DOI 10.5162/EUROSENSORSXXXVI/PT4.23

A New Area Efficient Folded Piezoelectric MEMS Speaker

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Summary:

This paper demonstrates a novel concept for an area efficient piezoelectric MEMS speaker. A folded piezoelectric diaphragm can utilize the whole chip volume by adding up multiple laterally vibrating actuators. The actuation is accomplished by conformally deposited aluminum nitride (AlN) layers, which are fabricated using atomic layer deposition (ALD). This work describes the design, functionality and first performance of a MEMS speaker. Acoustic measurements show a sound pressure level (SPL) of 59 dB in a 0.13 cm^3 big coupled volume.

Keywords: MEMS, AlN, Speaker, Sidewall, Piezoelectric

Introduction

Miniaturization of loudspeakers generally results in smaller radiating areas and stiffer structures compromising the acoustic performance. Especially state-of-the-art micro-electro-mechanical-system (MEMS) developments make use of innovative membrane concepts, which avoid these difficulties and allow closing the gap to conventional speakers on the market. One example for this is the work by Stoppel et al., which presents a piezoelectric MEMS speaker with slit membranes for compliance reduction [1]. Hirano et al. reports another embodiment, where corrugations increase the membrane displacement of the speaker [2]. Apart from that, Kaiser et al. developed a different MEMS speaker concept, which uses electrostatically actuated beams [3]. Here, they vibrate laterally, which creates an increased active area out of a minimized chip volume. The present work aims to present an alternative concept for an area efficient piezoelectric MEMS speaker. It increased the active radiating area by manufacturing a three-dimensional folded membrane for lateral actuation. Previous work already proves the manufacturing concept of such a membrane [4].

The folded piezoelectric MEMS speaker

The folded structure of the presented piezoelectric MEMS speaker consists of multiple vertical actuators, which vibrate laterally. The starting material is a deep trenched wafer with an aspect ratio of 5:1, which defines the geometry of the speaker. The layers of the membrane stack are conformally deposited. A release etch from the backside utilizing SiO_2 as etch-stop reveals the folded membrane structure (Fig. 1). AlN as piezoelectric thin film is deposited using ALD to actuate the vertical structures [5]. N-doped polycrystalline silicon (Poly-Si) layers with aluminum (Al) pads electrically contact the piezoelectric layer along the folded structure.

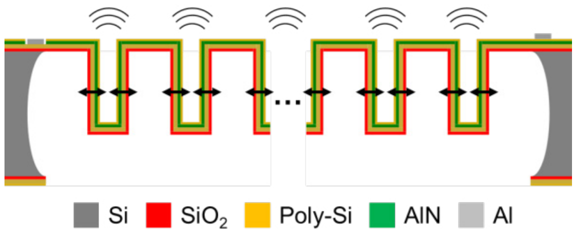

Fig. 1. Schematic cross-section of the folded piezoelectric MEMS speaker

This work utilizes lumped element modeling (LEM) to simulate the piezoelectric MEMS speaker on a multi-physical level. The equivalent circuit is separated into the electrical, mechanical and acoustical domains (Fig. 2). An electric capacitance $C_{e,AlN}$ represents the piezoelectric thin film. The electromechanical coupling T_{em} utilizes numerical simulations of the actuator deflection. Since the characterization of piezoelectric thin films on sidewalls of vertical structures is challenging, literature values are assumed for the modeling of the AlN [6]. A mass-spring-damper system is used to model the mechanical behavior $Z_{m,Mem}$ of the folded membrane. The resulting SPL is calculated in the acoustic domain with the measurement setup impedance $Z_{a,S}$. This allows a comparison of the simulated data with the acoustic measurements of the speaker samples.

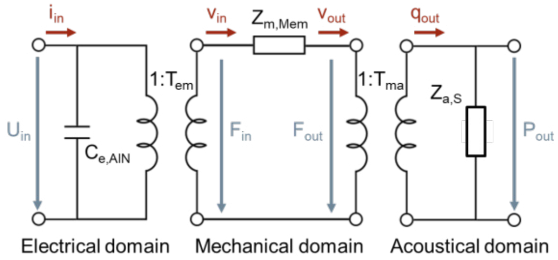

Fig. 2. Equivalent circuit of the piezoelectric MEMS speaker

Results

The MEMS speaker is characterized acoustically on wafer-level by placing the sample wafer on an Al-chuck and utilizing prober needles to apply the electrical input signal. Fig. 3 schematically illustrates the measurement setup.

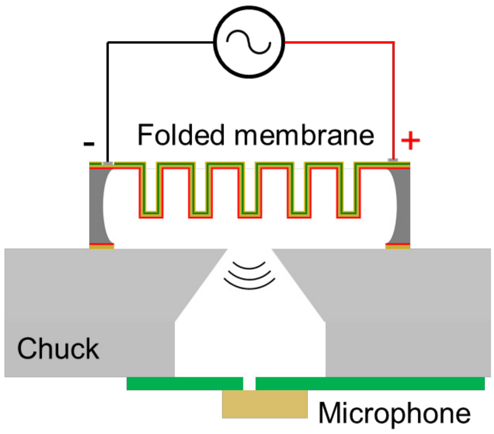

Fig. 3. Measurement setup for wafer-level speaker characterization

The audio analyzer APx525 from Audio Precision completes the measurement setup. An AC voltage is applied from 20 Hz to 20 kHz to drive the piezoelectric actuators against a coupled volume of 0.13 cm³. Fig. 4 compares the measured results with the LEM. A resonance is measured at 17.8 kHz. This is caused by the measurement setup and can also be seen in the modeled results at 17.3 kHz. Below this frequency, a flat response of 64 dB is simulated. The measurements show a SPL of 59 dB at 1 kHz, which is lower by nearly a factor of two compared to the simulation based on literature values. A leakage in the wafer-level measurement setup explains the high pass behavior for lower frequencies. Due to the miniaturized vertical actuators, the speaker resonance lies above the audible frequency range, which allows a desirable flat response up to 20 kHz.

In summary, this work proves the concept of a new piezoelectric MEMS speaker utilizing a folded area efficient structure. A piezoelectric ALD thin film laterally actuates multiple vertical structures to generate an acoustic signal of 59 dB. Compared with simulations based on literature values of sputtered AlN, these results only differ by 5 dB proving the functionality and potential of this MEMS transducer design.

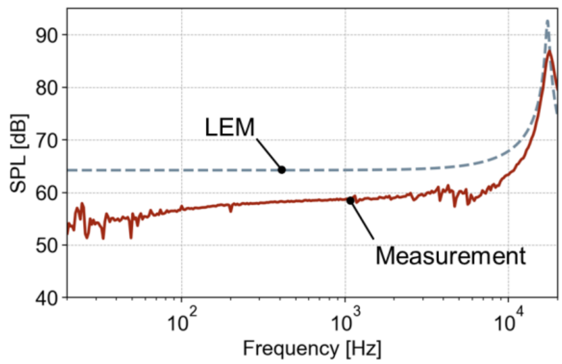

Fig. 4. Comparison of the measured and simulated SPL

This lays the foundation for the development of further design additions and novel characterization approaches, which could lead to an innovation boost in the field of acoustic MEMS transducers with its unique structure.

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