Excerpt from the Proceedings of the 2011 COMSOL Conference in Bangalore

A MEMS Condenser Microphone for Consumer Applications

Dr S L Pinjare, Veda Sandeep Nagaraj, Savita, Saurabh Kesari, Roshan K R, Sagar M S

Nitte Meenakshi Institute of Technology,Bangalore

Author contact details: Saurabh Kesari-srsk91@gmail.com

Abstract: The MEMS microphone is also called microphone chip or silicon microphone.The pressure sensitive diaphragm is etched directly into a silicon chip by MEMS techniques and is usually accompanied with integrated preamplifier.Most MEMS microphones are variants of the condenser microphone design.The device consists of a polysilicon diaphragm suspended over a single crystal silicon backplate fabricated on silicon on insulator (SOI) wafers. The MEMS microphone has been successfully fabricated and tested in an anechoic chamber. The microphone is fabricated using a process that is compatible with inexpensive high volume production using unit processes that are currently used to fabricate inertial sensors.

In this paper we discuss the COMSOL analysis of 5 different membrane structures of MEMS Microphone. As can be observed in figure 1.We also discuss about the sensitivity analysis of different membrane structures with respect to different pressures using COMSOL. In figure 2 we showcase the circuit diagram of the MEMS Microphone.

Keywords: :MEMS Microphone, silicon on chip ,sensitivity analysis, membrane analysis

1. Introduction

MEMS microphones have been around for more than twenty years,[1,2] but have been slow to achieve high volume commercial success. One possible reason for this is the availability of very low cost electret condenser microphones that meet the performance requirements of most consumer applications. Recently, however, interest in MEMS microphones has increased due to several factors.[3] These include surface mount capability, integration of signal processing capability and low susceptibility to acceleration effects. Electret condenser microphones cannot withstand high temperatures and therefore cannot go through a standard high volume surface mount manufacturing flow. The need to add in a custom assembly flow for the microphone can add cost to the total system. A MEMS microphone that can be assembled using standard low cost, high volume surface mount techniques, would provide a system cost savings. Electret microphones are a complex mechanical assembly and although they have been miniaturized tremendously over the years, it is widely believed that further miniaturization will be difficult. Conversion of the mechanical motion into an electrical signal and/or amplification of the signal in an electret can be achieved by including a JFET or other device in the package. However, inclusion of complex circuit functionality such as that required to convert the analog signal to a digital signal or further sound processing would be difficult due to package space constraints. A MEMS microphone would not necessarily have this limitation.[4]

Lastly, electret microphones can be sensitive to acceleration which can often be present in consumer as well as industrial applications. MEMS microphones can often be designed tobe less sensitive to acceleration and thus, more suitable to a wider range of applications.

MEMS microphones have been fabricated using a variety of methods, each having advantages and disadvantages. Many microphone designs use a polysilicon diaphragm which moves in response to pressure variations.[5-7] The microphone presented here utilizes a polysilicon diaphragm in combination with a perforated backplate, forming two plates of a variable capacitor which are used to read out pressure variations. Often the diaphragm is solid and supported completely around its periphery.[8] However, this design uses a spring supported, thin polysilicon diaphragm in order to increase sensitivity. To avoid an additional deposition of material for a backplate, this design uses the device layer of an SOI wafer to form the backplate.

Perforations are formed in the backplate which are designed to provide a minimum acoustic resistance while maximizing capacitive area. A cavity is etched in the handle layer of the

SOI wafer to form a backside cavity for the microphone.

2. DESIGN

Several methods were used in order to attempt to predict the MEMS microphone performance and design the device to meet desired specifications. A model was constructed using MathCAD software to describe the operation of the microphone. Performance parameters such as sensitivity, damping, noise, quality factor, frequency response,acceleration sensitivity, and maximum sound pressure level were calculated and optimized for the fabrication capabilities. COMSOL software as well as ANSYS finite element modeling software was also used to validate and further refine the design. The finite element model of the MEMS microphone diaphragm is shown in figure 2. A thin polysilicon diaphragm was chosen to reduce the response of the microphone to acceleration.A Thin polysilicon material was selected in COMSOL Software to demonstrate the characteristics of a MEMS Microphone Even with the thin diaphragm, the deflection occurs at the springs and the diaphragm can be assumed to act as a rigid plate.

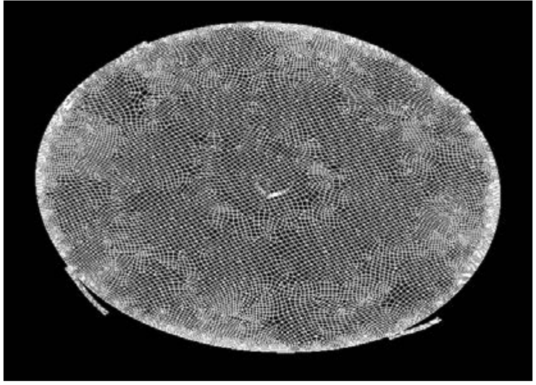


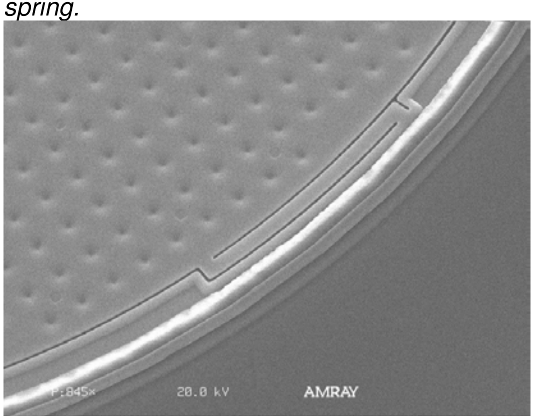
Figure 2: Finite Element Analysis model of MEMS Microphone Diaphragm

3. FABRICATION

The fabrication of this microphone structure draws upon processes used to fabricate over 200 million MEMS accelerometers. Trenches are etched in the device layer of an SOI wafer and then refilled with silicon dioxide and polysilicon. These trenches will later be the perforations in the backplate. Since the backplate is formed from the device layer of the SOI wafer, its thickness can be precisely controlled. Silicon dioxide is then deposited which will serve as one of the sacrificial layers and determine the capacitive gap of 3μm. The polysilicon diaphragm is deposited and then contact regions are patterned, followed by metal deposition. A scanning electron micrograph of the microphone diaphragm and one of its springs is shown in figure 3 Finally, the cavity is etched into the back of the microphone and XeF2 as well as HF are used to release the diaphragm. The cavity allows a high diaphragm compliance to be achieved resulting in a high sensitivity. The completed microphone is pictured in figures 4 and 5.

An 8 lead LCC package in which the MEMS microphone was packaged for evaluation is shown in figure 6. A hole in the package lid, allows pressure variations to reach the sensor diaphragm.

Figure 3: SEM of microphone diaphragm and spring.



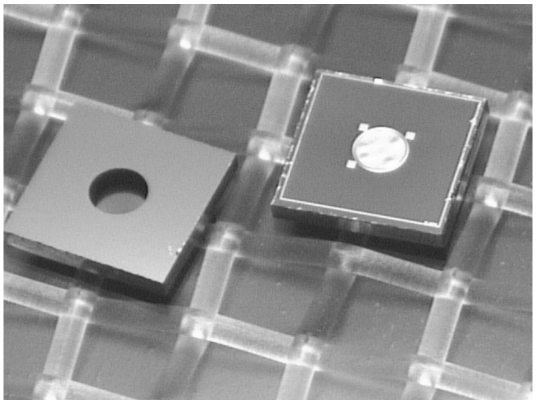


Figure 4: Photograph of backside of microphone die (left) next to frontside of die (right).

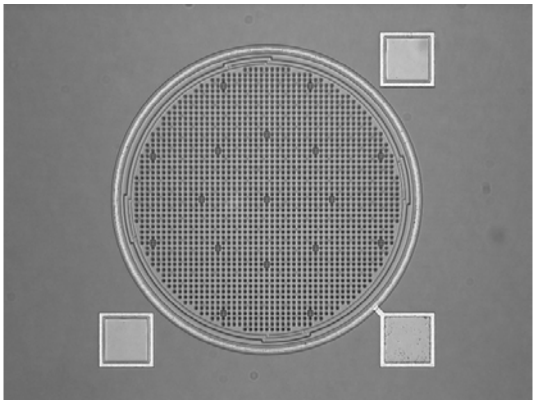


Figure 5: Photograph of MEMS microphone.

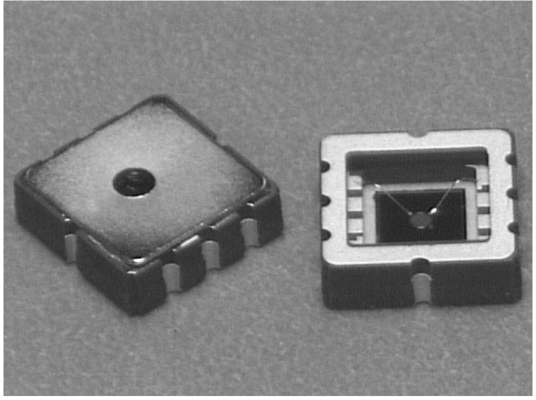
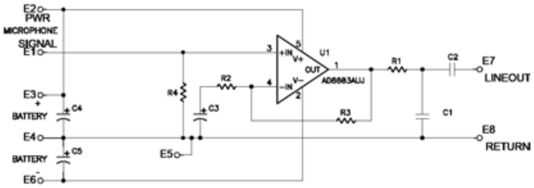


Figure 6: Photograph of MEMS microphone in 8 lead LCC package.

4. CHARACTERIZATION

Currently, the MEMS microphone does not integrate electronics on chip and thus must have a separate interface chip to provide the desired output. However, Analog Devices’ SOIMEMS inertial sensor process could be modified to integrate circuitry with the sensor.[13] A prototype discrete amplifier circuit was designed in order to verify and demonstrate the microphone. The circuit uses an Analog Devices AD8603 low noise, CMOS operational amplifier and is shown in figure 7. Small in size and offering sufficient dynamic performance, the amplifier circuit has been adequate for sound reproduction and initial dynamic performance characterization. The circuit works by translating the microphone's change in capacitance to a proportional voltage change through charge conservation. The ratio of capacitance change to the total nodal capacitance (amplifier input, PCB and static capacitance of the microphone plates) times the supply voltage, and gained by the amplifier gain (~ R3/R2) makes up the transfer function. Bipolar supplies and a ground referenced high value resistor are used to set the bias and keep static amplifier leakage currents from discharging the voltage across the sensor. The simplicity of the structure does yield trade offs for interference rejection and noise performance. With minimal voltage applied across the sensor and the relatively high input noise of the monolithic amplifier, the external circuit dominates the measured output noise. As well, the high gain of the amplifier requires that the system be shielded in order to avoid pick up of extraneous electrical interference sources such as 60Hz power. Measurements of various parameters of interest were made in a Bruel & Kjaer Type 4232 Anechoic Test Box with a speaker and reference microphone. Figure 8 shows the microphone’s response to a 94dB input sound pressure level at 1 kHz using the discrete readout circuit mentioned above. The typical sensitivity of the MEMS microphone with the discrete readout circuit is -47dB (ref 1V/Pa). Additional measurements will be presented which will highlight the performance of the MEMS microphone



Schematic of discrete circuit used to readout the changing capacitance of the senso

5. Use of COMSOL Multiphysics

The software package selected to model and simulate the microphone was COMSOL Multiphysics Version 4.1 . It is a powerful interactive environment for solving problems based on partial differential equations. Multiphysics was selected because there was previous in-house experience and expertise regarding its use as well as confidence in its capabilities. Initially, a non-acoustic model of the MEMS microphone (with the incident sound field represented by an analytic expression) was constructed. After successful implementation of the non-acoustic model, efforts were shifted to the implementation of an acoustic model by introducing the sound field. The sound field will impart a force onto the sensor. This is in direct contrast to some of the previous work whereby the acoustic wave was simulated by approximating the acoustic wave with a force applied to the surface of the sensor. To couple the acoustic and solid structure domains within Multiphysics, the Acoustic module was selected for the acoustic domain and the MEMS module was selected for the structural domain. After much research and work following examples in the Multiphysics manuals regarding how to couple the solid and fluid domains, a more efficient module was selected, which was the Acoustic-Structure Interaction module.

This module allows the user to couple the acoustical and structural domains by selecting which elements are of the fluid domain and which are of the solid domain. As well, boundary conditions can be applied and coupling equations are automatically established.

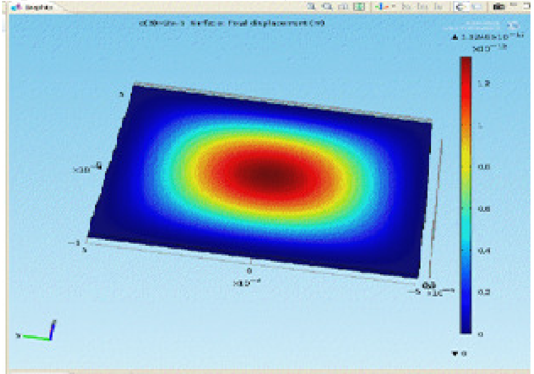


Figure 7: The Frequency analysis of MEMS Microphone indicating the centre region generating the highest frequency and correspondingly the frequency reduces.

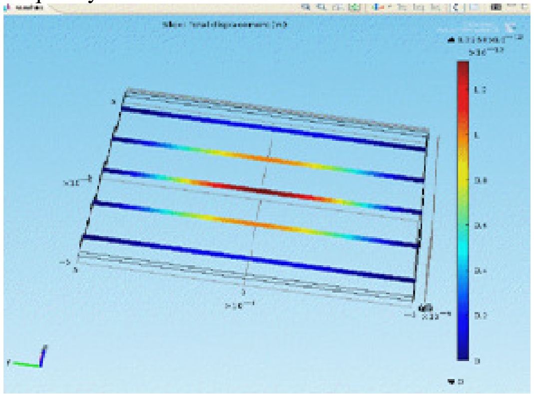


Figure 8:The Sensitivity Analysis of MEMS Microphone indicating the each region sensitivity and as illustrated the centre region is highly sensitive and correspondingly the sensitivity of a microphone reduces.

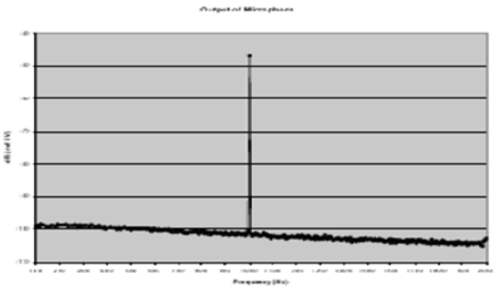


Figure 9 :*Graph of microphone response to 94dB input sound pressure level at 1 kHz using discrete readout circuit where the X-axis is frequency (Hz) and Y-axis is db level (ref 1v)..To indicate the output of a microphone.*

CONCLUSION

The Conclusion of the experiment is that a MEMS Condenser M icrophone was constructed using COMSOL Multiphysics Version 4.1 and different conditions of the microphone was tested using the software. Mainly the membrane analysis and sensitivity analysis was carried out using COMSOL Software and the results obtained was upto the expectations of the Researchers and the results were tallied with various international journals and the results obtained was according to the international Results.

ACKNOWLEDGEMENTS:

The authors of this paper would like to NPMASS for the establishment of National MEMS Design

Centre at Nitte Meenakshi Institute of Technology. The authors would also like to thank the Electronics and Communication Research and Development Lab of Nitte Meenakshi Institute of Technology for providing the opportunities to research on such a topic .We would also like to thank the COMSOL Multiphysics Pvt Ltd for providing the opportunity to present a paper for the COMSOL Conference at Bangalore 2011 .

REFERENCES

[1] D. Hohm, “Kapazitive Silizium-Sensoren fur Horschallanwendungen”, Fortschritt-Berichte VDI, VDI, Dusseldorf, 1986.

[2] P.R. Scheeper, A.G.H. Van der Donk, W. Olthuis, and P. Bergveld, “A Review of Silicon Microphones”, *Sensors and Actuators A,* vol. 44, pp. 1-11, 1994.

[3] Prismark Partners LLC, “The Prismark Wireless Technology Report”, www.prismark.com, March 2005.

[4] J. J. Neumann Jr. and K. J. Gabriel, “A Fully Integrated CMOS-MEMS Audio Microphone”, in *Digest Tech. Papers Transducers ’03 Conference*, Boston, June 8-12, 2003, pp. 230-233.

[5] P.R. Scheeper, A.G.H. Van der Donk, W. Olthuis, and P. Bergveld, “Fabrication of Silicon Condenser Microphones Using Single Wafer Technology”, *J. Microelectomech. Syst.,* vol. 1, pp. 147-154, 1992.

[6] P.-C. Hsu, C.H. Mastrangelo, K.D. Wise, “A High Sensitivity Polysilicon Diaphragm Condenser Microphone”, in *Digest Tech. Papers IEEE MEMS 1998*, pp. 580-585.

[7] S.B. Lee and P. V. Loeppert, “An Impedence Spectroscopic Study of MEMS Microphones”, in *Proc. IEEE Sensors,* vol. 2, pp. 1250-1255, 2002.

[8] J. J. Bernstein and J. T. Borenstein, “A Micromachined Silicon Condenser Microphone With On-Chip Amplifier”, in *Digest Tech. Papers Solid State Sensor and Actuator Workshop*, Hilton Head, SC, June 2-6, 1996, pp. 239-243.

[9] Z. Škvor, “On the Acoustical Resistance Due to Viscous Losses in the Air Gap of Electrostatic

[10] T. B. Gabrielson, “Fundamental Noise Limits for Miniature Acoustic and Vibration Sensors”, *Journal of Vibration and Acoustics,* vol. 117, pp. 405-410, 1995.

[11] T. B. Gabrielson, “Mechanical-Thermal Noise in Micromachined Acoustic and Vibration Sensors”, *IEEE Transactions on Electron Devices,* vol. 40, pp. 903-909, 1993. [12] L.E. Kinsler, A.R. Frey, A.B. Coppens, and J.V. Sanders, *Fundamentals of Acoustics,* John Wiley and Sons, Inc., New Jersey, 1982.

[13] T. Chen, T. W. Kelly, D. Collins, D. Bain, B. Berthold, T.J. Brosnihan, T. Denison, J. Kuang, M. O’Kane, and J.W. Weigold, “The Next Generation Integrated MEMS and CMOS Process on SOI Wafers for Overdamped Accelerometers”, in *Digest Tech. Papers Transducers ’05 Conference*, Seoul, June 5-9, 2005, pp. 1122-1125. 89