Acoust. Sci. & Tech. **32**, 1 (2011)

ACOUSTICAL LETTER

Measurement of speed and absorption of ultrasonic waves in air at low temperatures using P(VDF/TrFE) transducers

Sadayuki Takahashi*

Faculty of Education, Arts and Science, Yamagata University, Kojirakawa-machi 1–4–12, Yamagata, 990–8560 Japan

(*Received 17 February 2010, Accepted for publication 28 June 2010*)

Keywords: Piezoelectric polymer transducer, P(VDF/TrFE), Air-coupled ultrasonic transducer, Low-temperature, Speed of sound

PACS number: 43.28.Tc, 43.38.Fx, 43.35.Lq, 43.58.Dj [doi:10.1250/ast.32.23]

1. Introduction

The acoustic impedance of piezoelectric copolymer films of vinylidene fluoride and trifluoroethylene, P(VDF/TrFE), is one order of magnitude smaller than that of piezoelectric ceramics. Therefore, P(VDF/TrFE) transducers can be used as air-coupled ultrasound transducers effectively working at high frequencies (MHz band) because they have an excellent acoustic impedance matching response with air. We have reported on the research results of ultrasonic images taken with P(VDF/TrFE) transducers in air at 2 MHz [1], and on the speed and the absorption coefficient of 10 MHz ultrasound in air, which were measured by a phase difference comparison method with 10 MHz sound in air [2]. However, such ultrasonic properties in air were measured at room temperature. We have determined the electromechanical properties of P(VDF/TrFE) in a temperature range from room temperature to 10 K. In 1990, we measured the acoustic properties of poly(methyl methacrylate) (PMMA) at low temperatures and obtained an ultrasonic image in liquid nitrogen (LN_2) couplant (77 K) using P(VDF/TrFE) ultrasonic transducers [3].

For the development of an air-coupled transducer with high sensitivity at low temperatures, it is necessary to know, in addition to the response sensitivity of the transducer itself, the temperature dependence of the speed of sound and absorption loss in air at low temperatures.

In the present study, the speed and the absorption coefficient of ultrasound in air were measured in a temperature range from room temperature to 200 K utilizing P(VDF/TrFE) transducers to examine the transducer operation performance in air at low temperatures. The experiment showed that the velocity and the absorption coefficient of ultrasound in air at low temperatures could be precisely measured using ultrasonic P(VDF/TrFE) transducers (2 MHz and 4 MHz) and an ultrasound phase difference comparison method.

2. Setup for P(VDF/TrFE) transducers in a cryostat

2.1. P(VDF/TrFE) air transducers

Two kinds of air-coupled planar P(VDF/TrFE) transducers with center frequencies at about 2 MHz (aperture diameter $\phi = 22$ mm) and 4 MHz ($\phi = 18$ mm) respectively, were fabricated. The 4 MHz P(VDF/TrFE) transducers were manufactured by a solution casting method, in which a 20 wt% P(VDF/TrFE) (75/25 mol%) solution in dimethyl formide was cast directly onto the electrode (backing layer plate). On the other hand, the 2 MHz P(VDF/TrFE) transducer was composed of three 100-μm-thick P(VDF/TrFE) films bonded together on the Cu-electrode. Figure 1 shows the structure of these P(VDF/TrFE) air transducers. The components are an evaporated Au film electrode, P(VDF/TrFE) film and Cu-electrode, from the front side, as shown in Fig. 1. The temperature dependence of insertion loss observed for a pair of 2 MHz planar transducers increased about 20 dB with decreasing temperature from 230 to 180 K, as shown in Fig. 2, probably because of the effect of a change in the stiffness constant of P(VDF/TrFE) films and the air absorption loss. The frequency at which the transducer response showed maximum sensitivity shifted toward a higher frequency with decreasing temperature, as shown in Fig. 3.

2.2. Experimental ultrasonic system in a cryostat

The speed of sound and the absorption coefficient in air were measured at low temperatures using two planar P(VDF/TrFE) transducers (one as a transmitter, and the other as a receiver) set in a cylindrical chamber (inner diameter of 60 mm within a GM-type cryostat (SRD-204, Sumitomo Heavy Industries, Ltd.)). The distance between the transducers was controlled to be in the range from 0 to about 30 mm by sliding a rod mounted on a stepping motor. The temperature of the air in the chamber was controlled within ± 0.5°C. Figures 4(a) and (b) show photographs of the cryostat and the cylindrical cell in the vacuum chamber, respectively. The setup for the measurement of the speed of sound, absorption loss, and transducer loss in air at low temperatures is illustrated in Fig. 5.

The block diagram of the measurement system controlled by a computer for the phase difference comparison method is shown in Fig. 6 [1]. This system for measuring the differential velocity (10^{-5}) of the speed of sound is highly accurate, which makes it possible to determine the phase difference of the ultrasonic waves of a MHz band. The continuous waves from the frequency synthesizer were converted to burst waves by a gate switch, and then were amplified to about 500 V_{pp} and input to the 2 MHz-P(VDF/TrFE) transducer.

3. Results

Figure 7 shows the results of the measurement of the

*e-mail: takahasi@kekexafs.kj.yamagata-u.ac.jp

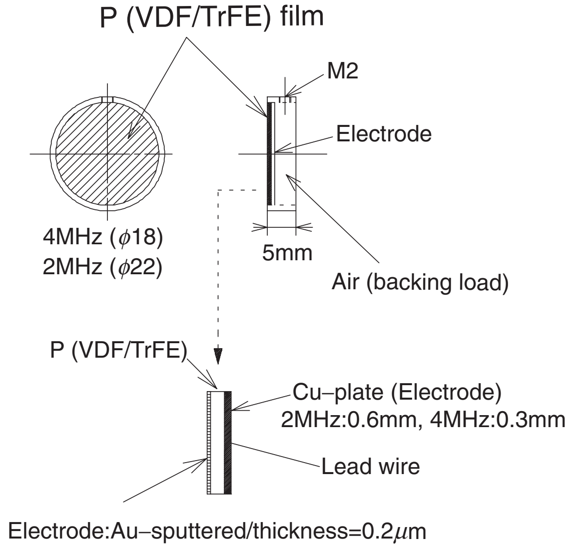

Fig. 1 Schematic configuration of air-coupled P(VDF/TrFE) transducer.

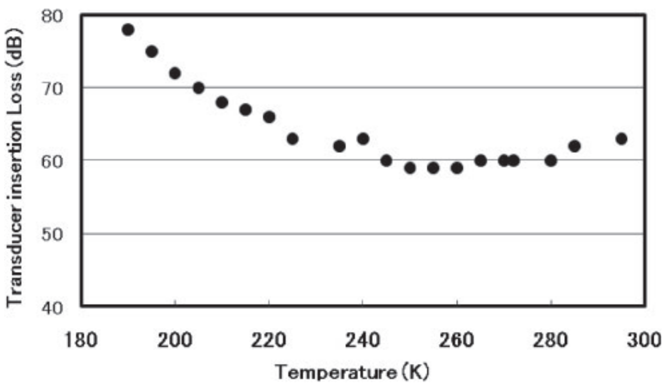

Fig. 2 Transducer insertion loss, using 2 MHz P(VDF/TrFE) transducers from 300 to 183 K (including air absorption loss. span of transducers = 15 mm).

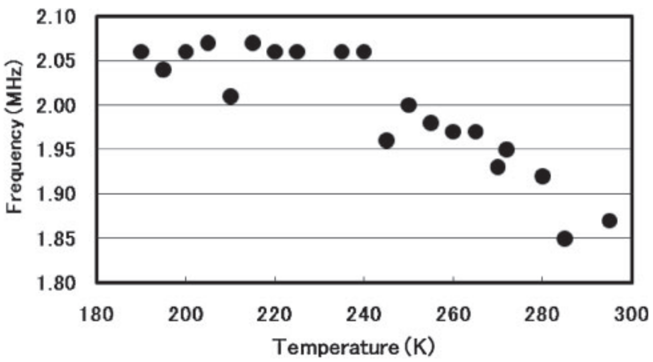

Fig. 3 Frequency of maximum efficiency of transducer response shifted to higher frequency side with decreasing temperature (observed: closed circles).

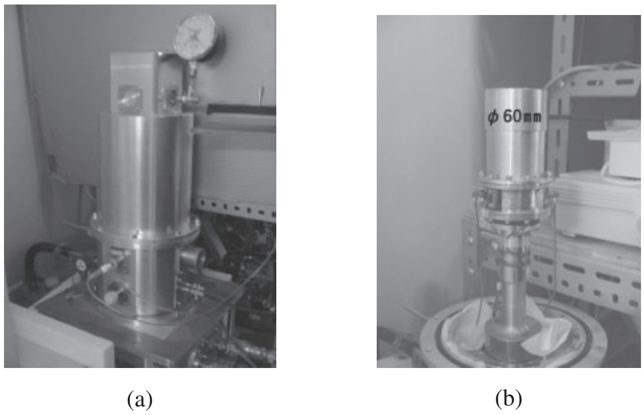

Fig. 4 Photographs of the cryostat: (a) external view and (b) cylindrical cell (two transducers holder).

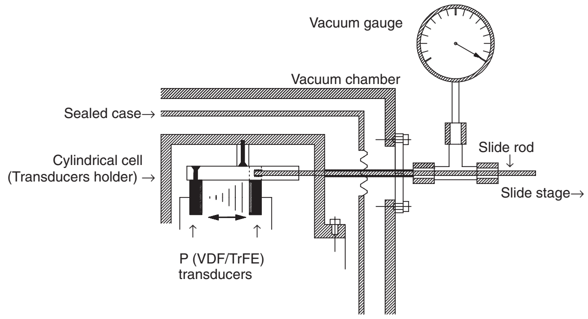

Fig. 5 Setup for measuring the speed of sound, absorption loss, and transducer loss in air at low temperatures.

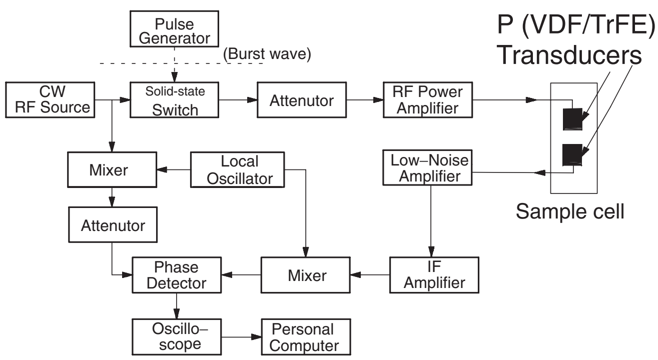

Fig. 6 Block diagram of the system for ultrasonic speed and absorption measurement by the phase difference comparison method.

speed of sound in air at low temperatures from 300 K to 180 K using the 2 MHz-P(VDF/TrFE) transducers. The results for the speed of sound in air using both the 2 MHz and 4 MHz P(VDF/TrFE) transducers in the same temperature range as shown in Fig. 7 are plotted in Fig. 8. The speed of sound in air measured using a cylindrical resonator at low temperatures has previously been reported by Younglove and Frederik (1992) [4]. In Fig. 8 the theoretical values of the speed of sound [4,5] and the values described by Younglove and Frederik are plotted.

With a pair of air-coupled P(VDF/TrFE) transmitting and receiving transducers, the absorption losses (dB/cm) of air

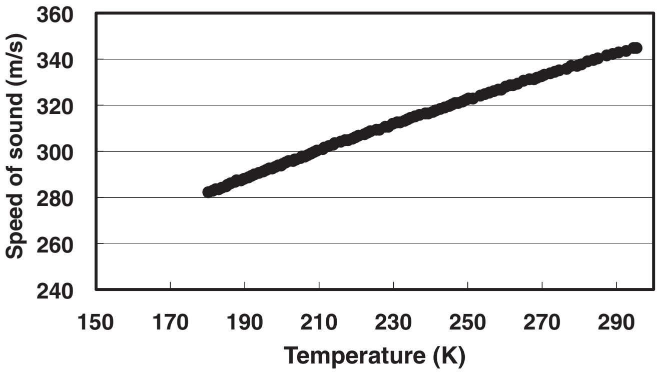

Fig. 7 Speed of sound in air measured at low temperatures from 300 to 180 K by phase difference comparison method using 2 MHz P(VDF/TrFE) transducers.

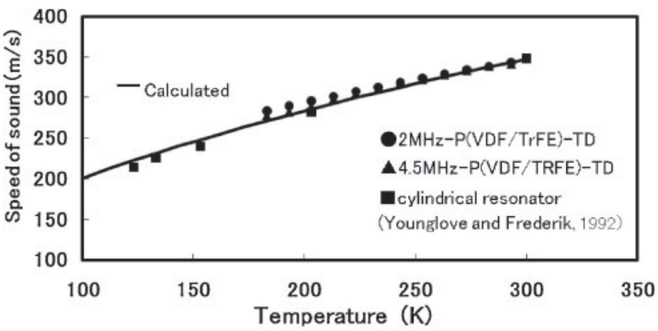

Fig. 8 Speed of sound in air measured using 2 MHz and 4 MHz P(VDF/TrFE) transducers in the same temperature range as shown in Fig. 7. The values reported by Younglove and Frederik [4] are also plotted. Line represents the theoretical value [5].

at 4.5 MHz from room temperature to 180 K are shown in Fig. 9. Although there existed some scattering in the observed values, the absorption loss can be confirmed to increase at an approximate rate of about 2.5 dB/10 K with decreasing temperature. Precise absorption measurement in the temperature below 180 K was not possible due to increased absorption loss.

4. Conclusion

The air-coupled P(VDF/TrFE) transducer with small acoustic impedance was very effective as a transducer of ultrasonic waves, as confirmed by our experimental results obtained in air at low temperatures (≈180 K). Because the absorption loss in air was greater than the efficiency of the P(VDF/TrFE) transducers at 180 K or less, as shown in Fig. 9, it was impossible to measure the speed of sound and the absorption loss in air. However, it considered that the

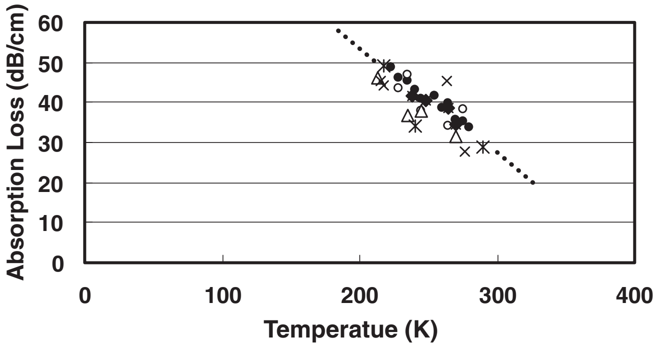

Fig. 9 Temperature dependence of absorption loss of ultrasound in air measured at 4.5 MHz using 4 MHz P(VDF/TrFE) transducers.

measurement of the speed of sound and the absorption loss in air at 180 K will be facilitated by improving the transducer insertion loss of the P(VDF/TrFE) transducer [6]. This air-coupled P(VDF/TrFE) transducer was not damaged at 100 K in the cylindrical cell. Ultrasonic images at 160 MHz were previously obtained using a P(VDF/TrFE) transducer at 77 K (LN_2) [3]. The piezoelectric polymer P(VDF/TrFE) is effective as an ultrasonic transducer and has flexibility at low temperatures.

Acknowledgments

The author is grateful to the members of the Device Group at Toray Engineering Co., Ltd., for their valuable advice on manufacturing the transducers and to Mr. T. Morita of Sumitomo Heavy Industrial, Ltd., for his advice on improving the cryostat for setting up the transducers. The author is greatly indebted to Dr. H. Ohigashi of Ideal Star Co., Ltd., for his valuable advice on this work.

References

[1] S. Takahashi and H. Ohigashi, "Ultrasonic imaging using air-coupled P(VDF/TrFE) transducers at 2 MHz," *Ultrasonics*, **49**, 495–498 (2009).
[2] S. Takahashi, "On the measurement of the coefficient of absorptivity in air at MHz band using P(VDF/TrFE) transducers," *Proc. Autumn Meet. Acoust. Soc. Jpn.*, pp. 1373–1374 (2008).
[3] H. Ohigashi, S. Takahashi, Y. Tasaki and G. R. Li, "Piezoelectric polymers of ferroelectric polymers at low temperatures," *Proc. Ultrason. Symp.*, pp. 753–756 (1990).
[4] B. A. Younglove and N. V. Frederik, "Speed-of-sound measurement in liquid and gaseous air," *Int. J. Thermophys.*, **13**, 1033–1041 (1992).
[5] http://www.sengpielaudio.com/calculator-speedsound.htm (accessed April 7th, 2009).
[6] S. Takahashi, "Effect and characterization on the adhesive on P(VDF/TrFE) transducer," *Proc. Spring Meet. Acoust. Soc. Jpn.*, pp. 1373–1374 (2010).