Novel simulation of DC voltage Electro thermo mechanical MEMS self-oscillator

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COMSOL CONFERENCE
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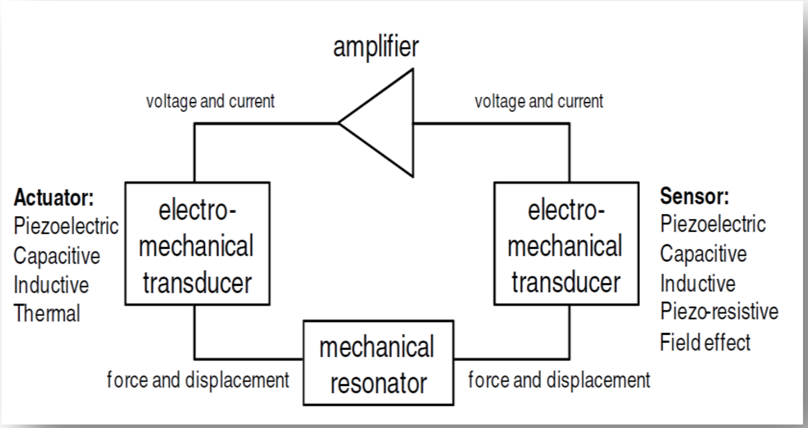
OUTLINE

- MEMS oscillators
- Principle electro thermo mechanical oscillator
- Modeling
- Use of COMSOL
- Future work

MEMS OSCILLATOR

An oscillator consists of a frequency selective element, which is the mechanical resonator, and a gaining element which is the feedback amplifier.

The feedback or sustaining amplifier is required to sustain a resonance in the frequency selective element.



Resonator and amplification separated ; integrated with the CMOS die in the same package

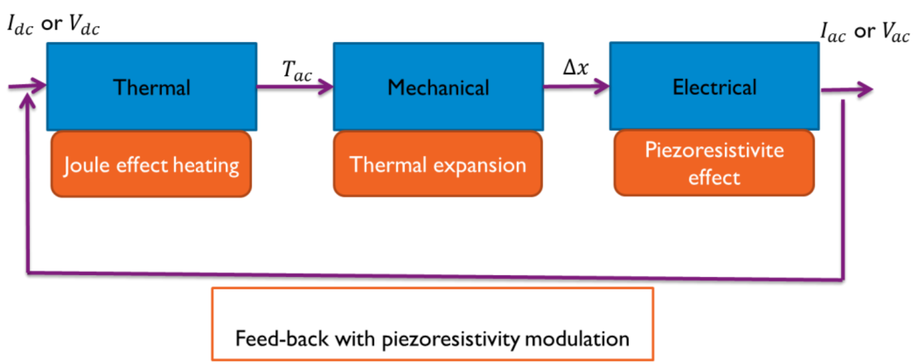
Resonator technology	Accuracy df/f_0 (ppm)	Noise FoM_2	System integration
mechanical	<10	~130	•Bulky hermetic package •Non-CMOS compatible
electrical	>100	~90	•Standard plastic package •CMOS design

ELECTRO-THERMO-MECHANICAL OSCILLATOR

.

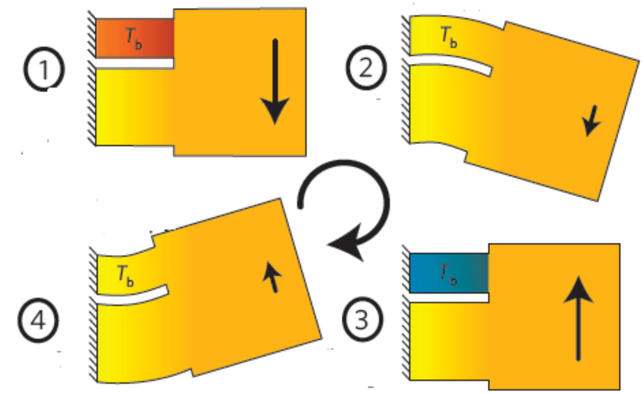
- NXP semiconductor (2009) and Rahafrooz (Denver 2010).

- The closed loop (self amplification) is obtained by crossing interaction between three physical domains: Joule heating (thermal domain) , thermal expansion(mechanical domain) and piezoresistivity effect (electrical domain**)**

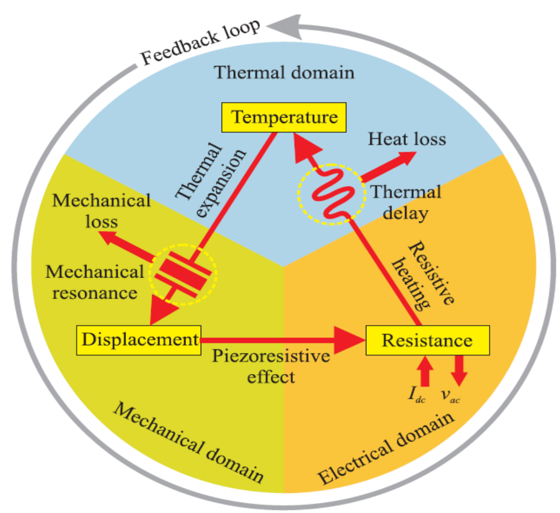


- The resistive heating power in the nanobeam, results in an increasing temperature, after a thermal delay. The temperature increase causes a thermal expansion force, which acts as a feedback force on the mass.

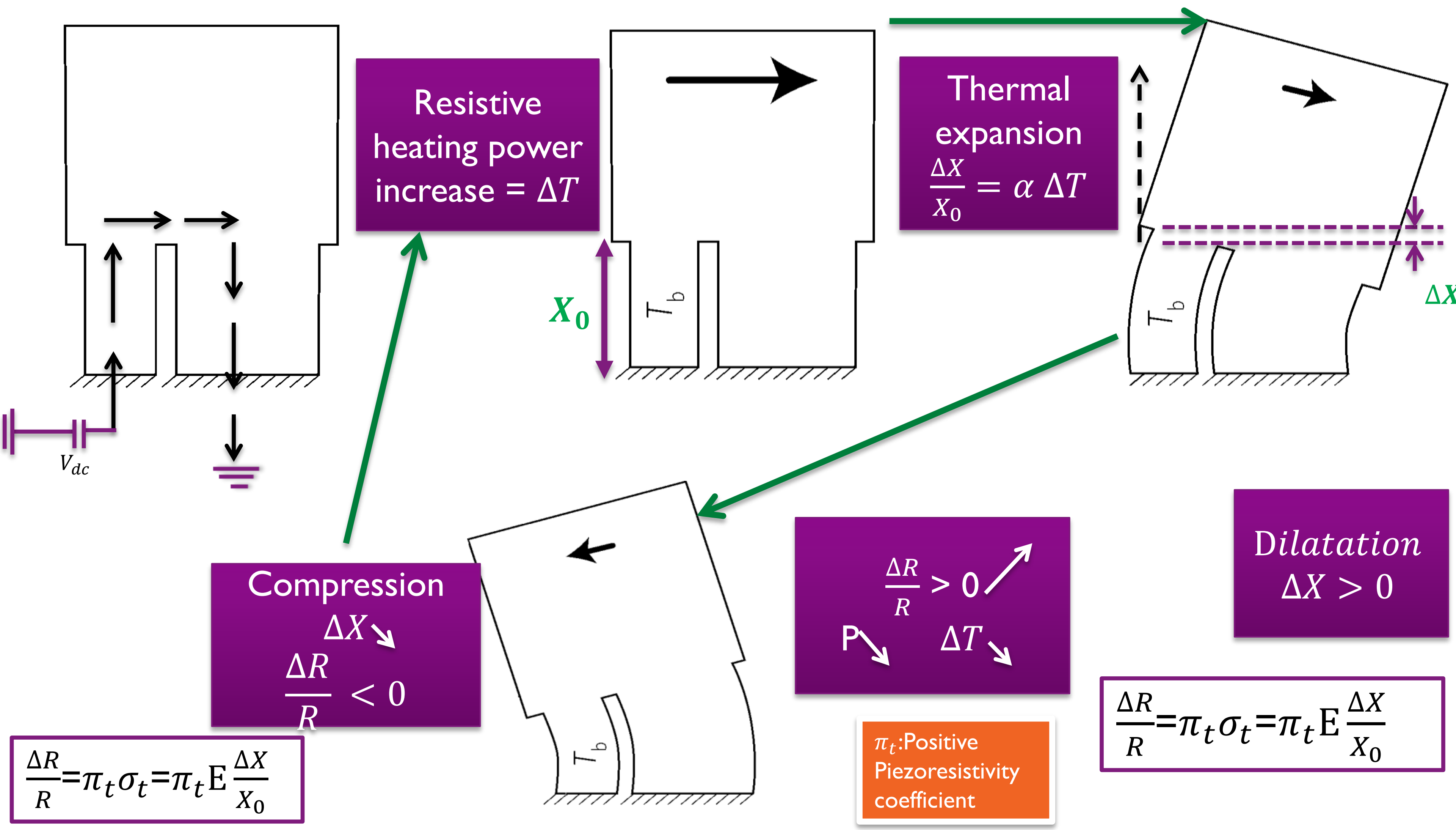
- The displacement of the resonator mass is amplified, because it modulates the resistive heating power in the nanobeam via the piezoresistive effect, which results in a power variation.



- Single crystal silicon resonator structure spontaneously starts to oscillate

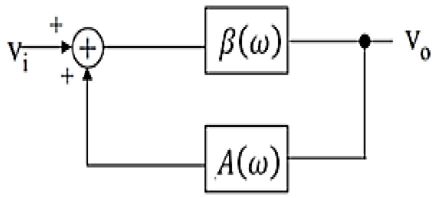


OPERATION SYSTEM



ANALYTICAL MODEL

Barkhausen criteria

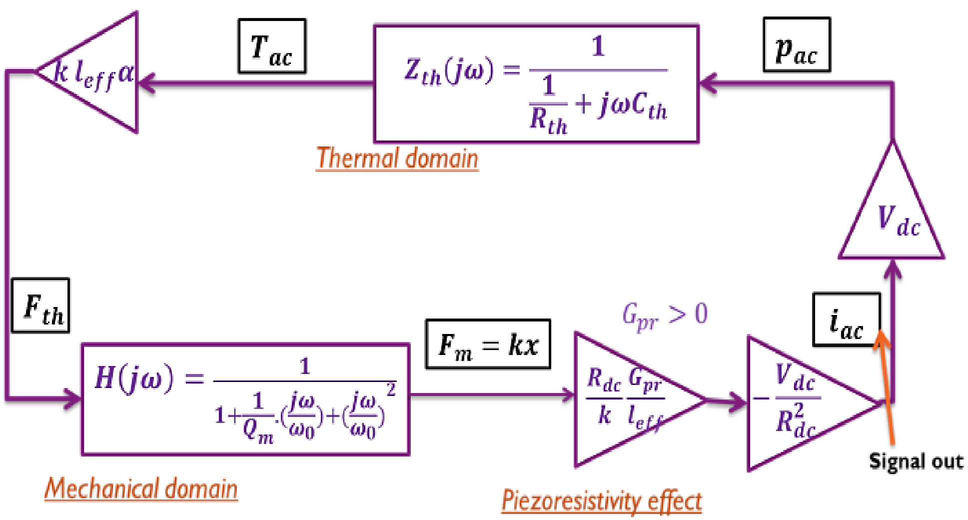


$|A(\omega)\beta(\omega)|=1$ and the phase $[A(\omega)\beta(\omega)]=2\pi n$, $n \in 0,1,2,..$

Novelty

- DC voltage driven oscillator (more simple) and positive coefficient of piezoresistivity (most commun)

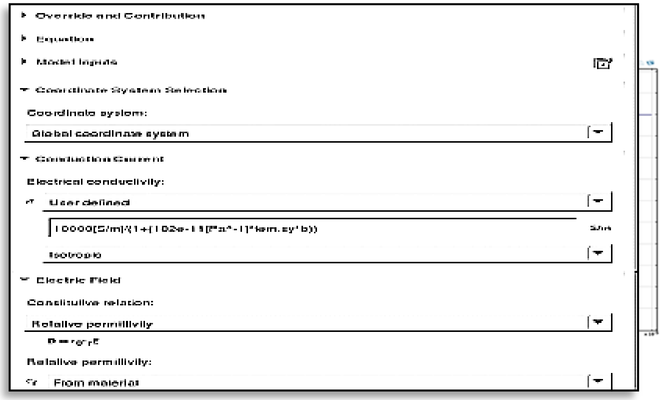
Bloc diagram model

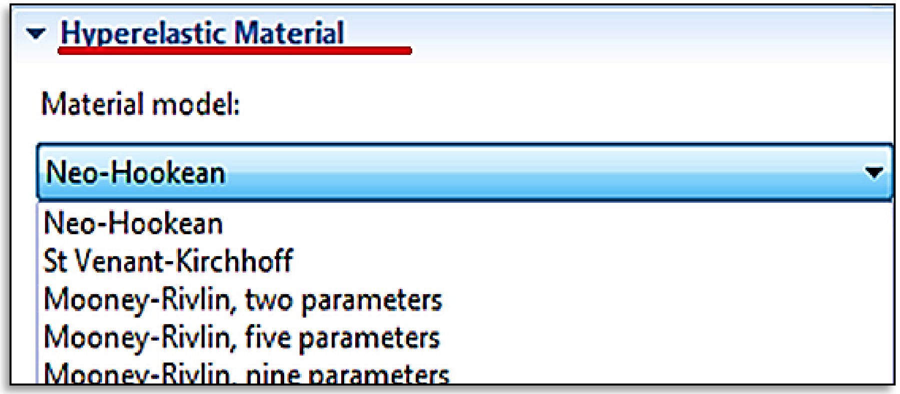


Conditions of oscillation

Dc voltage
$\omega_{0sc}^2 = \omega_0^2(1+1/C_{th}R_{th}\omega_0 Q_{int})$
$V_{dc}^2 = \frac{R_{dc}}{Q_{int}}\frac{1+\omega_0^2 C_{th}^2 R_{th}^2}{C_{th}R_{th}^2\omega_0\alpha K_{pr}}$

COMSOL SIMULATION (OSCILLATOR)



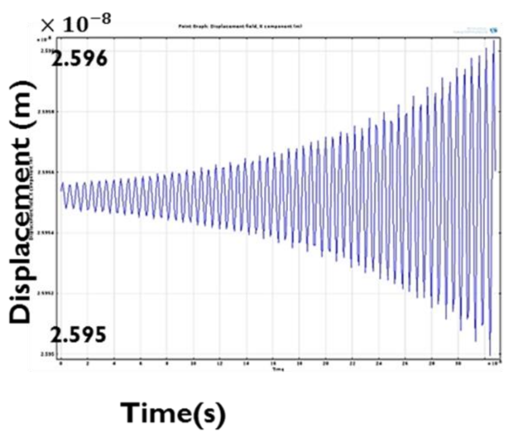


- <u>Piezoresisivity effect:</u> **Electrical conductivity expression** of the material as a function of the stress due to the piezoresistivity property of silicon.

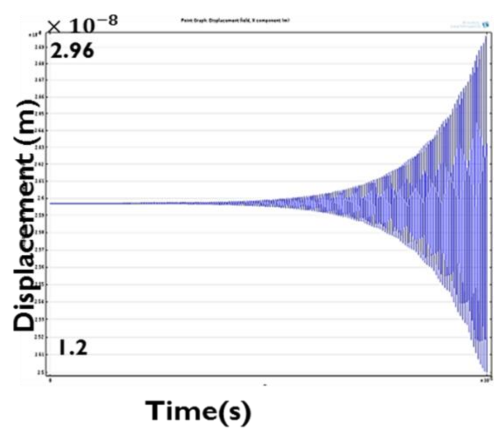
- <u>Simulation time optimization:</u> **Stationary study** as initial values for the complete **Time dependent study.**

- <u>Simulation "stabilization":</u> **Hyper elastic material** to accentuate the nonlinearity effect of the material.

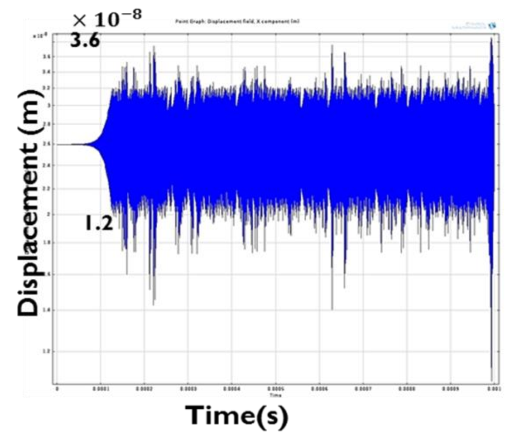
<u>Start oscillation</u>



<u>Oscillation established</u>

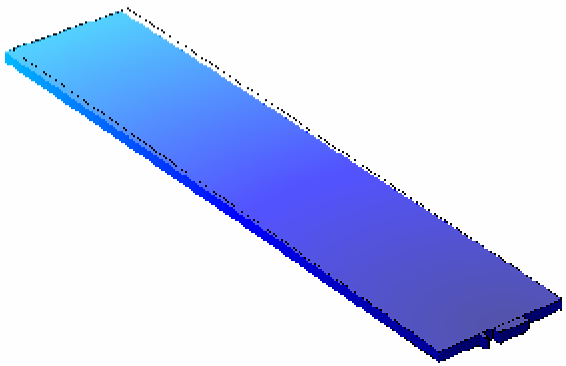


<u>Steady state (numerical noise)</u>

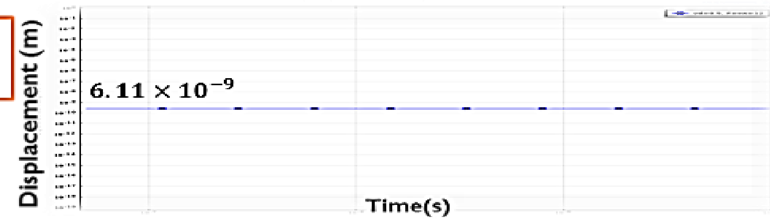


*Run implanting the piezoresistivity effect and presenting the growth oscillation aspect. (**Time dependent** simulation)*

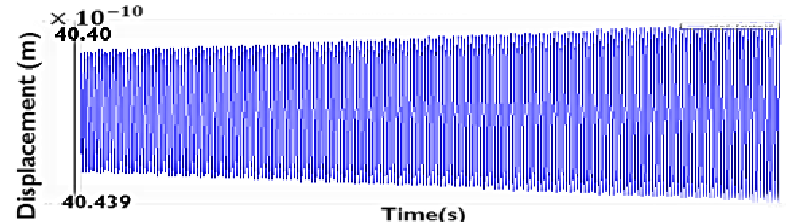
COMSOL SIMULATION (CONDITIONS VERIFICATION)



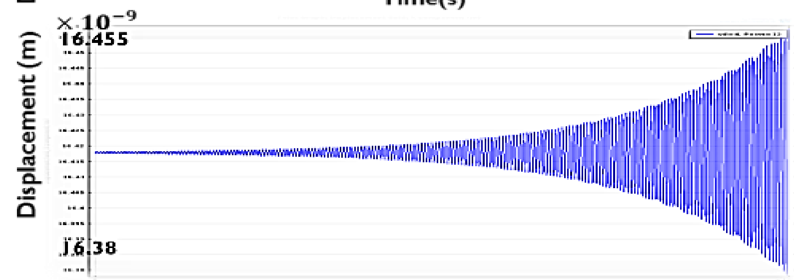
V_{dc}=0.5V (condition not satisfied) loop gain <1



V_{dc}=2V (condition satisfied) loop gain >1



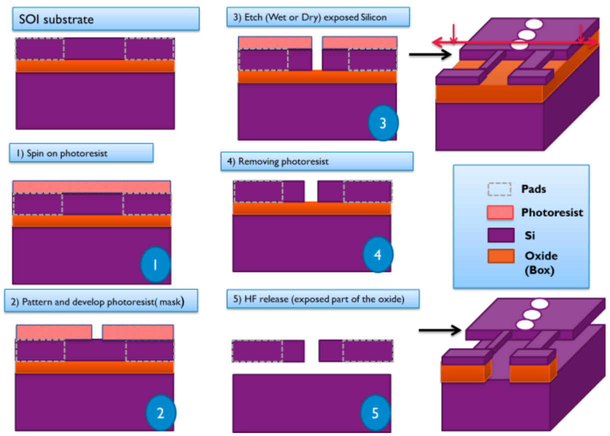
V_{dc}=4V (condition satisfied) loop gain >1

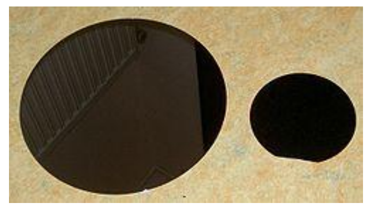


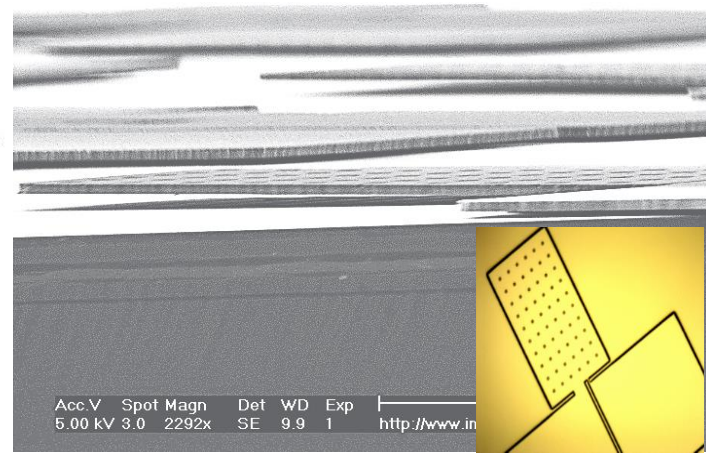
<u>Parametric sweep simulation to check the threshold limit voltage condition</u>

FUTURE WORK

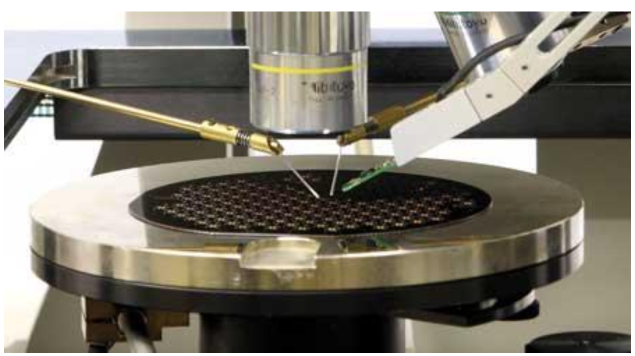
Fabrication







Measurements (just started)



Applications

- *Timing devices*
- *Sensors (gaz sensor)*
- *Heat engine, pumps..*
- *Sustained self system*
- *Energy harvesting..*

THANK YOU FOR YOUR ATTENTION

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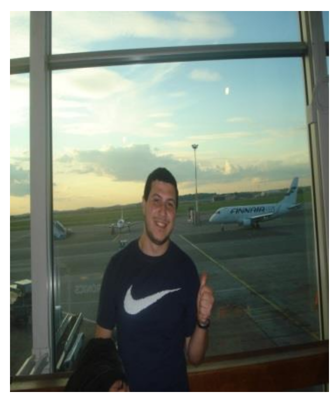

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