Designing Directional Micro-Machined Microphones

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Abstract:

The newest smart phone designs, using noise rejection algorithms, rely strongly on high signal-to-noise ratio (SNR) audio capture. Techniques currently used, involve measuring the difference signal between two “standard” omnidirectional microphones physically separated in space. However, the ability to resolve small difference signals is limited by poor matching or high noise microphones. We designed a pivoting micro-machined microphones that measure spatial pressure differences directly, therefore two microphones are no longer required, reducing cost, power consumption, size, and eliminating microphone matching issues. We found that the rocking structure of the device, anchored by pivots, naturally senses pressure gradients, making it potentially more sensitive than the standard two-omnidirectional-microphone techniques being used. When designing and simulating devices using AutoCAD and ANSYS, we obtained a figure of merit of the first modal resonance showing optimization near the center of the audio band, between (1-3 kHz) to ensure the highest sensitivity and good directivity over the desired range of operation. We discovered that designs that are more flexible will move more in response to an excitation force and have a higher voltage output per input acoustic pressure. During the designing process, we saw that devices with a thinner epitaxial layer and/or thinner and longer pivots produce better figures of merit allowing for lower minimal detectable signal.

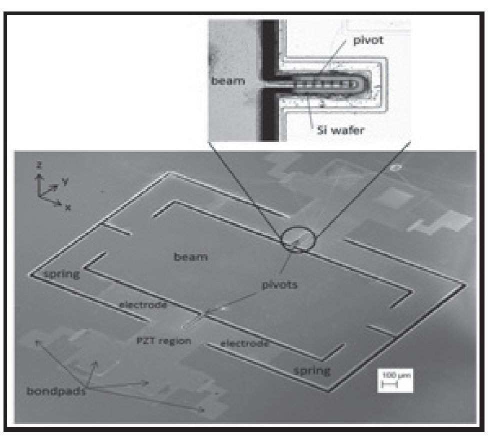

Figure 1: SEM of Generation 1 in-plane microphone with a micrograph inset on the anchored pivot region.

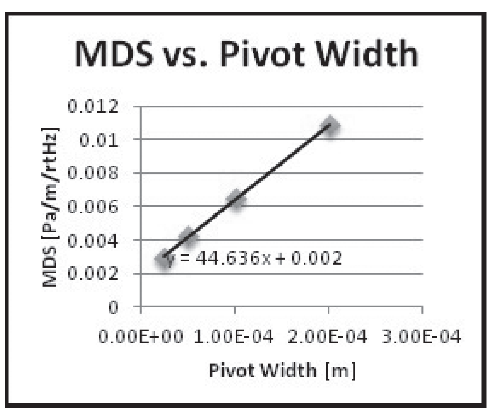

Figure 2: Minimal detectable signal is proportional to pivot width.

Introduction:

The purpose of this project was to design a new directional micro-machined microphone based on a previous design that would provide a lower minimal detectable signal (MDS). The MDS is one of the most important measures of fidelity of a microphone. It is the lowest possible signal that a device can read at the noise floor of the sensor and low MDS is critical for good audio quality and modern noise cancellation features. Figure 1 shows the original design of the in-plane directional microphone with a micrograph inset on the anchored pivot region [1]. It shows the spring component on the outside edge of the device. This was removed in the new device to enhance flexibility.

Experimental Procedure:

We first looked at Hooke’s law, $F = kx$, where “k” is the stiffness coefficient. From this formula, we determined that designs that are less stiff will move more in response to a given excitation force and will produce higher voltage output per Pascal of acoustic pressure, and therefore will be more sensitive. We want this in order to produce a low MDS. We used Microsoft Excel to calculate the MDS along with two other figures of merit: 1st modal resonance frequency and capacitance. The 1st modal resonance is proportional to the square root of k so devices with lower 1st modal resonance will have lower stiffness and higher sensitivity. With all other factors being equal, higher capacitances will relax the design requirements on the readout electronics. We tested independent variables that consisted of the thickness of the epitaxial layer between (4-200 μm), and the length between (50-600 μm) and width between (25-200 μm) of the beam pivots. Figure 2 shows a graph comparing the MDS and the pivot width, which shows to be proportional to each other; therefore we are able to conclude that devices with thinner pivots will produce a smaller MDS.

We used ANSYS simulation software to find the dependent variables consisting of the 1st and 2nd modal resonance frequencies. Figure 3 shows the ANSYS simulation of the 1st modal resonance frequency of Device A.

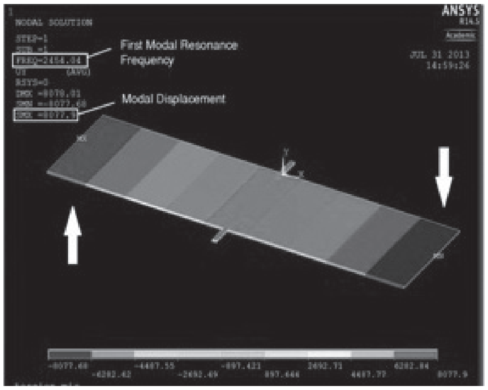

Figure 3: First mode of directional microphone excites from opposite forces pushing from opposite directions.

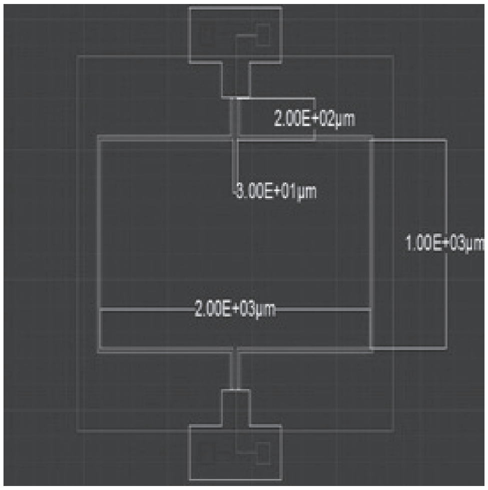

Figure 4: AutoCAD layout of Design B.

Results and Conclusions:

The final steps in the designing process were to decide on four devices that could be fabricated with high quality. We then used AutoCAD, which is a drafting software used to create mask files for fabrication. We decided on using a standard epitaxial layer thickness of 10 μm with all four designs, however alterations were made in the following designs:

Design A; a 50 μm pivot width and a 200 μm pivot length.

Design B; a 30 μm pivot width and a 200 μm pivot length.

Design C; a 25 μm pivot width and a 100 μm pivot length.

Design D; a 50 μm pivot width and a 300 μm pivot length.

We designed the masks in five layers: Top electrodes, bottom electrodes, backside etching, device layer, and lead zirconate titanate (PZT) layer, which is the piezoelectric material being used in the device. Figure 4 shows the AutoCAD mask layout of Design B with all five layers included. The final masks were successfully designed and are awaiting delivery for fabrication.

Future Work:

There is still much to accomplish in order to complete the project with fabrication and characterization of the final devices being the main finishing points. Given the high sensitivity of our mechanical structure combined with the low dielectric loss of our piezoelectric material, the device can result in much more efficient MDS than the current state of the art microphone with regard to pressure gradient measurements. The designs could have an immediate impact on the noise rejection capabilities of next generation smart phones.

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References:

[1] M.L. Kuntzman, J. Glorial Lee, N.N. Hewa-Kasakarage, D. Kim, N.A. Hall, Micro-machined piezoelectric microphones with in-plane directivity, Applied Physics Letters (2013) 054109.

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