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초음파 트랜스듀서에서의 cross talk 분석 및 방지 방안

노용래*, 김영신*, 이수성**

*경북대학교 기계공학부
**경북대학교 센서공학과

Analysis and Reduction of the Cross Talk in Ultrasonic Transducers

Yong-Rae Roh*, Young-shin Kim* and Su-Sung Lee**

*School of Mechanical Engineering, Kyungpook National University
**Department of Sensor Engineering, Kyungpook National University

*yryong@knu.ac.kr, *straiper@usound.knu.ac.kr, **susung@usound.knu.ac.kr

Abstract

Finite element models are constructed using the commercial code ANSYS for two most representative types of ultrasonic transducers, cMUTs and piezoelectric transducers. Calculation result shows the origin and level of cross talk between array elements in each transducer type. For reduction of the cross talk level, the effects of various structural variations are investigated for each transducer type. The results say that proper design of the coupling isolation structures between the transducing elements can significantly reduce the cross talk in ultrasonic transducers.

I. Introduction

In this paper, two dimensional finite element models of ultrasonic transducers are constructed using the commercial code ANSYS for multi-dimensional analysis of the cross talk mechanism. The transducers under consideration are the two most representative types, cMUTs (capacitive micromachined ultrasonic transducers) and piezoelectric transducers. Both are linear array immersion transducers. Through various analyses with the models, we investigate the origin and level of the cross talk between array elements, with evidence of coupling through Stoneley waves at the transducer-water interface and coupling through Lamb waves in the wafer or the acoustic lens. Further, the effects of various structural variations of the transducers are investigated to reduce the cross talk level. For cMUTs, the structural variations include change of the wafer thickness and placement of etched trenches in the wafer to prevent the cross coupling through Lamb waves, as well as placement of acoustic walls between elements to prevent the cross coupling through Stoneley waves. For piezoelectric transducers, the structural variations include change of kerf dimensions and materials that is placed between piezoelectric array elements.

II. Finite Element Analysis of cMUTs

As a first, a single cMUT transducer is modeled with the ANSYS. Figure 1 is the schematic view of the configuration. There are one cMUT transmitter and two cMUT receivers at the surface of a silicon wafer. Geometry of the three cMUTs is the same. Each cMUT consists of a Si_3N_4 membrane of 0.8 ㎜ thickness and 35 ㎜ diameter and a vacuum gap of 0.15 ㎜ depth in the wafer. The transmitter cMUT is excited by a surface pressure distributed over only half of its membrane surface, and the cross talk pressure and displacement is measured in response to the excitation at various points denoted R on the silicon surface. The theoretical complex impedance (dotted line) of a circular piston on an infinite baffle is also calculated and is compared with the numerical data [1]. In the result, Fig. 2-(a), the good agreement between numerical and theoretical data verifies validity of the *finite element model*, and proves that there is a direct relationship between the excitation pressure and the excited displacement. On the other hand, in Fig. 2-(b), the numerical impedance of the receiver cMUT does not show any agreement with the theoretical value, which means that the cross talk pressure has no cause-and-effect relationship with the cross talk displacement. This result indicates that the cross talk pressure and the displacement at the receiver cMUT are not coupled with each other, and each field has its own means of energy transport. According to the temporal analysis results, the pressure field propagates from the transmitter cMUT to the receiver cMUTs at the speed of the sound velocity in water (1,480 m/s). This result and our experimental results reported earlier [2] show that the Stoneley wave along the transducer -water interface is responsible for the cross talk pressure. Similarly, the propagation speed of the displacement field (3,660 m/s) and our experimental results prove that the Lamb wave propagating in the Si wafer is responsible for the cross talk membrane displacement.

A finite element model is constructed also for an underwater cMUT array transducer. Figure 3 is the schematic diagram of the array transducer. The load impedance of the transmitter array is calculated and compared with the theoretical radiation impedance of a circular piston of the same radius on an infinite baffle. The array transducer has much bigger radius than the single cMUT. Hence, the real part of the impedance is more dominant, which means that the array element transducer behaves more like a plane piston than the single cell cMUT. The finite element model also allows us to analyze the transient and harmonic responses of the array transducer.

III. Cross Talk Control Structures for cMUTs

Several structural schemes are investigated to reduce the cross talk level in cMUTs; change in the thickness of the silicon wafer, an etched trench between the array elements, and a wall of a polymer between the array elements. In Fig. 4, the cross talk level increases with the thickness of the wafer, although the effect is not very strong. According to this result, a thinner wafer is more desirable for cross talk reduction. In Fig. 5-(a), the influence of the trench increases as the trench gets deeper and wider. Inside the trench is vacuum. Of the two dimensional parameters, depth and width, the width turns out to be more influential in reducing the cross talk. For further reduction of the cross talk, the trench is filled with polyurethane. In Fig. 5-(b), the Rayleigh damping coefficient (ζ) of the filler is arbitrarily increased by ten times to see the effects of the damping material, where $\zeta=0$ corresponds to vacuum, $\zeta=1$ corresponds to poly-urethane, and $\zeta=10$ corresponds to a material having the ζ ten times larger than that of polyurethane. In Fig. 5-(b), filling the trench increases the cross talk level, and thus is not beneficial at all. On the other hand, filling the vacuum gap allows more stable propagation of the wave, which results in the increase of the cross talk level. Figure 6-(a) shows the effects of the wall dimensions. The wall is made of poly-urethane. The cross talk level decreases as the wall becomes higher and wider. Of the two dimensional parameters of the wall, the height turns out to be more influential. In Fig. 6-(b), increasing the damping properties of the wall does not change the cross talk level, either.

IV. Finite Element Analysis of a Piezoelectric Linear Array Transducer

Figure 7 is the schematic view of the structure of the immersion transducer under consideration. The transducer operates at 2.5 MHz. Results of complex load impedance analysis also show the direct relationship between the excitation pressure and the excited displacement for the transmitting PZT array as before, while not for the receiving PZT array. This result again confirms the coupling through Stoneley and Lamb waves for cross talk pressure and displacement, respectively. Figure 8 shows the effects of the kerf depth. In Fig. 8-(a), the kerf depth is increased from the thickness of the PZT to the thickness of the PZT and the first matching layer (M1) added, and to the thickness of PZT and the two matching layers (M1+M2) added. Above the PZT element, having the kerf etched up to the second matching layer turns out not good because it can cause the remaining acoustic lens to vibrate more freely. On the other hand, having the kerf deep into the backing material does not help at all as shown in Fig. 8-(b). In Fig. 9, larger width of the kerf is helpful in reducing the cross talk. To check the effects of damping materials inside, the kerf is filled with polyurethane and epoxy-resin. The epoxy-resin has the acoustic impedance of 3.0

Mrayl, the Young's modulus of 7.2 GPa, the Rayleigh damping coefficient of 31×10^{-9} while polyurethane has 1.6 Mrayl, 2.4 Gpa, and 53×10^{-9}, respectively. The results say that the damping properties of the filler do not help in reducing the cross talk. Instead, when the kerf is deep, i.e. when the kerf is etched up to the second matching layer, the filler prevents the free vibration of the acoustic lens.

V. Conclusion

The results in this paper say that proper design of the coupling isolation structures between array elements can significantly reduce the cross talk level in ultrasonic transducers. Detailed optimal design of the cross talk control structures can be made by considering overall time domain and frequency domain performance of the transducers.

References

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[2] X. C. Jin, F. L. Degeretekin, S. Calmes, X J. Zhang, I. Ladabaum, and B. T. Khuri-Yakub, Proc. of IEEE Ultra. Sym., 1998, p. 1877

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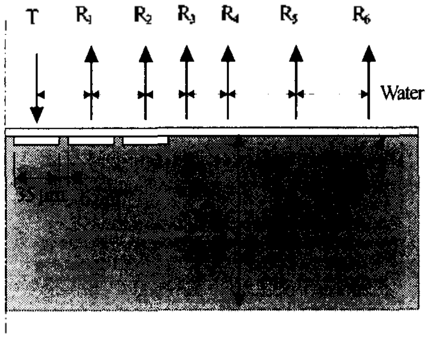


Fig. 1. Schematic view of an underwater single cMUT.

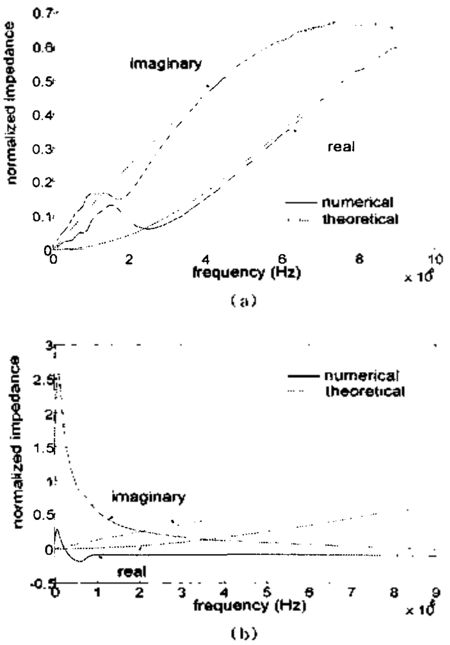


Fig. 2. Radiation impedance; (a) transmitter, and (b) receiver (R1).

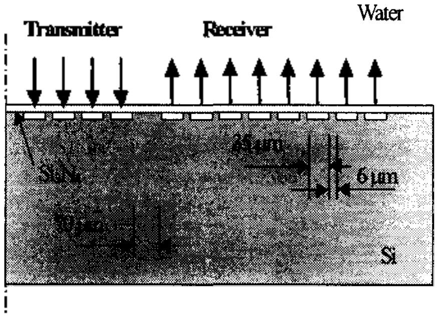


Fig. 3. Schematic view of an underwater cMUT array transducer.

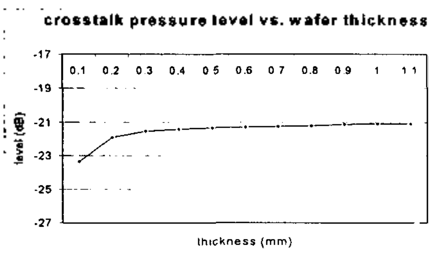
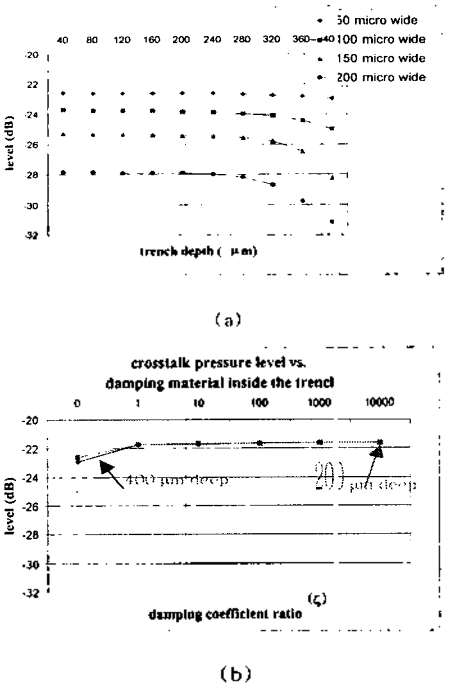


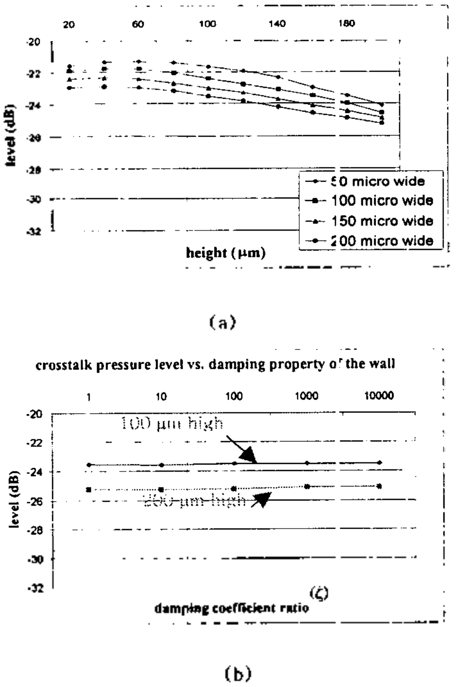
Fig. 4. Variation of the cross talk level in the cMUT in relation to the wafer thickness.



(a)

(b)

Fig. 5. Cross talk level vs. trench dimension and material; (a) pressure level vs. depth and width, (b) pressue level vs. ζ of the filler.



(a)

(b)

Fig. 6. Cross talk level vs. wall dimension and material; (a) pressure level vs. depth and width, (b) pressue level vs. ζ of the filler.

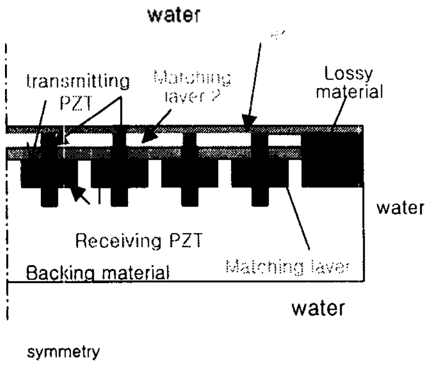
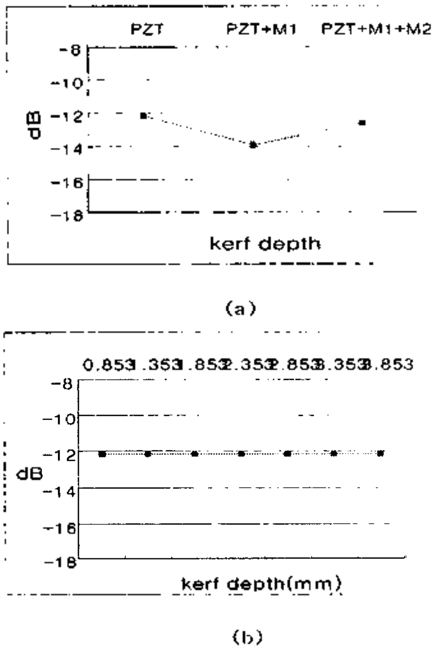


Fig. 7. Schematic view of a piezoelectric linear array transducer.



(a)

(b)

Fig. 8. Cross talk level vs. kerf depth; (a) kerf above the PZT, (b) kerf below the PZT.

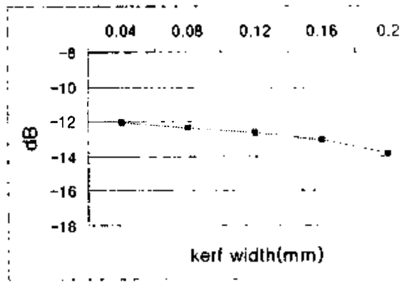


Fig. 9. Variation of the cross talk level in the piezo transducer in relation to the kerf width.