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COMSOL CONFERENCE
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Analysis of Mechanical Sensitivity of MEMS Pressure Diaphragm for contact formation

Overview

- Sensitivity of diaphragm governs the fundamental aspect of any pressure sensor design
- Novel design is presented to enhance mechanical sensitivity under atmospheric load
- Contact formation between diaphragm and a suspended rigid structure is established
- Role played by contact area in determining sensitivity

Introduction

Sensitivity is defined as increase in deflection of diaphragm as a result of increase in pressure acting on diaphragm

$$S_m = \frac{dw}{dP}$$

Single diaphragm becomes stiff upon deflection, to avoid stiffening a unique design has been introduced to be used for MEMS transducer

$$\frac{Pa^4}{Eh^4} = \frac{1}{A}\frac{y}{h} + \mathrm{B}\frac{y^3}{h^3}$$

where, ***P applied pressure***
E Young`s modulus
h thickness of diaphragm
y deflection at center
a diaphragm radius
A stiffness coeff. for linear term
B stiffness coeff. for non linear term

Resistance of diaphragm to load increases with cube of deflection

Previous designs using Corrugations achieved high sensitivities with Polycrystalline Silicon and Silicon Nitride as base diaphragm materials but extra fabrication processes increased the production cost

Design & Specifications

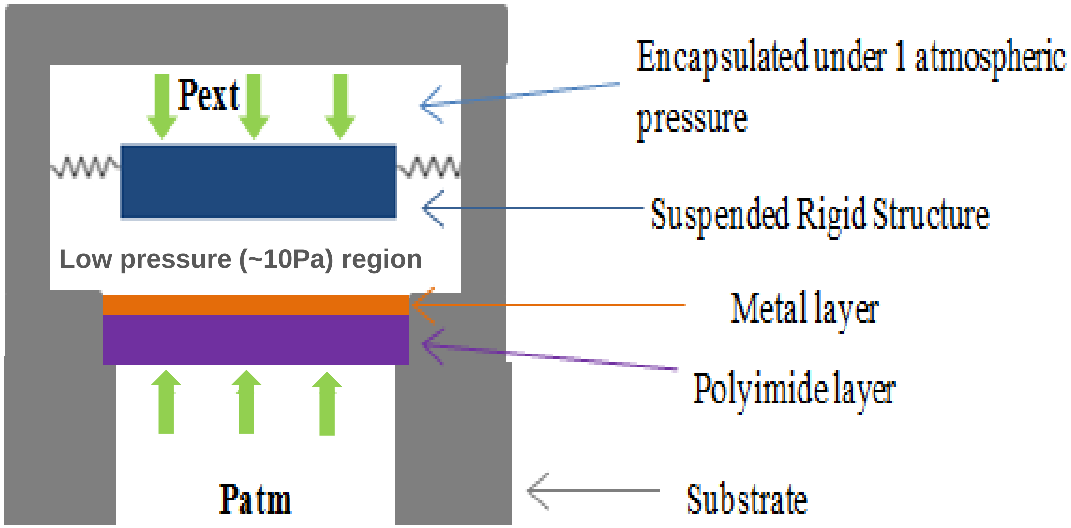


Table 1. Design Parameters

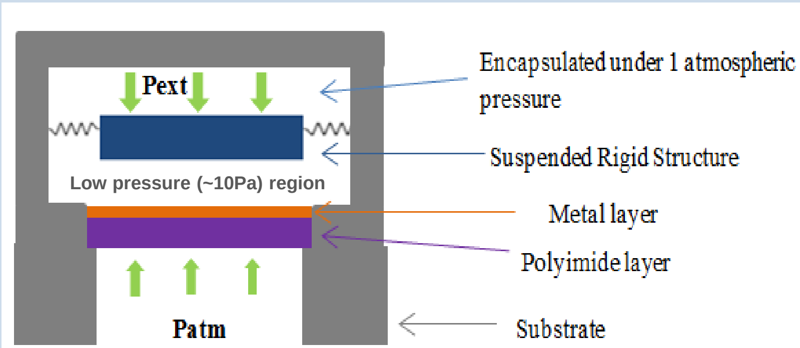
Parameters	Value
Diaphragm material	Polyimide and Metal
Diaphragm Radius	250 µm
Diaphragm (Polyimide) thickness	2 µm
Diaphragm (Metal) thickness	200 nm
Rigid Structure or Boss Radius	225 µm
Rigid Structure or Boss Thickness	10 µm
Thin suspension Radius	>250 µm
Suspension thickness	1 µm
Patm, Pext	100 kPa

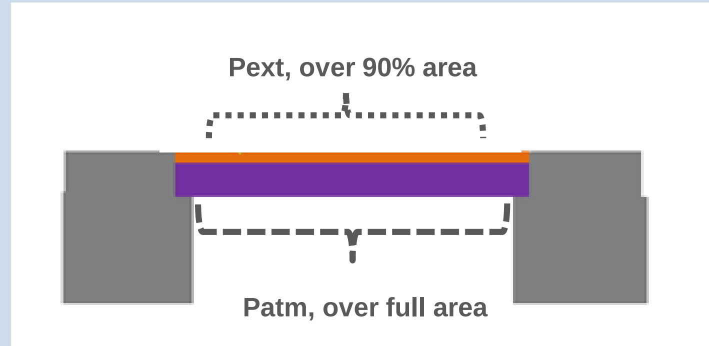
- **Diaphragm consists of Polyimide and metal layer**
- **Polymer materials are elastic and can withstand greater mechanical strain than silicon and are not so brittle**
- **Suspended rigid structure is encapsulated under 1 atm pressure or approx. 100kPa**
- **Metal layer is added to hold the very low pressure (~10Pa) between the two structures**

Diaphragm Sensitivity

With & Without contact formation

With contact formation	Without contact formation





- **Patm, atmospheric load (acting over 100% area) and Pext, external load (acting over 90% area)**
- **Assuming, external load in other situation is directly acting on diaphragm and there is no contact formation with suspended rigid structure**
- ***What difference in Sensitivity does that make ?***

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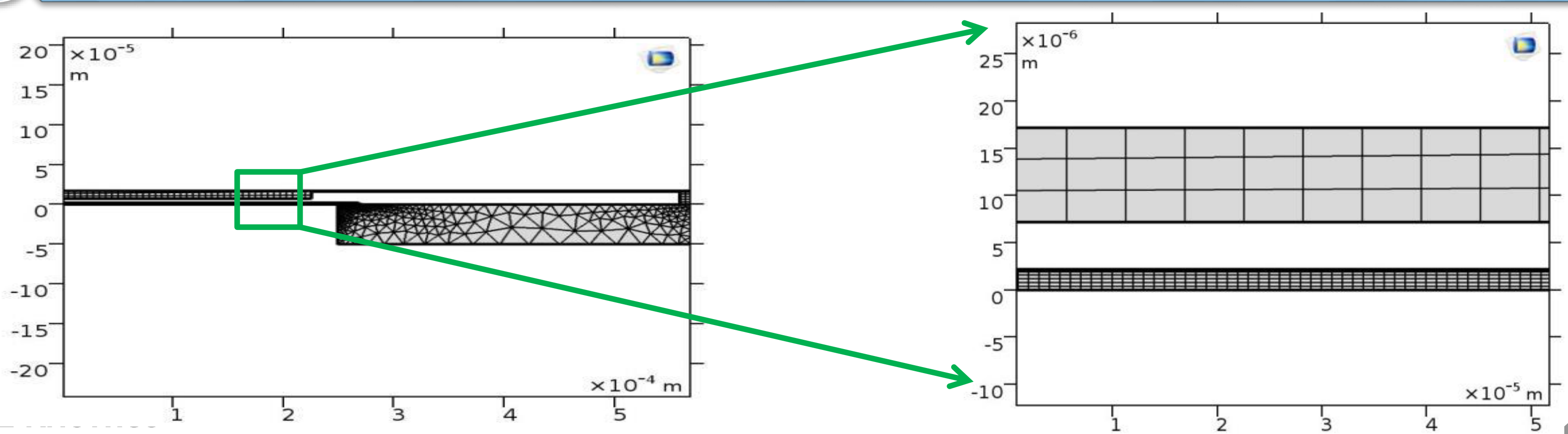
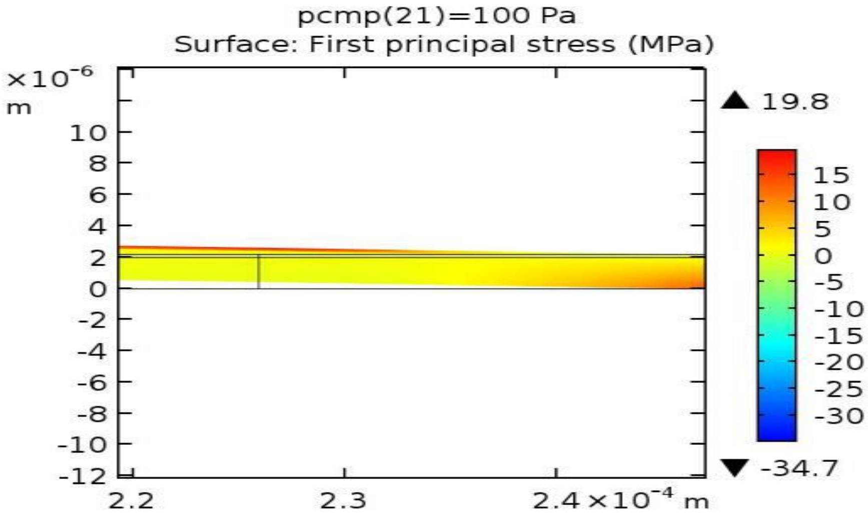
Use of COMSOL Multiphysics® software

- 2D axisymmetric model implemented for both cases in Structural Mechanics module
- Contact simulation uses *Augmented Lagrangian* algorithm which is more robust but computationally expensive, all surface are considered frictionless and adhesionless
- Highly non-linear problem is solved using Newton-Raphson iterative technique, this method converges if initial estimate for the solution is close
- Strategy used here is to ramp up load gradually, also called *Load ramping*
- *Destination (diaphragm)* surface is meshed twice compared to *Source (Rigid structure)*



Experimental Results

Without Contact Formation



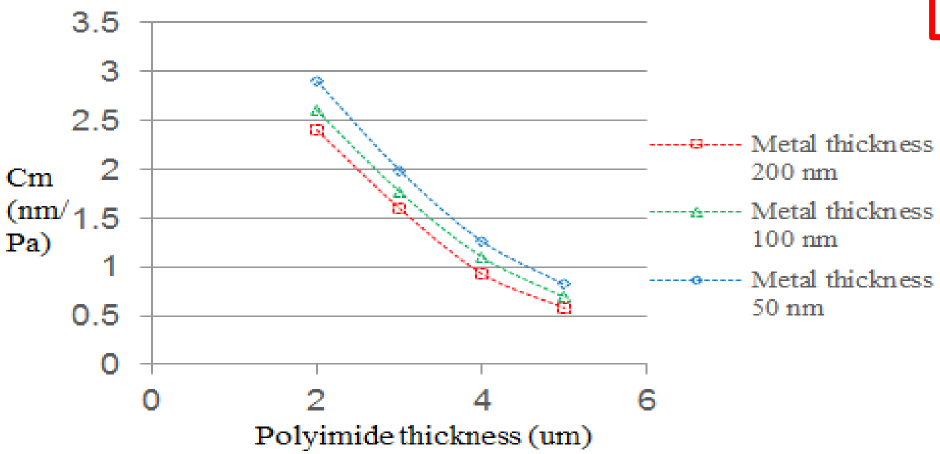


Table 2. Values and Results

Rad	Mat	td	Initial Stress	Sm	Max. Stress
250 [um]	PS	2.2 [um]	100 [MPa]	0.06 [nm/Pa]	125 [MPa]
250 [um]	PS	2.2 [um]	1 [MPa]	0.38 [nm/Pa]	33 [MPa]
250 [um]	PI	2.2 [um]	1 [MPa]	3.2 [nm/Pa]	27.4 [MPa]
250 [um]	PI +M	2 [um]+ 0.2[um]	1 [MPa]	2.4 [nm/Pa]	19.8 [MPa]

Rad: Diaphragm Radius, Mat: Material, td: Diaphragm thickness, PS: Polycrystalline Silicon, PI: Polyimide, M: Metal, Sm: Mechanical Sensitivity

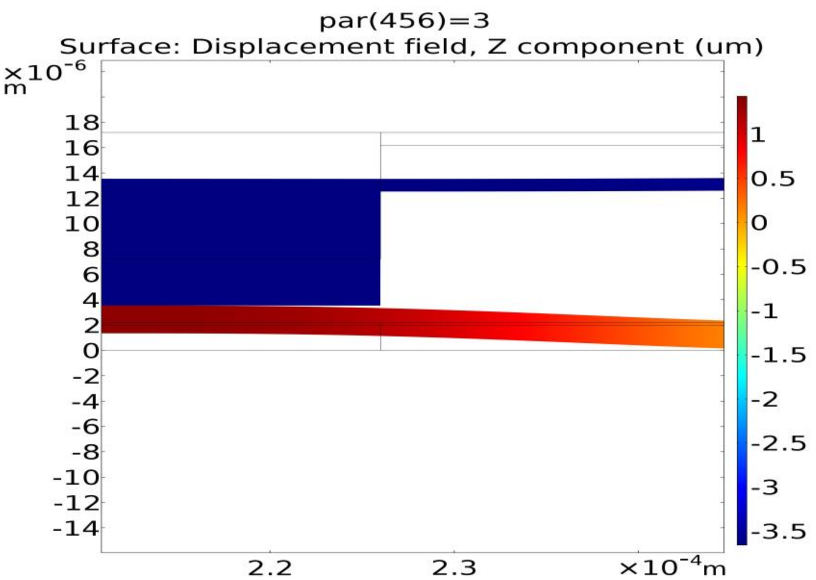
Thinner diaphragm offers higher sensitivity as,

$$S_m = \frac{A}{8\pi\sigma h_d}$$

*where **A** is area, **h_d** is thickness & **σ** is intrinsic stress*

Experimental Results

With Contact Formation



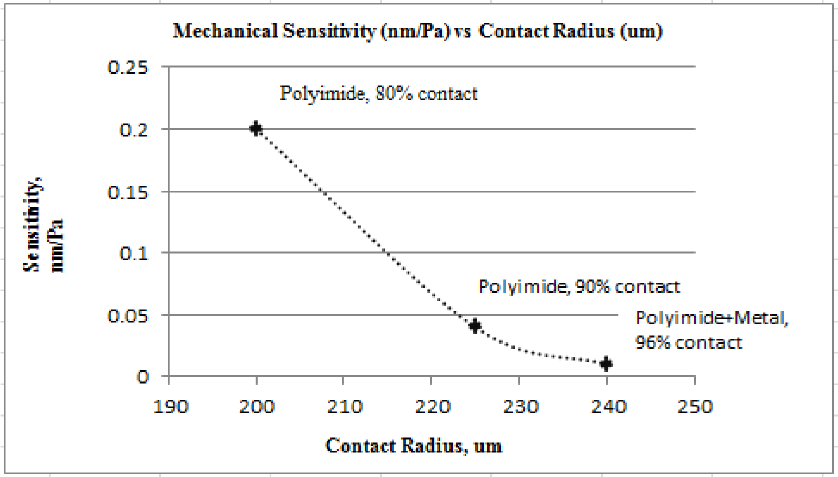


Table 3. Sensitivity variation with Contact Radius

Dia. Mat.	Rigid structure Mat.	Initial Stress	td	Contact Rad.	Sm
PI	PS	1 [MPa]	2.2 [um]	200 [um] (80%)	0.2 [nm/Pa]
PI	PS	1 [MPa]	2.2 [um]	225 [um] (90%)	0.04 [nm/Pa]
PI+M	PS	1 [MPa]	2.2 [um]	240 [um] (96%)	0.01 [nm/Pa]

Dia.Mat.: Diaphragm Material, td: diaphragm thickness, Rad.: Radius, Sm: Mechanical Sensitivity, PI: Polyimide, PS: Polycrystalline Silicon, M: Metal

- ❖ Expect sensitivity to be parallel combination of individual sensitivities of diaphragm and suspended rigid structure (*known sensitivity of >6nm/Pa*)

- ❖ **Sensitivity is extremely low compared to previous situation ! Why ???**

Conclusion

- Significant difference in sensitivities can be pointed to behavior of contact parts moving as a thick structure after contact establishment
- Sensitivity drops as contact area is increased
- ***COMSOL Multiphysics®*** simulation software helped in pointing out the differences between the two designs and how to approach further keeping sensitivity loss behavior in mind

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Thank You