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Analysis of the Effect of Non-piezoelectric Bonding Layer between Electrodes on PVDF Transducer Performance

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1. Introduction

In order to make a high frequency ultrasound transducer operated in quarter-wave (λ/4) mode, a one side metalized piezoelectric polymer PVDF (polyvinylidene fluoride) film is occasionally adhered to a metal by using an adhesive material, such as an epoxy[1]. In this case, the metal acts another electrode as well as a heavy backer. However, a nontrivial non-piezoelectric bonding layer exists between two electrodes and it affects the transducer performance[2,3]. In this study, to analyze the effects of the layer on pulse echo responses, the waveforms and insertion losses were simulated by using an equivalent circuit model and the results were compared to those of measurement for the PVDF transducers with different thicknesses of the bonding layer.

2. Equivalent Circuit Analysis

Several equivalent circuit models are well known for analysis of the performance of ultrasound transducers[4]. The KLM model[5] is most widely used for a high frequency wideband ultrasound transducer working in thickness mode. It is a three-port transmission line model with the electric port at the middle of a piezoelectric layer of which both two sides are metalized for electrodes. So, to analyze the performance of the transducer having any non-piezoelectric layers between the two electrodes, the model should be modified. However, the modification is not easy.

Another transmission line model suggested by Kikuchi et al.[6] is especially useful for the transducer with multiple piezoelctric layers between electrodes. It could be readily applied to any combination of piezoelectric and non-piezoelectric layers if their piezoelectric constants *h's* are set adequately. By the Kikuchi model, the transducer having a non-piezoelectric layer between the two electrodes as shown in Fig. 1 is depicted as Fig. 2 by set $h=0$ for the non-piezoelectric bonding layer. It is the same circuit as a transducer without any non-piezoelectric layer between electrodes except the driving input voltage V given by eq. (1) is divided by V_1 and V_2, respectively.

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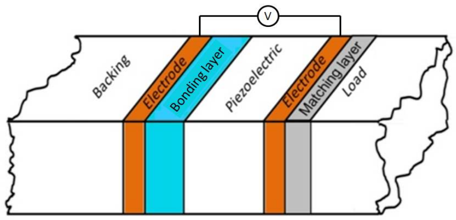

Fig. 1 Structure of the transducer with a non-piezoelectric bonding layer between electrodes.

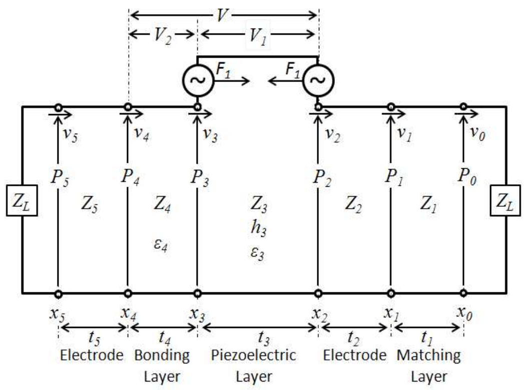

Fig. 2 Kikuchi model for the transducer.

$$V = V_1 + V_2 = \frac{1}{C_3} + \frac{1}{C_4} \div \frac{F_1}{h_3} \div \frac{h_3}{j}(v_3 \quad v_2), \quad (1)$$

where C_3 and C_4 are the capacitances of each layer, h_3 is for the PVDF, F_1 is the force on the surface of piezoelectric layer, and v_2, v_3 are the particle velocities on each boundary, respectively. The equation reveals that the two layers between electrodes are considered as a parallel connection of two capacitors.

Using the physical parameters shown in Table 1, the simulated results of pulse echo waveforms and insertion losses of the transducers with different thickness ratio of bonding layer (t_4) to the PVDF (t_3) are shown in Fig. 3(a) and (b), respectively. In Fig. 3(a), the peak amplitude of the pulse is decreased and vise versa the duration time of it is increased with increase of the ratio t_4/t_3=0~0.4. When t_4/t_3 is about 0.4, the waveform is a little bit distorted. Fig. 3 (b) shows that with the increase of t_4/t_3, the -6 dB center frequency decreases from 6.5 MHz to 4.8 MHz and the insertion loss increases from about 15.5 dB to 23.4 dB.

Table 1. Physical parameters of transducer elements

Elements	Material	Parameters	
Piezoelectric polymer	PVDF	Longitudinal velocity v_l	2110 m/s
		Density ρ	1800 kg/m^3
		Piezoelectric constant h	0.268
		Dielectric constant $\varepsilon^S/\varepsilon_0$	8.0
		Loss	0.3 Np/mm/MHz
Bonding layer	EPO-TEK 301	Longitudinal velocity v_l	2650 m/s
		Density ρ	1150 kg/m^3
		Loss	0.3 Np/mm/MHz
		Dielectric constant $\varepsilon^S/\varepsilon_0$	4.0
Backing	Cu	Acoustic impedance Z	41.6 MRayl

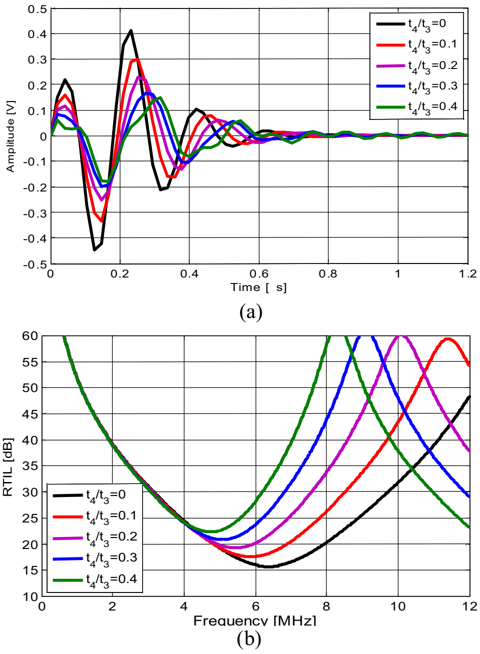

Fig. 3 Simulation waveforms (a) and insertion losses (b) of the transducers with different thickness ratio of bonding layer to the PVDF.

3. Measurement and Discussion

A one-side metalized 80 μm PVDF film and a Cu backing block were bonded together with EPO-TEK 301 epoxy (Epoxy Technology, Inc.) using a press-fit jig. A hydraulic press (SSP-10A, Shimadzu) was used to apply pressure on the press-fit jig. By changing the pressure, transducers with difference thickness of bonding layer were obtained. Pulse–echo responses were measured by a pulse/ receiver equipment (MKCNDT XTR- 2020, MKC Korea) in a water chamber with a fused quartz target.

For transducers with 10, 13, 20 μm bonding layer thicknesses, measured by an optical microscope, the ratio t_4/t_3 are 0.12, 0.16 and 0.25. Fig. 4 shows the measured waveforms and insertion losses of these transducers. As shown in Fig. 4 (b), the -6 dB center frequencies decreased from 6.1 MHz to 5.6 MHz. And the insertion losses increased from 16.5 dB to 21.0 dB. It was shown

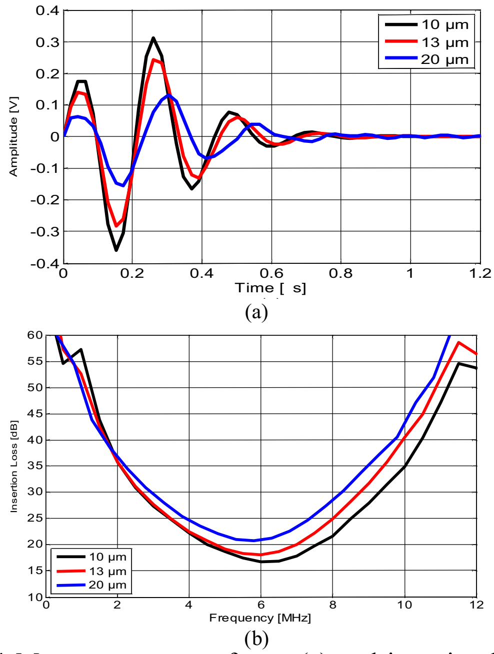

Fig. 4 Measurement waveforms (a) and insertion losses (b) of the transducers with different thickness of the bonding layer.

that the variations of the measured waveforms and insertion losses with bonding layer thickness are relatively well corresponded to the simulation results. It consists that the Kikuchi model is a unique equivalent circuit for this simulation.

4. Summary

In this paper, the waveforms and the insertion losses of PVDF transducers with different thickness of non-piezoelectric bonding layers between electrodes were simulated by the Kikuchi transmission line model and measured by a pulse-receiver equipment. Both simulated and measured results show that the increase of bonding layer thickness makes the waveform amplitude and center frequency decrease and the insertion loss increase. The results consist that the Kikuchi model is a unique equivalent circuit model for the simulation.

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