Presented at the COMSOL Conference 2008 Hannover

Modeling and Characterization of Superconducting MEMS for Microwave Applications in Radioastronomy

Nouha ALCHEIKH (PhD)

Pascal XAVIER

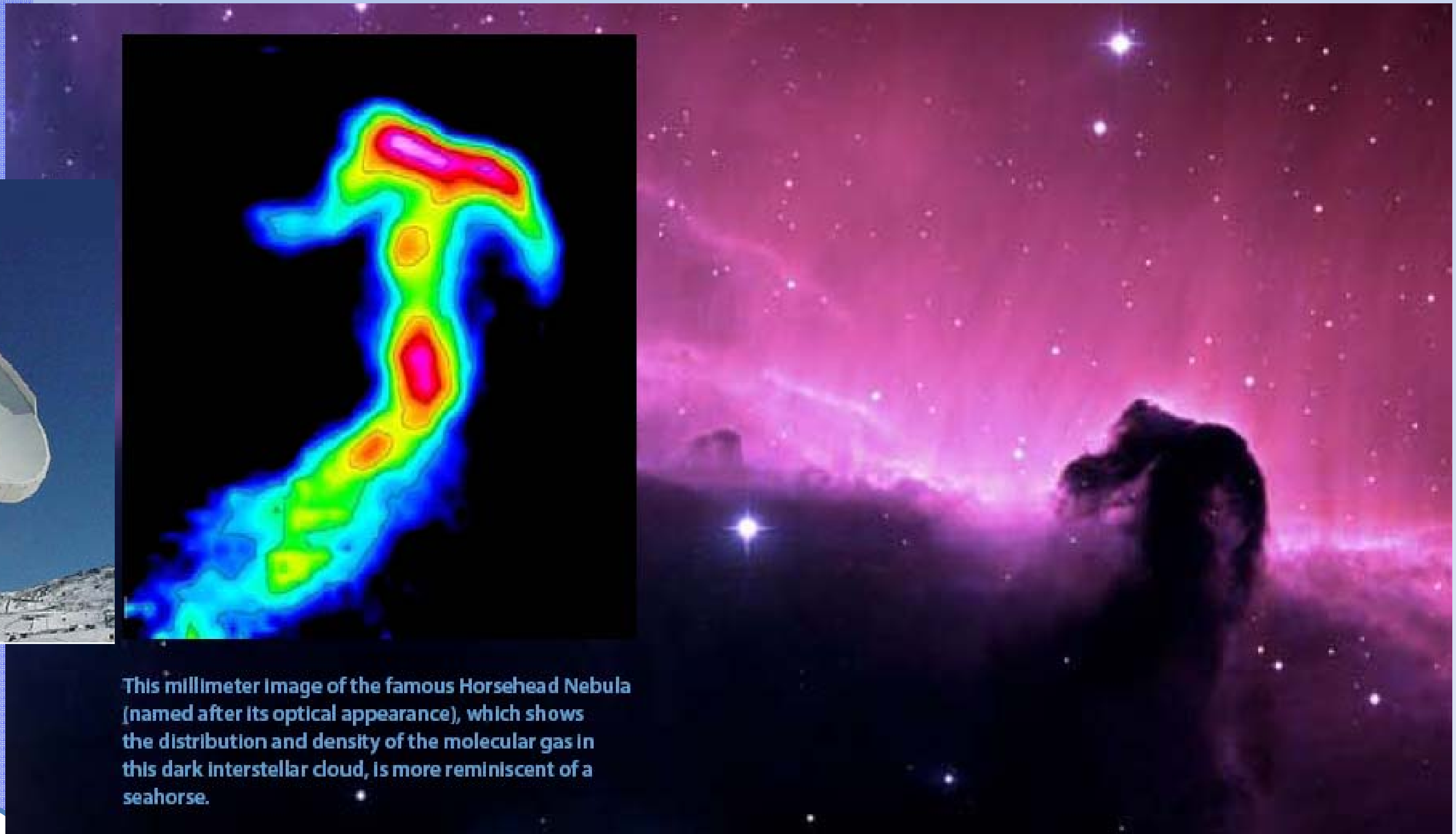
Jean Marc DUCHAMP

Project funded by the Rhône-Alpes Region(France)

IMEP-LAHC(Institute of Microelectronics, Electromagnetism and Photonics) , Grenoble,France

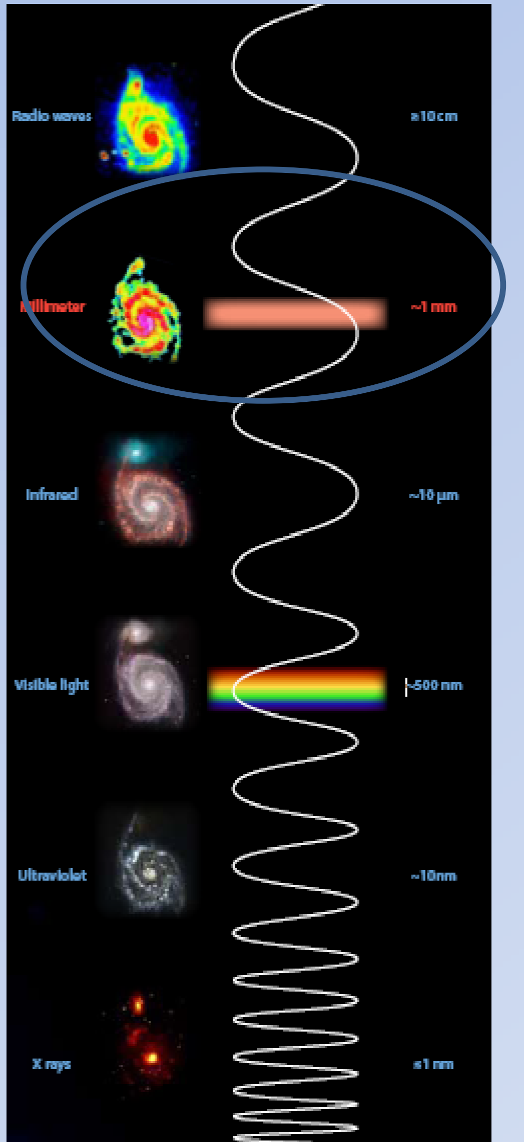
Introduction

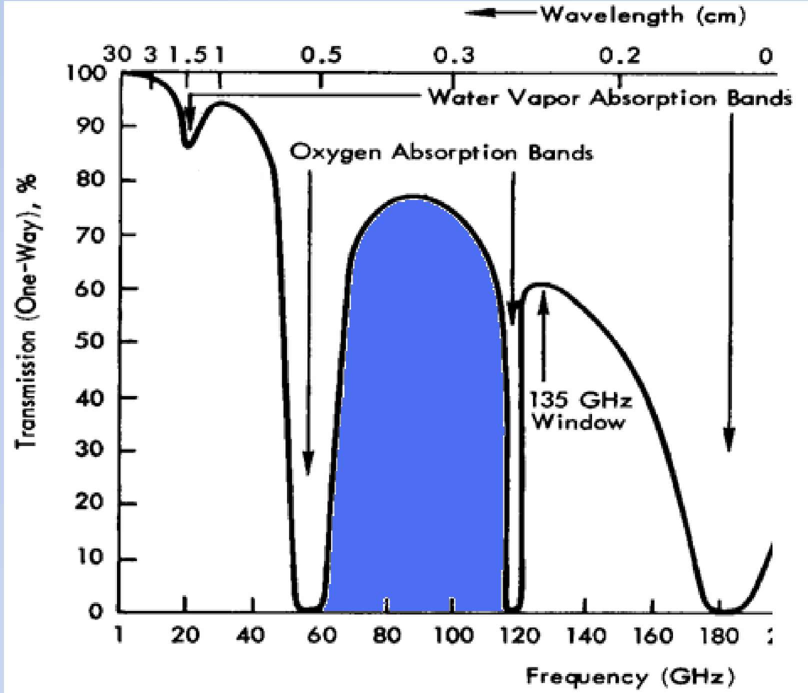
Radio-Astronomy Application by IRAM (Institute for Radio-Astronomy Millimetric)



Introduction

Radio-Astronomy Application by IRAM (Institute for Radio-Astronomy Millimetric)





Interstellar molecules

Many molecules were first detected in interstellar clouds, such as the famous Horsehead Nebula.

Rotating on their axis, molecules emit at millimeter wavelengths, each of them with their own characteristic frequencies.

The IRAM telescopes operate at wavelengths of 3, 2, 1 and 0.8 millimeters, the four atmospheric windows where the millimeter emission from space reaches the earth.

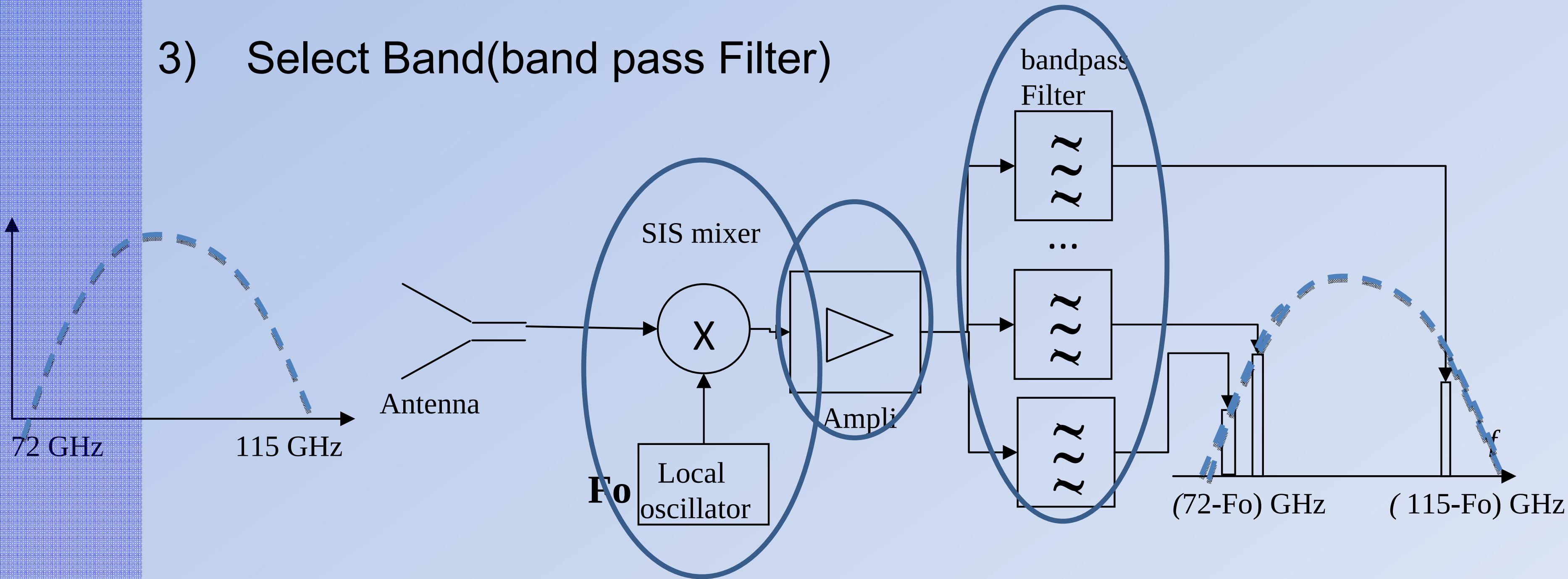
Introduction

HEterodyne Receiver Array(HERA)

1) signals from cosmic sources are extremely weak (amplifier)

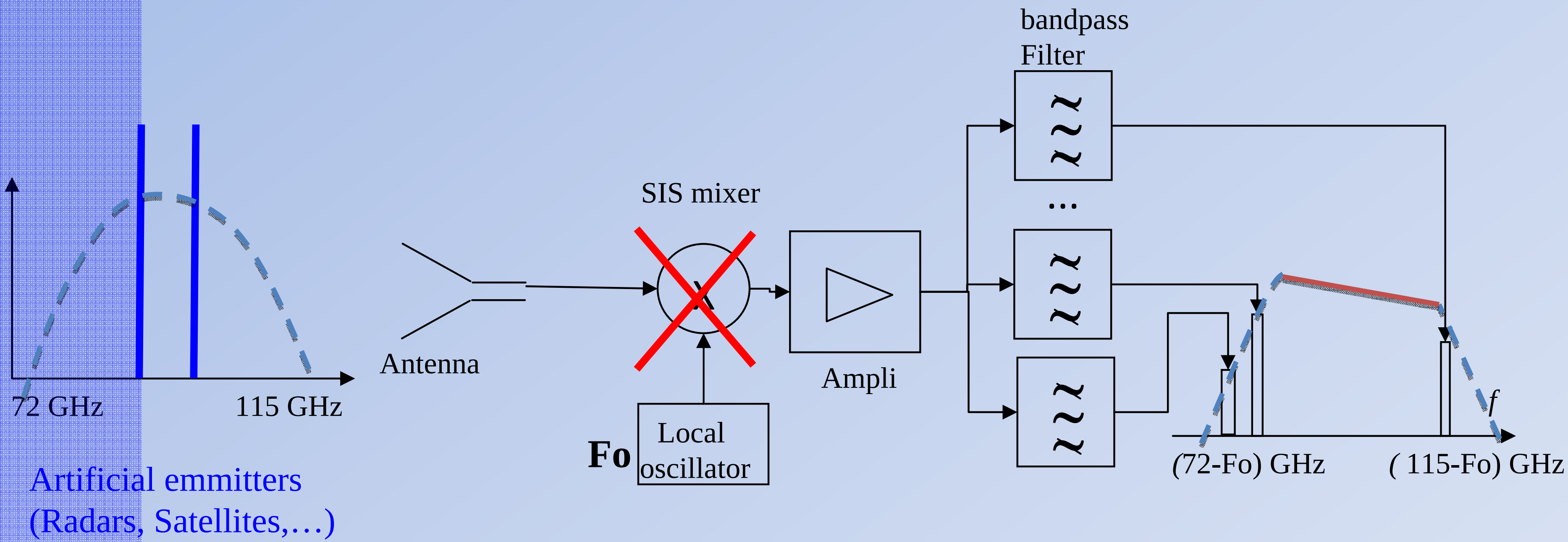
2) Impossible to amplify directly the signals so the frequency of the signal must be lowered(mixer-Local Oscillator)

3) Select Band(band pass Filter)



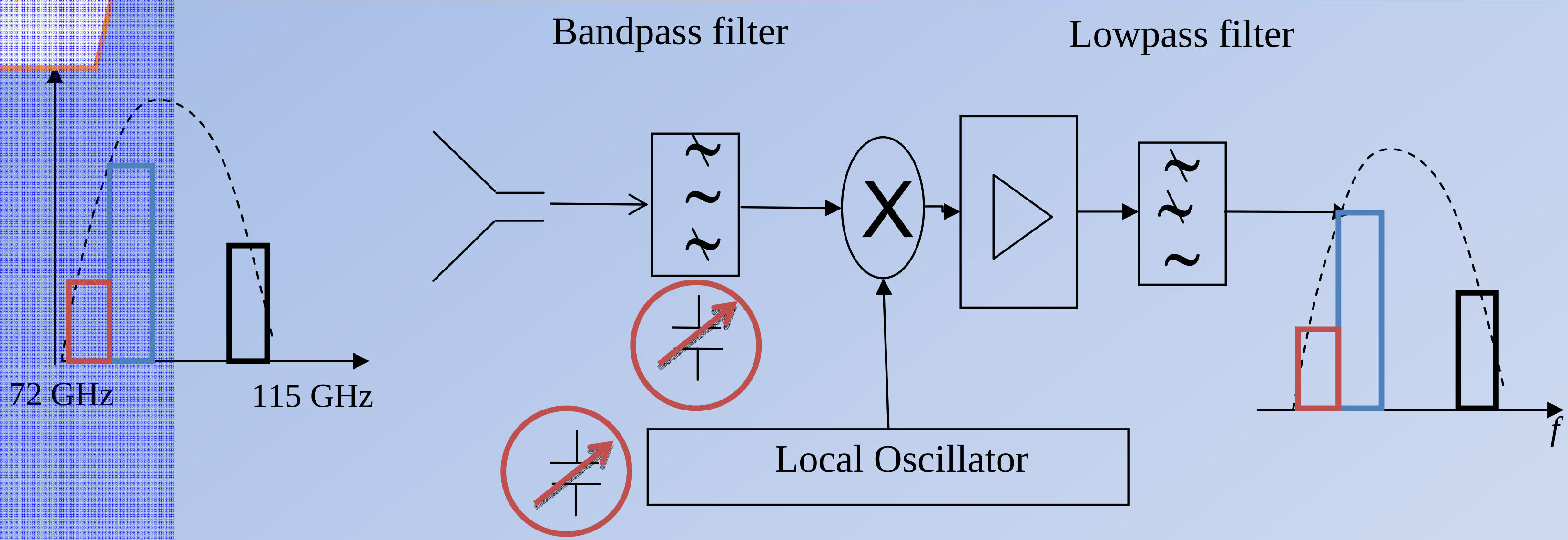
Introduction

HEterodyne Receiver Array(HERA)



Mixer saturation

Expected solution



1. Tunability

Solution : integrable tunable capacitor $\Rightarrow$ MEMS

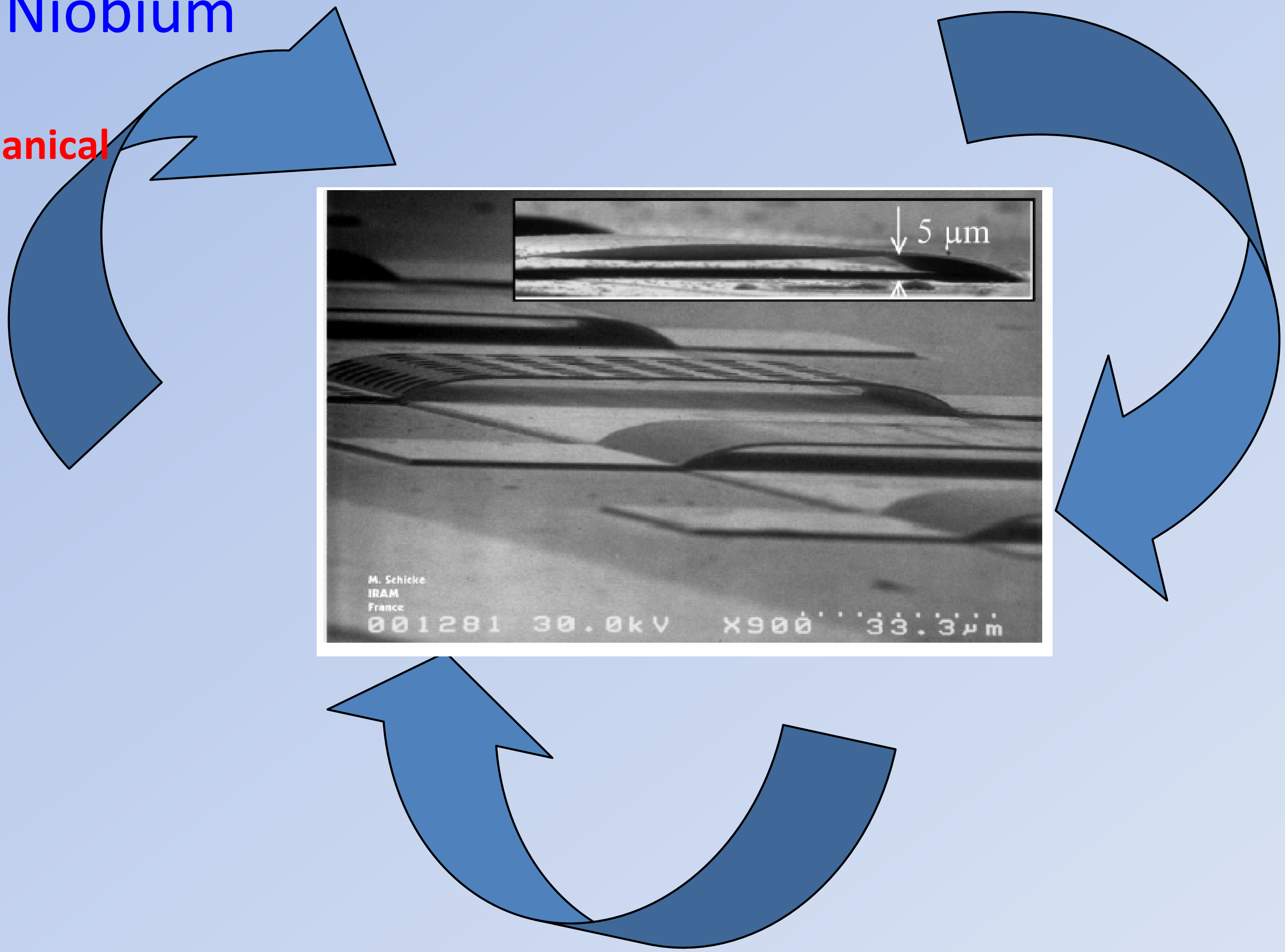
2. Sensitivity

Amplitude is very weak $\Rightarrow$ Disturbed signal by thermal noise.

Solution : very low temperature superconductor (4 K) « Niobium »

Multiphysics Modeling

IRAM Technology
based on Niobium



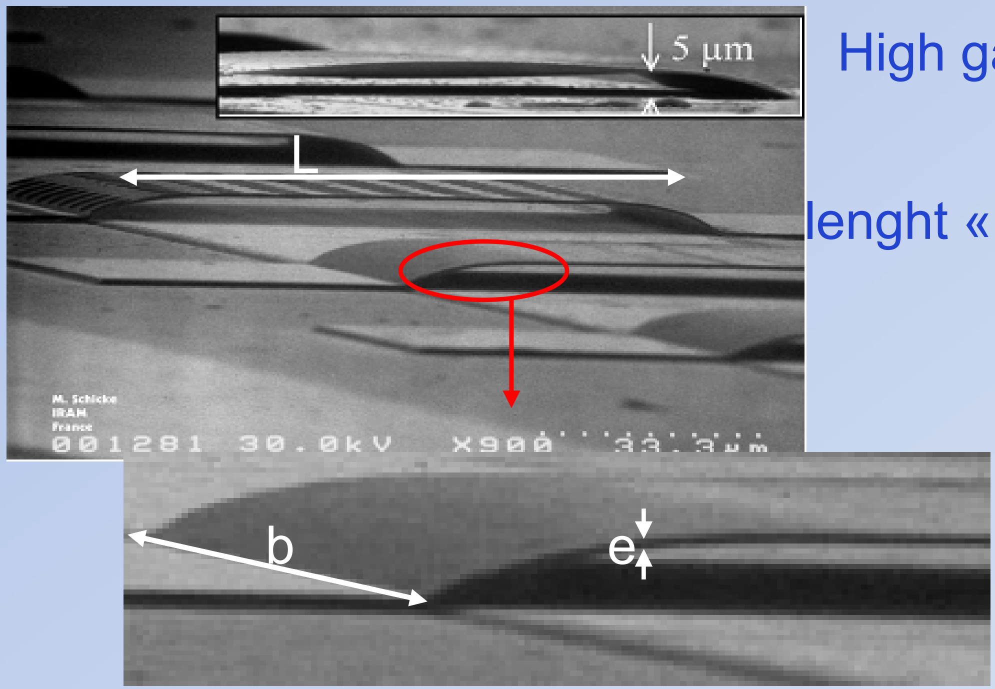
IMEP-LAHC

Outline

IMEP-LAHC

SupraMems Components?

- Mems: Micro systems Electro-mechanicals
- Supra: superconducting based on Niobium



High gap air «g » (4 µm ,5 µm)

lenght « L » between (60 µm and 90 µm)

Thickness « e » of the beam is (240 nm)

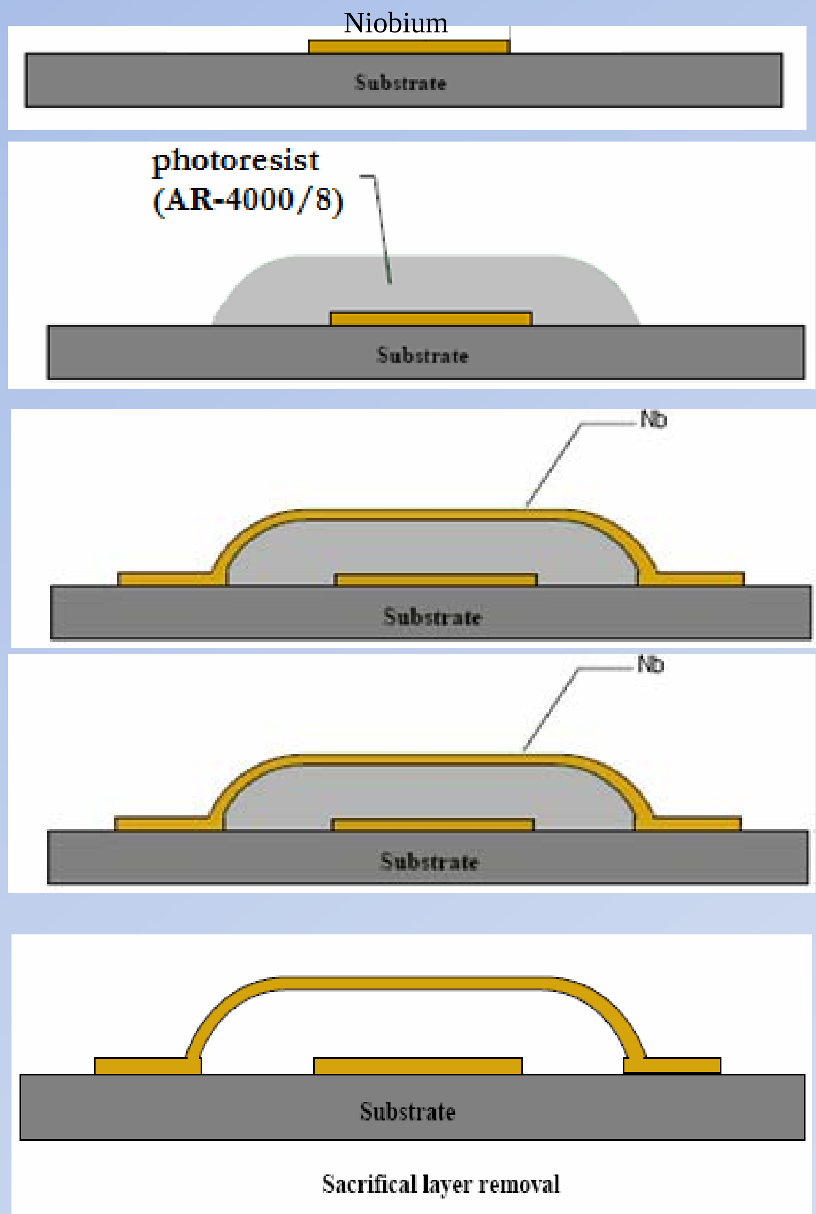
Width « b » is (100 µm)

Outline

1. Components Mems
2. **Fabrication process(Experimental observation)**
3. Theoritical beam modeling
4. Comsol Multiphysics beam simulation
5. Conclusion and Outlook

IMEP-LAHC

Fabrication process



In the first step a Nb contact line is realized

Then,Photoresist polymer AR-4000/8 is used as a sacrificial layer

the Nb layer was sputtered by Dc-magnetron

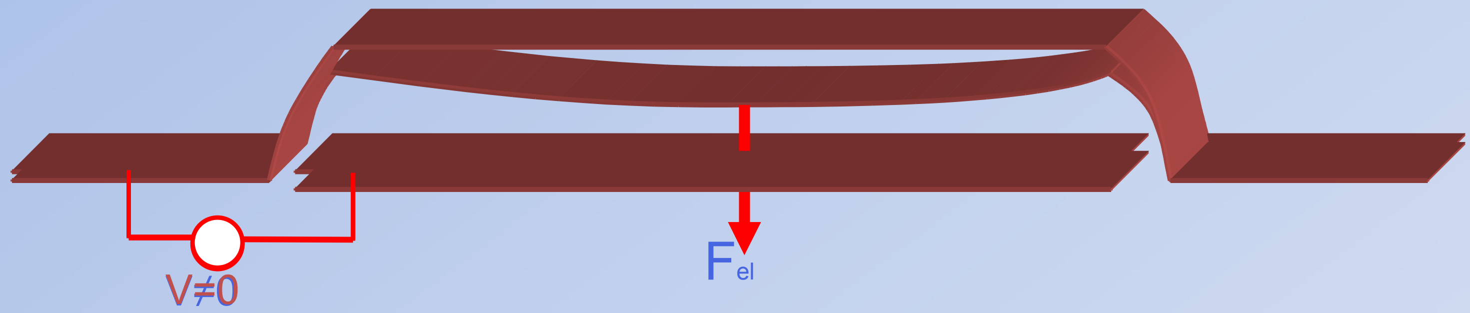
The widths of the bridges are defined by a photoresist mask and the no-covered parts of the Nb are etched by RIE(Reactive Ion Etching)

The final step washes away the sacrificial layer in hot acetone

Experimental observation

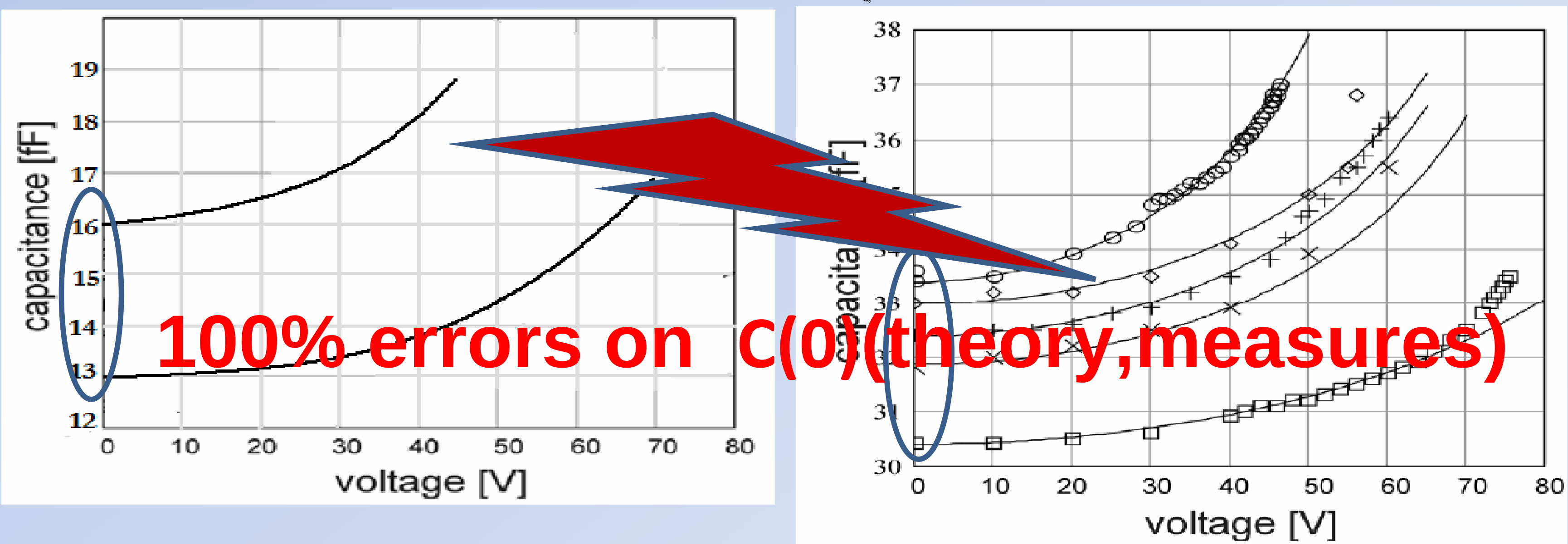
-Varactors capacitances

Actuated mode is:Electrostatic



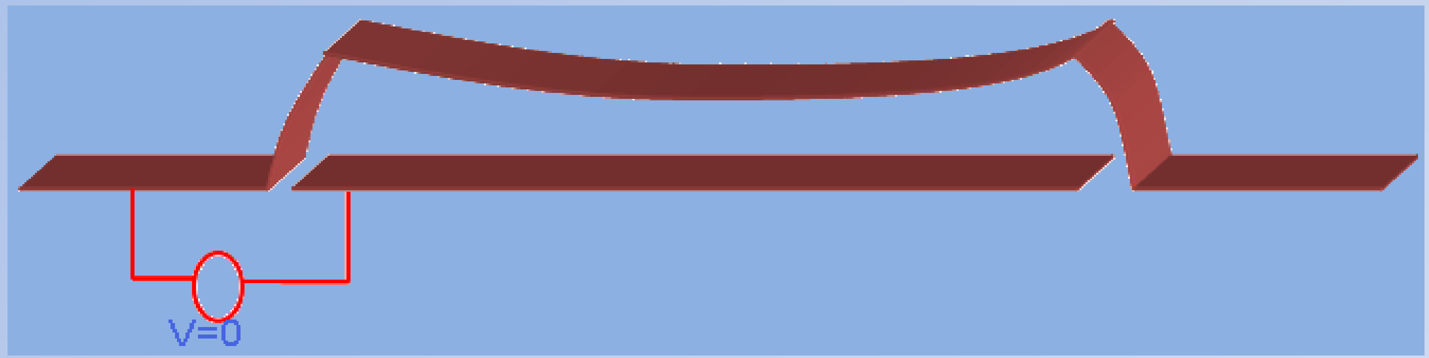
-The electrostatic force reduce the air gap “g”

-Expression of capacitor plan: $C = \frac{\varepsilon_0 \times b \times L}{\boxed{g}}$ → C ↗

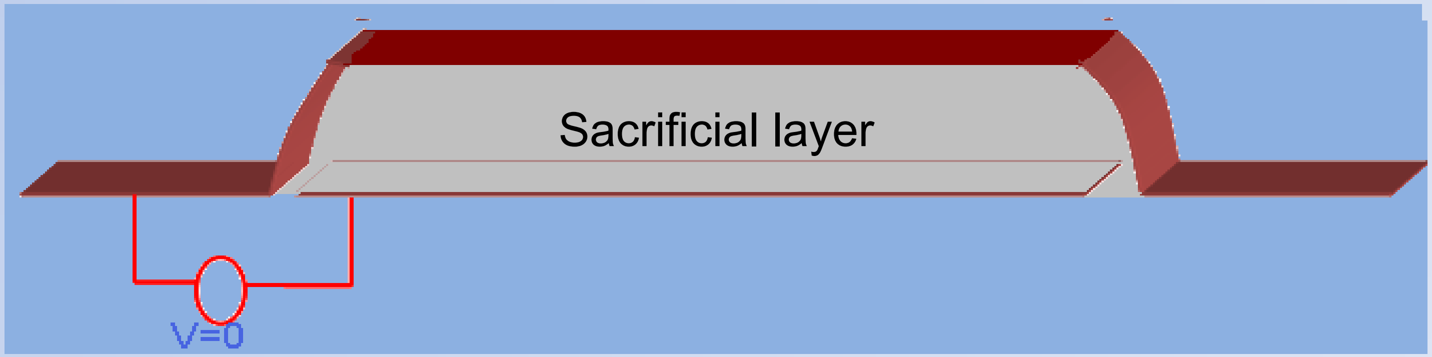


Experimental observation

$$C = \frac{\varepsilon_0 \times b \times L}{\boxed{g}}$$



➢Lengthening ΔL can be caused by a residual tensile stress at the niobium interface which is released when the sacrificial layer is removed



Outline

1. Components SupraMems
2. Fabrication process(Experimental observation)
3. **Theoritical beam modeling**
4. Comsol Multiphysics beam simulation
5. Conclusion and Outlook

IMEP-LAHC

Theoritical beam modeling

Objectives

- Find the values of the capacity C(0) by determining an equation which describe the profil MEMS

- Determine the expression of C(V)

Theoritical beam modeling

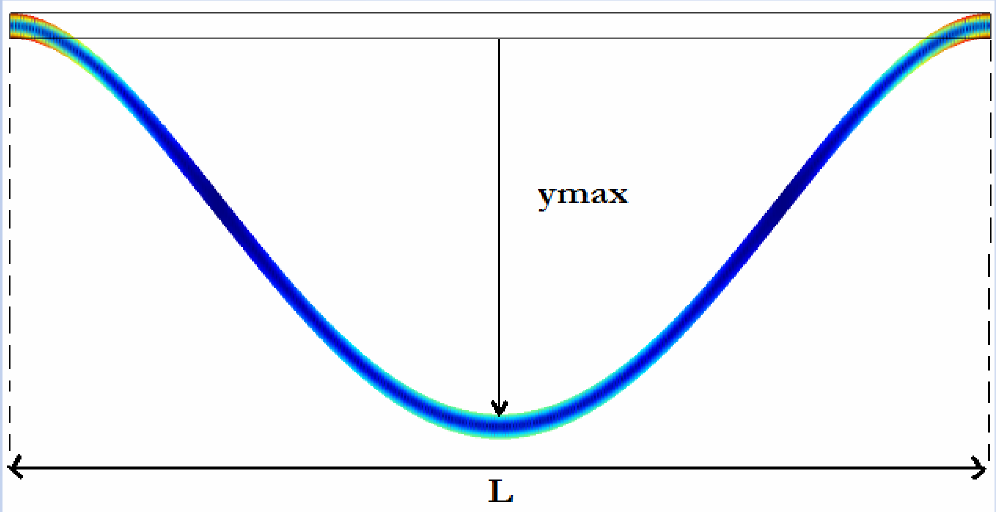
The bending bridge is a Fixed-Fixed beam with a length equal to *L*+ Δ*L*.

Profil en cos

$$y(x) = \frac{y\max}{2}\left(1 - \cos\left(\frac{2\pi x}{L}\right)\right)$$

$$C(0) = \int_0^L \frac{\varepsilon_0 b}{g - y(x)} dx$$

$$C(0) = \frac{\varepsilon_0 bL}{g\sqrt{1 - \frac{y_{max}}{g}}}$$



these capacities can be described as the sum of elementary plane capacitance, integration result is.

Theoritical beam modeling

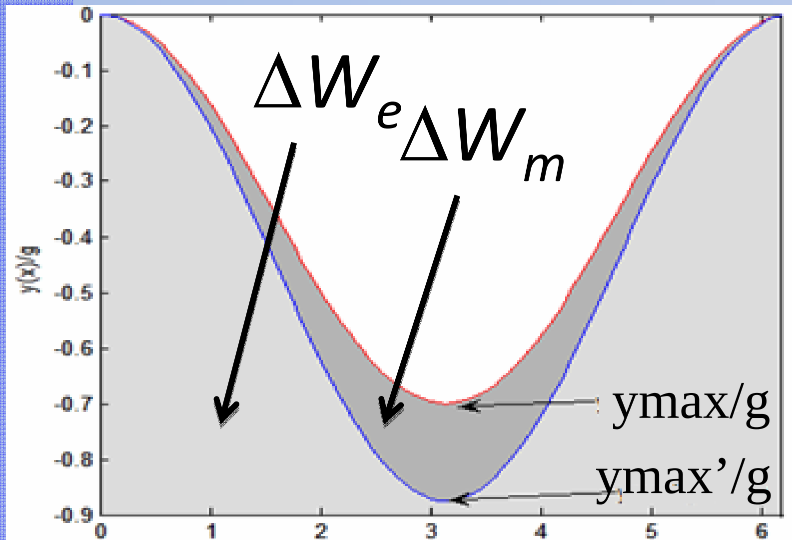
Objectives

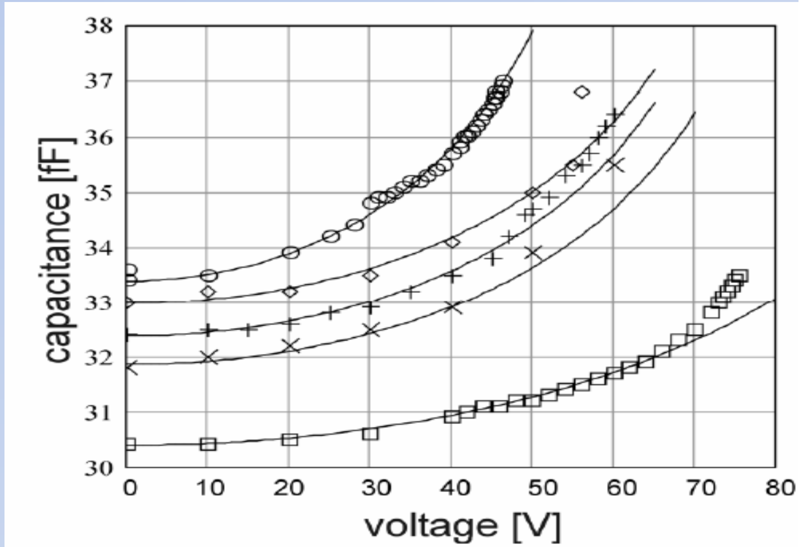
- Find the values of the capacity C(0) by determining ar equation which describe the profil MEMS

- **Determine the expression of C(V)**

Theoritical beam modeling

We assume the same profile on cosines is took when the voltage is applied



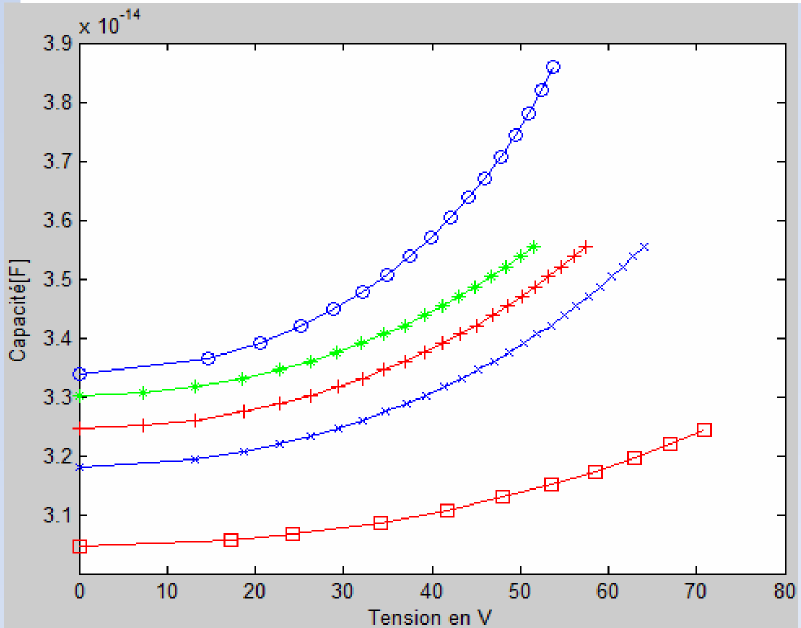


$W_e = W_m$

$$V = \sqrt{\frac{g\sqrt{1-\frac{ymax'}{g}}\,\pi^4 Eh\ ymax^2 (ymax' - ymax)^2}{16 L^4 \varepsilon_0 W}}$$

$$C = \frac{\varepsilon_0 b}{g_0 \sqrt{1 - \frac{y_{max'}}{g_0}}}$$

C(V)



Outline

1) Components SupraMems
2) Fabrication process(Experimental observation)
3) Theoritical beam modeling
4) **Comsol Multiphysics beam simulation**
5) Conclusion and Outlook

IMEP-LAHC

Comsol Multiphysique beam simulation

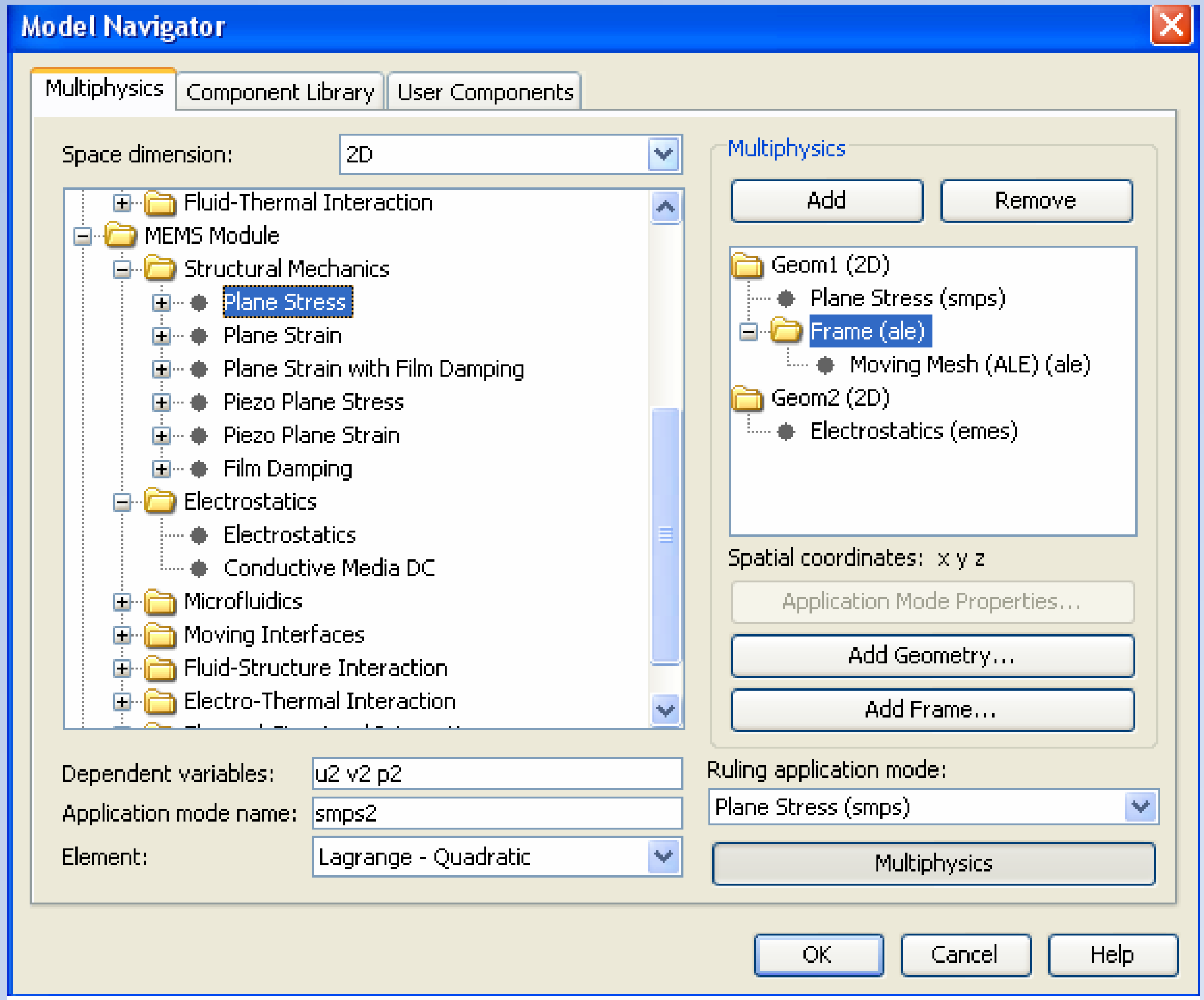
Objectives

- Validate the simple previous theoretical approach (cosinus profile, edge effects neglected) by a multiphysics electromechanical model of the SupraMEMS (COMSOL)

- This approach will be used in future filter designs

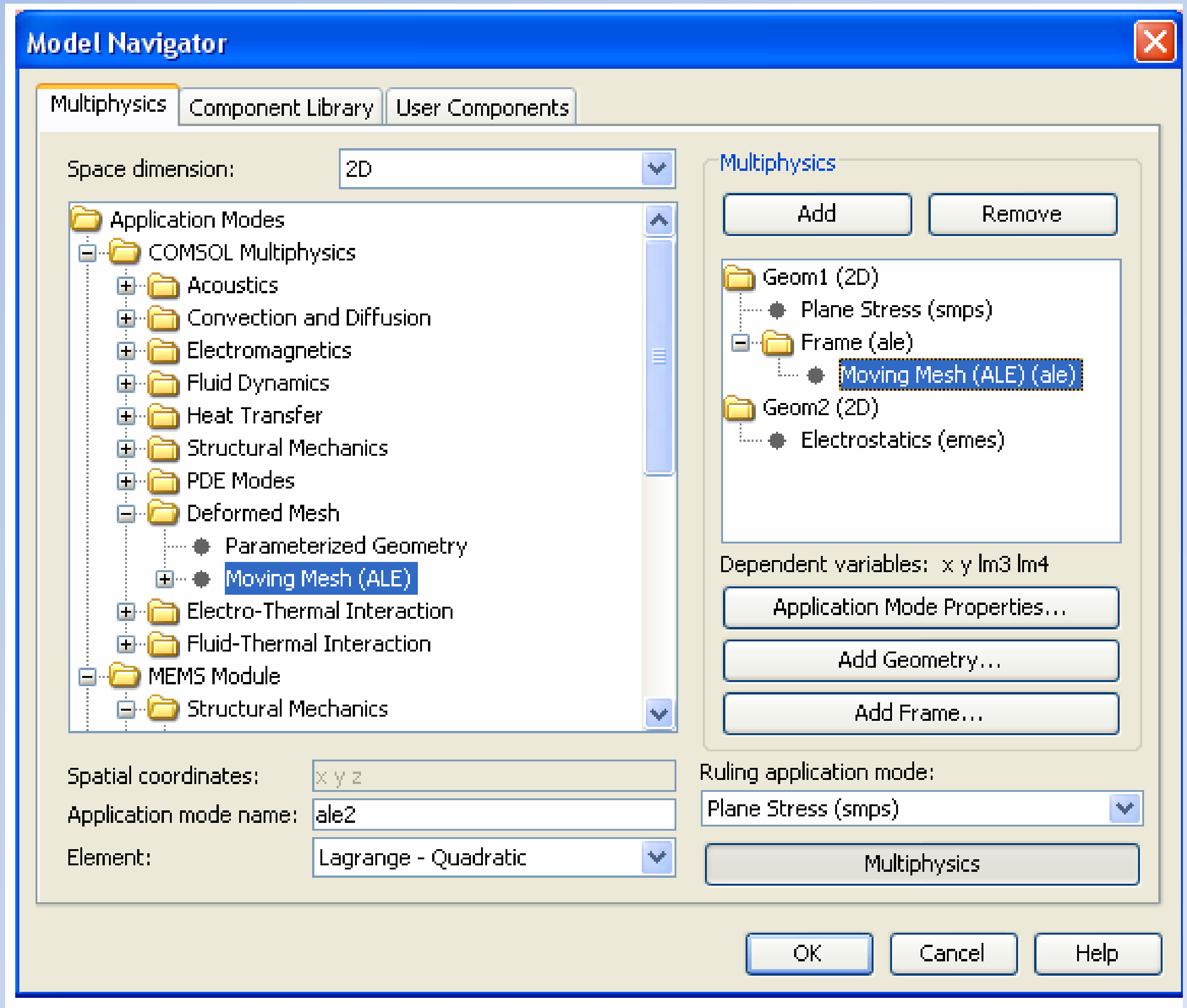
Comsol Multiphysique beam simulation

Calculate the capacity C(0)

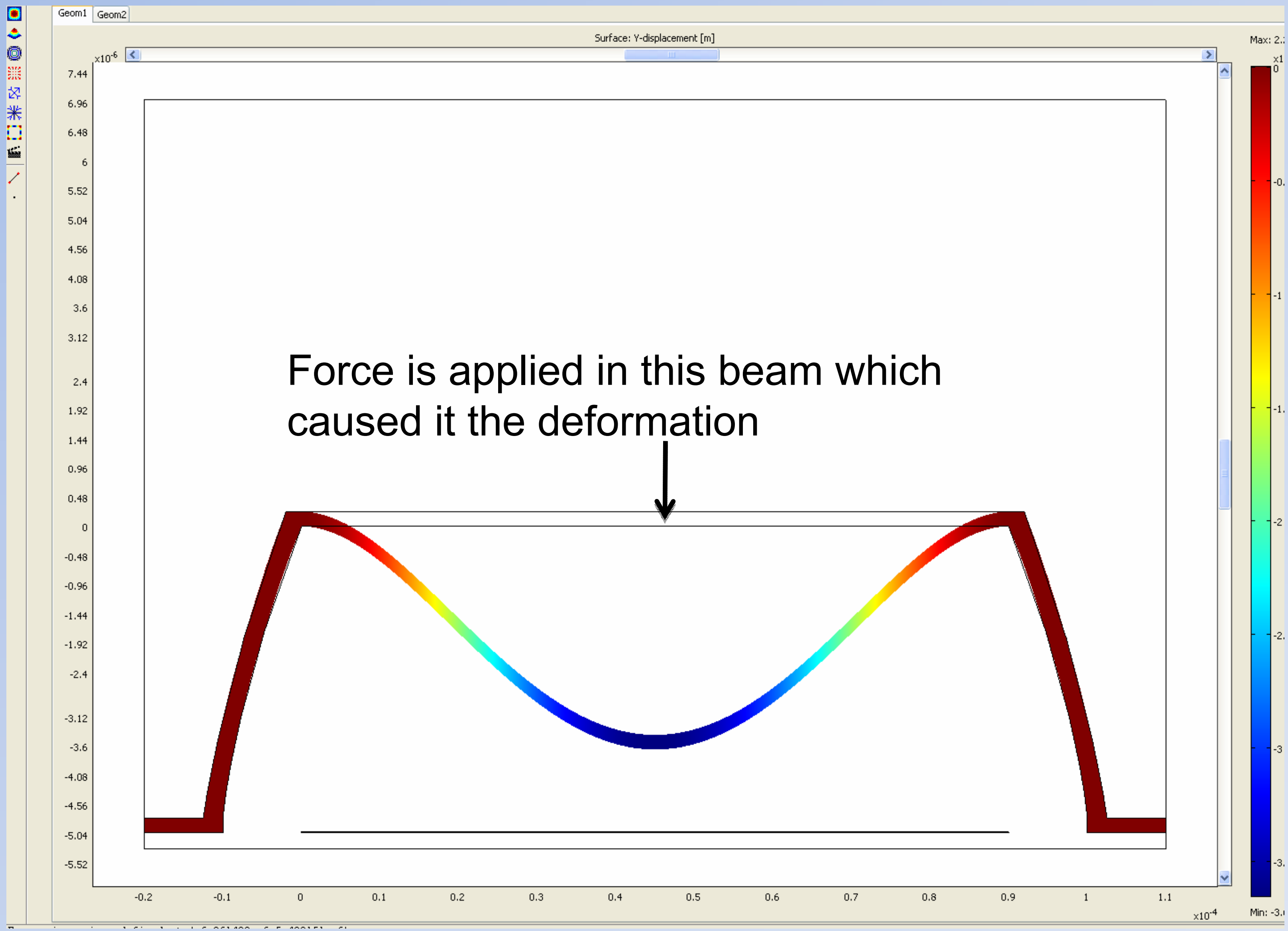


Comsol Multiphysique beam simulation

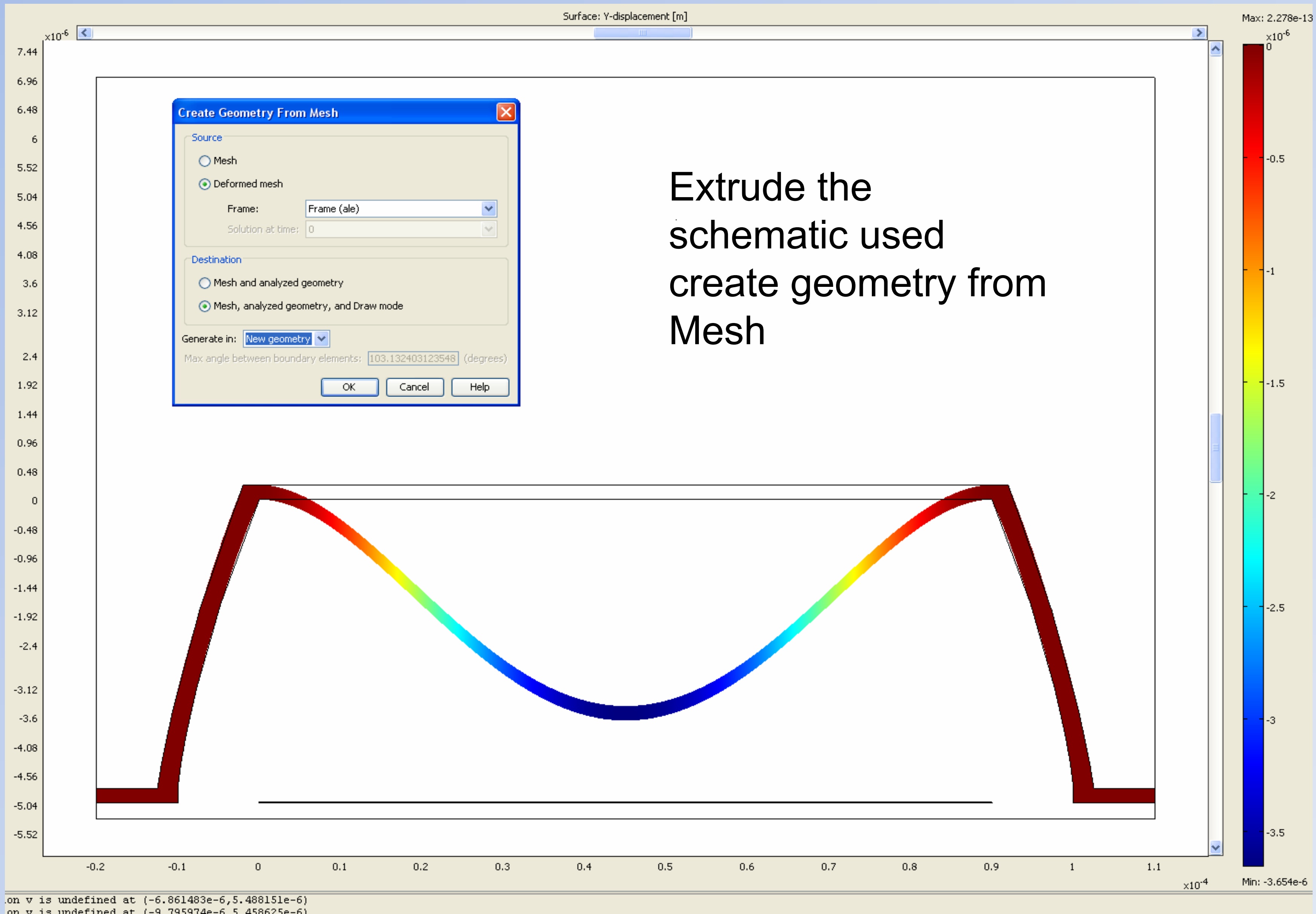
Calculate the capacity C(0)



Comsol Multiphysique beam simulation



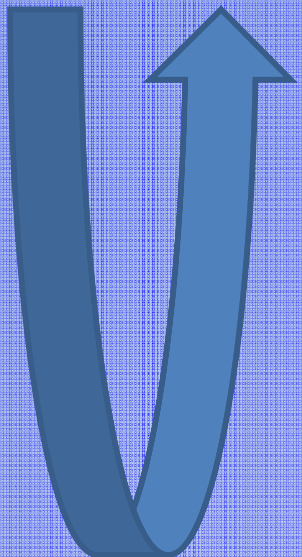
Comsol Multiphysique beam simulation

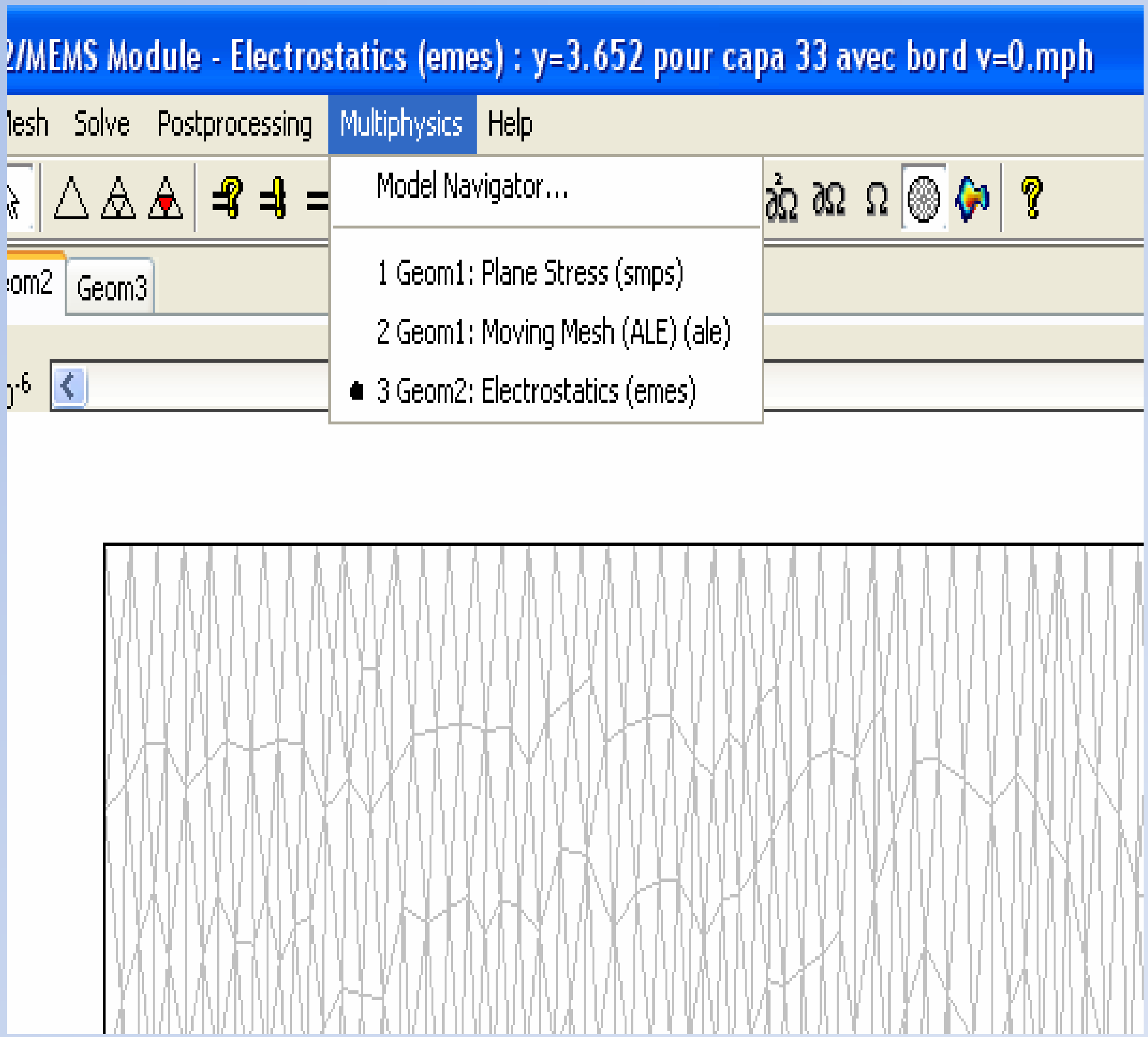


Extrude the schematic used create geometry from Mesh

Comsol Multiphysique beam simulation

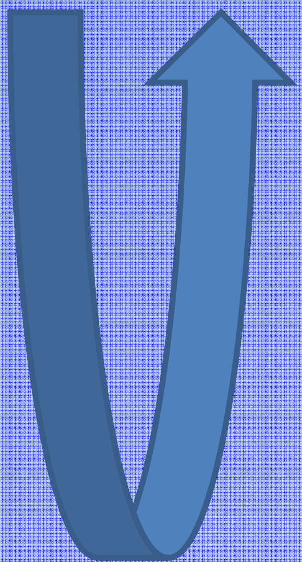
Closed-circuit

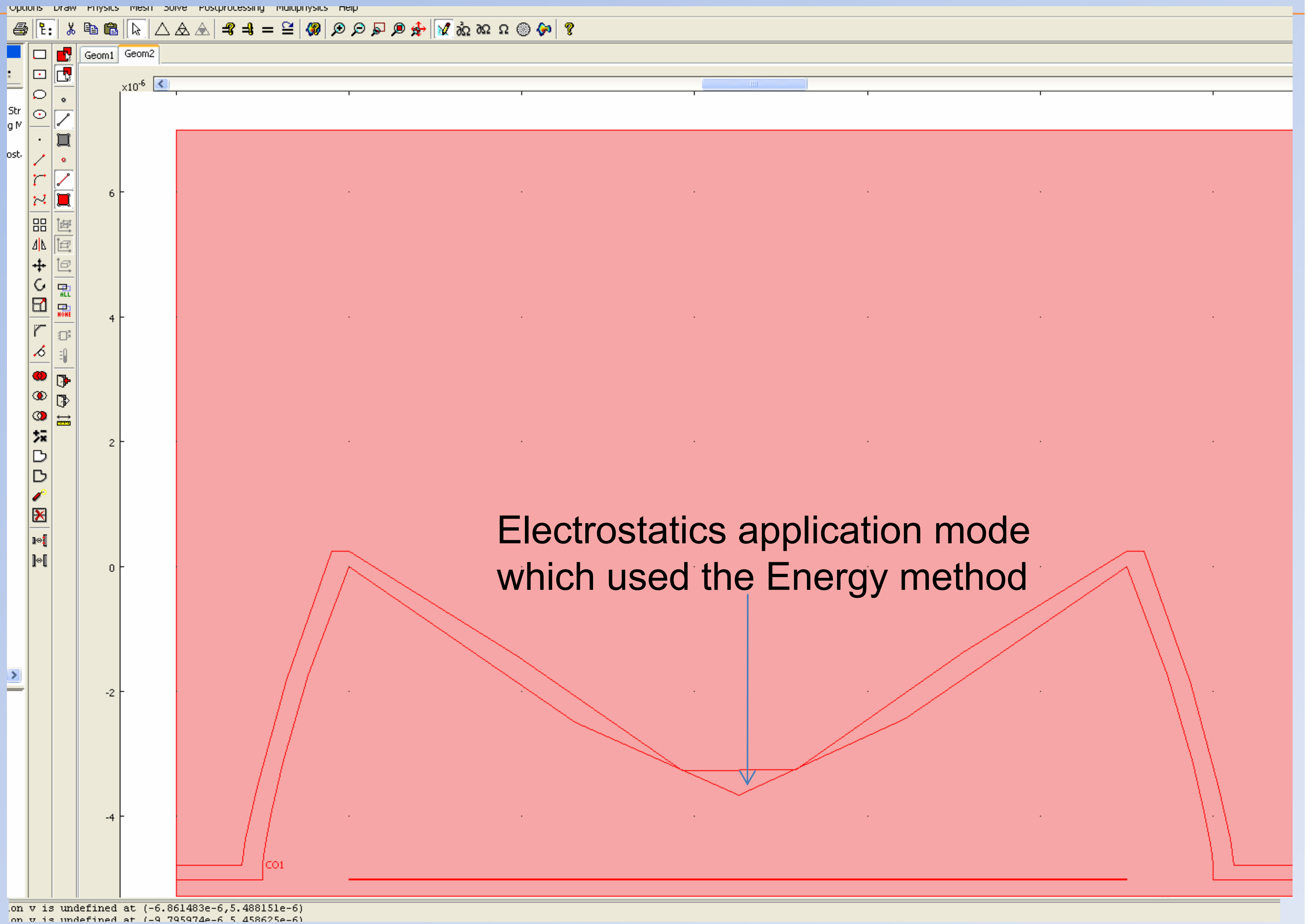




Comsol Multiphysique beam simulation

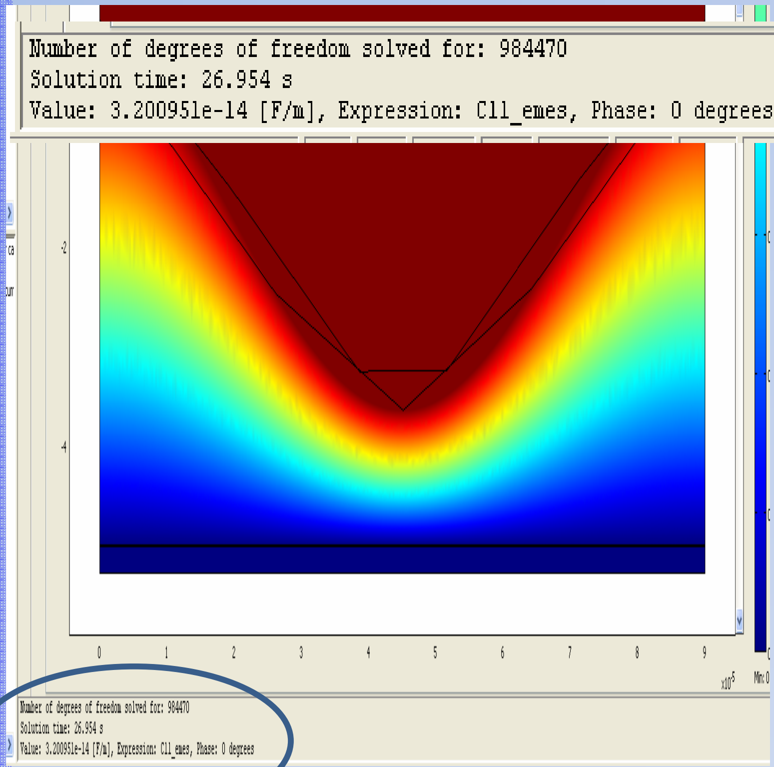
Closed-circuit

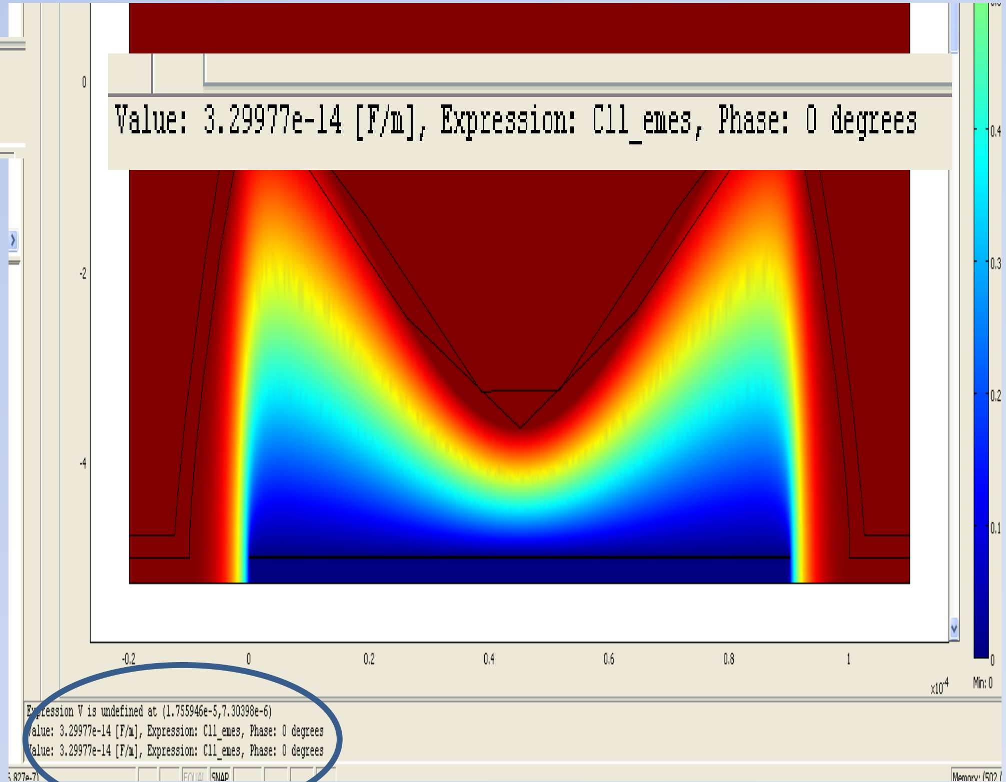




Comsol Multiphysique beam simulation

Surface Electric potentiel





The value of the capacitance is

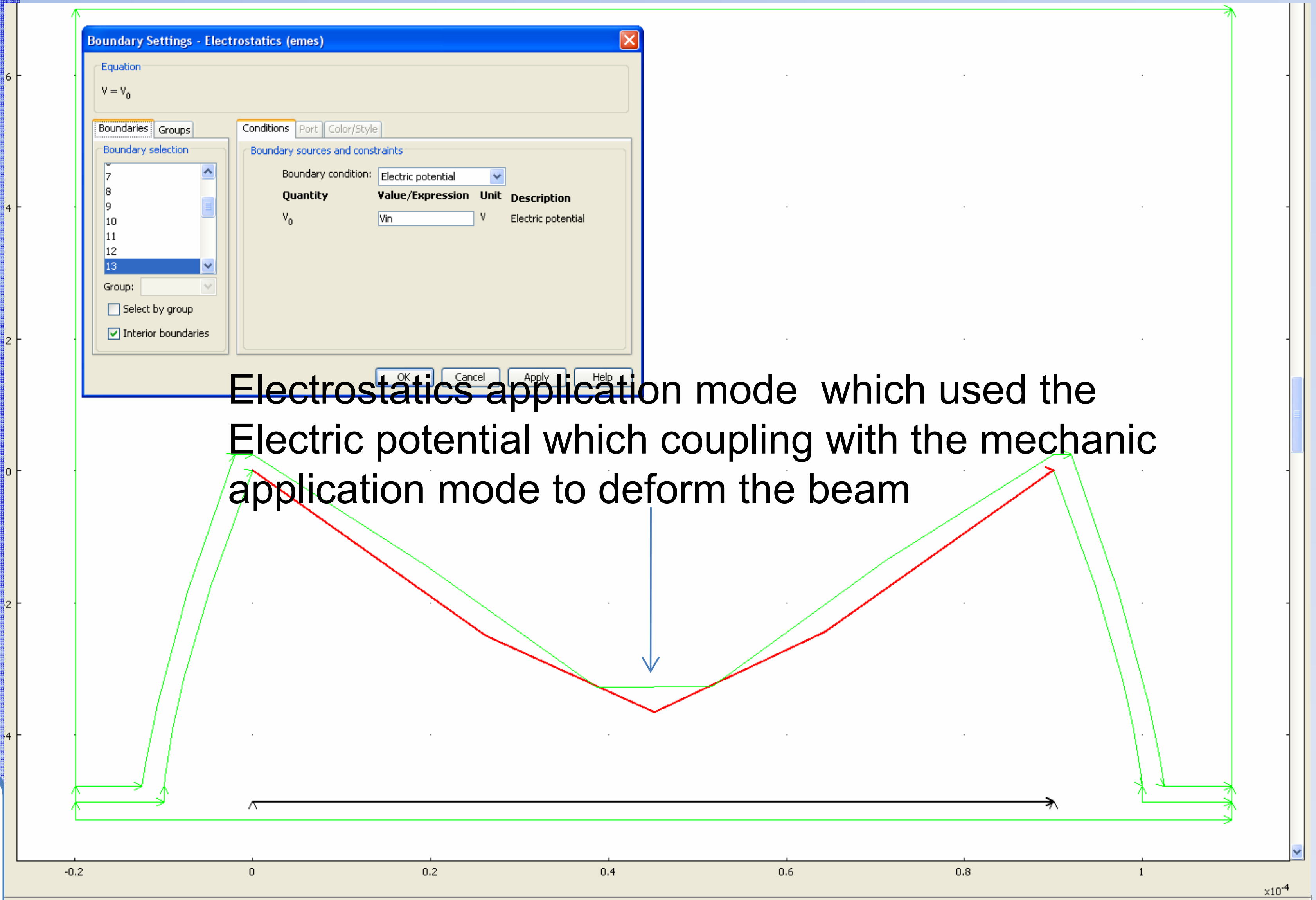
$$C(0) = 2W_e / \Delta V^2 = 32 fF$$

The value of the capacitance is

$$C(0) = 2W_e / \Delta V^2 = 32{,}99 fF$$

Comsol Multiphysique beam simulation

Calculate the capacity C(V)



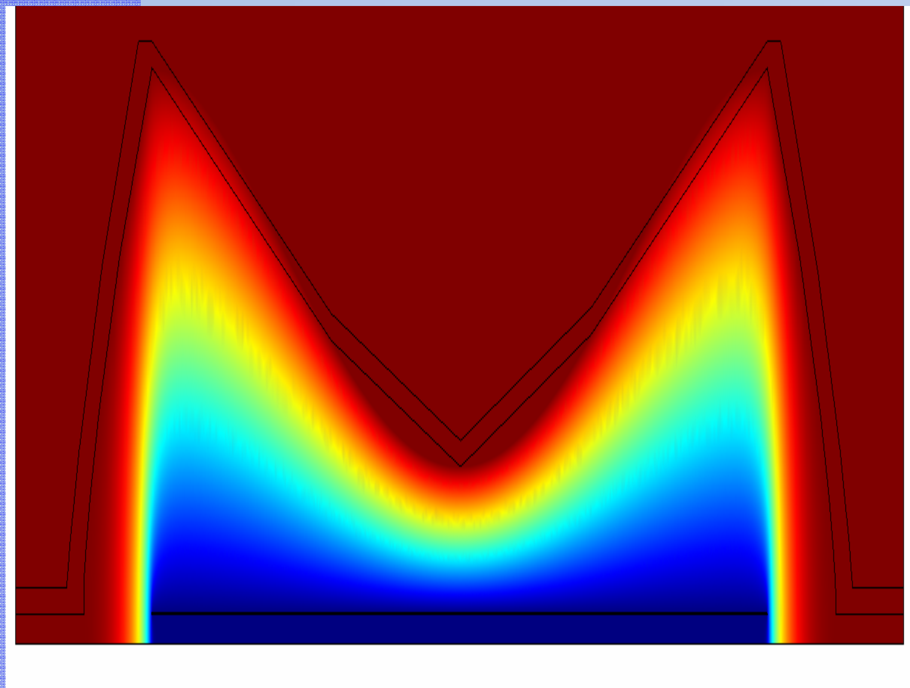
Electrostatics application mode which used the Electric potential which coupling with the mechanic application mode to deform the beam

Voltage V=45

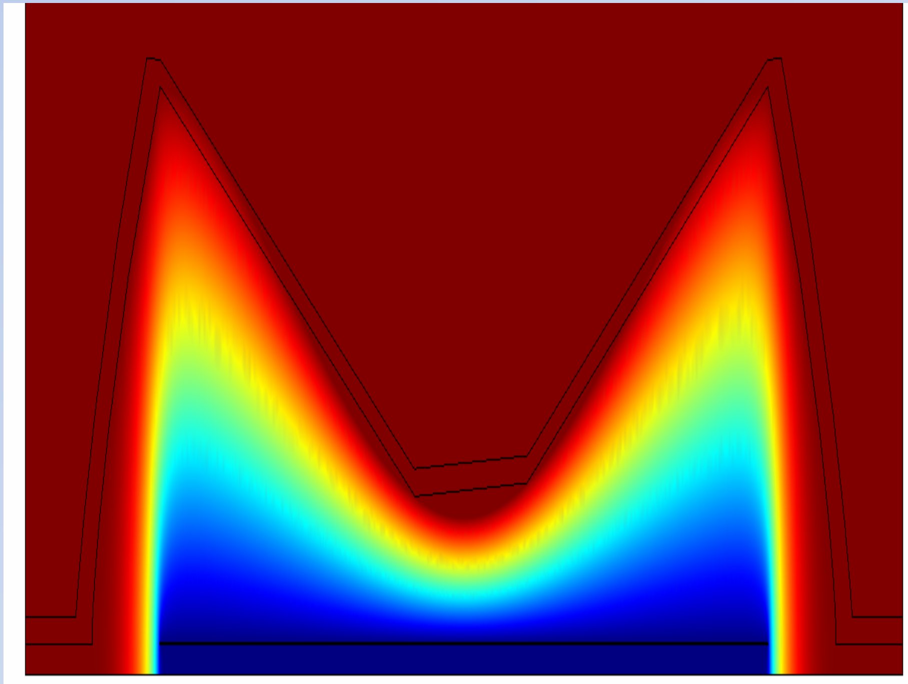
Comsol Multiphysique beam simulation

Calculate the capacity C(V)

Surface Electric potentiel



Voltage V=10

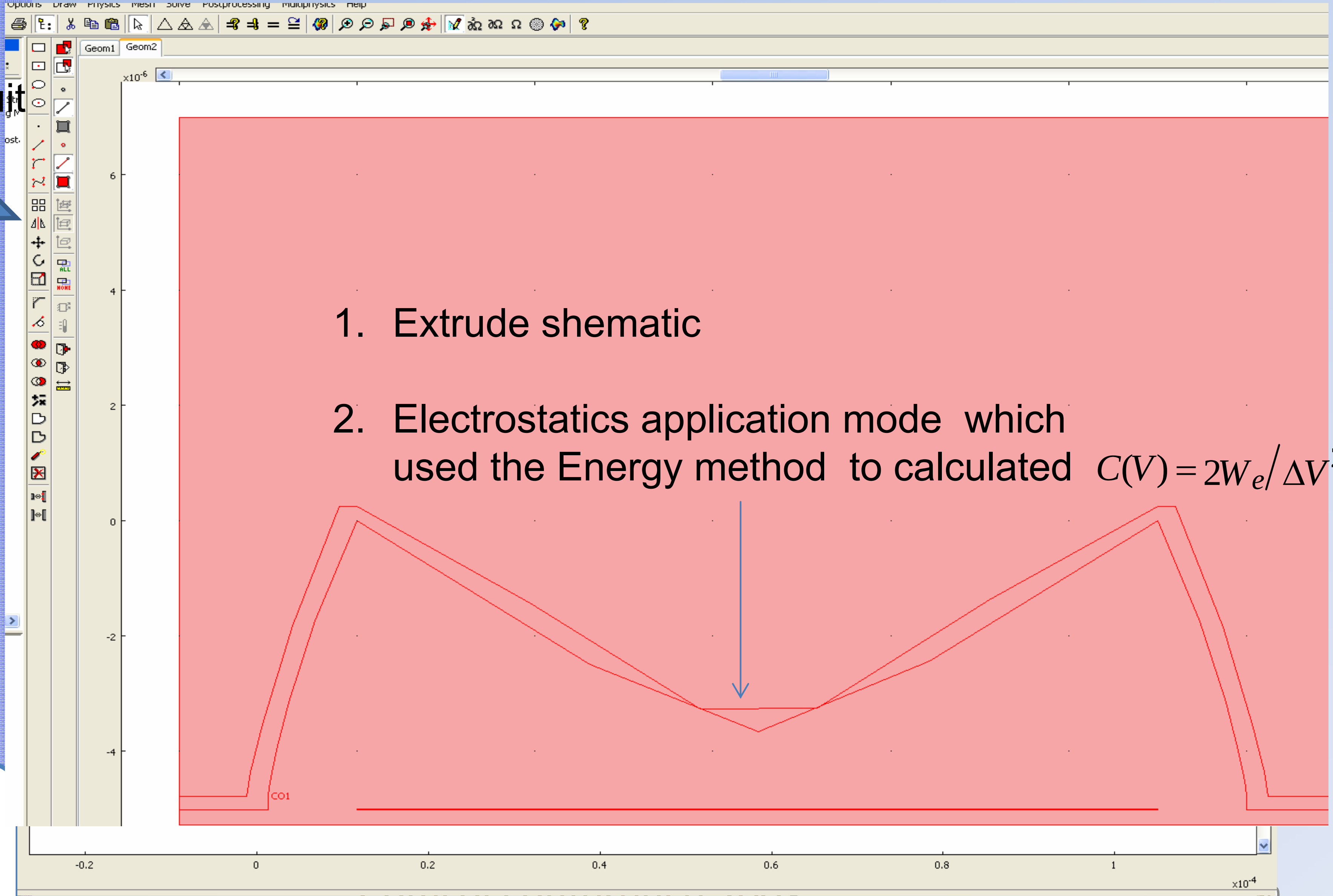


Voltage V=60

Comsol Multiphysique beam simulation

Calculate the capacity C(V)

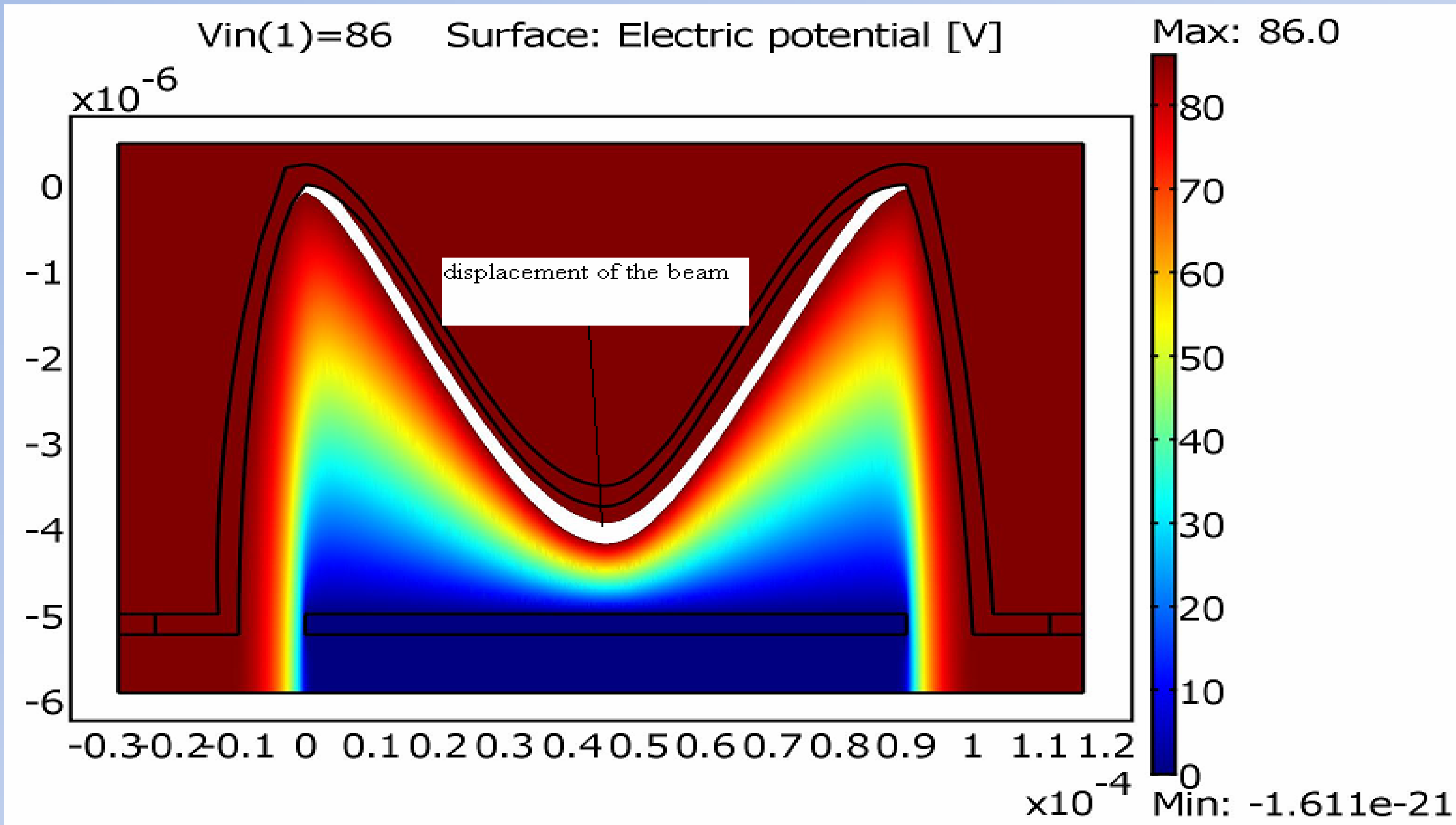
Closed-circuit



1. Extrude shematic

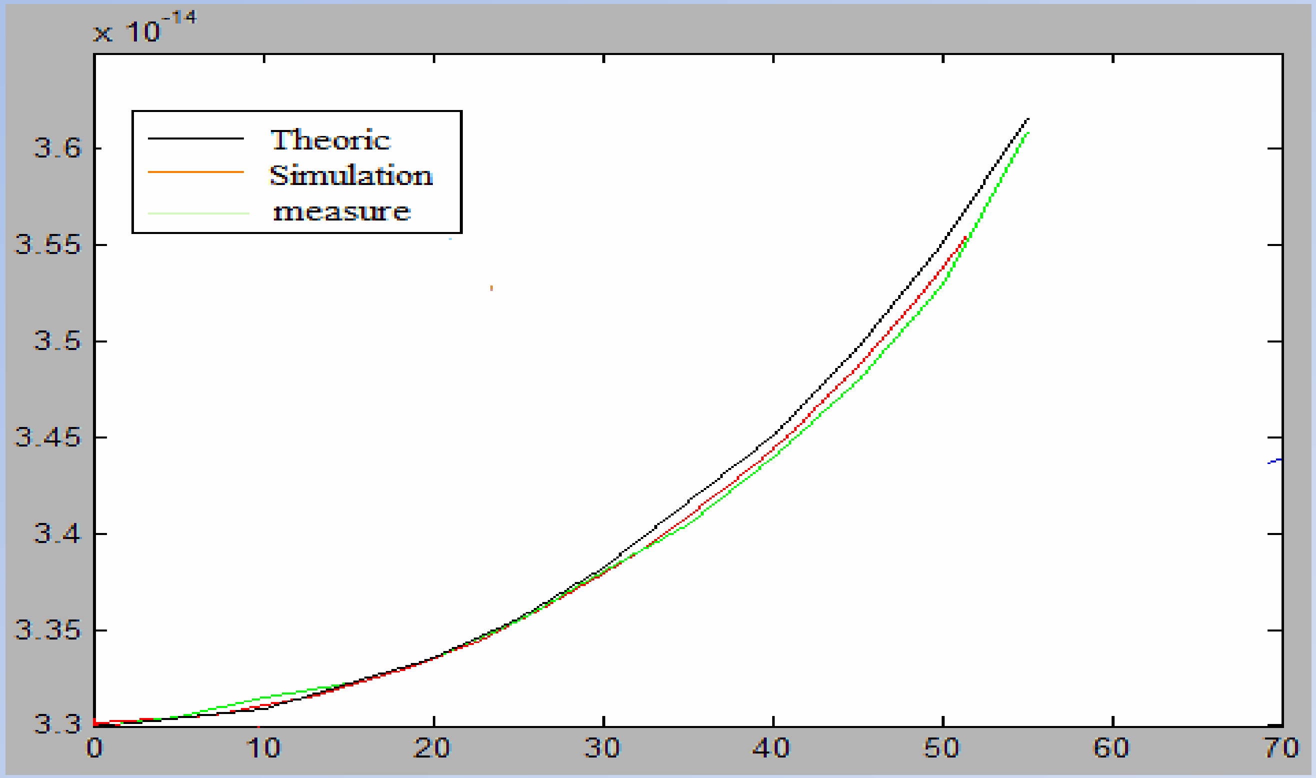
2. Electrostatics application mode which used the Energy method to calculated $C(V) = 2W_e / \Delta V^2$

Comsol Multiphysique beam simulation



Surface Electric potential, the white color represents the displacement y after the coupling Electrostatics-Mechanics

Comsol Multiphysique beam simulation



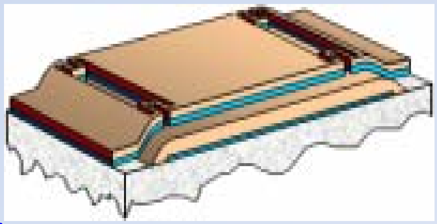
Curves of the comparison between :
(Theoric, Simulation and measures)

Outline

1. Components SupraMems
2. Fabrication process(Experimental observation)
3. Theoritical beam modeling
4. Comsol Multiphysics beam simulation
5. **Conclusion and Outlook**

Conclusion and Outlook

- Expression of C(V) from simple electro-mechanical model, validated by simulation and measures
- Edge effect is neglected
- Problem : $\Delta C/C$ maxi is lowered by the buckling
- Confirm this model by profilometry measures
- Refine this model with 3D simulations (COMSOL)
- Use of these Nb MEMS in millimetrics : superconducting modeling



- New MEMS device with meandering (2)

(2) *Mathias Schicke and Karl.F.Schuster,IEEE Transactions on Applied Superconducting , vol.3,No.2,june 2003.*

IMEP-LAHC

THANK YOU