HIGH SENSITIVITY AND HIGH S/N MICROPHONE ACHIEVED BY PZT FILM WITH CENTRAL-CIRCLE ELECTRODE DESIGN

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ABSTRACT

This study based on piezo-electric sensing principle to develop a high S/N ratio MEMS microphone. The patterned PZT and electrodes designed implemented above the clamped diaphragm to generate high stress concentration on PZT and Si bimorph diaphragm. The proposed central-circle electrode design can induce more charge than the edge-surrounded electrode design (served as the reference design). The proposed design also provides a smooth stress distribution across electrode to tolerate more process variation such as offset from double-side alignment and boundary change by DRIE undercut. The measured results demonstrate the S/N is about 64dB (reference design: 53dB) for the piezo-electric microphone.

INTRODUCTION

The MEMS microphone could offer the advantages of size reduction, high signal-to-noise ratio (S/N), high sensitivity, quick response, and long-term stability [1]. More, the Si based microfabricated microphone could tolerate the temperature during the solder reflow process. Thus, the MEMS microphone is considered as a promising replacement for the ECM microphone, especially in the consumer applications. Capacitive and piezoelectric sensing are the two major principles utilized in MEMS microphone. The condenser MEMS microphone [2-6] generally consists of a diaphragm, back chamber, and a back-plate. The flexible diaphragm will be deformed when loaded by the acoustic pressure. After that, the gap between the diaphragm and back-plate will be changed and further lead to the variation of sensing capacitance. For such design, the air damping effect of back-plate will lead acoustic impedance to decrease the microphone sensitivity. The vent holes on back-plate has been designed to reduce the air damping, yet the size of sensing area is also reduced.

Therefore, single diaphragm without back-plate features piezoelectric microphone can offer dust-proof and moisture-proof advantages accompanying with great sound performances [7-10]. AlN and ZnO are the most popular piezoelectric materials for MEMS microphone. These piezoelectric microphones demonstrate good sensitivity but low signal-noise-ratio (S/N) because of lower d31 coefficient (<10). The lead-zirconate-titanate (PZT) has advantages on larger d31 (>100), yet the larger dielectric constant (>1000) causes the dramatic decreasing of sensitivity.

This work applies the customized PZT with -150pC/N d31-coefficient and 350 dielectric-constant, together with the proposed superior electrode design, to implement the piezoelectric microphone with both high sensitivity and high S/N ratio.

DESIGN CONCEPT

The proposed central-circle electrode design and the edge-surrounded electrode design (served as the reference design) are shown in Fig.1a. A main circular clamped membrane consists of the PZT and the silicon with 1mm×1mm diaphragm. The finite element simulation results in Fig.1b show the stress distribution on membranes. In Fig. 1c, the smoother stress distribution is yielded by the proposed central-circle PZT electrode design. Moreover, the simulations also indicate that the central-circle electrode design could introduce more charge for a given electrode area. In addition, the proposed design also provides a smooth stress distribution across electrode to tolerate more process variation such as offset from double-side alignment and boundary change by DRIE undercut.

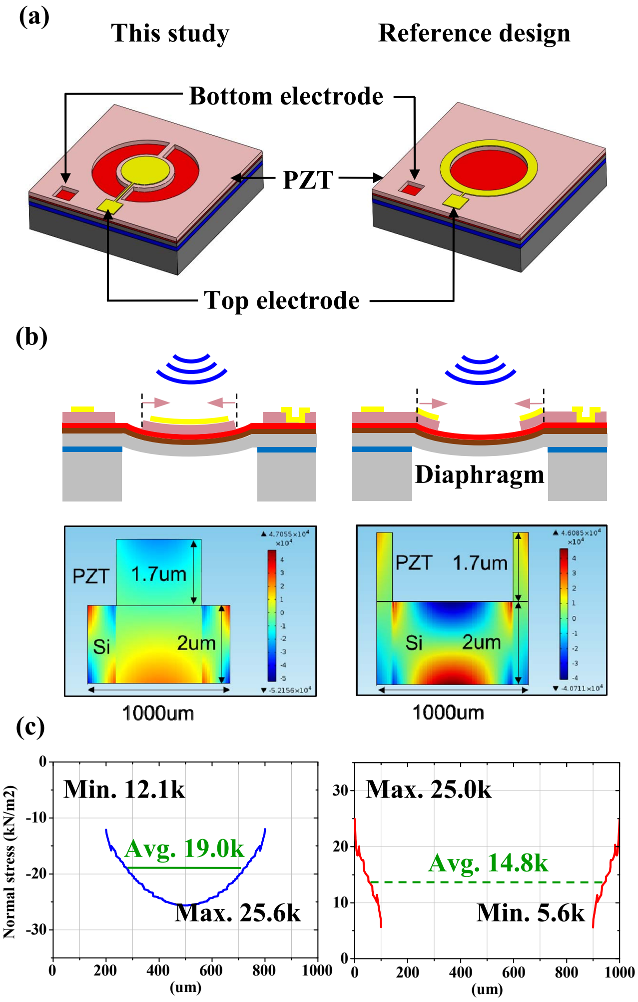

Figure 1: (a) Design concept of proposed piezoelectric microphone, and (b) simulation of stress distribution on PZT top surface.

Moreover, the d_{31} piezoelectric coefficient and dielectric constant of customized PZT film are -150pC/N and 350 respectively so as to provide the microphone a superior mechanical to electrical conversion efficiency. Both of higher d_{31} coefficient and lower dielectric constant used by this work can induce more charge and further increase the sensitivity of microphone.

FABRICATION

The process flow of this work is shown in Fig.2. The process was performed on a silicon-on-insulator (SOI) wafer with a 2μm thick active silicon layer. A 50nm Pt was deposited on SOI wafer as the bottom electrode of PZT. And the 0.2-μm-thick ZrO_2 deposition between Pt and silicon layers to insulation which avoids generating leakage current. In Fig.2a, after deposited a 1.7μm PZT layer as the piezo-electric material by sol-gel process, the PZT film was then patterned by wet etching (stop on Pt layer) to define the bond pads of bottom Pt electrode and pattern structure. In Fig.2b, the Cr/Au (20nm/200nm) films were deposited on PZT and then patterned by lift-off process to act as the top electrode. In Fig.2c, the backside of handle Si layer was patterned by DRIE to define the boundary of microphone diaphragm. Note the DRIE etching was stopped at BOX oxide. Finally, the BOX oxide was removed by BOE wet-etching to release the diaphragm of microphone (Fig.2d).

The micrographs in Fig.3 display the fabrication results of piezo-electric microphone. Micrographs in Fig.3a-b respectively show the fabricated central-electrode and edge-surrounded designs respectively. Fig.3c shows the cross-section of PZT/Si bimorph structure. Fig.3d shows the back-side cavity and diaphragm defined by DRIE etching.

The package results of proposed and reference microphones were shown in Fig.4a-b. The sensor chips were wire-bonded on PCB with a 1mm diameter hole. In addition, as in Fig.4c, to increase the acoustic pressure loading on the microphone, a 5mm×5mm×2mm acrylic back chamber is attached to the backside of PCB during measurement.

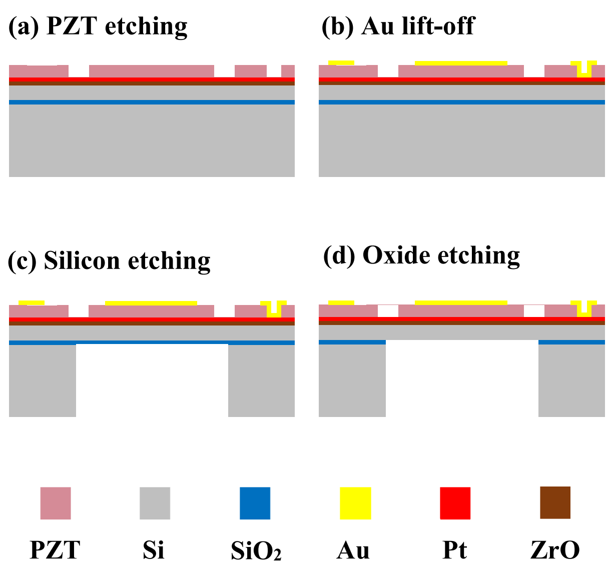

Figure 2: Fabrication processes of PZT microphone (a) wet etching, (b) lift-off process, (c) Deep RIE etching, (d) BOE wet etching.

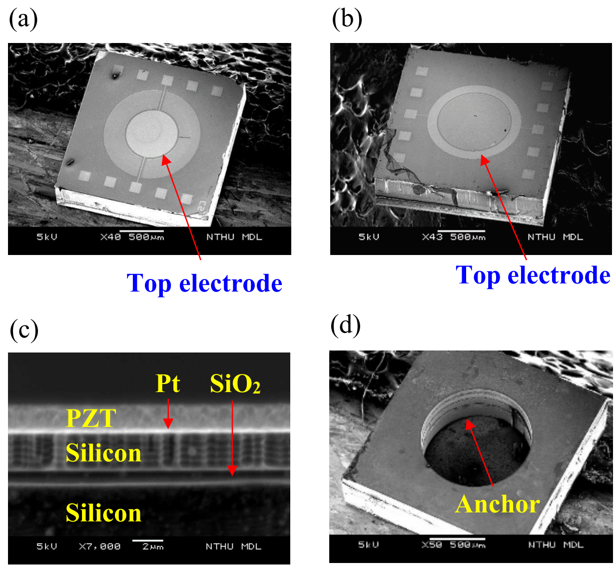

Figure 3: SEM micrographs of (a) proposed device, (b) reference device, (c) cross-section view, (d) backside.

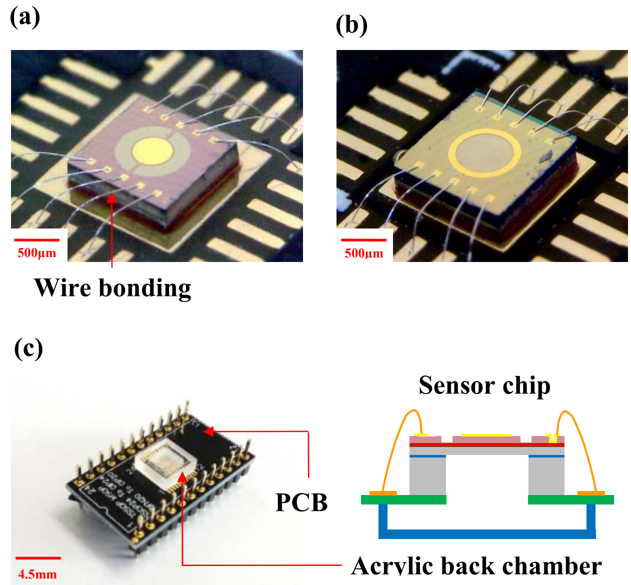

Figure 4: Wire-bonded and packaged piezo-electric microphone for acoustic measurement, (a) proposed device, (b) reference device, (c) system of package.

MEASUREMENT

To isolate or reduce the interference of noise source is the key factor to realize high S/N microphone. Thermal noise intrinsically existed inside piezo-electric material is the major noise source of proposed microphone. Lower the di-electric constant can significantly improve the noise characteristic. Fig.5 shows the LCR meter setup to diagnose the dielectric constant of PZT film. Measurement results indicate the dielectric constant of utilized PZT film is about ~350 from 0~20kHz. This value is 3.5-fold lower than that of the conventional PZT film [11]. Thus, the PZT film employed in this study is a promising material for high S/N microphone applications [12]. In addition, the capacitance of proposed and reference microphone measured by LCR meter is 683.4pF and 671.5pF respectively.

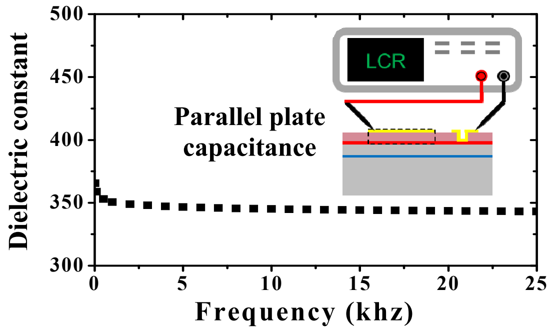

Figure 5: Dielectric constant measurement.

Fig.6a shows the setup inside the anechoic room for acoustic tests. The anechoic room shows in Fig.6b. The computer controlled B&K pulse spectrum analyzer could modulate the sound pressure by loudspeaker and also record the output signals from both testing and reference microphones. Fig.6c shows the PGA board and interface circuits. The output signal of microphone is amplified by two stages amplifier. The variable capacitance and constant capacitance were utilized by MEMS sensor chip and PGA board respectively in the first stage. The second stage is typical voltage amplifier.

Fig.7a shows the sensitivity of proposed microphone is -34dB (ref. 1V/1Pa) at 1kHz and S/N is about 64dB. In comparison, the sensitivity of reference design is only -45dB (ref. 1V/1Pa) at 1kHz and S/N is about 53dB. Thus, measurements indicate the proposed microphone improves sensitivity for 11dB, and further increase the S/N for 11dB accordingly. In addition, the acoustic frequency response in Fig.7b indicates the presented piezoelectric microphone has a low cutoff frequency of 188Hz. The specification achieve identical standard of microphone.

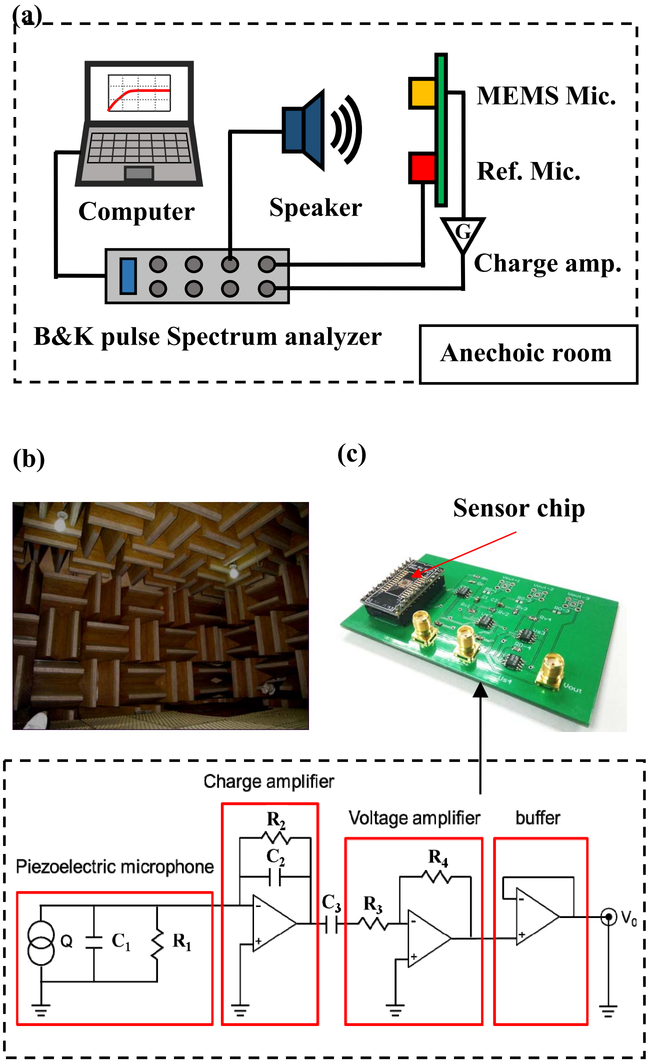

Figure 6: (a) Acoustic measurement setup, (b) anechoic room, (c) amplifier circuit.

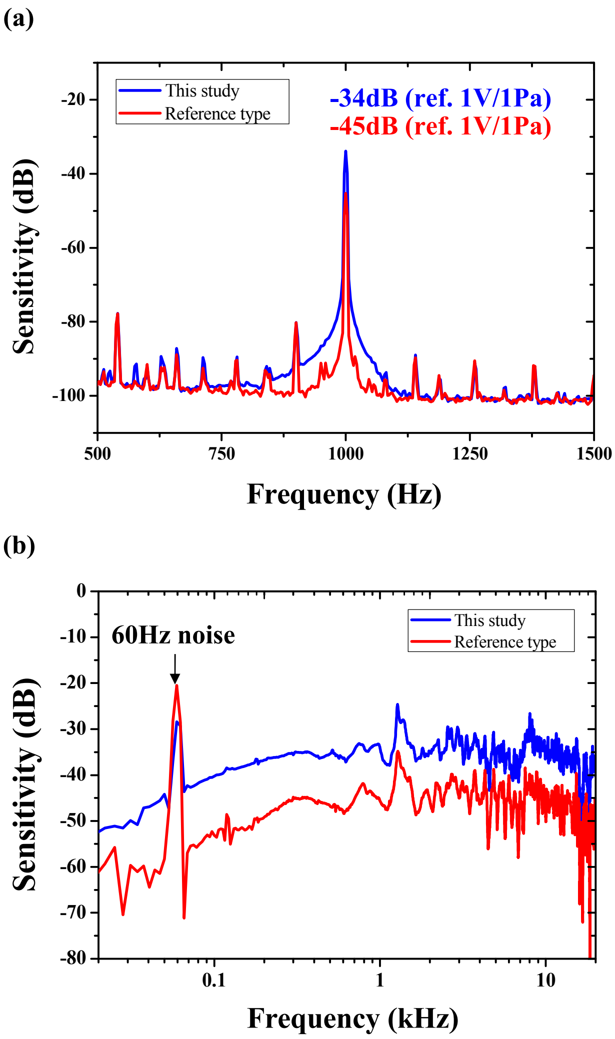

Figure 7: (a) Signal-noise-ratio (S/N) of microphone, (b) acoustic frequency response of microphone.

CONCLUSION

This study demonstrates a high signal-noise-ratio piezoelectric microphone using the thin film PZT technology. The microphone was designed and implemented on the SOI wafer with a 2μm thick silicon device layer as the suspended structure. The microphone is a circular clamped membrane and its diameter is 1mm. The sensitivity of proposed microphone can reach -34dB (ref. 1V/1Pa). Moreover, a high S/N ratio of 64dB can be achieved. Table 1 summarizes the comparison of the proposed microphone and the reference one. The sensitivity and S/N of reference design is only -45dB and 53dB. For fair comparison, the reference microphone has the same dimensions and MEMS process but different design with the proposed one. The frequency response of proposed microphone also demonstrates a great performance between 188Hz~10kHz.

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Table 1: Specification of piezo-electric microphone

	This study	Reference
Diaphragm diameter	1mm	1mm
Acoustic freq. response	188~10k	213~10k
PZT dielectric constant	~350	~350
d31 coefficient	-150	-150
Polarization voltage	~3V	~3V
Capacitance	683.4pF	671.5pF
Sensitivity	-34dB	-45dB
Signal to Noise Ratio	64dB	53dB

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