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DEVELOPMENT OF CAPACITIVE TYPE MEMS MICROPHONE WITH SIMULLATION AND ELECTRO-MECHANICAL CHARACTERIZATION

Youngdo Jung/Presenter, Young Hwa Lee, Junhyuk Kwak, and Shin Hur

Korea Institute of Machinery and Materials, Daejeon, SOUTH KOREA, yjung@kimm.re.kr

Abstract: Capacitive type MEMS microphone was designed, fabricated and characterized. Finite element model was used in the design process of the MEMS microphone and the fabrication was carried out using MEMS fabrication process including low stress silicon nitride membrane deposition and eutectic bonding process. The simulation results show that the designed MEMS microphone has the resonant frequency above the operation frequency range and the sensitivity of 9.1 mV/Pa (@18V). The experimental results show that the MEMS microphone has 3 dB cut-off frequency of 144 kHz.

Keywords: MEMS, microphone, capacitive, finite element model.

1. INTRODUCTION

Microphone is a device that converts acoustic signal into electrical signal. MEMS microphones has replaced the electrets-type microphone rapidly these days in consumer electronics such as smart phone for their advantages as high reliability, miniaturization, and compatibility to surface mount process on printed circuit board [1,2]. Various types of MEMS microphones have been developed including CMOS integrated capacitive type microphone [3] and piezoelectric type [4]. In our work, we designed the capacitive type MEMS microphone with various design parameters. Also, our MEMS microphones have thick backplate to limit the noise from the vibration of backplate, thus improving overall performance considering effects.

2. SIMULATION

For the MEMS microphone to function properly within the operation frequency range, the resonance frequency of membrane should be placed outside the operating frequency range (above 20 kHz). Finite element model (COMSOL Multiphysics) was used to simulate the resonance frequency of low stress silicon nitride membrane for the MEMS microphone. Various design parameters of MEMS microphone were considered for the simulation such as membrane diameter, residual stress of membrane, air gap between membrane and back plate (Table. 1). The simulation results show that in all cases we considered, the resonance frequency is over 20 kHz. Another simulation was carried out to estimate the sensitivity of MEMS microphone by calculating the membrane displacement by bias voltage between membrane and backplate and pressure applied on the membrane (Fig. 1 ~ 2) using electrostatic and structural coupling. The simulation results show that the sensitivity of designed microphone is 9.1 mV/Pa (membrane diameter: 2000 μm, residual stress: 400 MPa, bias voltage: 18 V, air gap: 1.5 μm).

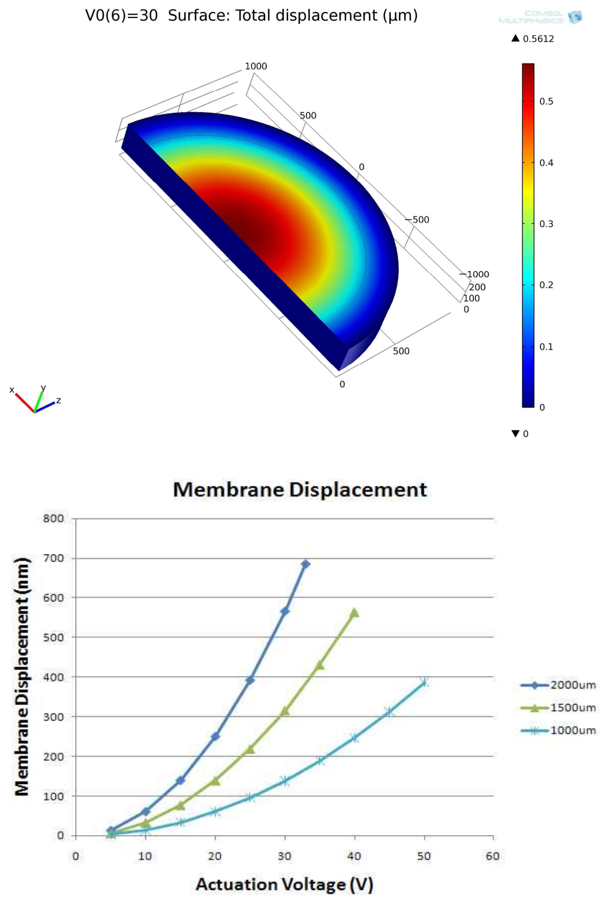

__Figure 1:__ Membrane displacement by applied DC voltage using finite element modeling

Table 1. Resonant frequency of MEMS microphone with various design parameters

Membrane Diameter, ㎛	2,000		1,500		1,000	
Membrane Thickness, ㎛	1.0	0.5	1.0	0.5	1.0	0.5
Residual Stress 100 MPa	70.34	69.98	94.58	93.94	144.3	142.8
Residual Stress 200 MPa	99.14	98.86	133.1	132.6	202.6	201.4
Residual Stress 300 MPa	121.3	121	162.8	162.4	247.4	246.4
Residual Stress 400 MPa	139.9	139.7	187.8	187.4	285.3	284.4

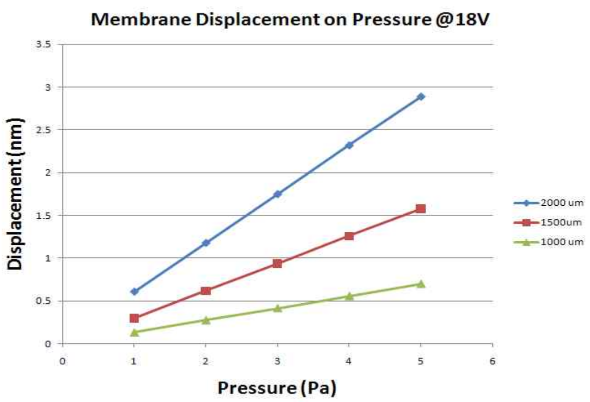

Figure 2: *Membrane displacement by applied pressure using finite element modeling.*

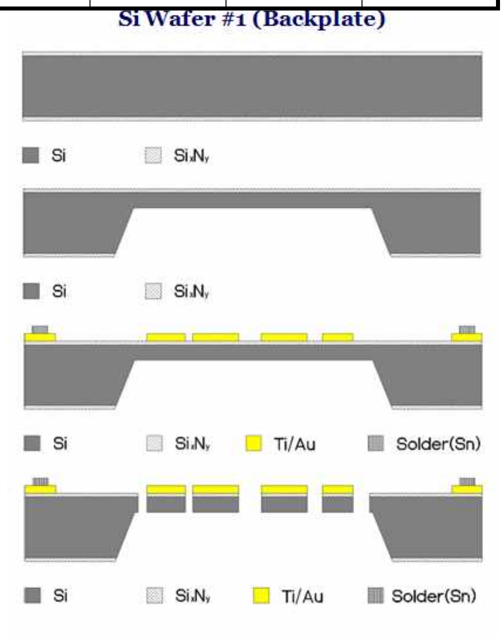

Figure 4: *Fabrication process of backplate wafer*

3. FABRICATION

The fabrication process of MEMS microphone starts with anisotropic Si wet etching to make a 250 µm-thick backplate and deep reactive ion etching of Si wafer to create air holes in the back plate respectively in Si wafer #1. Ti/Au layers are evaporated on the backplate to create one side of round-shaped capacitor. Si wafer #2 has a 1 µm-thick low stress silicon nitride membrane released by deep reactive ion etching and has counter side of Ti/Au capacitor on top of the membrane. Finally, both Si wafers were bonded through a Sn/Au eutectic bonding process (Fig. 3 ~ 5).

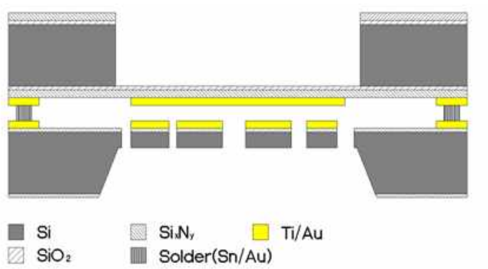

Figure 3*: Schematic of fabricated MEMS microphone*

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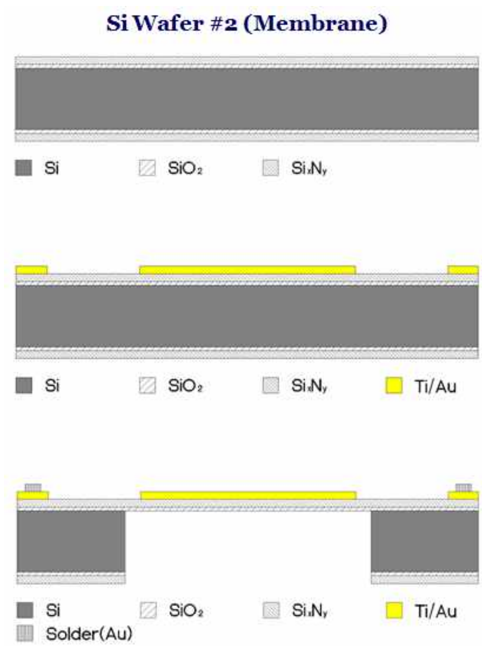

Figure 5*: Fabrication process of membrane wafer*

The fabricated MEMS microphone is shown in figure 6.

The overall size is 4 mm × 4 mm × 1 mm(t). Two contact pads are shown at the lower edges of the device (Fig. 6(a)). The circles in figure 6(b) are membrane electrode (small one) and membrane (large one).

(a)

(b)

(c)

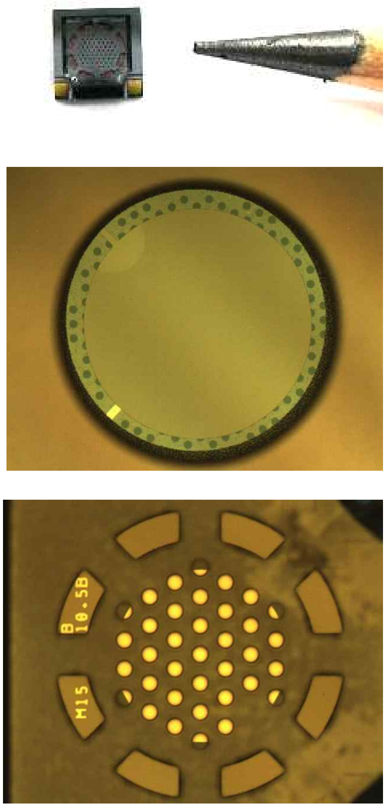

Figure 6: *(a) Fabricated MEMS microphone and microscopic images of (b) membrane side and (c) backplate side (image taken from MEMS microphone with* 100 μm air hole diameter and 1500 μm membrane diameter)

4. CHARACTERIZATION

The residual stress of the membrane plays important role in the performance of MEMS microphone as shown in the finite element modeling. The residual stress of the fabricated membrane was measured using indentation method to be between 380 MPa and 430 MPa.

The electro-mechanical property of the fabricated MEMS microphone was characterized by measuring the center displacement of the membrane while applying AC voltage of various magnitude and frequency between membrane electrode and backplate electrode. The displacement of the membrane during the experiment was measured using Laser Doppler Vibrometer (Fig. 7).

The measurement results show that the MEMS microphone of the largest diameter (2,000 μm) deformed most.

The relationship between electrostatic force and spring force can be expressed as

$$F_{\text{electro}} = \frac{\varepsilon A V_{bias}^2}{2(g_o - \Delta g)} = F_{spring} = k \times \Delta g \qquad (1)$$

$F_{electro}$: electrostatic force by bias voltage capacitance
F_{spring}: spring force by bent membrane,
k: spring constant of membrane

The magnitude of applied bias voltage required for the operation of capacitive-type MEMS microphone is chosen based on the 'pull-in' voltage, over which the force balance between electrostatic force by applied DC voltage on both electrodes and spring force as the membrane bends downward can't sustain any more. At this voltage, the airgap become 66% of initial airgap. The operation DC voltage is typically chosen as 60% of pull-in voltage. The pull-in voltage is calculated as

$$V_{PI} = \sqrt{\frac{8kg_O^3}{27\varepsilon A}} \qquad V_{PI}\text{: pull-in voltage} \qquad (2)$$

The relationship between the residual stress, applied voltage, and displacement is expressed as

$$k = 8\pi\sigma t_f \qquad (3)$$

$$\sigma = \frac{\varepsilon r^2 V_{bias}^2}{16\Delta g(g_O - \Delta g)t_f} \qquad r\text{: radius of membrane} \qquad (4)$$

Based on the experimental results and formula, the measured pull-in voltage of the developed microphone with 2,000 um diameter was 27 V, thus the operation voltage was determined to be 18 V (Fig. 8).

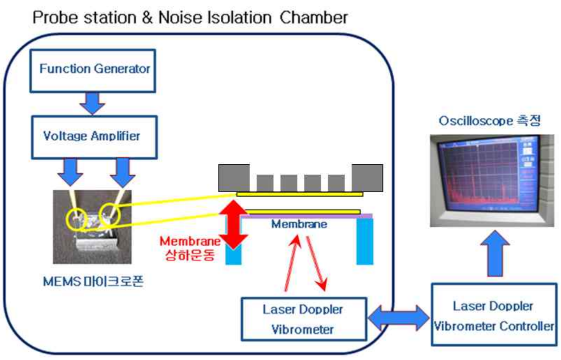

Figure 7: *Experimental setup of membrane displacement measurement by Laser Doppler Vibrometer.*

The displacement measurement of MEMS microphone with different air hole diameters was also carried out to compare their frequency response using the same experimental setup mentioned above. The frequency of applied AC signal between membrane electrode and backplate electrode was gradually increased and the displacement of membrane at each frequency was measured.

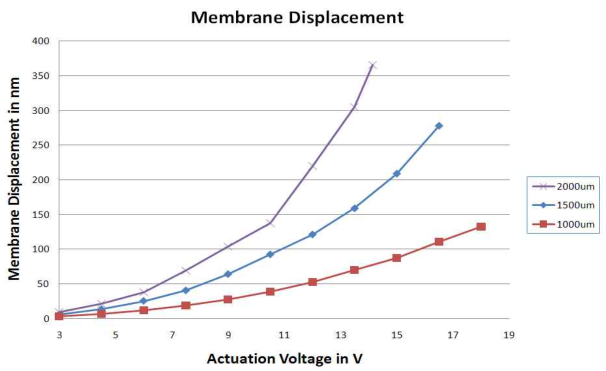

Figure 8: *Measured membrane displacement by applied voltage on MEMS microphone with different membrane diameter.*

The cut-off frequencies were decided as frequencies at which the displacement of the membrane becomes 3 dB smaller than the displacement at 50 Hz. Figure 9 shows the measurement of the displacement of the membrane over the frequency of 50 Hz ~ 300 kHz. The measured cut-off frequencies were 24 kHz with 50 µm wide air holes and 144 kHz with 100 µm wide air holes in the backplate.

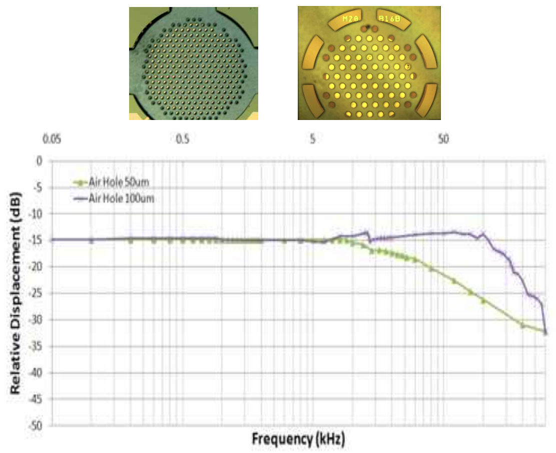

Figure 9: *Measured frequency response of MEMS microphone with different air hole diameter 50 µm (left) and 100 µm (right)*

5. DISCUSSION AND FUTURE WORK

In this research, we have successfully measured the electro-mechanical property of low stress silicon nitride membrane of MEMS microphone by using Laser Doppler Vibrometer in the electro-mechanical test setup. The displacement of the membrane was measured and the results were plotted against the magnitude (RMS value) and frequency of the applied AC voltage, respectively. The measured results suggest that the fabricated MEMS microphone would operate properly within the designed operating frequency range (below 20 kHz). The operational bias voltage required for the developed MEMS microphone was 18 V, which is higher than commercially available MEMS microphone. Smaller airgap between membrane and backplate would reduce the required bias voltage, but there is fabrication limitation in reducing the airgap using eutectic bonding process. Additional research such as development of new fabrication method or usage of membrane with lower residual stress will be carried out to overcome the high bias voltage requirement

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