FO-1-5-3

# A Capacitive-type MEMS Acoustic Sensor with a Diaphragm of $Al/Si_3N_4/Al$ Based on a Polyimide Sacrificial layer

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## Abstract

*A capacitive-type micro-electro-mechanical system (MEMS) acoustic sensor with a diaphragm of $Al/Si_3N_4/Al$ (0.1/0.4/0.1 μm) multi layers on a sacrificial layer of 3.0 μm polyimide is presented. It can make the total fabrication process simpler due to using $O_2$ gas as a releasing material. Furthermore, equivalent circuit modeling for the MEMS acoustic sensor is implemented with a lumped model. The acoustic sensor had a modeled open-circuit sensitivity of -38.5 dBV/Pa at 1 kHz with a bias of 10.0 V, which shows good agreement with the measured one in the range from 100 Hz to 16 kHz.*

**Keywords:** MEMS, acoustic sensor, Microphone, Equivalent circuit modeling.

## 1. Introduction

MEMS acoustic sensors have been widely applied to the mobile phone with the greatly increasing demand for microphones, especially in the smartphone market. Consequently, numerous design issues and fabrication methods have been reported on the basis of surface and bulk micromachining [1]-[4]. In this paper, the capacitive-type MEMS acoustic sensor is proposed and investigated. In addition, to characterize the frequency performance, structure-based equivalent circuit modeling [5] is implemented. Ultimately, measured data is compared with modeled values in order to verify the validity of the proposed structure-based lumped-parameter model of the MEMS acoustic sensor.

## 2. Design and Fabrication

As shown in Fig. 1, a MEMS acoustic sensor was designed to have a plate-type diaphragm, where it had a diaphragm of 650 μm diameter. In addition, to improve frequency response, a back-plate anchor with wheel-shaped inner cross bars was placed and fixed underneath the back-plate by using DRIE patterning. For the fabrication, first, a back-plate anchor was patterned on a Si substrate by using DRIE, which could work as a passivation layer against SF6 etchant. After patterning, it was filled with a multilayer back-plate, in which the layers comprised 1.0 μm of oxide and 0.8 μm of nitride. The back-plate electrode was a 0.5 μm-thick layer of Al. After that, 3.0 μm of polyimide was deposited and patterned as a sacrificial layer. A diaphragm of $Al/Si_3N_4/Al$ layers was implemented. After the back chamber was etched by DRIE, the sacrificial layer was finally released using $O_2$ gas. The sensor had a chip area of $1.0 \times 1.05\ mm^2$.

## 3. Characterization

To determine an open-circuit sensitivity ($S_0$) of the sensor, the pull-in voltage ($V_P$) was measured by

$$V_p = \sqrt{\frac{8g_0^3}{27\varepsilon_0}\frac{1}{S_m}} = \sqrt{\frac{8g_0^3}{27\varepsilon_0}\frac{K_{eff}}{A_{eff}}}\ , \qquad (1)$$

where $S_m$ was the mechanical sensitivity, $g_0$ was the air-gap between the diaphragm and the back-plate, $\varepsilon_0$ was the dielectric constant of a vacuum, $K_{eff}$ was the effective spring constant, and $A_{eff}$ was the effective area of a diaphragm. The $V_P$ was 15.0 V at $g_0$ of 3.0 μm. The residual stress of the diaphragm was determined to be +10 MPa. Furthermore, to evaluate the frequency response, an equivalent circuit model [5] was used as

$$S_0(\omega) = \frac{v_{oc}(\omega)}{P(\omega)} = \frac{1}{A_{eff}\cdot K_1(\omega) + (1/A_{eff})\cdot K_2(\omega)}\cdot\frac{\Gamma}{j\omega\,(C_0 + C_P)}\ , \qquad (2)$$

where $K_1(w)$ and $K_2(w)$ are given by

$$K_1(\omega) = R_r(\omega) + R_h + R_g + j\omega\,M_r + \frac{1}{j\omega\,C_{bc}} \qquad (3)$$

$$K_2(\omega) = j\omega\,M_d + \frac{1}{j\omega\,C_d} + \frac{\Gamma^2}{j\omega\,(C_0 + C_P)}\ . \qquad (4)$$

Fig. 2 describes a schematic cross section of the model and its equivalent circuit is in Fig. 3. In addition, Fig. 4 shows a set-up of resonance frequency ($f_r$) measurement, where $f_r$ was 55 kHz at 3 $V_{DC}$, and a de-capped MEMS microphone module. The measured sensitivity $S_{mea}$ was -39.4 dBV/Pa at 1 kHz (0 dB = 1 V/Pa, ROIC gain = 6 dB at 1.6 pF input capacitance). The measured $S_0$ was extracted to -38.5 dBV/Pa. As a result of modeling, the modeled $S_0$ had a good agreement with the measured $S_0$, as shown in Fig. 5.

## Acknowledgement

This work was supported by the IT R&D program of MKE/KEIT. [10035570, Development of self-powered smart sensor node platform for smart&green building]

## References

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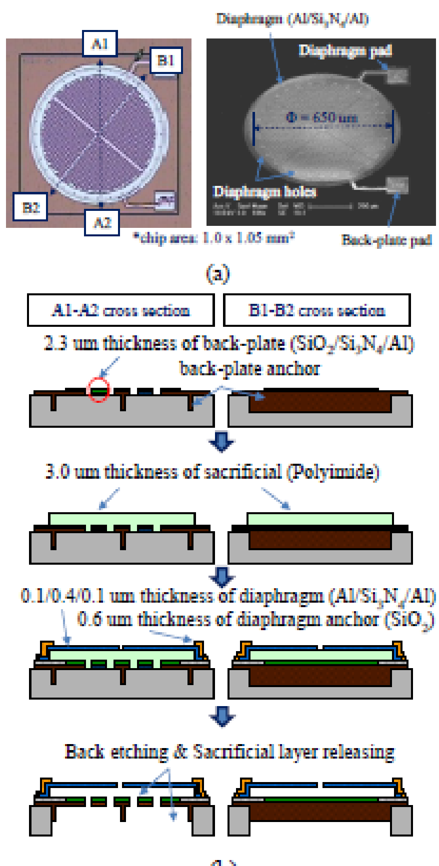


**Fig. 1.** Images (a) and schematic cross section views (b) for the fabrication process for the MEMS sensor.

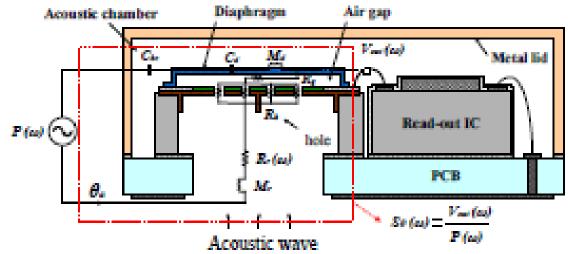


**Fig. 2.** The cross section schematic view for an equivalent circuit model of the proposed MEMS sensor.

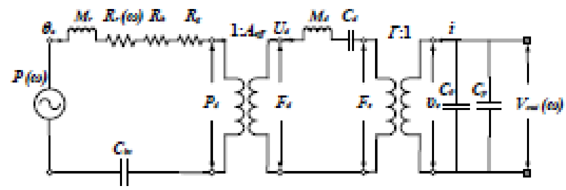

**Fig. 3.** An equivalent circuit for the open-circuit sensitivity of the proposed MEMS sensor.

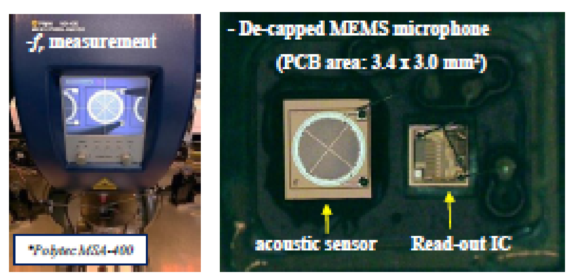


**Fig. 4.** A set-up of resonance frequency measurement and de-capped MEMS microphone module.

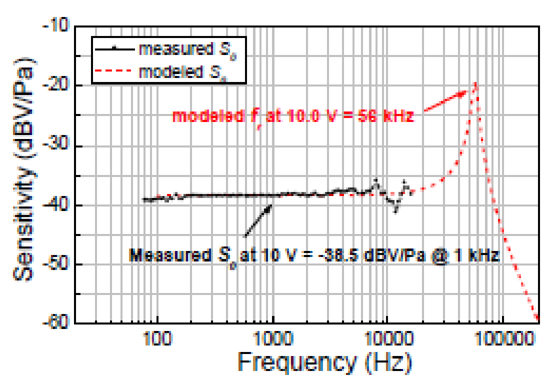


**Fig. 5.** Modeled and measured $S_0$ as a function of frequency for the proposed MEMS sensor.