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Sergey Y. Yurish

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FEM Based Optimization of Thin Membrane for Thermoelectric Energy Harvesting Devices

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Abstract: To ensure that any proposed microstructure design fortifies the device from the stress due to load applied during and post fabrication process its structural modeling is mandatory. The work presented in this paper highlights the need to optimize the thin membranes or films for fabrication of thermoelectric microstructures. This paper analyses the stress and deformation in thin film due to suction load during photolithography (SUSS MicroTec Lithography) which exerts 0.8 bar pressure on the film. Investigation and characterization of 3 types of thermoelectric membrane designs are presented using Finite Element Method software COMSOL Multiphysics^{TM} 3.3a at applied load of 80000 N/m^2. These characterizations are significant for the stability and feasibility of structures during processing and thereafter. A membrane experiencing stress above 5e^8 dynes/cm^2 is considered stressed film for the thermoelectric membrane. However, a microstructure with stress below 5e^8 dynes/cm^2 is taken low stressed. The microstructure device sized 9.7 mm × 9.7 mm is optimized by doing comparison of stress and deformation observed in differently designed membranes of varying thickness and widths. For successful fabrication and operation of a device it is necessary that before moving to fabrication stage, the proposed micro-structure device must be analyzed and optimized by structural modeling to avoid any kind of undesirable deformation or ductile failure.
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Keywords: Stress-strain analysis, Thermoelectric devices, Thin membrane, COMSOL Multiphysics^{TM} 3.3a, Ductile failure.

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1. Introduction

Thin films or membranes are vital components for microstructure devices especially for the application of micro-sensors. The small scale sensing devices such as temperature sensors, pressure sensors and ultrasonic sensors employ thin membranes in their structures. Some applications require highly sensitive membranes (e.g. ultrasonic sensing, piezoelectric devices etc.) whereas some applications need deep cavity formation in their device (such as micro-heaters) leading to thin membrane structures. The thickness of membrane varies according to need of the application. To ensure reliability of these thin film structures their optimization and characterization is mandatory as the membrane of these thin film devices is the most critical and fragile part which is easily subjected to ductile failure. The characterization results give the stress and deformation tolerance limit; beyond which if the load is applied device can face undesirable deformation or even structural failure. Kuan H. Lu et al. has presented that stress are directional and can be minimized [1].Three main factors that cause a membrane-based structure to bow are presented by Lynford O. Davis [2].

The micro-fabrication process involves various stress exerting steps which can affect device operation and performance if the structure is not optimized prior to fabrication stage. Our work is focused on investigating the induced stress and deformation in thin films of thermoelectric energy harvesting device when they are subjected to lithography process. SUSS MicroTec Lithography process exerts 0.8 bar pressure on Silicon microstructure that is equivalent to 80000 N/m^2 load on the film. Membranes of various thickness and widths have been analyzed for the load applied perpendicularly to the plane of membrane. Our interest is to observe Von-Mises stress and deformation in z-axis as x and y-axis deformation have negligible contribution to device failure. The static structural analysis is performed by using “Solid, Stress-Strain” option of “Structural Mechanics Module” in COMSOL 3.3a. It helps in understanding the displacements, stresses, and strains resulting in 3D objects under applied loads and constraints. After fabrication surface profiler can be used to investigate the deformation created on membrane [3].

2. Device Design and Simulation

A thermoelectric device works on principle of Seebeck effect which converts a temperature difference across junctions of two different materials into a potential difference inducing a flow of current through thermocouple of the two dissimilar materials. A membrane is an essential part in a thermoelectric device as cavity below it maintains a thermal isolation between the junctions [4]. A large potential difference or current flow at output requires a big cavity beneath the membrane reducing the thickness of membrane. Thus a thin membrane is desirable from thermoelectric device operation point of view but it also makes the structure more fragile and delicate. In this work mechanical stresses due to suction load during lithography process are evaluated for silicon membrane of thermoelectric energy harvesting device by using Structural Mechanics Module provided in COMSOL Multiphysics 3.3a. The device dimension is 9 × 9 mm^2. Simulation helps in knowing Von-Misses stress and deformation in target structure to checking ductile failure conditions before beginning fabrication process. An elastic body that is subjected to a system of loads in 3 dimensions, a complex 3 dimensional system of stresses is developed [5-6]. If the “Von-Mises Stress” exceeds the yield stress (ultimate tensile strength) then the material is considered to be at the failure condition. The applied load is 80000 N/m^2.

2.1. Notations of Parameters for Si in COMSOL 3.3a

E = Young’s Modulus : 160e^9 Pascal
V = Poisson’s Ratio : 0.28

a = Thermal Expansion coefficient : 2.6e^{-6} [1/K]
ρ = Density : 2329 [kg/m^3]

2.2. Optimization of Designs

The thermocouples of a thermoelectric device are designed to place laterally on the thin membrane between the 2 Silicon substrates – enclave and periphery respectively. Enclave is the enclosed hot portion encapsulated by the outermost substrate i.e. Periphery/Edge which is kept at low temperature. A thermocouple extends from enclave to periphery and so junctions lying on enclave have high temperature and junctions lying on periphery have low temperature. The in-between portion between these hot and cold junctions relies on membrane. Our target is to get optimum dimensions of membrane so that it contributes to achieve high output without putting risk to device structure. The thin membrane acts as a platform forming a bridge between the 2 substrates. We considered three types of membrane designs for investigation:

2.2.1. Ring-shaped Membrane

A thin membrane which acts as a platform forms a bridge between the enclave and periphery is evaluated for different thickness and width. The Fig. 1 displays the structural model of membrane illustrating ring-shaped membrane, periphery and enclave portion of structure. The sensitivity of membrane increases with increase in depth cavity beneath the membrane. To optimize the design membrane width varied from 200 to 600 µm with varying thickness of 10 to 90 µm as shown in Table 1.

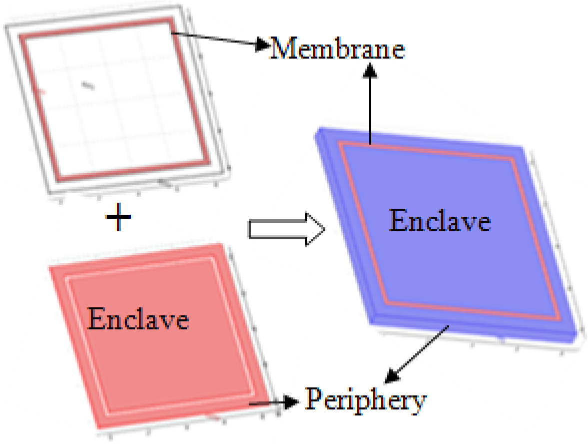


Fig. 1. COMSOL structural model for ring-shaped membrane.

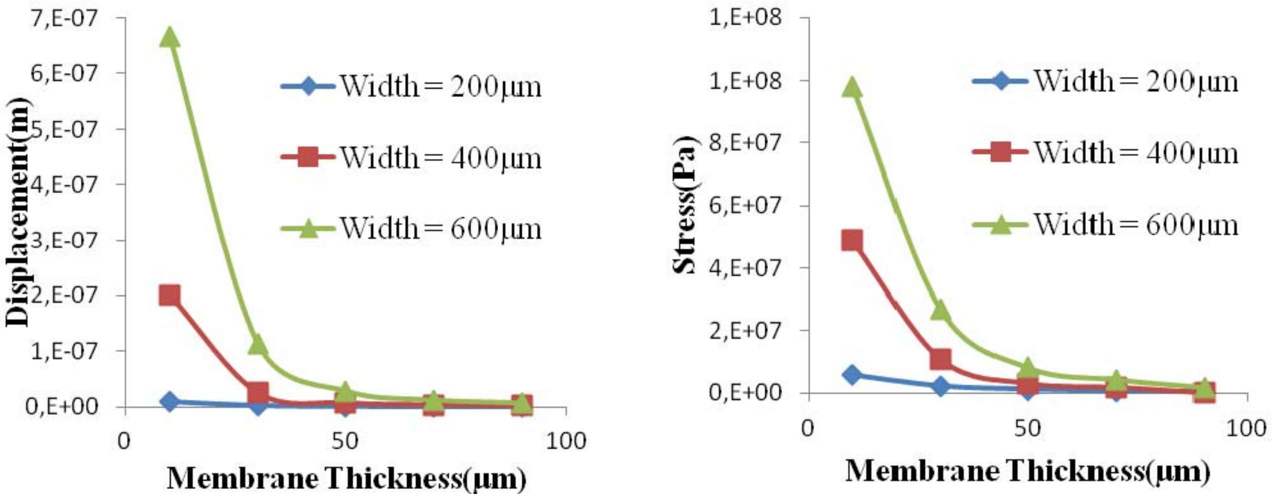
2.2.1.1. Observation

(a) 200 µm wide membranes show least stress and deformation where as 600 µm wide membranes faces high level of stress and deformation in them.
(b) For thickness below 30 µm, membranes show steep rise in value of stress and deformation as compare to higher range value of membrane thickness.

The graph plot in Fig. 2 gives a complete overview of dimensional effects of membrane size on its stress holding ability and deformation resisting capability.

Table 1. The stress and deformation observed Design (1) for different dimensions of membrane.

S. No.	Membrane Thickness (um)	Membrane width = 200 µm		Membrane width = 400 µm		Membrane width = 600 um	
		Stress (Pa)	Displacement (z-direction) (m)	Stress (Pa)	Displacement (z-direction) (m)	Stress (Pa)	Displacement (z-direction) (m)
1.	10	$5.9e^{6}$	$8.5e^{-9}$	4.9e7	$2.0e^{-7}$	$9.8e^{7}$	$6.7e^{-7}$
2.	30	$2.2e^{6}$	$2.4e^{-9}$	$1.1e^{7}$	$2.5e^{-8}$	$2.7e^{7}$	$1.12e^{-7}$
3.	50	$1.1e^{6}$	$1.01e^{-9}$	$3.1e^{6}$	$6.7e^{-9}$	$8.2e^{6}$	$2.78e^{-8}$
4.	70	$5.2e^{5}$	$6.2e^{-10}$	$1.86e^{6}$	$3.3e^{-9}$	$4.4e^{6}$	$1.16e^{-8}$
5.	90	$2.8e^{5}$	$4.45e^{-10}$	$1.2e^{5}$	$1.8e^{-9}$	$1.9e^{6}$	$6.3e^{-9}$



(a) (b)

Fig. 2. Ring-shaped membrane design evaluated for varying dimensions.

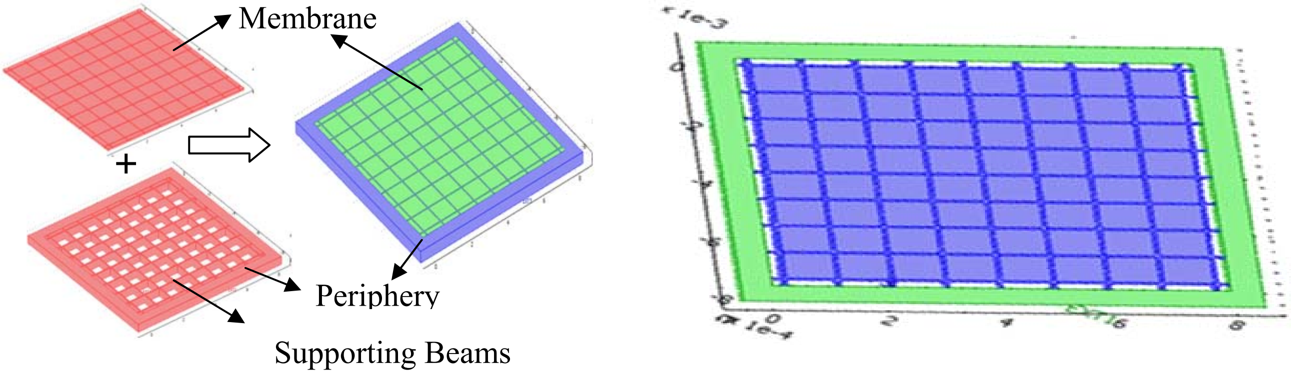
2.2.2. Beam-supported Membrane

The Enclave portion is reduced to same thickness as that of membrane in this design. The complete membrane structure is supported by 9 vertical 60 µm wide beams at a gap of 870 µm apart as shown in Fig. 3(a). The thickness of beams extends to thickness of the wafer. The number of beams can be more or less depending on stress tolerance limit and size of membrane.

A further modification is made in 2nd Design by eliminating the thin membrane between enclave and periphery increasing capability of thermal isolation between the hot and cold junctions. The modified design is displayed in Fig. 3(b). The difference in stress level experienced and deformation occurred on structure of both types of design 2 membrane is evaluated and analyzed in Table 2 and the comparison is displayed in Fig. 4 for stress and displacement at varying thickness level of membrane.

2.2.3. Freely-Suspended Membrane

The third proposed membrane design has the freely suspended enclave with supports provided at corners in 2 different ways. A comparison is drawn between the two different styles in Table 3 which is graphically plotted in Fig. 5.

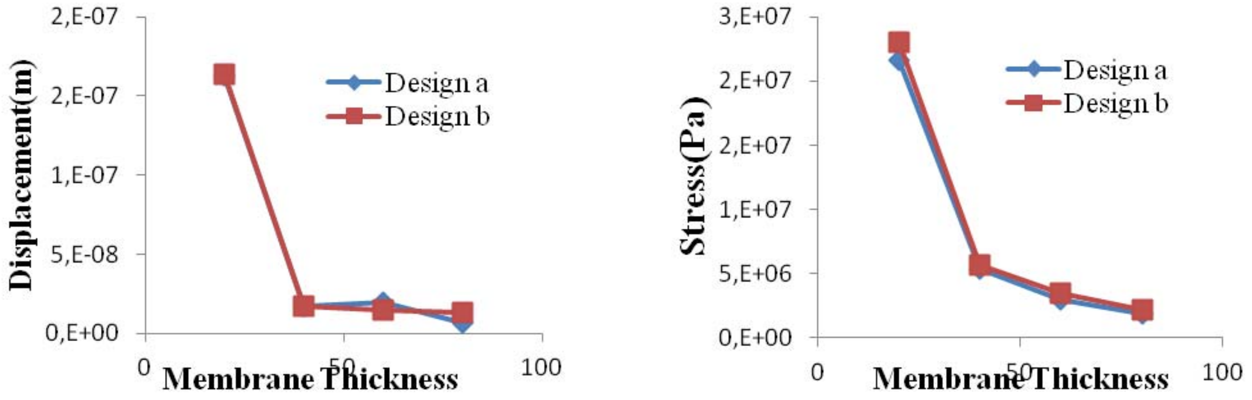


(a) (b)

Fig. 3. COMSOL Structural model for (a) design 2, and (b) modified style of Beam-supported Membrane.

Table 2. Comparison of Design 2(a) and 2(b) for stress and deformation in respective membranes.

Design 2	**Membrane Thickness**							
	20 μm		**40 μm**		**60 μm**		**80 μm**	
	Stress (Pa)	Displ. (m)	Stress (Pa)	Displ. (m)	Stress (Pa)	Displ. (m)	Stress (Pa)	Displ. (m)
a	$2.16e^{7}$	$1.63e^{-7}$	$5.4\ e^{6}$	$1.75e^{-8}$	$3.0\ e^{6}$	$1.94e^{-8}$	$1.9e^{6}$	$6.96e^{-9}$
b	$2.3e^{7}$	$1.64e^{-7}$	$5.7\ e^{6}$	$1.69e^{-8}$	$3.5e^{6}$	$1.49e^{-8}$	$2.2\ e^{6}$	$1.28e^{-8}$

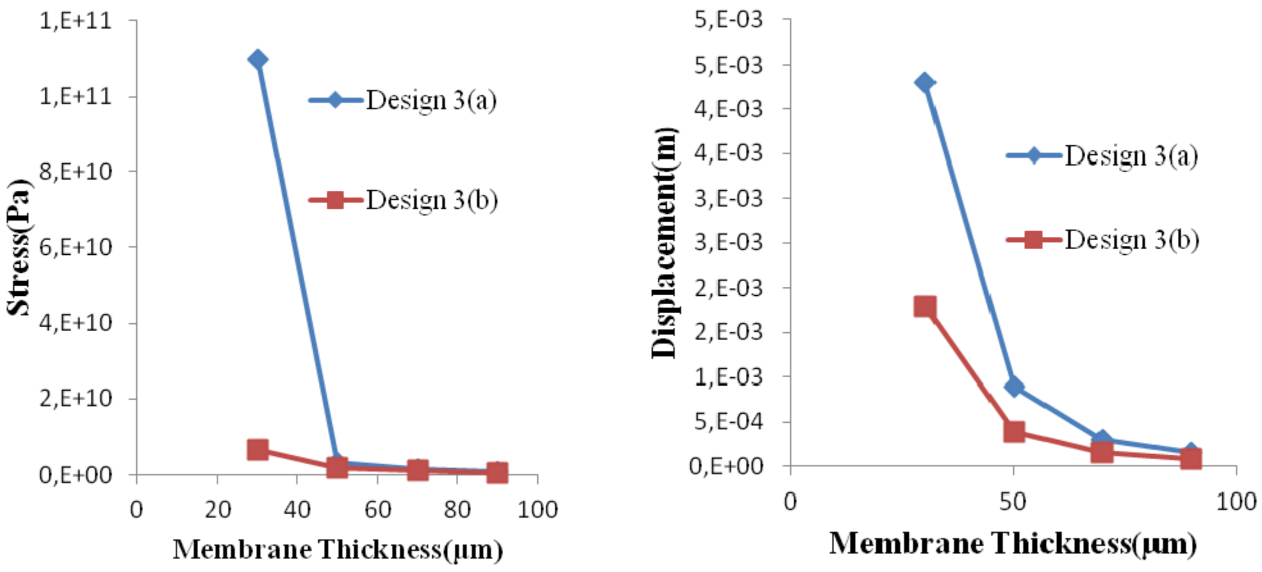


(a) (b)

Fig. 4. Comparison of Design 2(a) and 2 (b) beam-supported membranes for (a) displacement, and (b) stress occurred in membrane**.**

Table 3. Comparison of Design 3(a) and 3(b) for stress and deformation in respective membranes.

Design 3	**Membrane Thickness**							
	30 μm		**50 μm**		**70 μm**		**90 μm**	
	Stress (Pa)	Displ. (m)	Stress (Pa)	Displ. (m)	Stress (Pa)	Displ. (m)	Stress (Pa)	Displ. (m)
a	$110e^{9}$	$4.3e^{-3}$	$3.17e^{9}$	$9e^{-4}$	$1.58e^{9}$	$3e^{-4}$	$1.02e^{9}$	$1.5e^{-4}$
b	$6.5e^{9}$	$1.8e^{-3}$	$1.82e^{9}$	$3.8e^{-4}$	$1.10e^{9}$	$1.6e^{-4}$	$0.49e^{9}$	$0.78e^{-4}$



(a) (b)

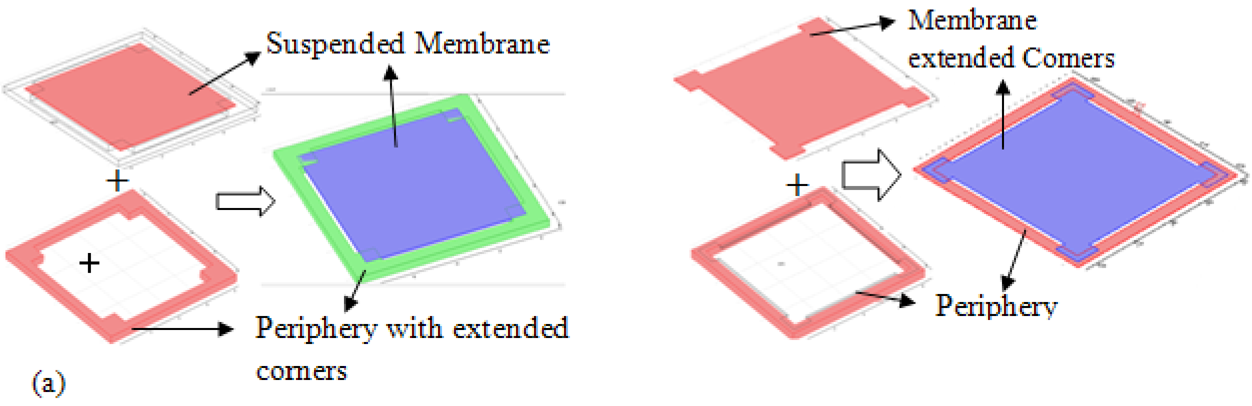
Fig. 5. Comparison of Design 3(a) and 3(b) on basis of stress experienced, and (b) deformation occurred.

2.2.3.1. Extended Membrane Corners

The extended corners of membrane rely on periphery substrate and enclave portion remains freely suspended as shown in Fig. 6 (a). The applied load will exert pressure and deformation on the suspended membrane.

2.2.3.2. Extended Periphery Corners

Periphery corners are extended to support suspended membrane without changing size of enclave periphery corners as shown in Fig. 6 (b).



(a) (b)

Fig. 6. COMSOL Structural model of freely suspended membrane design for (a) extended periphery corners, (b) extended membrane corners.

The structural simulation observation for deformation and stress is investigated in ring shaped membrane presented in Fig. 7 (a) and 7 (b) using COMSOL 3.3 a. The observations indicated clearly that maximum level of deformation and stress are experienced at corners represented by red colour in Fig. 7. This is due to tension created at corners in different planes.

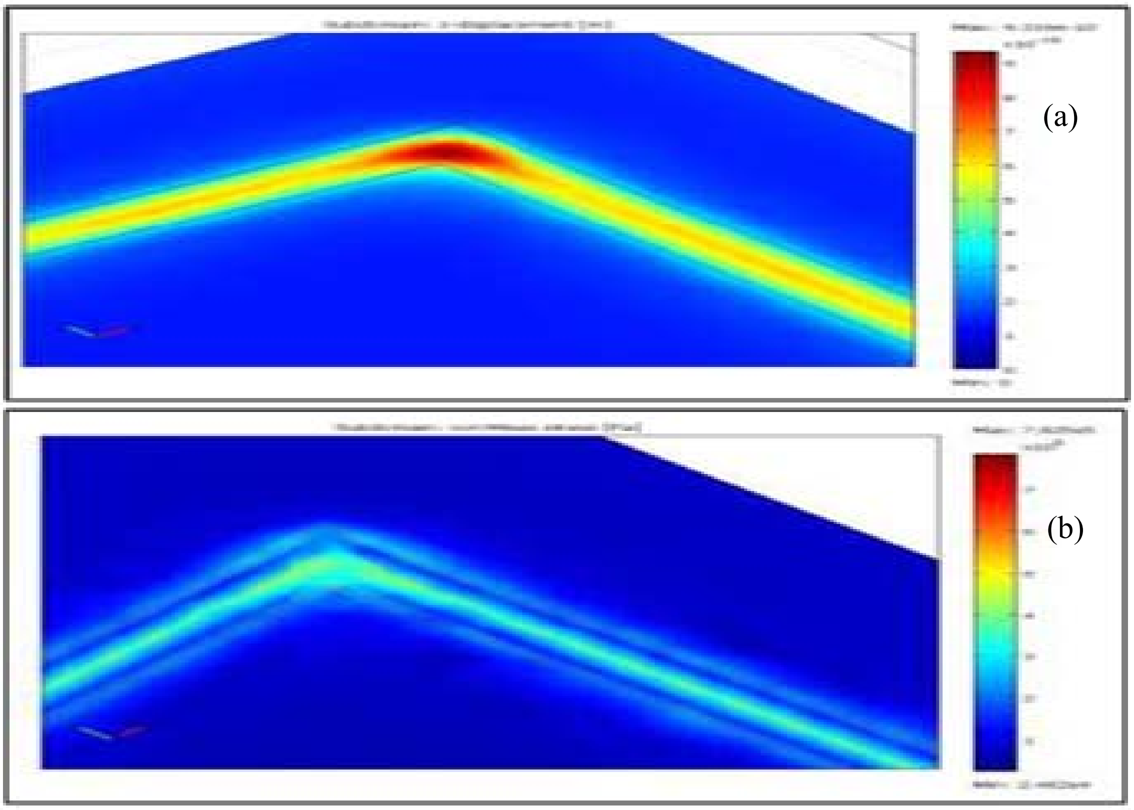


Fig. 7. Simulation image for (a) deformation, and (b) stress observed in ring shaped membrane design.

Deformation and Stress observed after "Stress-Strain" structural simulation of beam-supported membrane and freely-suspended membrane are depicted in Fig. 8 and Fig. 9 respectively.

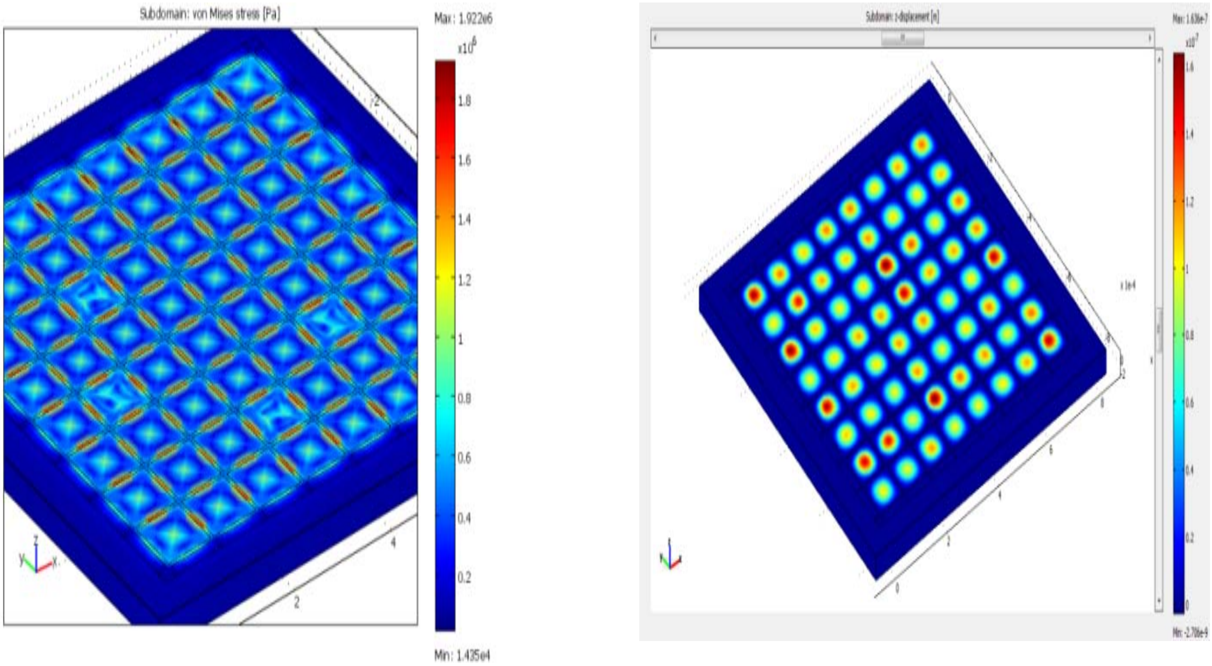
In suspended membrane design maximum deformation takes place in center portion and high stress is observed at membrane corners relying on extended periphery portion as seen in Fig. 9.

3. Evaluation and Results

Each of the proposed design is evaluated for the varying thickness level of membrane to find influence of thickness on membrane stress and deformation in Table 4.

By analyzing Table 4 it was concluded that freely suspended design i.e. design 3 of membrane is highly sensitive to structure breaking conditions as compare to design 1 and 2.

The graph is plotted to illustrate the influence of dimensional parameters on membrane capability to withstand the stress level and deformation occurrence. As Design 3 is highly stressed and lies far behind in terms of fortifying structure as compare to design 1 and design 2, so design 1 and 2 are compared for stress and displacement observed in membrane in Fig. 10.



(a) (b)

Fig. 8. Simulation image for (a) deformation and (b) stress observed in beam-supported membrane.

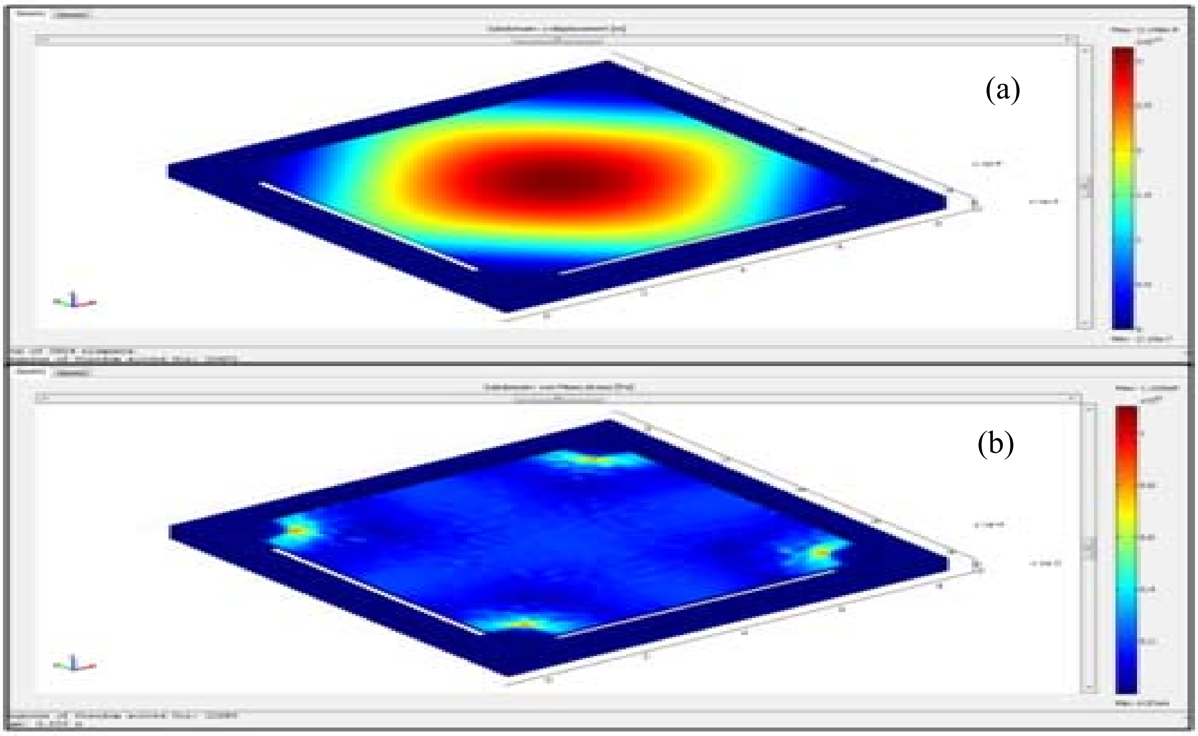
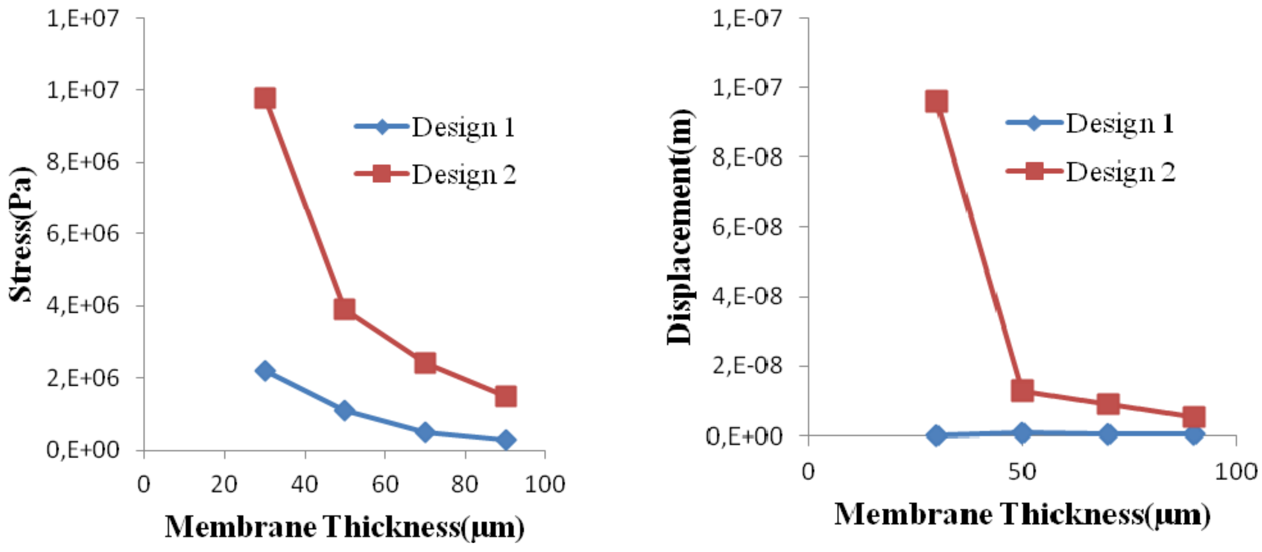


Fig. 9. Simulation image of freely suspended membrane design for (a) deformation, (b) stress.

It is evident that Design 1 i.e. ring-shaped membrane is less stressed and faces less deformation as compare to Design 2 i.e. beam-supported membrane. Moreover the deformation observed in ring-shaped membrane is almost negligible i.e. in nanometers or much smaller than that.

Table 4. Comparison of membrane design 1, 2 and 3 for developed stress and displacement in membrane.

DESIGN	Membrane Thickness							
	30 µm		50 µm		70 µm		90 µm	
	Stress (Pa)	Displ. (m)	Stress (Pa)	Displ. (m)	Stress (Pa)	Displ. (m)	Stress (Pa)	Displ. (m)
1.	$2.2e^{6}$	$0.24e^{-10}$	$1.1e^{6}$	$1.01e^{-9}$	$0.5e^{6}$	$6.2\ e^{-10}$	$0.3e^{6}$	$4.5e^{-10}$
2.	$9.8e^{6}$	$9.6e^{-8}$	$3.9e^{6}$	$1.28e^{-8}$	$2.4e^{6}$	$9e^{-9}$	$1.56e^{6}$	$5.6e^{-9}$
3.	$1.1e^{10}$	$0.43e^{-4}$	$3.2e^{9}$	$9.0e^{-4}$	$1.6e^{9}$	$3.1e^{-4}$	$1.02e^{9}$	$1.5e^{-4}$



(a) (b)

Fig. 10. Comparison of ring shaped and beam-supported membranes for (a) Stress and (b) Displacement.

4. Assessment

Design 1 experience least stress and deformation as compare to design 2 and 3 for any scale of membrane dimension. Design 3 (a) experienced larger stress and displacement in membrane as compare to design 3(b); however, 3 (a) and (b) both are highly stressed films. It will not be able to fortify the device or resist the ductile failure stage without showing any undesirable deformation in membrane.

5. Conclusion

Among the various membrane designs we considered, design 3 i.e. freely suspended membrane design is highly stressed and value of Von-Mises stress goes beyond the Young's Modulus value of Silicon which indicates that a freely suspended membrane cannot handle the applied load and is easily breakable. Thus it is mandatory that a wide freely suspended membrane should be supported by help of beams. Stress experienced by design 2 can be reduced by increasing the number of beams or by increasing width of applied beams to support the membrane. Design 1 i.e. ring-shaped membrane faces least stress and deformation; however, membrane corners experience maximum stress and deformation as compare to other portion of membrane as shown in Fig. 7. By providing support beams at corners the stress and deformation can be further reduced. So depending on application various measures can be implemented to reduce stress and unwanted deformation in membrane. The analyses of Design 1 by varying membrane thickness and width showed that films are highly stressed for thin and wider membranes especially for 30 µm or further thin films. As the thickness increases or width reduces the stress level also reduces. Similarly the deformation observed in thin membranes is larger than thick membranes. Also wider membranes are highly deformed in z-axis which is not desirable for a thermoelectric device.

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References

[1]. K H. Lu, X. Zhang, Suk-Kyu Ryu, R. Huang, and P. S. Ho, *Thermal Stresses Analysis of 3-D Interconnect*, Tenth International Workshop on Stress- Induced Phenomena in Metallization, in *Proc. of the AIP Conf.,* Vol. 1143, Texas, November 2008, pp. 224-230.

[2]. L. O. Davis, Investigation of residual and thermal stress on membrane-based MEMS devices, Master of Science thesis, *University of South Florida*, October 2009.

[3]. M. W. Denhoff, A measurement of Young's Modulus and residual stress in MEMS's bridges using a surface profiler, *J. Micromech. Microeng*, Vol. 13, 2010, pp. 686–692.

[4]. Till Huesgen, Peter Woias, Norbert Kockmann, Design and fabrication of MEMS thermoelectric generators with high temperature efficiency, *Sensors and Actuators A,* 145–146, 2008, Dec 2007, pp. 423–429.

[5]. http://www.keytometals.com/Article107.htm

[6]. http://ocw.mit.edu/courses/materials-science-and-engineering/3-11-mechanics-of-materials-fall-1999/modules/ss. David Roylance, Stress-Strain Curves, Department of Materials Science and Engineering *Massachusetts Institute of Technology*, August, 2001.

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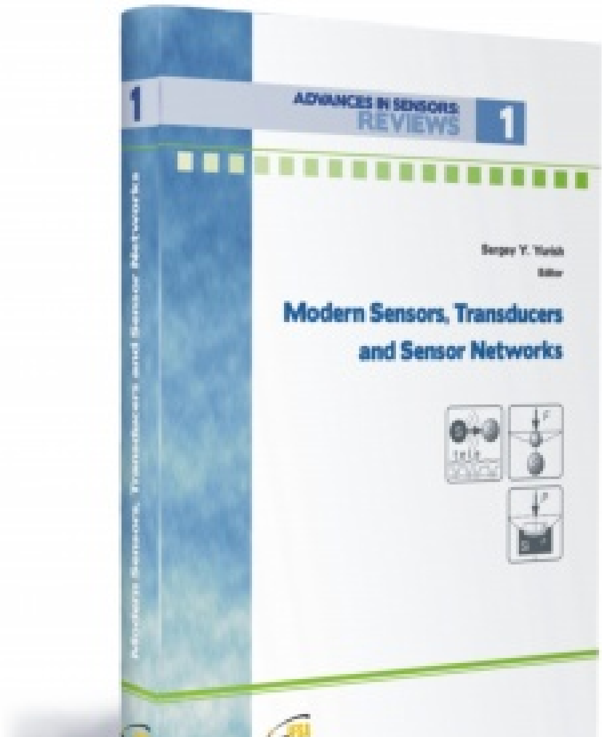

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