# Design and Investigation of Photoacoustic Detector


BITS Pilani
Pilani Campus

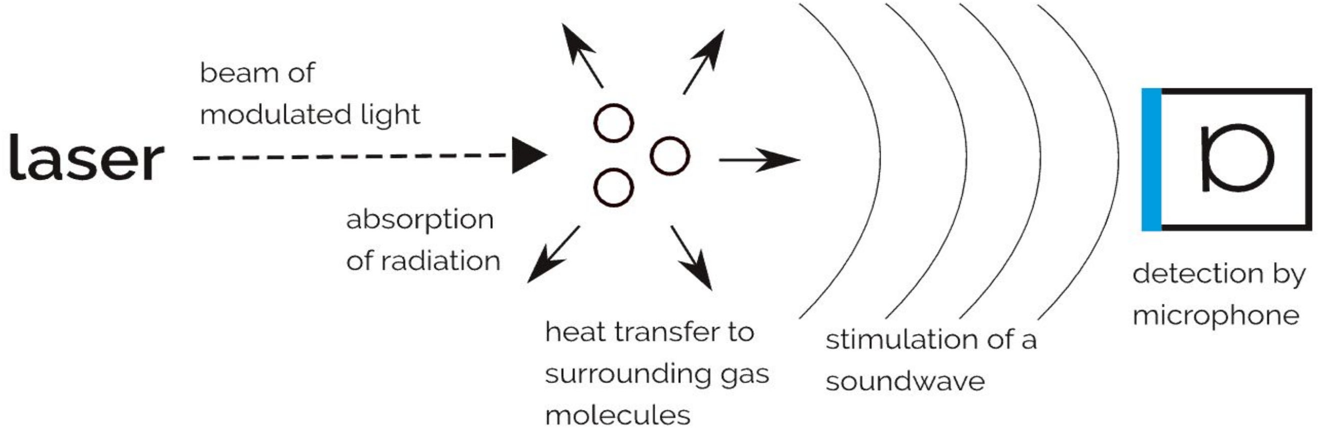
Reva Teotia
2019A3PS0268P

Dr. Aditi
Dr. Pankaj Arora

# Motivation and Background

Photoacoustic detectors are used in photoacoustic spectroscopy and imaging. Photoacoustic spectroscopy based gas sensors offer high sensitivity and long term operation stability. The gas detectors can be used for pollution check, breath analysis, leakage in manufacturing plants, etc.

It is based on photoacoustic effect.




MEMS microphone are used for detection due to their small size, high sensitivity and stable operation.

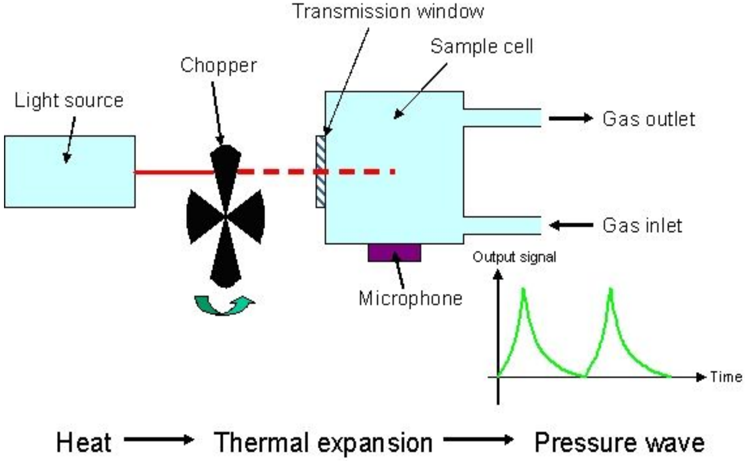
# Objectives

The main objective of the project is to design a MEMS microphone for photoacoustics based trace gas sensing application.

- Understanding the photoacoustics spectroscopy and application.
- Theoretical understanding of the design of MEMS microphone.
- Design of capacitive MEMS microphone in COMSOL Multiphysics 5.6.
- Study the relationship among various microphone parameters.

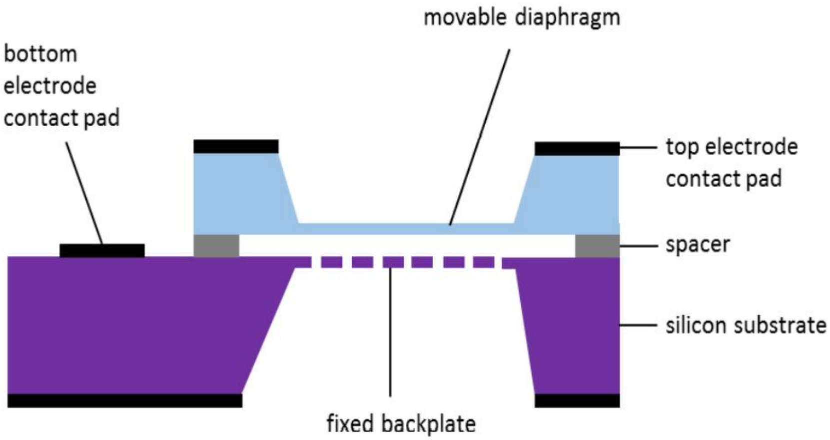
# Work done

Literature review of the theoretical background of photoacoustic spectroscopy and MEMS microphones.




This includes -

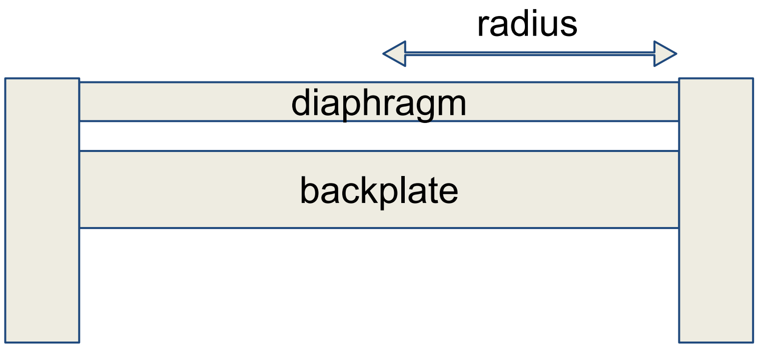
- The working principle of photoacoustic detectors.
- Different types of setups and methods employed in enhancing the photoacoustic response of molecules.
- Comparison among various light sources/emitters and detectors.
- Working of piezoresistive, piezoelectric and capacitive MEMS microphones
- Development and design aspect of capacitive microphones.
- Factors affecting the sensitivity and the methods employed to overcome them.

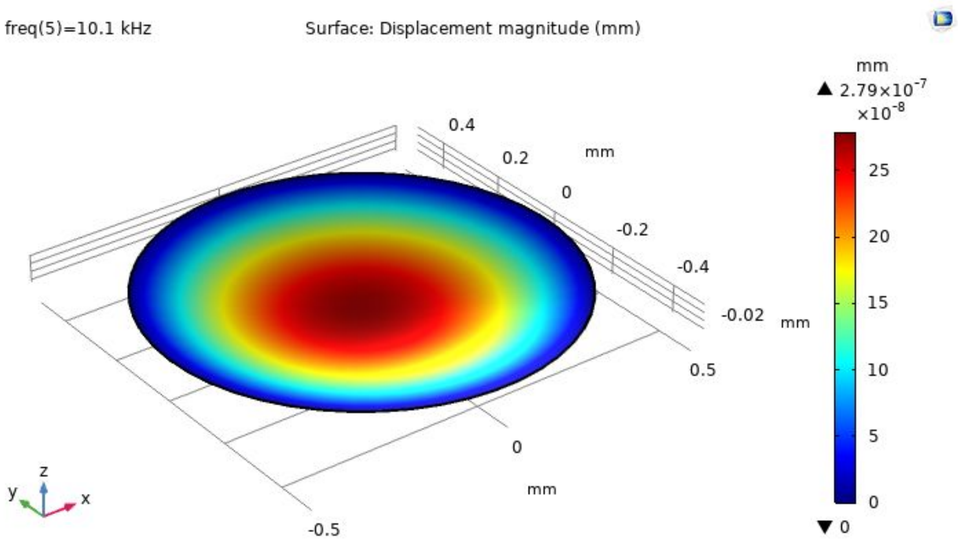


# Work done

Design of capacitive MEMS microphone in COMSOL Multiphysics 5.6.

An axisymmetric microphone with poly-Si diaphragm of radius 0.5mm and thickness 2 μm is studied with varying parameters.



# Work done

- Variation of diaphragm radius

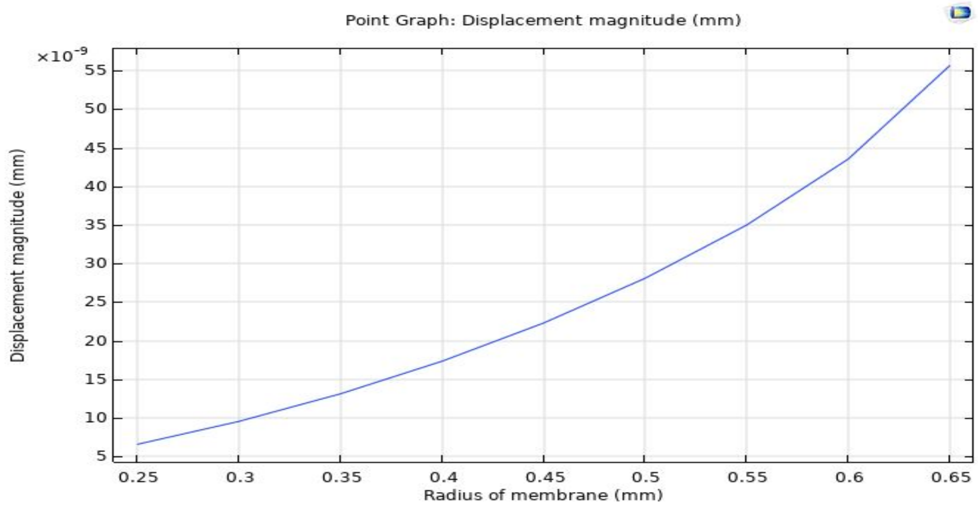
The mechanical sensitivity of a flat circular diaphragm is given by:

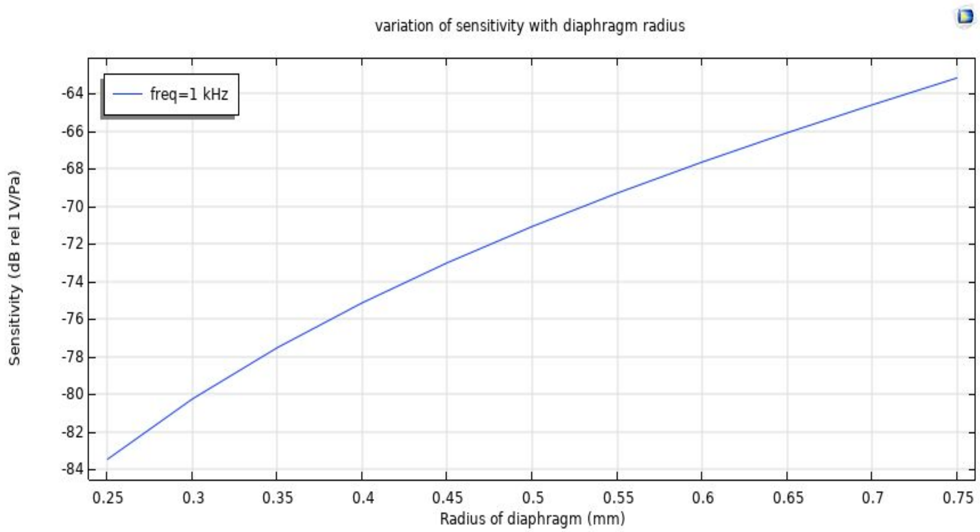
$$S_m = \frac{R^2}{4h[\sigma_0 + \frac{4Eh^2}{3(1-\nu^2)R^2}]}$$

The center deflection is expressed as:

$$\frac{PR^4}{Eh^4} = \left(\frac{5.33}{1-\nu^2} + \frac{4\sigma_0 R^2}{Eh^2}\right)\frac{y}{h} + \frac{2.83}{1-\nu^2}\left(\frac{y}{h}\right)^3$$

It can be seen that by making radius double, the displacement increase by 4 times.



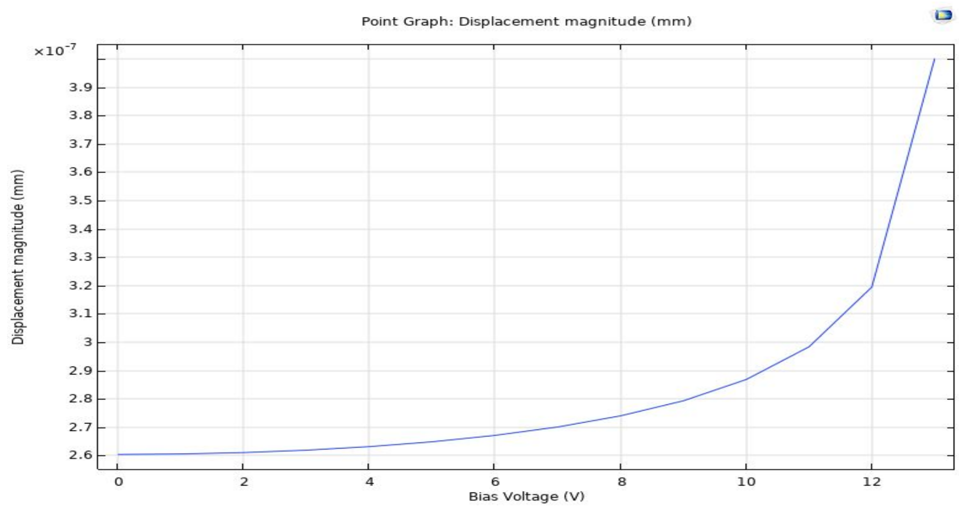



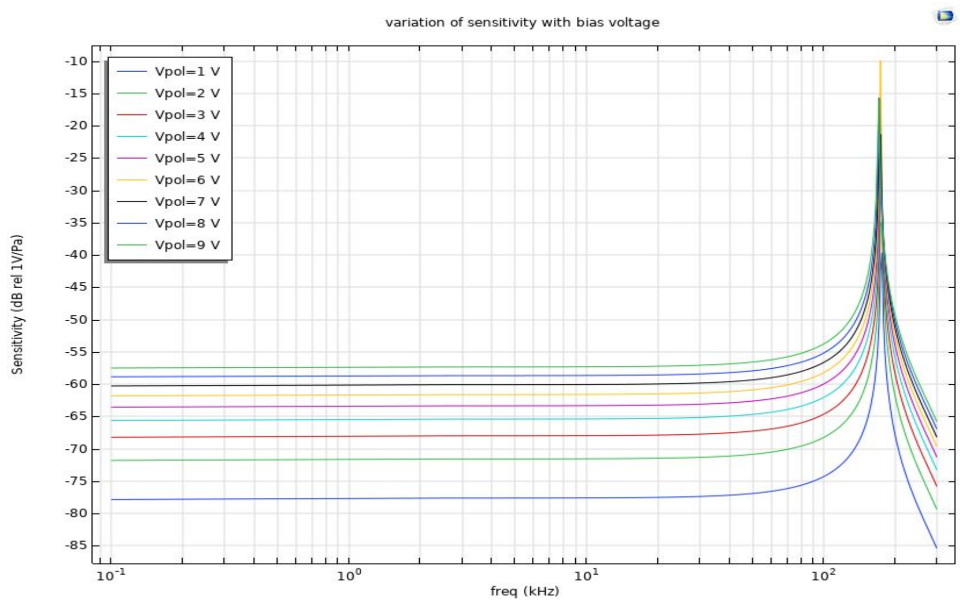
# Work done

- Variation of bias voltage

Pull-in voltage 16V. This aligns with the simulation. The bias voltage is taken as 9V.

As open-circuit sensitivity is directly proportional to bias voltage, increase in bias voltage the from 1V to 9V, the sensitivity increased from -77.7dB to -57.4 dB.



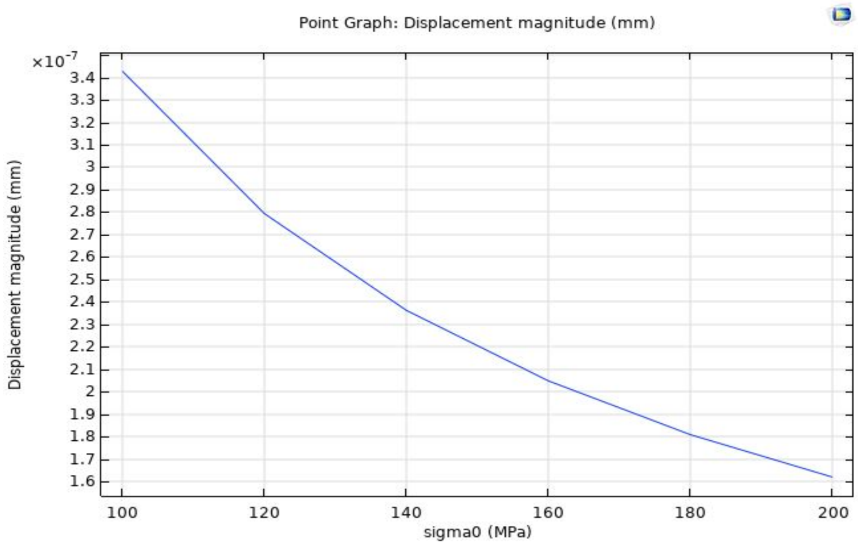



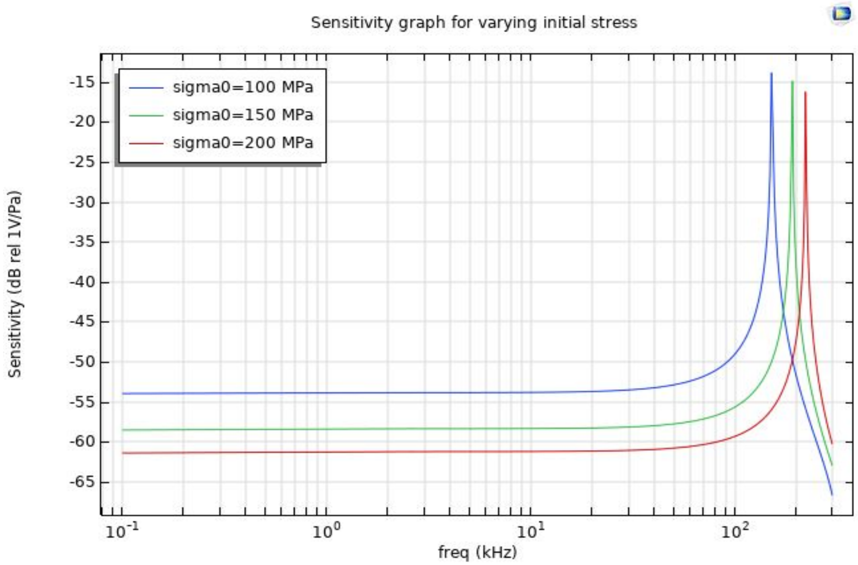
# Work done

- Variation of residual stress

Increasing residual stress results in decreased diaphragm movement.

As the diaphragm movement decrease, the sensitivity of the microphone decrease to about 7dB.



# Work done

- Corrugated Membrane

The center deflection of a corrugated circular diaphragm with clamped edges can be expressed as:

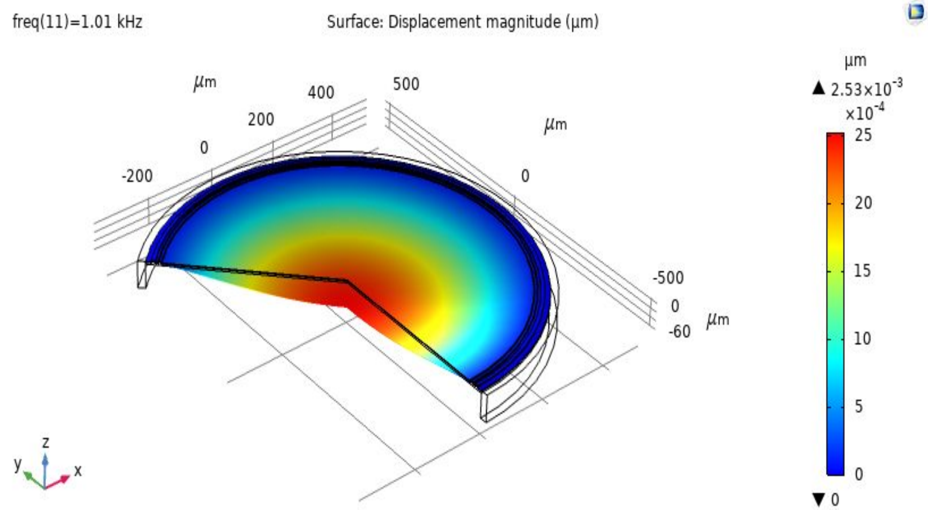
$$P = [a_p E \frac{h^4}{R^4} + \frac{4h^2\sigma}{R^2}]\frac{y}{h} + b_p \frac{E}{(1-v^2)} \cdot \frac{h^4}{R^4} \cdot \frac{y^3}{h^3}$$

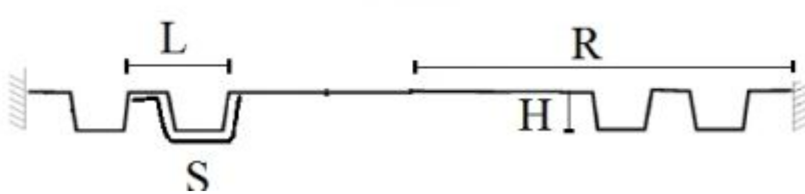
where $a_p$ and $b_p$ are given by:

$$a_p = \frac{2(q+1)(q+3)}{3(1+\frac{v^2}{q^2})} \qquad b_p = 32\frac{1-v^2}{q^2-9}\left(\frac{1}{6} + \frac{3-v}{(q-v)(q+3)}\right)$$

and q is corrugated profile factor

$$q^2 = \frac{S}{L}(1 + 1.5\frac{H^2}{h^2})$$



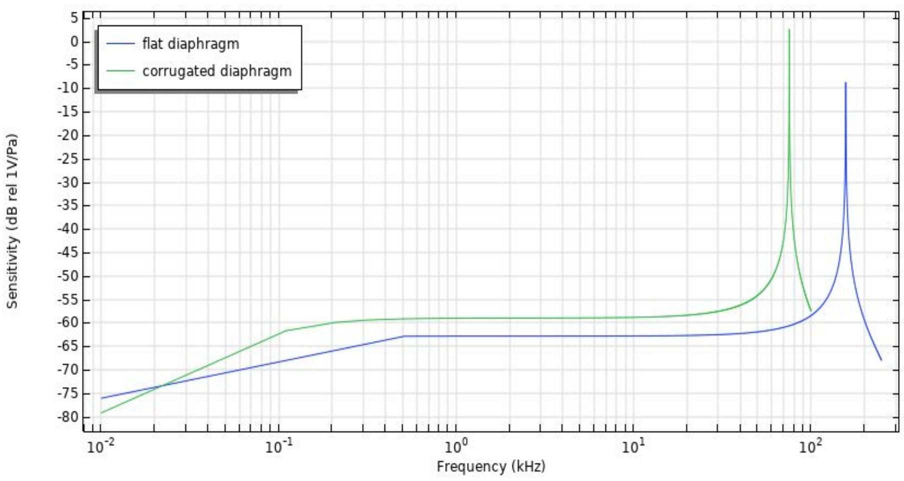



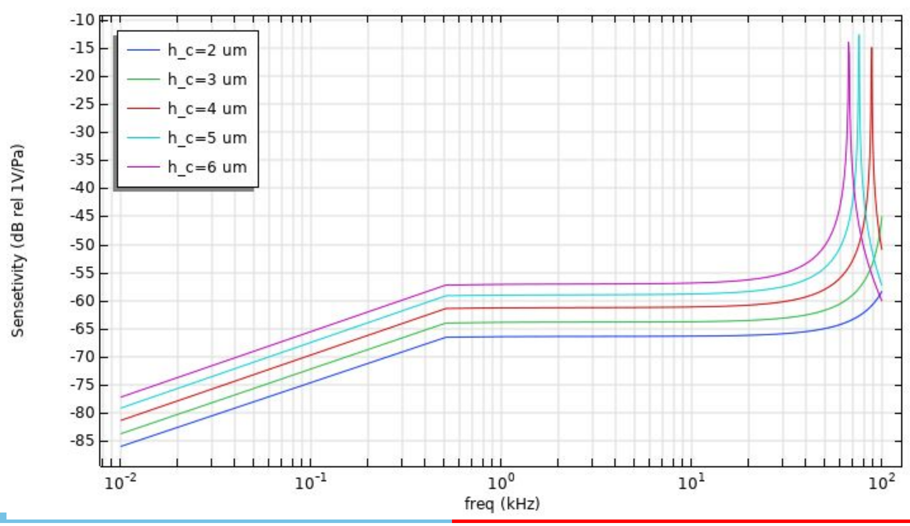
# Work done

- Corrugated Membrane

Corrugated membrane reduce the effect of residual stress and therefore perform better than flat diaphragm.

With increasing corrugation height, the mechanical sensitivity of the microphone increases.



# Results and discussion

- Increasing bias voltage increases the open-circuit sensitivity.
- The mechanical sensitivity increases with increase in diaphragm radius but this results in smaller bandwidth.
- The residual stress significantly affects the performance of the microphone.
- To reduce the effect of residual stress, corrugated diaphragm is being used. The sensitivity of corrugated diaphragm microphone increases with increase in corrugation height.

# Future Scope

- Study of viscous damping in the air-gap and backchamber.

  Effect of air-gap, holes in the backplate and volume of backchamber on the microphone response.

- Thermal and mechanical noise in the microphone response.

  Determination of noise floor in the application settings.

- Analysis of microphone array.

  Signal-to-noise ratio can be improved by using microphone array.

  Various scheme for microphone placement and its effect on the signal can be studied.

# Thank You