

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

OUENZERFI SAFOUENE PhD









KACST

مركز التميّز لتطبيقات تقنية النــانـو



- 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 FoM₂	Systemintegration	
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)





Single crystal silicon resonator structure spontaneously starts to oscillate



- The resistive heating power in the nanobeam, results in an increasing temperature, after a thermal delay. The temperature increase causes a <u>thermal expansion</u> 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 <u>piezoresistive effect</u>, which results in a power variation.

OPERATION SYSTEM



ANALYTICAL MODEL

Barkhaussen criteria





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)

Overside and Contribution			
▶ gquation	· · · · · · · · · · · · · · · · · · ·	Hyperelastic Material	
 Model legide 	1		
▼ Coordinate System Selection	· ·		
Coordinate system:		Material model:	
Global coordinate system	1 🗌 🛛 🕹		
- Paulutina Paulut			
		Neo-Hookean	-
Exected conductivity:	1 🗌 🛛 🚺	Neo-Hookean	
		Maa Haalaaa	
10000(5/m]/(1+(102e-11(****-1)*kem.sy*b))		Neo-Hookean	
		St Venant-Kirchhoff	
Cleatric Field		St venant-kirchnon	
Constitutive relation:		Mooney-Rivlin, two paramet	ers
Refailve permittivity		incomely ranni, enco percine	
$D = r_0 r_0 E$		Mooney-Rivlin, five paramet	ers
Relative permittivity:		D' I'	1
Sr From malerial		<u>Vioonev-Rivlin, nine parame</u>	ters
		-	
Piezoresisivity effect: Flectrical conductivity	🖞 🚸 Simulation	time optimization.	Simulation "stabilization" Hyper
expression of the material as a function of the	Stationar	y study as initial values for	elastic material to accentuate the
	Н., .		
stress due to the piezoresistivity property of silicon.	the comple	ete Time dependent stud	iy. nonlinearity effect of the material.
	·	-	
Start coallation	Oscillation	established Sta	eady state (numerical noise)
Start oscillation	<u>Oscillation</u>		cady state (numerical noise)
× 10 ⁻⁸	0		$\times 10^{-8}$ there first had conserved for a conserved for
X 10 Protectured find the second field of compared field of compar	× 10 ⁻⁸	Indexeen for Compared for	······································
¹⁷ 2.596	¹⁰ 2.96	A	
	146		🚬 👘 waa na baha ka
	E	2. H	
S	ب		14 ······
	5	Standard States	
	č.	and the second	an a dù arta di danai a itanini addat an airita dad an da andi
	5	and the second se	1.2
S. C.	ö	and the second se	┫╺┝─────┦╽╴║──╟╶╢────┤╢╎╶╌╌╌╵╵╸╵┈╿╴║╌╎╴╹╴╹╴
	<u>a</u> "	C	<u>5.</u>
<u>.</u>	O		2
$\overline{\mathbf{O}}$	i.)
2.595			
100	1.2		u
	15	1	
			8 8.0001 8.0002 8.0004 8.0004 8.0004 8.0007 8.0008 8.0005 8.001 72ma
Time(s)	Time(s)		Time(s)

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

COMSOL SIMULATION (CONDITIONS VERIFICATION)



Parametric sweep simulation to check the threshold limit voltage condition

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



ACKNOWLEDGMENTS



Xavier Rottenberg MDM leader group IMEC



Tilmans Harrie Project manager & Principal Scientist IMEC



Makarem Hussein Founding Director, Technology and Manufacturing Group, <u>Intel Corporation (</u>USA)



Ahmed Morsy , MS student, <u>IMEC</u>