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Equivalent Circuit Analysis of Efficiency Improvement in Multilayered Polyurea Ultrasonic Transducers

等価回路解析による多層ポリ尿素膜超音波トランスデューサの効率改善

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1. Introduction

The authors have developed applications of polyurea piezoelectric thin film, such as ultrasonic transducers[1)], three axis acceleration sensor[2)], multi-layered ultrasonic transducer[3)], variable line focus transducer for acoustic wave velocity measurement[4,5)]. In ref. 3, the authors designed multi-layered polyurea ultrasonic transducers by using transfer matrix formalism described in ref 6. However, backing material and loaded material (e.g. water) have not been considered in the design. Moreover, designed resonant frequencies did not agree with experiments due to improper material constant. In this paper, we calculated the multilayered polyurea transducer with consideration of backing material and loaded material by using the equivalent circuit method. We designed the multilayered polyurea ultrasonic transducer to improve the efficiency for water-loaded configuration.

2. Calculation method

In this paper, we used the equivalent circuit analysis with transfer matrix formalism[6)] for electrically parallel connected multilayer piezoelectric transducer. In ref. 3, boundary conditions for backing and load of the transducer are not taken into account. In this paper, we introduced acoustic impedance of load and backing to calculate effects of these materials. Basic formulation is shown as follows.

$$\begin{pmatrix} F_N^+ \\ U_N^+ \\ -V_N \\ \{I_N^+\} \end{pmatrix} = T_{\{N\}} \begin{pmatrix} F_1^- \\ -U_1^- \\ V_1 \\ 0 \end{pmatrix} \quad (1)$$

$$F_N^+ = -Z_{load} U_N^+ \quad (2)$$

$$F_1^- = -Z_{backing} U_1^- \quad (3)$$

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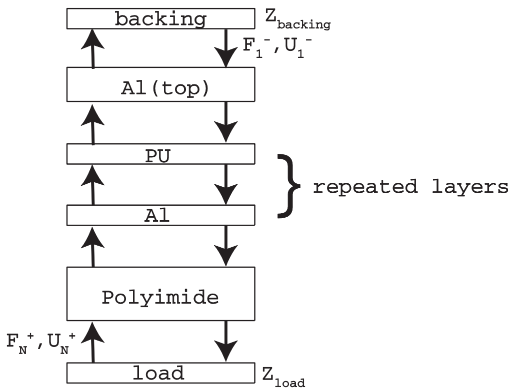

Figure 1 Geometry of polyurea multilayered transducer.

where $T_{\{N\}}$ is total multilayered transducer 4×4 transfer matrix defined in refs. 3 and 6, F_N^+ and U_N^+ are force and particle velocity of load side of the transducer, F_1^- and U_1^- are these of backing side, V_1 and V_N are input and output voltage, $\{I_N\}$ is total output current, Z_{load} and $Z_{backing}$ are acoustic impedance of the load (e.g. water) and backing (e.g. air), respectively. When the transducer is used as transmitter, we give V_1 as input voltage. The rest of the values $\{F_N^+, U_N^+, F_1^-, U_1^-, V_N, \{I_N\}\}$ can be determined by solving (1)-(3) as the six elements coalition linear equation.

Table I shows the measured resonance frequencies of the multilayered transducer in free space designed in ref. 3, and calculated resonance frequencies by using above method. Thicknesses of each layer of the transducer are $d_{Altop} = 5\ \mu$m, $d_{Al} = 0.125\ \mu$m, $d_{PU} = 1.5\ \mu$m, and $d_{PI} = 25\ \mu$m, respectively. Material constants are as listed in ref. 3 except polyimide. Resonance frequencies of the first, second, and third for one, two, and four polyurea layers transducers are listed. As shown in the Table I, measurement and calculated frequencies agree well. In ref. 3, designed and measured resonant frequencies did not agree well. Although acoustic velocity of polyimide base layer was not indicated in ref. 3, it might be improper value. In this report, we used longitudinal wave velocity of polyimide as 2250 m/s.

Table I Resonant frequencies in the measurements and calculations.

Layers	f_{r1} [MHz]	f_{r2} [MHz]	f_{r3} [MHz]
1 (meas.)	32.1	68.9	108.8
1 (calc.)	32.5	69.8	109.8
2 (meas.)	30.5	66.3	103.9
2 (calc.)	30.8	66.2	103.6
4 (meas.)	28.0	60.5	94.4
4 (calc.)	28.1	59.9	92.7

3. Multilayered polyurea transducer design for water-loaded conditions

Fig. 2 shows the calculated output sound pressures at the water-loaded surface of the multilayered transducers designed in ref. 3. Inputted voltage V_1 is 1V. The one, two, and four layers transducers are shown. As shown in the figure, maximum value of sound pressure is about 50 kPa for each transducer. However, the maximum resonant frequency of each transducer is not clear. For the transducers in ref. 3, thickness of the inner aluminum electrode is 0.125 μ m, thus the resonant frequencies do not go down sufficiently.

To obtain efficient sound pressure for low frequencies, we changed the design for multilayered transducer. For the newly designed transducer, d_{Altop} = 3 μ m, d_{Al} = 3 μ m, d_{PU} = 1 μ m, and d_{PI} = 25 μ m, respectively. **Fig. 3** shows the calculated sound pressure of the newly designed multilayered transducers. As shown in the figure, maximum output sound pressure reach 100 kPa for each multilayered transducers. Maximum sound pressure frequencies are obtained clearly at 185, 133, 83 MHz for 1, 2, and 4 layers transducer, respectively. **Table II** summarizes the resonance frequency f_s, (where maximum conductance is obtained) for newly designed transducers. The third, fourth, or fifth resonance show the maximum outputs for each transducer.

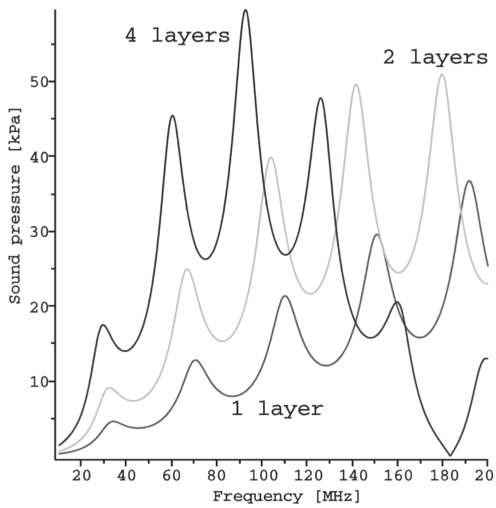

Figure 2 Calculated output sound pressure for previous designed multilayered transducer with water loaded.

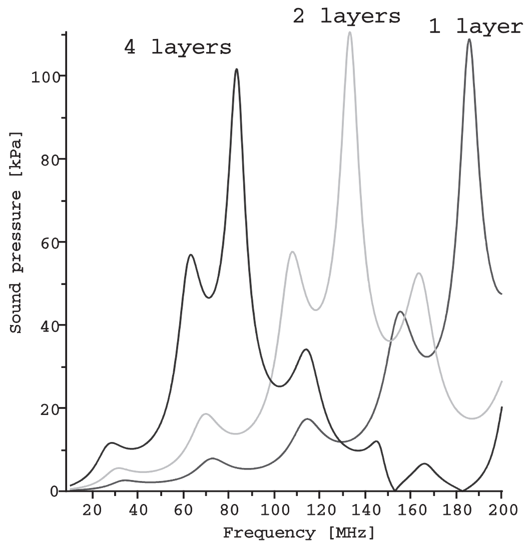

Figure 3 Calculated output sound pressure for newly designed multilayered transducer with water loaded.

Table II Calculated resonance frequencies for newly designed multilayered transducer with water loaded.

Layers/f_s [MHz]	f_{s1}	f_{s2}	f_{s3}	f_{s4}	f_{s5}
1	34.4	72.9	115	155	186
2	31.6	69.8	108	133	163
4	28.5	63.1	83.3	114	145

4. Conclusion

In this report, we carried out the equivalent circuit analysis for multilayered transducer including backing and load effects. The calculated resonance frequencies showed good agreement with previous measurement values. Improved multilayered transducers exhibit good characteristics for output sound pressure when water loaded. Fabrication for designed transducers and measurements are left for further study.

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