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Effect of acoustic properties of lens materials on the performance of capacitive micromachined ultrasonic transducers

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1. Introduction

Ultrasound transducers based on piezoelectric materials have been mainly used for medical ultrasound imaging[1,2]. Although the design and the fabrication process of the transducers are well established, their imaging performance is limited due to difficulty in finding optimal materials for matching and backing layers and precise fabrication of array elements. A capacitive micromachined ultrasonic transducer (cMUT) is known as an alternative method to surpass the limitations of the piezoelectric ultrasound transducers. This is so because cMUT is capable of generating broadband ultrasound signals without matching and backing layers and it is relatively easily constructed using MEMS technologies. For this reason, cMUT have been in the spotlight and intensively researched to seek optimal membrane structure and electrical driving conditions[3]. However, there is not enough investigation on the effect of acoustic lens materials on the imaging performance of cMUT. Acoustic lens in cMUT is responsible for not only elevation focusing but also insulation from a high DC bias voltage. The selection of a lens material is crucial to achieve the full performance of cMUT. Through FEM (finite element method) simulation, therefore, we ascertain how the acoustic properties of lens materials affect signal strength, center frequency, and spectral bandwidth of cMUT.

2. Materials and Methods

A FEM simulator, i.e., PZFlex (Weidlinger Associates Inc., Mountain view, CA) was used in this study. RTV, PDMS and Urethane are general acoustic lens materials for cMUT[4-6]. Among them, the acoustic properties of RTV (see **Table I**) were utilized as a standard lens material. The effect of acoustic impedance on the cMUT performance was investigated with the different acoustic impedance of 1.082 (A), 1.322 (B), and 1.591 MRayls (C) while other properties remained unchanged. For the ultrasound attenuation in a lens material, the different values of 2.31 (A), 4.08 (B), and 25dB/cm/MHz (C) were used. Also, the shear velocity of a lens material was changed to 125 (A), 200 (B), or 500 m/s (C). Furthermore, the effect of

	RTV
Density (kg/m³)	1294
V_{long} (m/s)	1022
Z_{acc} (MRayls)	1.322
ATTEN (dB/cm/MHz)	4.08
V_{shear} (m/s)	125

Table I. Acoustic properties of RTV as a standard in the PZFlex simulation

Performance	P_{p-p} (Pa)	Fc (MHz)	BW (MHz)	(%)
Z_{acc} (A)	8.04	4.08	4.64	114%
Z_{acc} (B)	7.32	3.95	4.39	111%
Z_{acc} (C)	7.64	3.87	4.47	115%
ATTEN (A)	8.05	4.11	4.71	115%
ATTEN (B)	4.70	3.34	3.34	100%
ATTEN (C)	2.60	2.78	2.47	89%
V_{shear} (A, I)	7.32	3.95	4.39	111%
V_{shear} (B, I)	7.21	4.32	4.06	94%
V_{shear} (B, II)	17.30	4.00	3.99	100%
V_{shear} (C, I)	3.59	5.69	5.62	99%
V_{shear} (C, III)	13.33	5.61	5.50	98%

Table II. FEM simulation results

DC bias voltage was examined: 31 (I), 62 (II), and 93 V (III). Note that DC bias voltage causes deforming the membranes in cMUT so that ultrasound can be effectively generated by AC pulse signals.

For the simulation, cMUT was modeled to have a membrane diameter of 44 ㎛, a membrane support of 5.5 ㎛, a membrane thickness of 1 ㎛, a gap height of 0.24 ㎛, a substrate thickness of 50 ㎛, and a ground thickness of 0.3 ㎛. Also, the substrate and membrane of the cMUT were made from silicon and the ground and membrane support were silicon dioxide (SiO2). It was assumed that the cMUT was immersed into water and the distance between the cMUT and a reflector was 2 cm. At a given DC bias voltage, the AC pulse of a 5-MHz sine wave with 5 V was applied to the cMUT model. For performance evaluation, the center frequency, the spectral bandwidth, and the magnitude of

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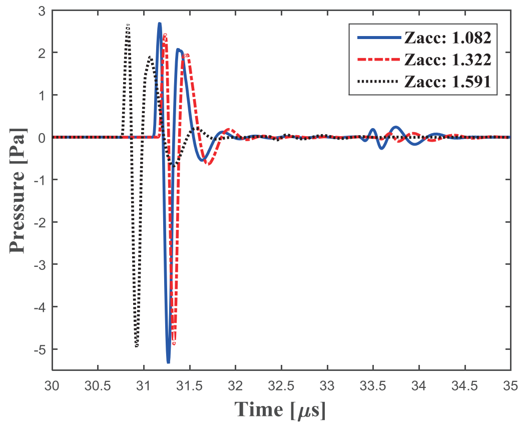

Fig. 1 Pulse echo responses obtained with the different acoustic impedance of a lens material

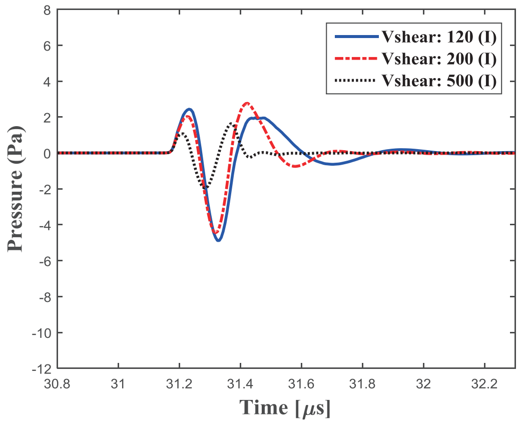

Fig. 2 Pulse echo responses obtained with the different shear velocity at a DC bias of 31 V.

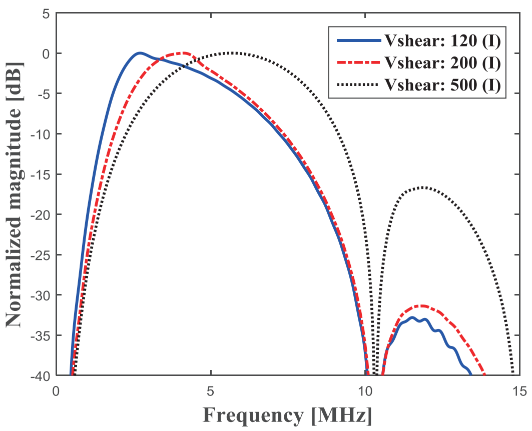

Fig. 3 Spectra of the pulse responses in Fig. 2.

ultrasound were examined in the each case. The evaluation metrics were chosen because these are directly related to spatial and contrast resolutions of ultrasound images as well as a signal-to-noise ratio.

4. Results and Conclusion

The simulation results are summarized in **Table II**. Acoustic impedance did not much affect the center frequency, the spectral bandwidth, and the magnitude of ultrasound (see **Fig. 1**). However, acoustic impedance mismatching between the lens material and the water led to producing the echo signal from their boundary. When ultrasound travels through a medium, it experiences the frequency dependent attenuation, which causes a downshift of the center frequency and reducing the bandwidth as well as decreasing the signal strength[7]. This is so because the higher frequency energy decreases more. The phenomena were also observed in the simulation as shown in **Table II**. In the case of the lens material with a shear velocity of 120 m/s, the DC bias voltage higher than 60 V resulted in membrane collapse. When the shear velocity was increased, higher DC bias voltage could be applied. Since shear velocity is proportional to shear modulus, a material with a low shear velocity is easily deformed. As shown in **Fig. 2**, therefore, cMUT with the material produced ultrasound with higher amplitude than that with higher shear velocity material. However, the lateral vibration in the low shear velocity material led to increasing low frequency energy, thus downshifting the center frequency and reducing the bandwidth. At a given shear velocity, the increase in DC bias voltage caused increasing the signal strength (see **Table II**).

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