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“A New Concept for on-Chip Differential Resonant Gyro and Pressure Nanosensor”

Cornel Cobianu

Sensors and Wireless Laboratory Bucharest,
Honeywell Automation and Control Solutions, Honeywell Romania srl
Calea Floreasca 169 A, Building A, 014459, Bucharest

1. Resonant sensors: general view
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4. Double ended tuning fork sensors-background
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Principle: frequency change as a function of external measurand variation

Excitation : electrostatic, magnetic, piezoelectric
Detection: capacitive, piezorestive, piezoelectric

Applications

•Mechanical sensors: pressure, acceleration, rotation rate

-sensing structure
-"feels" the stress
- isolated from the measurand by package
- vacuum in package : high values of quality factor Q

•Bio-Chemical Sensors : gases, (bio) molecules

-sensing structure
-"sees" the measurand by an opening in the package
-"feels" the mass loading of selectively adsorbed (bio)molecules
- detector exposed directly to RH and chemicals from environment

Roadmap for NEMS resonant sensors

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Society's needs	-Low cost/size/power-High sensitivity/selectivity gas sensors for air monitoring -High sensitivity biodetection for rapid response (<10 min) at nanoliter sampling volume - Real-time detection-analysis-computing-wireless communication and feed-back			
Potential Future Products	Hybrid NEMS for zg mass detection in vacuum and cryogenic Temp Acceleration, pressure and gyro sensor	Hybrid NEMS-based Mass spectrometer (MS) for sensing protein and biomolecules	Wireless NEMS Computing RF-NEMS Gas & Bio Sensor array, 300K, 1 atm	Miniaturized, Hybrid MS for single bio molecule detection Large NEMS Array
Components	NEMS resonator off-chip: electronics, actuation detection	NEMS resonator 450MHz-1 GHz off-chip electronics, actuation, detection, electrospray ionization system (ESI), ion guiding system	Self-sustaining NEMS oscillators, 1GHZ ? in plane-VB-FET on-chip actuation on-chip front end RF electronics & signal processing NEMS front end RF	Self-sustaining NEMS oscillators, array of NEMS on-chip actuation and detection Microfluidic processor chip, Nano ESI
Technologies	Si/SiC NEMS technology Electron Beam Lithography (EBL)	Si/SiC NEMS, technology IC technology DPN functionalization	SOI-CMOSFET EBL, on-chip selective nano-functionalization	SOI-CMOSFET technology EBL, 3D-NEMS DPN functionalization
Enablers	S &T of MEMS-NEMS resonators IC technology Governmental support	Reaching the mass limit of detection in the zg range Governmental support	Active nano devices and sensors Nanomechanical RF signal processing Gvnm support	Reaching mass LOD toward yg. Understanding NEMS-SOI-CMOS V(U)LSI integration

Source: Li, Tang, Roukes , Nature Nanotechnology 2007

- Status

  -Encouraging resonant NEMS gas sensing at 127 MHz, 300K and 1 atm

  Q factor of 400

  Off-chip, piezoceramic actuation of the NEMS cantilever

  On-chip piezoresistive detection in thin metallic film

  1 attogram (resolution 100 zg) of gas adsorbed on vibrating beam!

- Challenges

  - Resonant NEMS at 1 GHz, 300K and 1 atm

  - Sub-ppb sensitivities for gas sensitivities in the environmental air

  - Selective functionalization of vibrating beams with width below 100 nm.

Fully integrated resonant NEMS gas sensors:

–A major scientific/technical target !

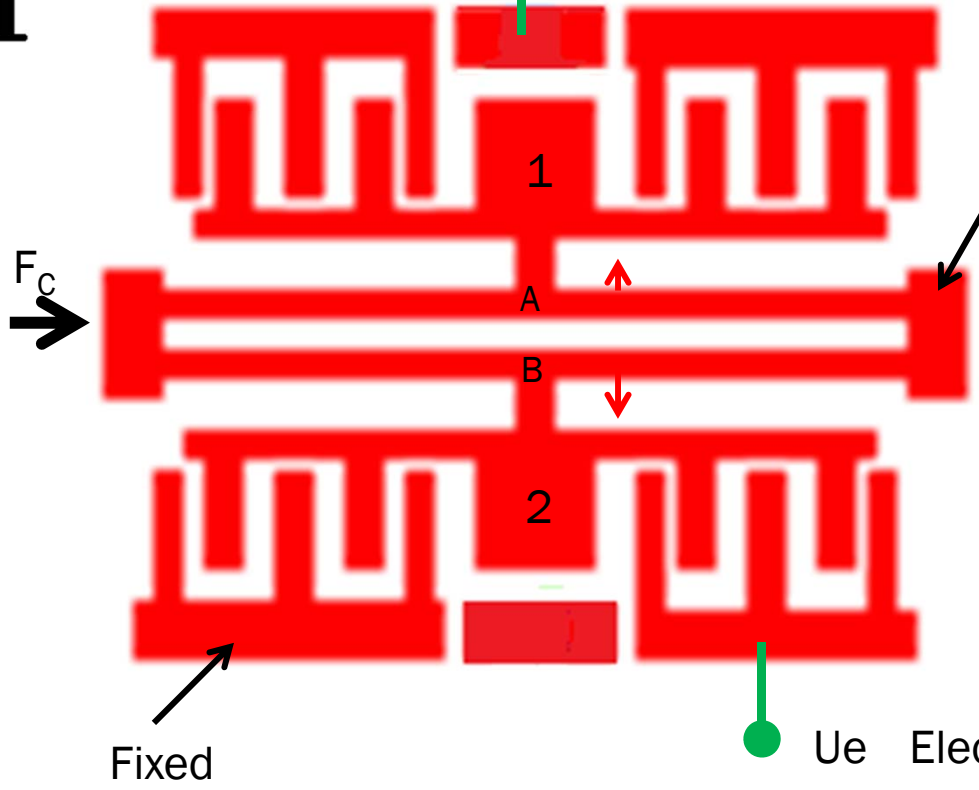
Tuning fork

Ud Capacitive detection

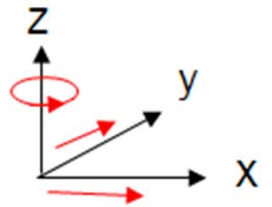
$f_r=(1/2\pi)\ (k/m)^{1/2}$

K=K (F) ⟹ resonant mechanical sensor

$f_r=f_r(F)$



Resonance frequency decreases

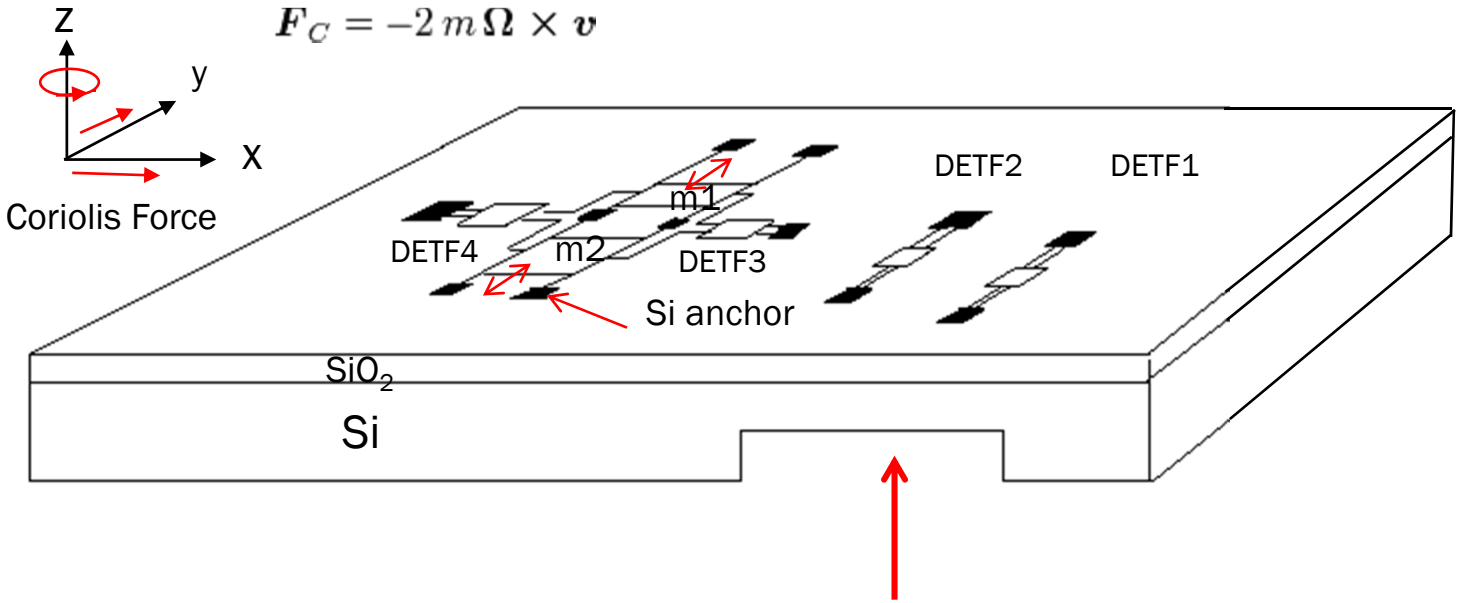


Coriolis Force

$$\boldsymbol{F}_C = -2\,m\,\boldsymbol{\Omega} \times \boldsymbol{v}$$

Packaging in vacuum : preserves high Q and electrical stability of the vibrating gate transistor

$$\boldsymbol{F}_C = -2\,m\,\boldsymbol{\Omega} \times \boldsymbol{v}$$



- SOI-CMOSFET technology with packaging in vacuum
- Differential sensing
  - -increased sensitivity
  - - temperature compensation
  - - reduced ageing effects

Novelty :
detection principle based on active device !

Pressure :
DETF1 : tension; fr ↗
DETF2 : compression; fr ↘

Rotation rate :
DETF3 : compression fr ↘
DETF4 : tension; fr ↗

DETF Resonator with detection by vibrating gate transistor

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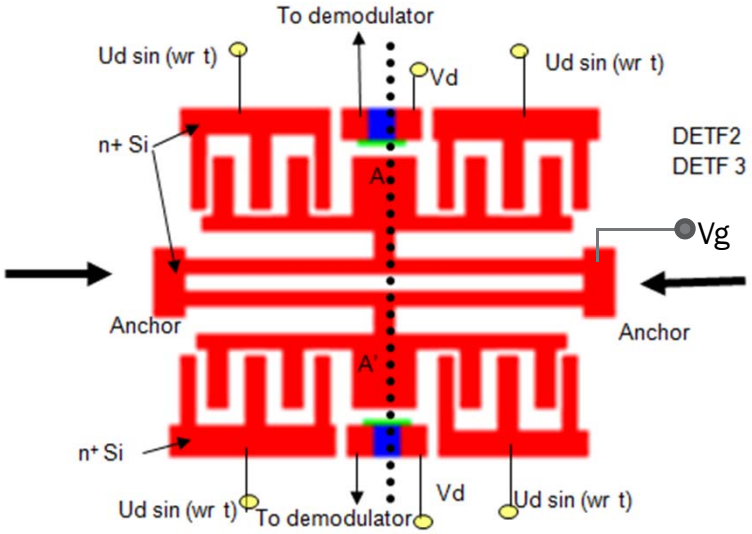

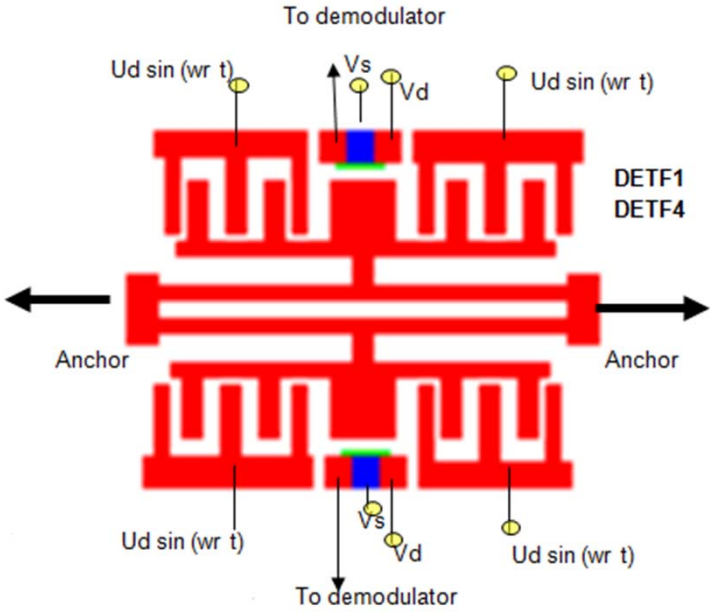

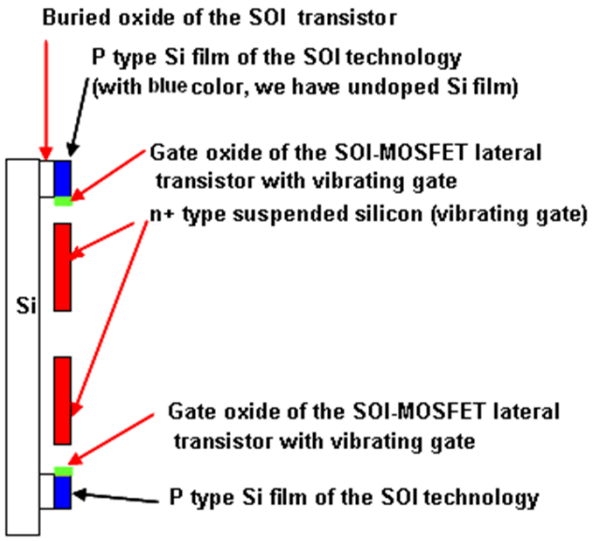

•Vibrating gate MOSFET transistor

-minimizes complex electronics specific to capacitive detection

- Replaces capacitance measurement by a frequency – modulated drain current measurement

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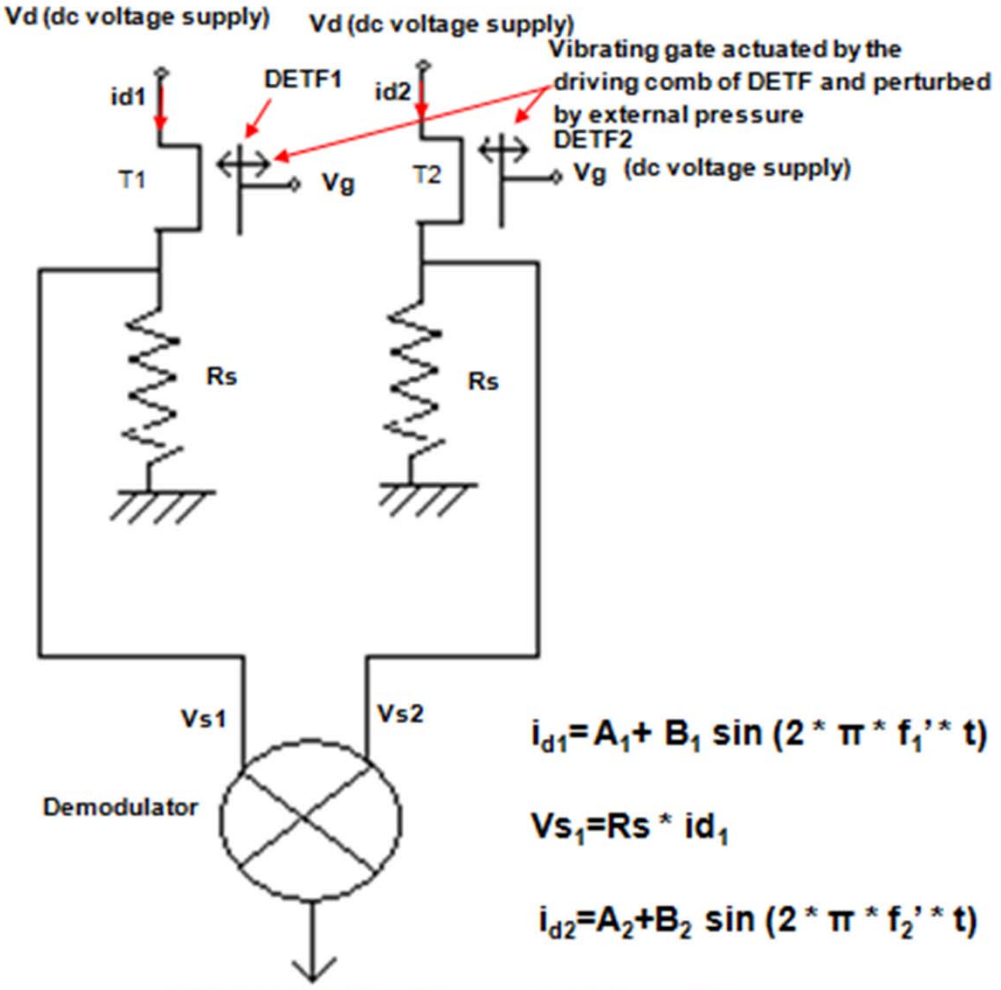

$i_{d1} = A_1 + B_1 \sin(2 * \pi * f_1' * t)$

$Vs_1 = Rs * id_1$

$i_{d2} = A_2 + B_2 \sin(2 * \pi * f_2' * t)$

$Vs2 = Rs * id_2$

$A1 = A2$

$B1 = B2$

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7. Cornel Cobianu , 2012, EP patent pending

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•SOI-CMOS is expected to become a large technology platform for resonant NEMS applications:

mechanical sensing : pressure, acceleration , rotation rate

-bio-chemical detection: organic molecules, gases

•Mechanical resonant SOI-CMOSFET-NEMS smart sensors to go faster to industrial applications

•Differential sensing

-increased sensitivity,

- temperature compensation

- reduced drift

•A novel detection circuit is proposed based on vibrating gate transistor replacing the complex capacitive principle

• Vibrating gate transistor simplifies the detection circuit providing directly a frequency-modulated drain current

The author would like to express his thanks to *EU-FP-7-NEMSIC project* and *Honeywell International* for the financial support of this research

Thank you for your attention !