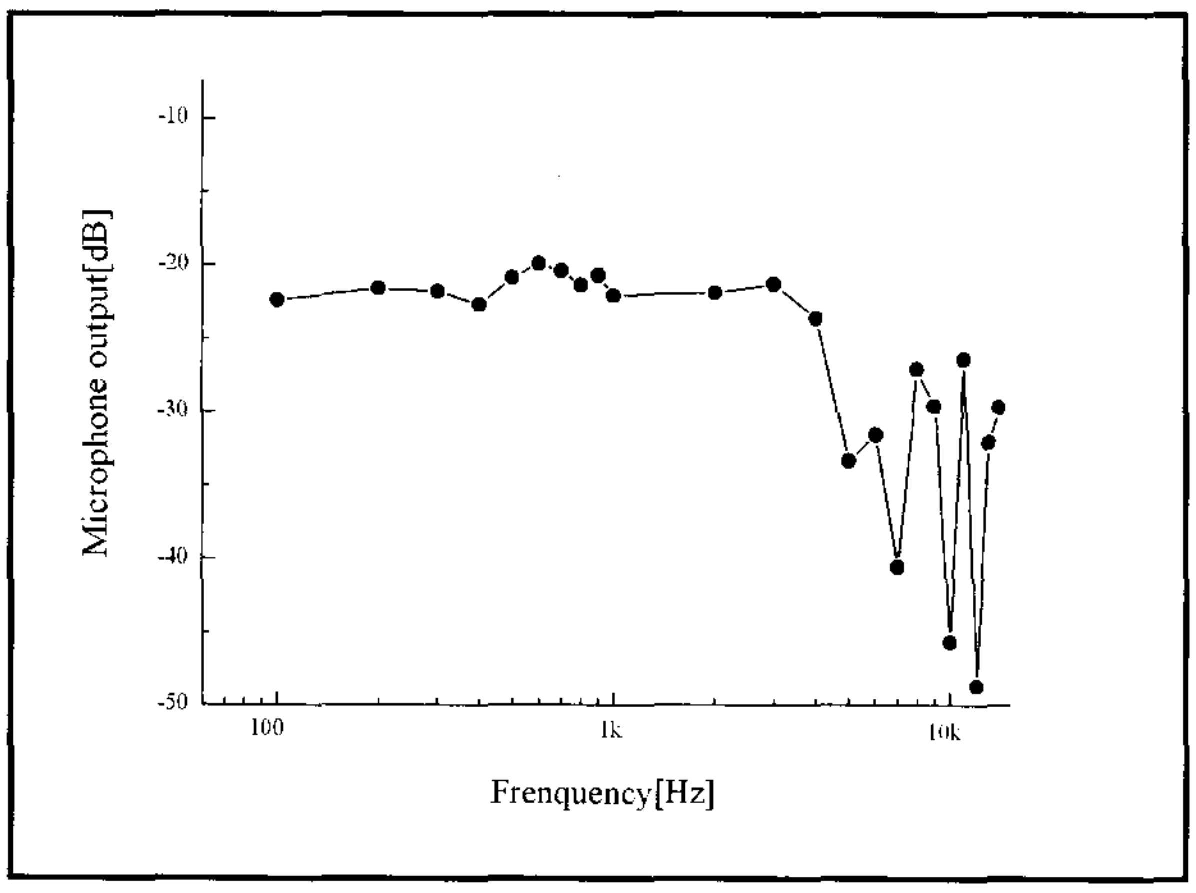


Fig. 7. Measured frequency response of the optical microphone.

Next, as we change only frequency with fixed the magnitude of sound signal, we measured the output signal of optical microphone. The result is illustrated in Fig. 7. From Fig. 5, the output to the frequency 4 kHz is almost constant within the fluctuation of ±3 dB, and we can see the similar output characteristic to condenser microphone. Around frequency 5 kHz, the phenomenon of dramatically decreasing output signal is appeared, we guess that this is caused by the natural resonance of the vibrating plate[12]. Thus the bandwidth of the proposed optical microphone is about 4 kHz. To increase the bandwidth of active frequency, we should decrease the size of the vibrating plate and the size of the reflecting plate to make the natural resonance frequency higher, so if that frequency is out of sound frequency range, 20 Hz-20 kHz, then we can implement the microphone with wider bandwidth. And for the correct measurement, the measurement of the sound signal should be conducted in the silent room.

3. CONCLUSION

In this paper, we has implemented the optical microphone, which has acousto-optic sensor system with laser diode and detector. Used vibrating plate moves back and forth in proportional to the sound signal. The PC program, Smaart Live and Oscilloscope, Spectrum analyzer is used to the measurement/analysis of the sound signal. By change the frequency, we do the experiment of the characteristic of frequency respond of optical microphone.

According to the result of the experiment, the Figs. 5, 7 from Smaart Live and Oscilloscope represents that the optical microphone has almost same signal to condenser microphone with the input of 4 kHz frequency sound signal. Fig. 5 suggest that commercial condenser microphone and proposed optical microphone have almost same output characteristic. And around 3 kHz, optical microphone has better sensitivity to condenser microphone, the measurement is conducted in non-silent room, we just neglect the external sound noise.

The bandwidth of sound signal frequency of proposed optical microphone is 4 kHz, we can guess that this bandwidth can be extended by decreasing sizes of vibrating plate and reflecting plate. It would increase the frequency of natural resonance, so the bandwidth of the frequency would be extended.

Based on the change of the optical coupling efficiency by optical axis deviation, we measured the sound signal by using Optical Sensor, confirmed the base technology to produce the optical microphone, and checked its possibility.

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