Microfabrication & Testing of Directional Piezoelectric Microphones Using AlN

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Abstract:

This project focused on the fabrication and characterization of piezoelectric microphones with out-of-plane directivity. These devices use a 1.2 µm thick aluminum nitride (AlN) thin film as the piezoelectric transduction material in place of lead zirconate titanate (PZT), utilized in earlier prototypes. Previous devices exhibited undesirably high resonance quality factors close to 40 at a frequency of 2.6 kHz, distorting recorded sound. One of the main focuses of this project was to provide an even response within the audible frequency range. AlN shows a lower dielectric loss (tanδ) than PZT (i.e., a smaller leakage resistance and thus achieves a higher signal-to-noise ratio). In addition, AlN opens the possibility for complementary metal-oxide semiconductor (CMOS) integration in system-on-a-chip designs. Lastly, AlN does not require a poling process, as the internal polarization of AlN is defined by crystalline orientation (i.e., c-axis) achieved in this study via direct current (DC) reactive sputtering. Fabricated prototypes had a diaphragm made of 10 µm thick epitaxial Si, supported by a thin Si beam — both the beam and the diaphragm being the same thickness — and on top of which, the piezoelectric thin film and electrodes were deposited. In preliminary testing, application of an AC voltage signal across the device electrodes yielded motion of the diaphragm detected with a laser doppler vibrometer, showing evidence of a functional piezoelectric AlN film.

Purpose:

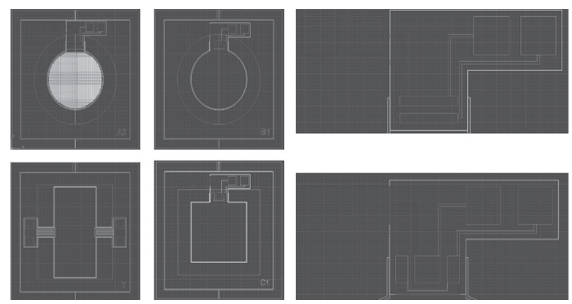
Directional microphones are used in products where consumers would like to receive sound from a particular direction or source rather than give all directions equal weighting. These directional microphones could be used in devices to detect movement, to capture higher quality signals for hearing aids, and in products such as video game devices where noise from the back of the console can be ignored and only signal from the front of the device captured.

Introduction and Background:

A PZT-based microphone with out-of-plane directivity was previously explored. To achieve a higher signal-to-noise ratio (SNR) than the previous prototype, a new piezoelectric material (AlN) is implemented to create a new prototype sensor. The lower dielectric loss of AlN compared to PZT is the key for a high SNR. In addition, new designs are developed and fabricated followed by device characterization.

Design:

The mask layouts of various microphone designs are shown in Figure 1a. The cross-section and top view of one such structure are shown in Figure 2. The designs included a perforated paddle, which would allow for a reduction in mass of the paddle, classic



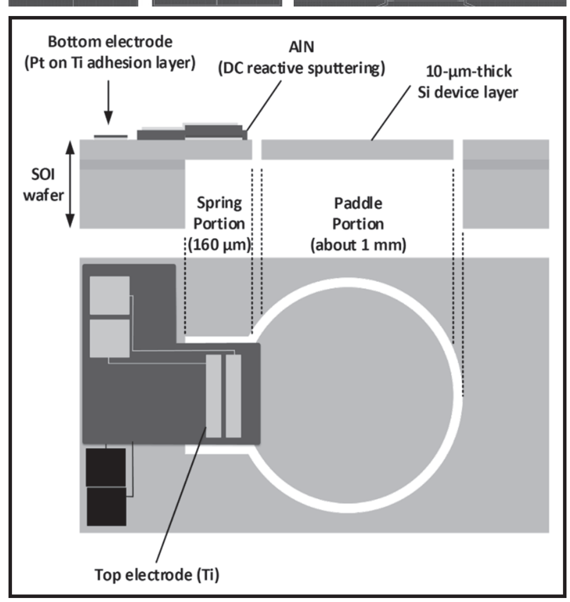


Figure 1, top: *Computer-aided design layouts of paddle and electrode structures.* ***Figure 2, bottom:*** *Cross section and top view of the proposed microphone that was fabricated.*

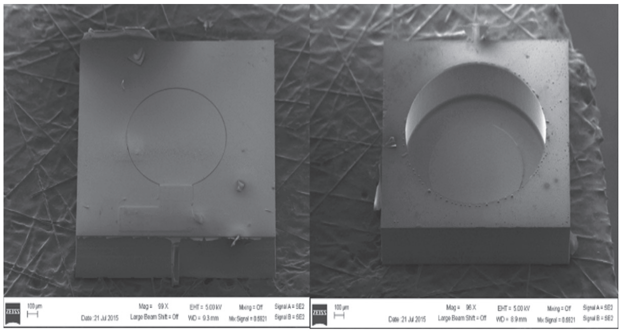


Figure 3(a-b): SEM images showing the front and back of one of the fabricated microphones.

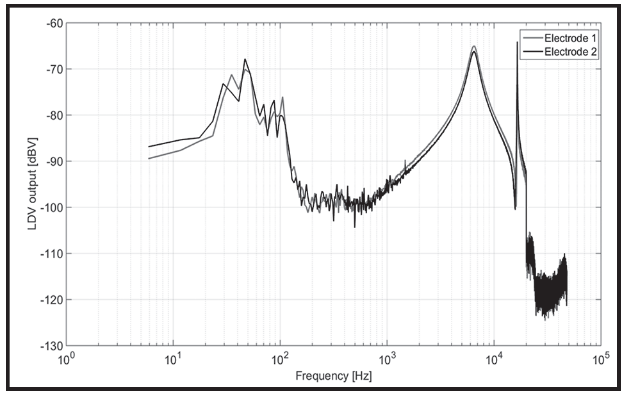


Figure 4: Velocity measurements of a diaphragm taken using a laser doppler vibrometer. The diaphragm is actuated by applying AC voltage across the AlN film on the device.

circular and square paddles, and a biologically inspired torsional microphone. In addition, the diaphragm designs had two different electrode configurations, which theoretically would increase the sensitivity of our devices.

Experimental Procedure and Fabrication:

The fabrication of the microphones used a silicon-on-insulator (SOI) wafer as the starting substrate. Aluminum oxide (Al_2O_3) masking layers were deposited using an atomic layer deposition tool and then patterned using a reactive ion etch (RIE) process. The device layer was then etched using this mask and a deep RIE (DRIE) tool. The etch was stopped by the insulator layer of the SOI wafer. The masking layers were then removed and the bottom electrodes were fabricated using a layer of platinum/titanium (Pt/Ti). This was followed by deposition and patterning of the aluminum nitride (AlN). Finally, top electrodes were realized using titanium.

The moving element of the design was the suspended silicon region formed by a deep silicon etch of the backside of the SOI wafers. This backside etch was completed with a DRIE process using Al_2O_3 as a hard mask. The completed microphones had AlN as the piezoelectric material, thin silicon suspended diaphragms, and Pt/Ti electrodes. These devices were further characterized to determine their electrical and physical proprieties.

Physical and Electrical Characterization:

The completed devices were singulated and are shown in Figure 3 a-b. Scanning electron microscope (SEM) characterization of these devices showed well-defined diaphragm regions. Dynamic frequency response measurements are shown in Figure 4. In these measurements, the motion of a paddle was measured using an LDV while the paddle was excited by applying a broadband electrical signal into the piezoelectric port. As shown, the devices were functional and the results of these tests met the goals for this project to realize a resonance with a quality factor close to unity. The previous device's resonance peak was located at 2.3 kHz whereas these devices had a resonance peak at 6.3.

Results and Future Work:

Rigorous characterization of the microphones will be conducted including acoustic frequency response and directivity measurements in an anechoic chamber, as well as further characterization of each device structure (perforated, square, circle, and torsional). Optimization of process conditions for uniform AlN deposition will be further explored as well as methods for depositing higher quality AlN film with less surface defects and higher c-axis orientation, as measured in the x-ray diffraction (XRD) tool.

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