COMSOL MODELS OF TWO DIFFERENT MICROPHONES MEMBRANE WITH A PIEZORESISTIVE SENSING ELEMENT

Petricca Luca¹, Per Ohlckers¹ and Dag Wang²

¹Vestfold University College; IMST, Borre, Norway
²Sintef, Oslo, Norway

Abstract — In this paper we present Finite Element (FEM) models for two different piezoresistive microphones, fabricated using the MultiMEMS process at SensoNor Technologies in Norway with an additional Deep Reactive Ion Etching step done at Sintef. We simulated the membrane displacement and the Eigen frequencies of the systems. Furthermore, we evaluated the stresses in the suspending beams in order to estimate the changes in resistances of the four piezoresistors. The relative sensitivity of the Wheatstone bridge has also been found to be 0.44 mV/(VPa) for the thin membrane microphone and 1.4 mV/(VPa) for the thick membrane microphone.

Keywords: MultiMEMS, Microphones, Comsol, FEM simulation.

I - Introduction

The microphones presented here were fabricated using the MultiMEMS process at Sensonor with additional Deep Reactive Ion Etching (DRIE) carried out at Sintef (a similar process has been used for the fabrication of triaxial silicon accelerometer presented in [1] and the blood cell counting described in [2]).

The two silicon microphones differ from each other both regarding to the membrane shape and to the beam thickness.

The first type consists on a round shaped membrane with 2118 µm diameter. The membrane is suspended by four beams with a nominal thickness of 3.1 µm. The membrane thickness is also 3.1 µm in the external ring (Figure 1), the area at the centre of the membrane is 13 µm (see Figure 1). The gap between the beams and the membrane and between the membrane and the frame is 3 µm as in the previous case. However in this case, in order to release the membrane, it was needed to create 23 µm recesses and thus hawse have used a DRIE process available at Sintef.

The second type consists of a square shaped membrane with 3414 µm side length. In this case the thickness of the membrane is uniform and is 23 µm (see Figure 2). In order to maximize the sensitivity of the device, the four piezoresistors were connected in a full Wheatstone bridge configuration.

The sensing elements consist of four piezoresistors; particular care has been used to place them in the points of maximum stresses at the base of each beam (Figure 2). In order to maximize the sensitivity of the device, the four piezoresistors were connected in a full Wheatstone bridge configuration.

Figure 1: Thin Membrane; (a) Top view of the membrane with the piezoresistor position (in blue); (b) cross section over the green line view

Figure 2: Thick Membrane; (a) Top view of the membrane with the piezoresistor position (in blue); (b) cross section over the green line view.
Further detail on the microphone designs and the fabrication processes can be found in [3].

II - Modelling Details

For the FEM models of the microphones, we have used the COMSOL software version 4.2a. In order to reduce the computation load of the models, in both the described cases we reduced the model to one quarter of the actual membrane and then applied symmetry plane during the simulation. Together with the designs, we also defined probes in the centre of the membranes for evaluating the displacements and two other probes on the beam base (on the piezoresistor position), in order to evaluate the stresses of the piezoresistors during the displacement and estimate the sensibility of the devices. For simulation, we used the linear elastic model of mechanical physics; however we took into consideration the geometric non-linearity of the model.

A. Thin Membrane Microphone.

For the thin membrane, we used particular care for modeling the transition area between the thick region and the thin region of the membrane. For doing this, we reproduced the etching profile reported in the MultiMEMS handbook [4]. The model is shown in Figure 3.

Figure 3: Thin membrane microphone; COMSOL drawing

B. Thick Membrane Microphone.

Also for the thick membrane model, we reproduced the transition zone between the thin beam and the membrane using the profile from the MultiMEMS handbook [4]. The final model of the thick membrane microphone is shown in Figure 4.

III - Results

A. Thin Membrane Microphone Results

The first simulation was focused to estimate the lumped parameter k of the membrane. We simulated the structure to find the linear working region as reported in the Figure 5. By using the formula:

\[ F = pA = kx \]  \hspace{1cm} \{1\}

Where F is the force, p is the pressure, A is the area, k is the stiffness and z is the displacement we can easily determine (by using data from Figure 5) the stiffness k in the linear region which come out to be 10 N/m. Once we calculated the stiffness coefficient k,

we can easily extract the resonance frequency of the system by [5]:

\[ f_0 = \frac{1}{2\pi} \sqrt{\frac{k}{m}} \]  \hspace{1cm} \{2\}
Where \( m \) is the mass of the membrane in the approximation that all the points are moving at the same rate. By executing the calculation we found an \( f_0 \) of 2650 Hz.

We also calculated the resonance frequencies by FEM methods and we found an \( f_0 \) of 2459 Hz.

Figure 6 it is shown the higher resonance modes calculated by the COMSOL model. In this case we found an \( f_0 \) of 2459 Hz which is 191 Hz below the analytic estimated one.

Figure 6: Thin membrane microphone; Total displacement for different Eigen frequencies.

We also estimated the stress on the piezoresistors for both the x direction and y direction as reported in Figure 7 (2 probes for each direction placed in the corner of the piezoresistor).

Figure 7: Stress in x direction (green and light blue) and y direction (red and light blue) for the piezoresistor in the thin membrane microphone

By inserting the values of the stress \( \sigma_L \) and \( \sigma_T \) in \{3\} (the piezoresistor coefficients \( \Pi_L \) and \( \Pi_T \) are found in [4]) we can easily estimate the two \( \Delta R \) for the resistors.

\[
R = R_0(1 + \Pi_L \sigma_L + \Pi_T \sigma_T)
\]  \{3\}

Since the two couples of resistors on top of the membrane form a whetstone bridge it can be now estimated the total sensitivity (S) of the devices which come out to be:

\[ S_n = 0.44 \text{ mV/(VPa )} \]

**B. Thick Membrane Microphone Results**

Similar to the previous case, also for the thick membrane we simulated the membrane displacement with different pressures to find the linear region as shown in the Figure 8.

Figure 8: Pressure Vs Displacement for the thick membrane microphone; non-linear region

Using pressure and displacement from the above graph and substituting into \{1\} we can find the lumped parameter \( k \) in the linear region for the new system which it turned out to be \( k = 1.4 \text{ N/m} \). We can now use the new \( k \) for finding the resonance frequency using \{2\}. In this case we found a resonance frequency \( f_0 = 486 \text{ Hz} \) which is lower of the previous case as we expected.

In Figure 9, the first four Eigen frequencies resulting from FEM simulation of the thick membrane are shown. In this case the simulated \( f_0 \) is 437 Hz which is 49 Hz below the one calculated by the lumped element model.

The stresses in the piezoresistors were also estimated by using probes placed in their corners. The resulting x-stresses and y stresses are reported in Figure 10.

Figure 9: Thick membrane microphone; Total displacement for different Eigen frequencies.
By averaging the stress in x and y direction we calculated the resistance change for transversal and longitudinal piezoresistor. Again by inserting these resistance values into the Wheatstone bridge we estimated the new sensitivity for the thick membrane microphone which turn out to be $S_n = 1.2 \text{ mV/(VPa)}$.

IV – Discussions

There is a slight difference between the eigenfrequency $f_0$, estimated by the lumped element model and the simulated one. For the thin membrane microphone, we have under estimated the resonance frequency by 191 Hz which is around 7%. For the thick membrane microphone, again we underestimated the frequency by 49 Hz, which correspond an error around 10%. In both the cases we believe that the mismatches are given by the rough estimation of the mass. Furthermore we have implicitly assumed that the membranes are moving all at the same rate, which this is not completely true (the area closer to the beams and the beams do not have the same displacement as the centre of the membrane).

Regarding the sensitivity we found that the thick membrane microphones are around four times more sensitive compared to the thin membrane. This difference in sensitivity is also responsible of the higher non linearity of the thick membrane microphone which can be easily seen by comparing Figure 5 and Figure 8.

However, the preliminary measurements presented in [1] show that the thick membrane microphone is in reality twenty times more sensitive than the thin membrane. This is believed to be due to the gas flow through the slits which affects the pressure distribution motion and thus the sensitivity. Since a fully coupled simulation of the membrane in a fluid will be practically impossible to be simulated due to the high computational load, in the future work we will analytically model the cavity and the fluid flow going into the microphone cavity.

V – Conclusion and further work

In this work we used COMSOL for modeling two silicon microphones with different membrane thickness and shape. We calculated Eigen frequencies of the devices by using the lumped element model and compared with the simulated one. We found a difference around 7% for the thin membrane microphones and around 10% for the thick membrane microphone. Furthermore we estimated the sensitivity starting from the stress level of the piezoresistors, finding that the thick membrane microphone is around four times more sensitive of the thin membrane microphone. In the future work we will compare the simulated results with measurements and build an analytic model for the pressure inside the microphone cavity.

References

[1] Luca Petricca, Christopher Grinde and Per Ohlckers, A miniaturized bulk micromachined triaxial accelerometer fabricated using deep reactive etching through a multilevel thickness membrane, Journal of Microsystem Technologies, springer, volume 18, number 5 (2012), 613-622