Silicon Nitride Corrugated Membrane with High-Width-Aspect-Ratio for MEMS Microphones

S. Shubham
Knowles Electronics, Itasca, IL, USA

INTRODUCTION: In this work, the corrugated membrane design with focus on the corrugation width to improve the acoustic sensitivity of the micro-machined silicon MEMS microphones has been presented. Finite Element Modeling approach and analytical analyzes have been carried out to optimize the acoustic sensitivity of the corrugated membrane. The measurement shows very good agreement with the simulated values using FEM. Acoustic sensitivity as high as 13.4nm/Pa, can be achieved with 65um corrugation width at 220MPa of initial silicon nitride stress for *N=3* corrugations, for a given diaphragm thickness,1.1um and corrugation height, 3.5um.

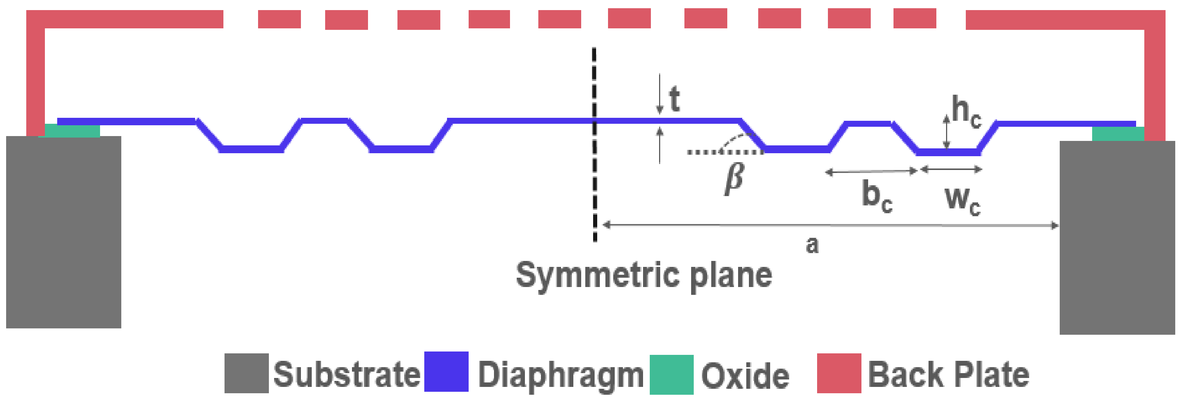

Figure 1. Cross-section schematic representation of corrugated membrane MEMS microphone

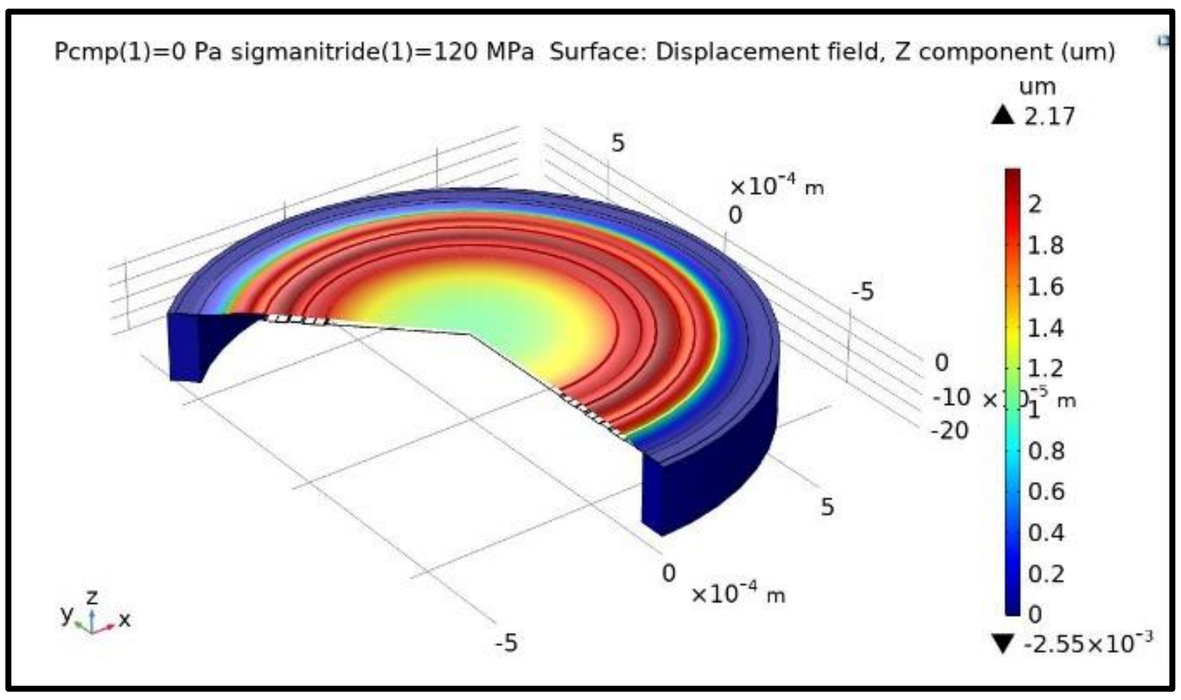

Figure 2. 3D deflection profile of corrugated membrane with initial stress if silicon nitride as 120MPa and N_c= 3 corrugations

COMPUTATIONAL METHODS:

$$\text{Acoustic Sensitivity} = \frac{\text{Center Deflection, m}}{\text{Sound Pressure, Pa}}$$

$$S\,(circular) \approx \frac{R^2}{8.t.\sigma_0}.\left(\frac{2.E.t^2}{(1-\vartheta^2).\sigma_0.R^2}+1\right)^{-1}$$

$$C_{corrugated} = C_{circular}\,(\sigma_0).$$

$$(1+6.sin\beta\,.\frac{{h_c}^2}{t^2}.N_C.\frac{w_c}{R-N_c.(w_c+b_c)})$$

$$S_1 = (1e-6).{w_c}^3 - (6e-4).{w_c}^2 + 0.0818.w_c + 1.9228$$

$$S_2 = (4e-6).{w_c}^3 - (0.0018).{w_c}^2 + 0.2324.w_c + 1.7295$$

$$S_3 = -(1e-7).{w_c}^4 + (7e-5).{w_c}^3 - (0.0114).{w_c}^2 + 0.7084.w_c - 1.4439$$

where, $S_1, S_2\ and\ S_3$ are acoustic sensitivity of the 1, 2 and 3 number of corrugations, respectively and w_c is the corrugation width

2D and 3D models have been implemented using Structural Mechanics module of the COMSOL Multiphysics® simulation software. The analytical expression is represented as mentioned.

Table 1. Geometry and Material Properties

Parameters	Value
Diaphragm Radius, a	700 um
Diaphragm material	Silicon Nitride
Diaphragm Thickness, t	1.1um
Corrugation Height, h_c	3.5um
Number of Corrugations, N_c	1, 2 and 3
Wall angle, β	60°
Distance between two corrugations, b_c	30um
Distance from constrained region to first corrugation	70um
Sacrificial oxide thickness	1.5um
Sacrificial oxide initial stress	100 MPa (compressive)
Density (Silicon Nitride)	3100 [kg/m^3]
Young`s modulus (Silicon Nitride)	250e9 [Pa]
Poisson`s ratio (Silicon Nitride)	0.23
Density (Sacrificial Oxide)	2200 [kg/m^3]
Young`s modulus (Sacrificial Oxide)	70e9 [Pa]
Poisson`s ratio (Sacrificial Oxide)	0.17

RESULTS:

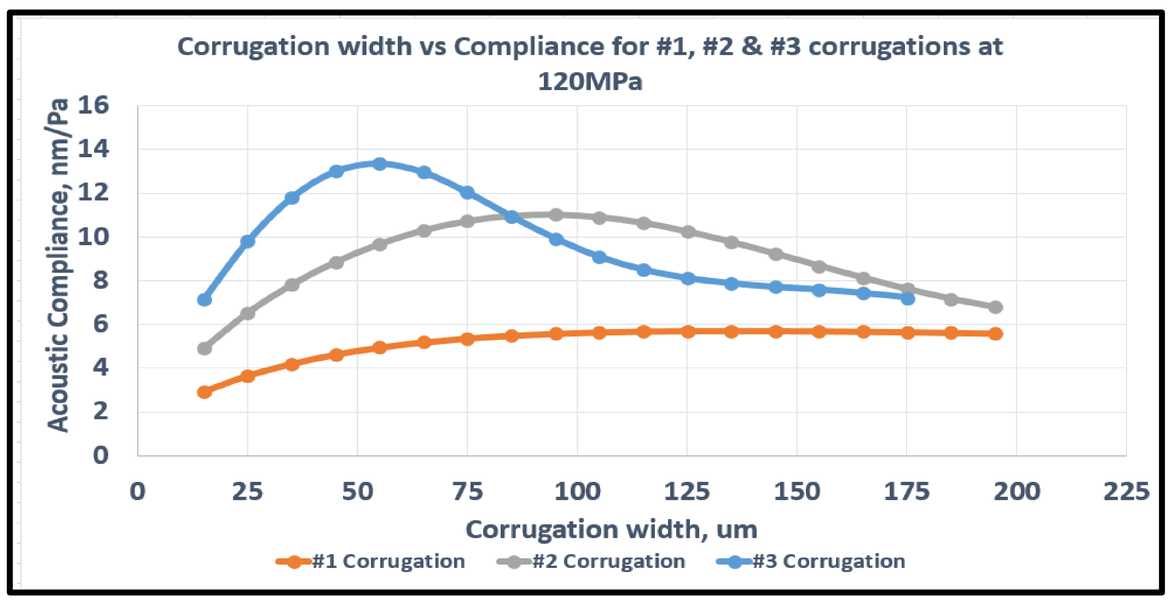

Figure 2. Acoustic compliance vs corrugation width for120MPa of initial silicon nitride stress with N_c= 1, 2 and 3 corrugations

Table 2. Microphone Acoustic Compliance

	#1 Corrugation		#2 Corrugations		#3 Corrugations	
Corrugation width	15um	35um	15um	35um	15um	35um
Simulated (nm/Pa)	1.45	1.86	2.5	3.74	3.73	6.1
Experimental (nm/Pa)	1.47	1.75	2.3	3.7	3.7	5.8

CONCLUSIONS:

The measurement shows very good agreement with simulated values at 220MPa of initial silicon nitride stress and can help to optimize acoustic sensitivity to boost sensor performance.

REFERENCES:

[1] P. R. Scheeper, W. Olthuis, and P. Bergveld, "The design, fabrication and testing of corrugated silicon nitride diaphragms", *J. Microelectromech. Syst.,* vol. 3, no. 1, pp. 36-42, Mar. 1994.

[2] M. Fuldner, A. Dehé, and Reinhard Lerch, "Analytical Analysis and Finite Element Simulation of Advanced Membranes for Silicon Microphones", *IEEE Sensors Journal*, vol. 5, no. 5, pp. 857-863, 2005.