

# Acoustic Transmission Measurements of Folded MEMS Membranes for Mechanical Characterization

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## Summary:

Three-dimensional folded membranes are set to innovate MEMS designs for acoustic transducers by using lateral movement to increase their active area. Determination of the mechanical characteristics of such membranes is challenging, since established techniques mainly target in-plane structures. This paper presents an acoustic method to determine the mechanical compliances of such folded membranes. The results show compliances between  $0.08 \cdot 10^{-15}$  and  $10 \cdot 10^{-15}$  m<sup>3</sup>/Pa for different membrane lengths.

**Keywords:** MEMS, membrane, characterization, acoustics, modeling

## Introduction

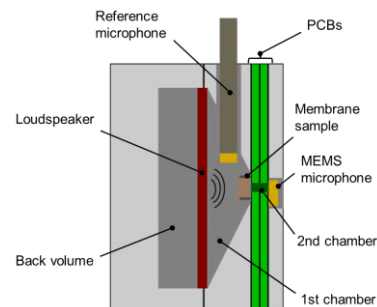
The miniaturization of acoustic transducers in MEMS is technologically challenging due to their small volumes and displacements. To overcome these challenges, a novel transducer design is presented in [1] using a folded piezoelectric membrane design. This new three-dimensional approach is truly utilizing the entire chip volume. Lateral movements of multiple lamellas allow an increased volume displacement out of a fixed chip size.

For the development and optimization of various applications like microphones, speakers or micropumps, the detailed knowledge of the mechanical characteristics of such membranes is mandatory. State of the art methods like the Bulge test [2], vibrometry [3] or atomic force microscopy [4] are tailored for in-plane and near surface structures. However, these methods are not suitable for the deep lateral deflecting three-dimensional folded membrane without translating the deflection in known directions by extensive sample preparation. This paper presents a new measurement method, which uses acoustic transmission measurements (ATM) and lumped element modeling (LEM) to analyze the mechanical characteristics of folded MEMS membranes.

## Measurement Method

The ATM measurement method utilizes two chambers, which are separated by the folded membrane to be characterized (Fig. 1). The first chamber comprises a reference microphone

and an electrodynamic loudspeaker with a closed back volume. The loudspeaker causes a pressure wave, which sets the folded MEMS membrane in motion. A second microphone detects the acoustic signal radiated into the second chamber.



*Fig. 1. Schematic representation of the measurement setup*

From the pressure difference between the chambers information of the mechanical behavior of the folded membrane can be deduced. Pre-test measurements of the setup are performed to exclude external vibrations or influences, by calibrating the results.

The parameter extraction out of these measurements is done by LEM of the measurement setup in the acoustic domain (Fig. 2). Both chambers are modeled as acoustic compliances  $C_1$ ,  $C_2$  and the folded membrane as mass-spring-damper system  $Z_{a, Mem}$ . The extraction takes place by fitting the values of the membrane impedance to match the measured sound pressure level (SPL) in the second chamber.

The membrane mass is calculated from its geometry and thin film composition. Since the measurements do not take place in the resonant regime of the membrane, its damping can be neglected. As consequence, the compliance dominates the mechanical behavior in this frequency bandwidth.

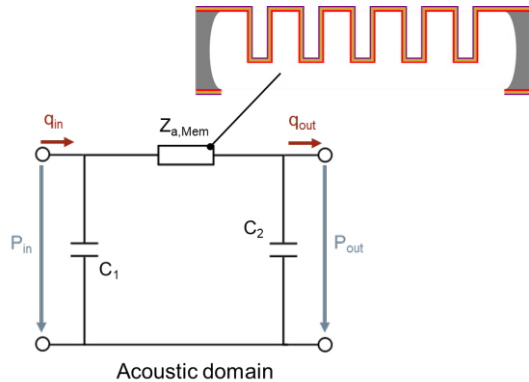


Fig. 2. Lumped element model of the measurement setup

## Results

The acoustic measurements are performed with the APX525 audio analyzer from Audio Precision. Folded MEMS membranes made out of a SiO<sub>2</sub>, n-doped polycrystalline silicon (Poly-Si) and Si<sub>3</sub>N<sub>4</sub> [1] stack are characterized in this paper. Three different lengths of 500  $\mu\text{m}$ , 1000  $\mu\text{m}$  and 2000  $\mu\text{m}$  are measured using three samples each to identify the influence on the membrane compliance. Fig. 3 illustrates the measured frequency response of one of the 1000  $\mu\text{m}$  long membranes in the measurement setup.

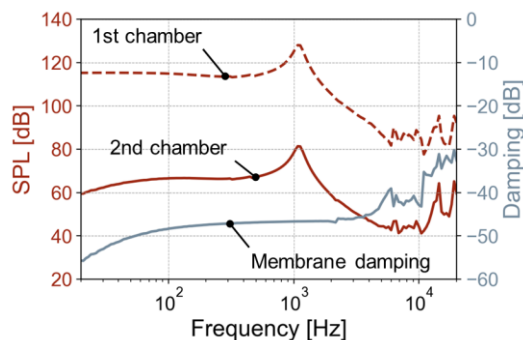


Fig. 3. Frequency responses of both chambers and the damping of a 1000  $\mu\text{m}$  long folded membrane

The electrodynamic loudspeaker causes the resonance peak at 1.1 kHz and the drop of SPL towards higher frequencies in both chambers. The MEMS microphone in the second chamber exhibits a high-pass behavior below 100 Hz. The parameter extraction is done at 1 kHz, since here the membrane behavior is not influenced by the measurement setup. The comparison of the results for the different lengths

shows a nearly linear behavior on the membrane compliance. The membranes of 1000  $\mu\text{m}$  and 2000  $\mu\text{m}$  length show an expected increase of compliance by nearly a factor 2.

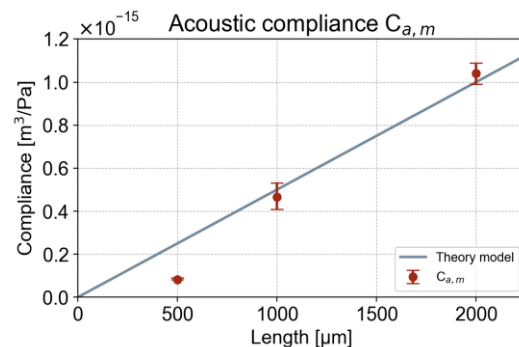


Fig. 4. Extracted acoustic compliances  $C_{a,m}$  of folded MEMS membranes with different lengths

In contrast, the shorter membrane with 500  $\mu\text{m}$  length shows a lower compliance than expected. This is likely caused by the fixed support of the membrane front faces in the Si frame. The shorter the membrane, the greater the support compliance influences the displacement. For longer membranes, the membrane geometry dominates the compliant behavior while the support can be neglected. This ensures a linear relationship between membrane compliance and membrane length.

In summary, a new measurement method for the mechanical characterization of folded MEMS membranes is shown. By making assumptions for the membrane mass and damping, it is possible to extract the compliance for different membrane geometries without extensive sample preparation.

## References

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