

A system using a piezoelectric polymer transducer for acoustic imaging of amplitude and phase differences in air

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1. Introduction

The acoustic impedance of piezoelectric polymers is one order of magnitude smaller than that of piezoelectric ceramics such as lead zirconate titanate (PZT). Therefore, the transducer matching loss between a transducer and an object is greatly reduced using piezoelectric polymers. Poly (vinylidene fluoride) (PVDF) is the best-known piezoelectric polymer. In particular, copolymer of vinylidene fluoride and trifluoroethylene [P(VDF/TrFE)] has the largest coupling factor ($k_t = 0.3$) among piezoelectric polymers. The attenuation of ultrasonic energy in air is about 3 orders of magnitude larger than that in water and is proportional to the square of its frequency. Thus, it is thought that the transmitting and receiving of an ultrasonic wave of high frequency in air is difficult, but it is considered possible to receive attenuated weak echo wave signals using a piezoelectric polymer transducer. An acoustic image using a PZT transducer was reported by Fox *et al.* in 1985 [1]. However, because of technical difficulties there have been few papers reporting the imaging of an object at a resolution of 1 mm or less using a transducer operated at MHz frequencies in air. We have reported a high-resolution acoustic image at 2 MHz using a P(VDF/TrFE) transducer [2]. This acoustic amplitude image has a transverse resolution of 150 μm . Using the acoustic imaging system, there are two imaging methods for obtaining amplitude and phase-difference images. In this study, we introduce an acoustic imaging system that uses a single P(VDF/TrFE) transducer to detect amplitude and phase difference signals in air, because in the previously reported papers [3,4] we used two transducers separately, one for transmitting sound waves and the other for receiving the reflected waves (separation-type). The scattering noises, which strongly occurred in the separation-type transducers, are decreased using the present acoustic imaging system and the single P(VDF/TrFE) transducer. As a result of our experiments, we have succeeded in obtaining an acoustic image with a much better resolution than that of previous images.

2. Piezoelectric polymer P(VDF/TrFE) air transducers

The parallel-type transducer that operates at 2 MHz in air

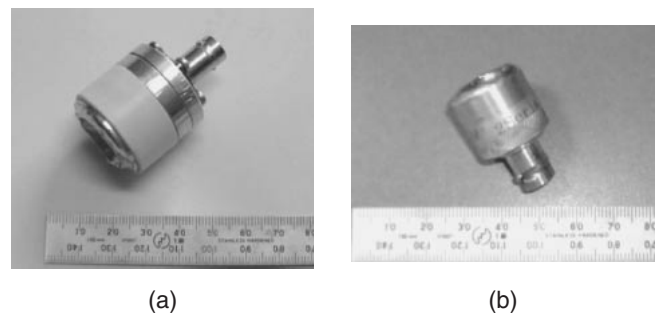


Fig. 1 (a) Photograph of a concave transducer for use at 2 MHz in air with three (parallel) P(VDF/TrFE) films of 95 μm thickness. (b) Concave transducer for use in air with two films (serial) of P(VDF/TrFE).

(Fig. 1(a)) is composed of three stacked layers of 95 μm -thick P(VDF/TrFE) (75 mol% VDF) film, each of which is driven parallel by a common electric source. Figure 1(b) shows a P(VDF/TrFE) transducer that operates at 3 MHz in air. The two P(VDF/TrFE) films of the transducer shown in Fig. 1(b) are stacked in the same polarization direction (serial-type). The transducers shown in Figs. 1(a) and 1(b) have wide aperture angles ($\theta = 70^\circ$ and 65° , respectively) to improve the angular resolution of the acoustic image. The focal lengths are 10 mm (a) and 7.5 mm (b). The fact that these transducers have almost semi-spherical concave surface are advantageous for high-resolution imaging with high sensitivity. It is possible to design similar transducers in various forms because of the flexibility of P(VDF/TrFE) film.

The two-way losses measured for the transducers in Figs. 1(a) and 1(b) were 96 dB at 1.87 MHz and 103 dB at 2.93 MHz, respectively (including air losses). These transducer losses are about 20 dB larger than the theoretical values calculated from the Mason's equivalent circuit [5,6]. The reason for this decrease in efficiency is most probably because the P(VDF/TrFE) films are not bonded to each other sufficiently. Thus, it is concluded that the P(VDF/TrFE) transducers having high-sensitivity in air with a loss of about 60 dB or less at 2 MHz [2] could be developed by overcoming this bonding problem.

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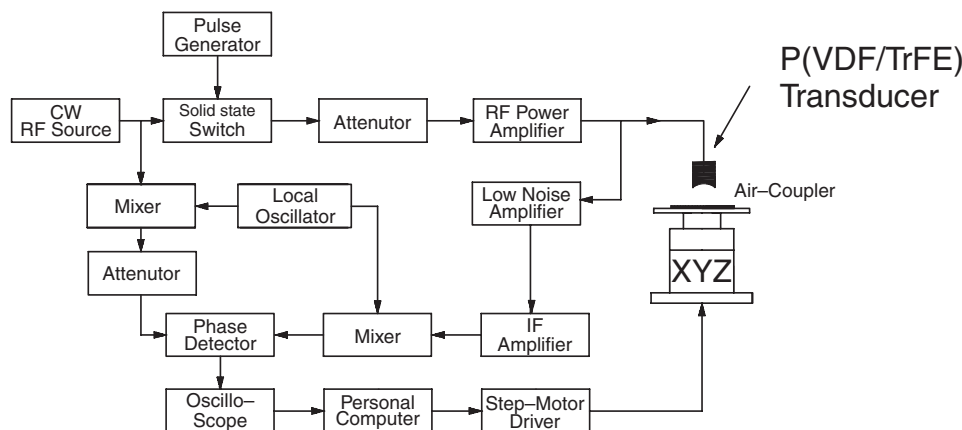
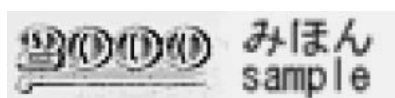
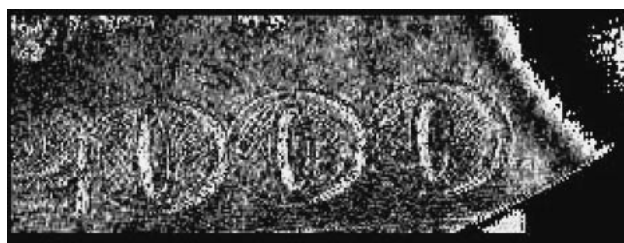


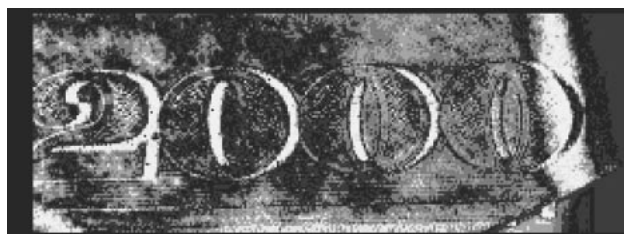
Fig. 2 Diagram of the experimental phase-difference imaging system.



(a)



(b)

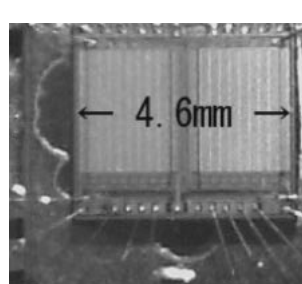


(c)

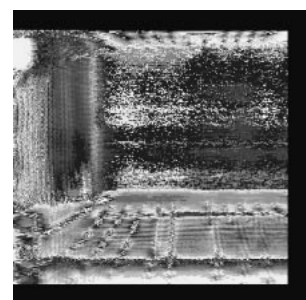
Fig. 3 (a) Detected part of a 2,000 yen bill for acoustic imaging. (b) Amplitude image of part of the 2,000 yen bill in Fig. 3(a). (c) Phase-difference image of the bill shown in Fig. 3(a).

3. Ultrasonic imaging system and acoustic images

A block diagram of the acoustic imaging system controlled by a computer program is shown in Fig. 2. Although this system forms phase-difference images, it also is possible to operate as an amplitude imaging system. The continuous wave from the frequency synthesizer was converted by a gate-switch to the burst waves, which were then amplified to about $400 V_{pp}$. The high voltage burst was input to the transducer, transmitting the acoustic burst. The echo signal from the sample on the stage was detected by the same transducer. The amplitude image of the printed part ($10 \text{ mm} \times 25 \text{ mm}$) of a Japanese 2,000 yen bill (Fig. 3(a)) is shown in Fig. 3(b). The



(a)



(b)

Fig. 4 (a) Photograph of a ROM IC chip (width 4.6 mm). (b) Phase-difference image at 2.9 MHz with resolution of $20 \mu\text{m}/\text{step}$.

phase-difference image is shown in Fig. 3(c). Both images (b) and (c) were obtained using the 2 MHz transducer shown in Fig. 1(a) [2]. The mechanical scanning width of the pulse motor used to obtain a geometric image is $100 \mu\text{m}/\text{step}$. Figure 4(a) shows a photograph of a ROM IC chip (width 4.6 mm), and Fig. 4(b) shows its phase-difference image obtained in air at 2.9 MHz using the transducer shown in Fig. 1(b) with a stepping displacement of $20 \mu\text{m}/\text{step}$. The phase-difference image clearly displays bonding wires of $20 \mu\text{m}$ in diameter.

4. Conclusion

We developed an acoustic air-coupled transducer manufactured from P(VDF/TrFE) films with a small acoustic impedance. We also developed the scanning acoustic microscopy system necessary to operate the P(VDF/TrFE) transducer. The P(VDF/TrFE) transducer presented here appears to be useful for acoustic imaging in air at frequencies as high as 3 MHz. However, the transducer loss is still large, as noted above. In the future, high-resolution acoustic images can be expected from a high-driving-frequency P(VDF/TrFE) transducer with a loss of 50 dB [3]. In this note, we have described reflection imaging only. However, we have confirmed that P(VDF/TrFE) transducers are also useful for detecting ultrasonic signals transmitted through such materials as a $10 \mu\text{m}$ -thick aluminum foil, a 1.5 mm-thick polystyrene plate, and a 3 mm-thick silicone rubber sheet [2,7].

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