Modeling and Characterization of Superconducting MEMS for Microwave Applications in Radioastronomy

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Introduction

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

This millimeter image of the famous Horsehead Nebula (named after its optical appearance), which shows the distribution and density of the molecular gas in this dark interstellar cloud, is more reminiscent of a seahorse.
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.
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)

Artificial emitters (Radars, Satellites, …)

Mixer saturation

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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

Electro-mechanical

Thermics (superconducting)

Microwaves

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1. SupraMems Components

2. Fabrication process (Experimental observation)

3. Theoretical beam modeling

4. Comsol Multiphysics beam simulation

5. Conclusion and Outlook
SupraMems Components?

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

High gap air \( g \) (4 \( \mu m \), 5 \( \mu m \))

Length \( L \) between (60 \( \mu m \) and 90 \( \mu m \))

Thickness \( e \) of the beam is (240 nm)

Width \( b \) is (100 \( \mu m \))
Outline

1. Components Mems

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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:
  \[ C = \frac{\varepsilon_0 \times b \times L}{g} \] → C

100% errors on C(0)(theory, measures)
Lengthening $\Delta L$ 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. **Theoretical beam modeling**

4. Comsol Multiphysics beam simulation

5. Conclusion and Outlook
Objectives

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

• Determine the expression of $C(V)$
The bending bridge is a Fixed-Fixed beam with a length equal to $L + \Delta L$.

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

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

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

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

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

• Determine the expression of $C(V)$
We assume the same profile on cosines is took when the voltage is applied.

\[ \Delta W_e \Delta W_m \]

\[ V = \sqrt{\frac{g}{1 - \frac{y_{\text{max}'}}{g}} \pi^4 E_h y_{\text{max}}^2 (y_{\text{max}} - y_{\text{max}'})} \]

\[ C = \frac{\varepsilon_0 b}{g_0 \sqrt{1 - \frac{y_{\text{max}'}}{g_0}}} \]

\[ W_e = W_m \]
Outline

1) Components SupraMems
2) Fabrication process (Experimental observation)
3) Theoretical beam modeling
4) Comsol Multiphysics beam simulation
5) Conclusion and Outlook
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
Calculate the capacity $C(0)$
Comsol Multiphysique beam simulation

Calculate the capacity C(0)
Force is applied in this beam which caused it the deformation.
Extrude the schematic used create geometry from Mesh
Force is applied in this beam which caused it to deform. The Electrostatics application mode, which used the Energy method, is employed to simulate the behavior of the beam under force.
Electrostatics application mode which used the Energy method.
The value of the capacitance is
\[ C(0) = \frac{2W_e}{\Delta V^2} = 32fF \]

Surface Electric potential

The value of the capacitance is
\[ C(0) = \frac{2W_e}{\Delta V^2} = 32,99fF \]
Calculate the capacity C(V)

Electrostatics application mode which used the Electric potential which coupling with the mechanic application mode to deform the beam.
Calculate the capacity $C(V)$

Surface Electric potential

Voltage $V=10$

Voltage $V=45$

Voltage $V=60$
Calculate the capacity \( C(V) \)

1. Extrude schematic

2. Electrostatics application mode which used the Energy method to calculated 
\[
C(V) = \frac{2W_e}{\Delta V^2}
\]
Surface Electric potential, the white color represents the displacement $y$ after the coupling Electrostatics-Mechanics.
Curves of the comparison between:
(Theoric, Simulation and measures)
Outline

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Conclusion and **Outlook**

- Expression of C(V) from simple electro-mechanical model, validated by simulation and measures
- Edge effect is neglected
- Problem: $\Delta C/C_{max}$ 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)

THANK YOU