POLITECNICO DI MILANO

Thesis proposals related to MEMS

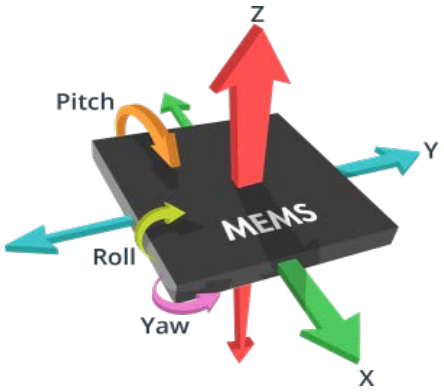
Alberto Corigliano

Department of Civil and Environmental Engineering

www.mems.polimi.it

www.mems3d.polimi.it

MEMS @ Polimi

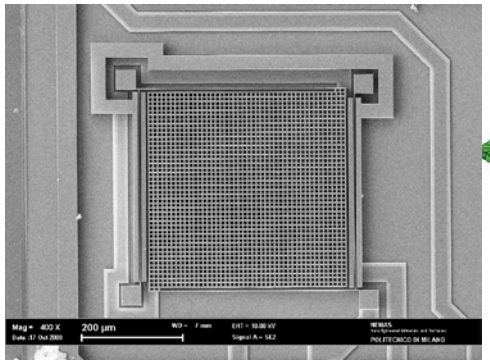


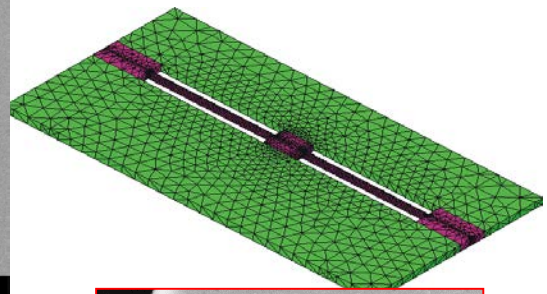
- Research on MEMS since 2002
- Strict cooperation with STMicroelectronics
- Industrial, Regional, National and EU projects.
- Teaching at master and PhD levels in Materials Eng. & Nanotechnology and Electronics study courses

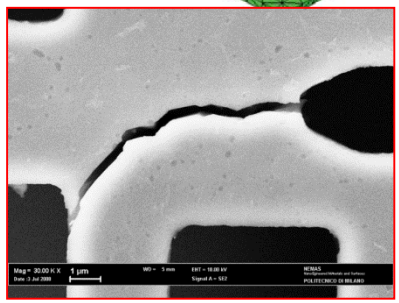
MEMS @ Polimi

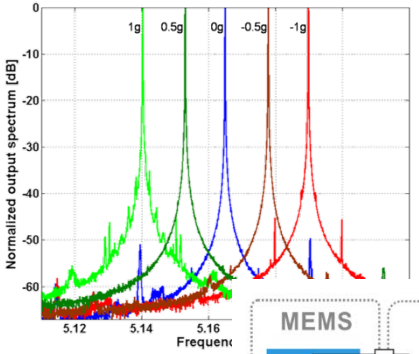
Research activities

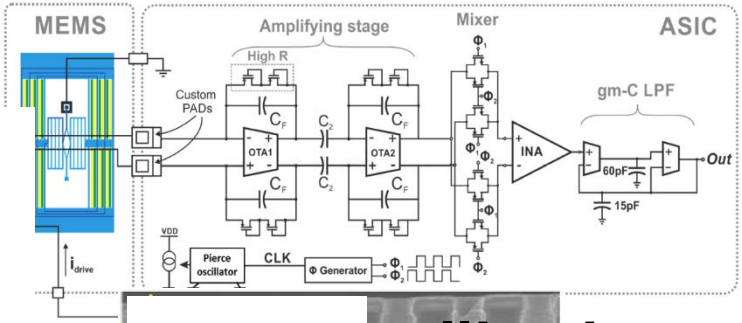
- Theory
- Modelling and simulation
- Design
- Characterization and reliability
- Devices
- Interface electronics
- Instrumentation for MEMS
- Fabrication processes
- Additive manufacturing
- Applications

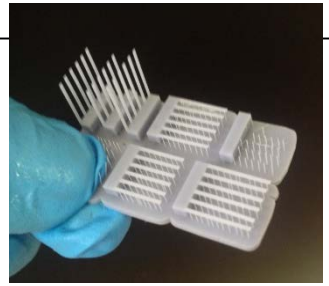


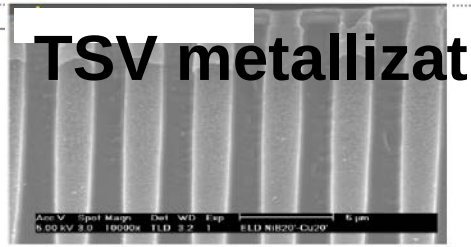












TSV metallization

MEMS @ Polimi

- **Polimi network on MEMS**:

  Dep. Civil and Environmental Eng. (DICA)

  Dep. Electronics, Information T. and Bio-Eng. (DEIB)

  Dep. Chemistry, Materials and Chemical Eng. (DCMIC)

  Dep. of Mechanical Eng. (MEC),

  + Dep. of Mathematics, Dep. of Aerospace Sciences

- **MEMS&3D lab**. www.mems3d.polimi.it DICA, DEIB, DCMIC, MEC, on microsystems and additive manufacturing (3D + ink-jet printing at micro scale)

- **Parallel initiative**: **Polifab**, clean room for micro-fabrication

Civil and Environmental Engineering for MEMS

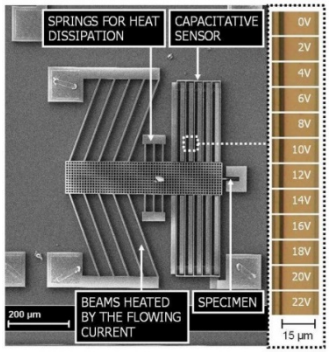
MEMS modelling and design group

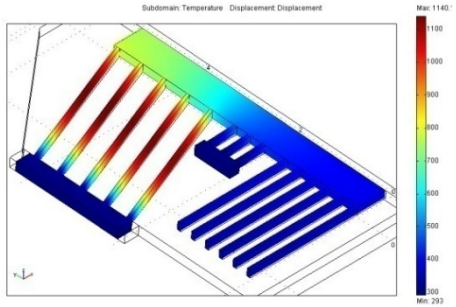
Raffaele Ardito, Claudia Comi, Alberto Corigliano, Attilio Frangi, Aldo Ghisi, Stefano Mariani

Structural and materials mechanics at micro (μ) and nano (n) scale

www.mems.polimi.it

Dip. Ingegneria Civile e Ambientale





Contact:
Alberto Corigliano
tel. +390223994244, Fax +390223994330 – alberto.corigliano@polimi.it

MEMS research activities

Characterization and reliability

- Mechanical characterization at the micro scale
- Fracture-fatigue
- Accidental impacts
- Dissipative phenomena: fluid damping, solid damping, anchor losses
- Stiction (spontaneous adhesion)

Device design

- Electro-thermo-mechanical actuators
- Capacitive accelerometers
- Resonant accelerometers
- Electrostatic micropump
- Resonant gyroscope + accelerometers
- Magnetometers
- Piezoelectric devices
- Threshold shock sensors
- Energy harvesters
- Resonators

Modelling & Simulation

- Multi-physics
- Fracture initiation and propagation in polycrystalline materials
- Domain Decomposition methods
- Model Order Reduction methods + Domain Decomposition

Research subjects which can be related to MS theses

1. MEMS reliability
2. MEMS modelling & simulation
3. Theoretical study and numerical modelling of damping
4. Resonators
5. Micro-mirrors
6. Micro-gyroscopes
7. Piezoelectric Energy harvesters
8. Piezo Micro Ultrasound Transducers PMUT
9. Technology and fabrication process related activities
10. Additive manufacturing applied to MEMS

Most of the activities in strict cooperation with STMicroelectronics, other groups of Polimi and international groups at: MIT, UC Davis, Northwestern University, EU partners in EU funded projects

1. MEMS reliability

Objective: To deeply investigate issues related to micromechanical components reliability (mechanical effects, rupture, spontaneous adhesion…)

Main achievements:

1.1 Experimental mechanical characterization of polysilicon through on-chip test methodology (elastic stiffness, tensile strength, Weibull approach, fracture, fatigue,…)

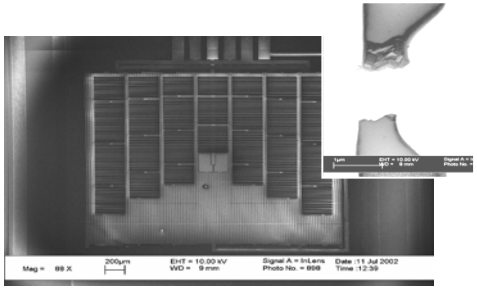
1.2 Experimental set-up for on chip testing with lock-in methodology

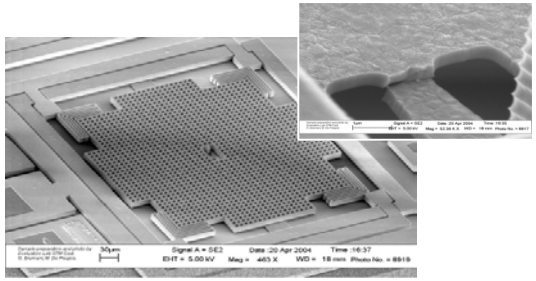
1.3 Theoretical, experimental and numerical study of spontaneous adhesion phenomena in MEMS (stiction)

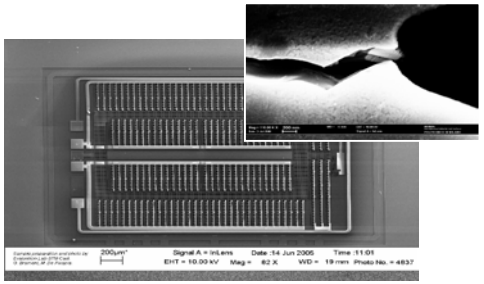
- Collaboration with STM and electronics and material science groups in Polimi

1.1 Reliability - Experimental mechanical characterization of polysilicon through on-chip test methodology (elastic stiffness, tensile strength, fracture, fatigue, Weibull approach…)

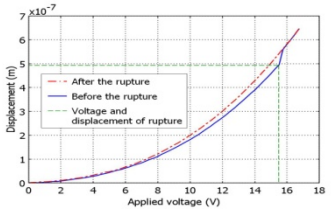
- Electrostatic actuators for tensile, bending, fracture and fatigue tests

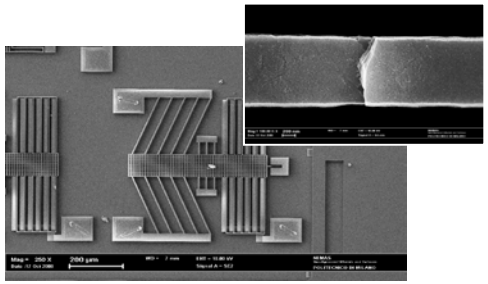




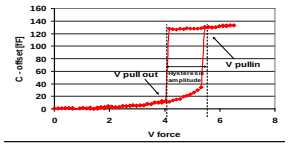


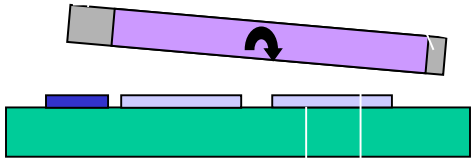
- Electro-thermo-mechanical actuator for tensile tests

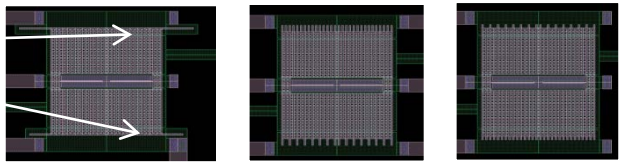




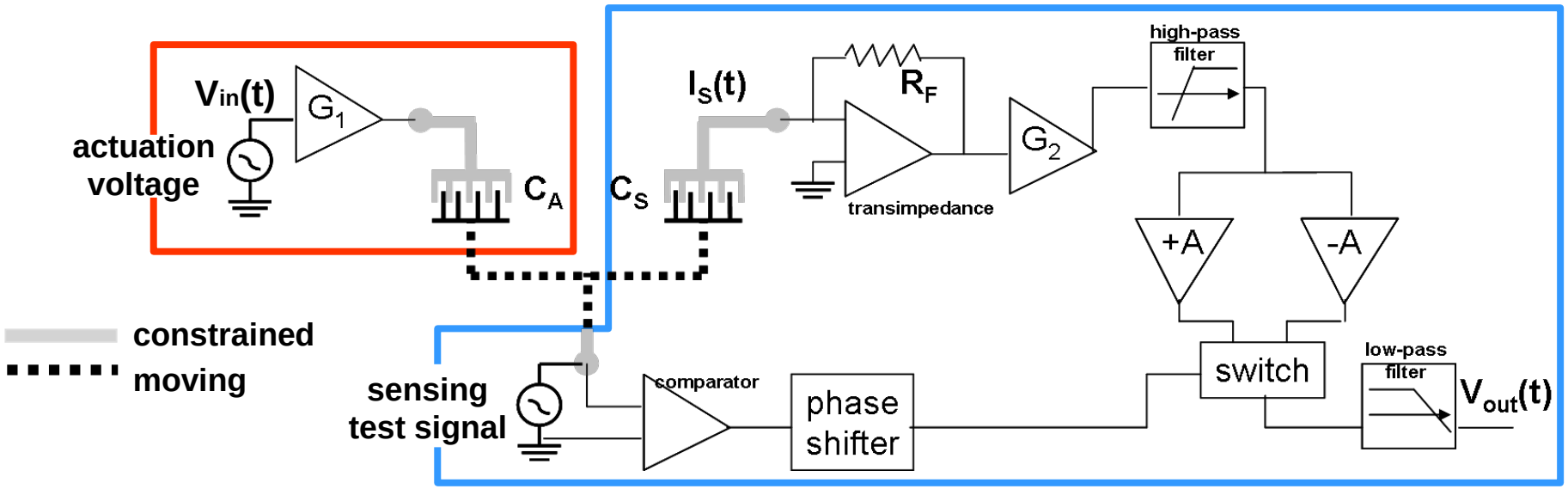
- Test structures for spontaneous adhesion detection





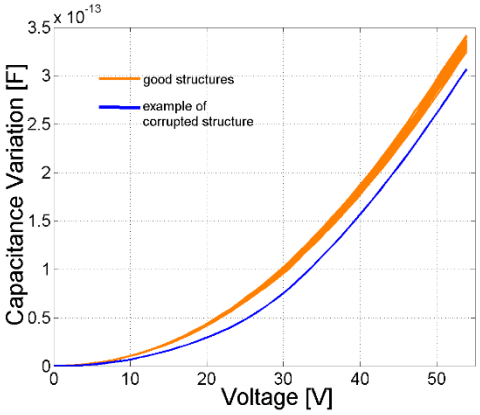


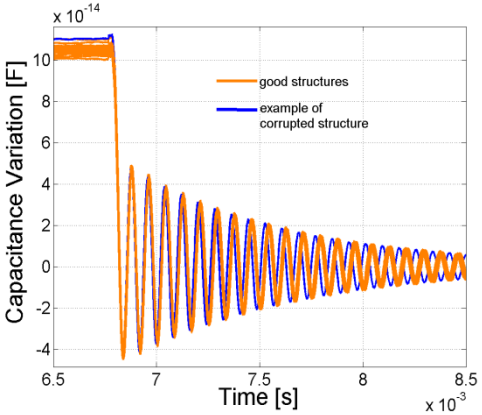
1.2 Reliability - Experimental set-up for on chip testing with lock-in methodology



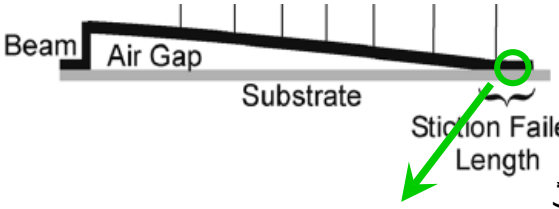
Laboratory set-up for the execution of on-chip testing.

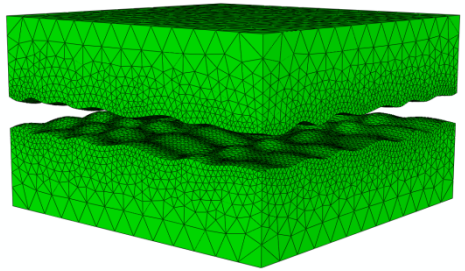
Applied to fracture and fatigue tests, resonant accelerometer characterization

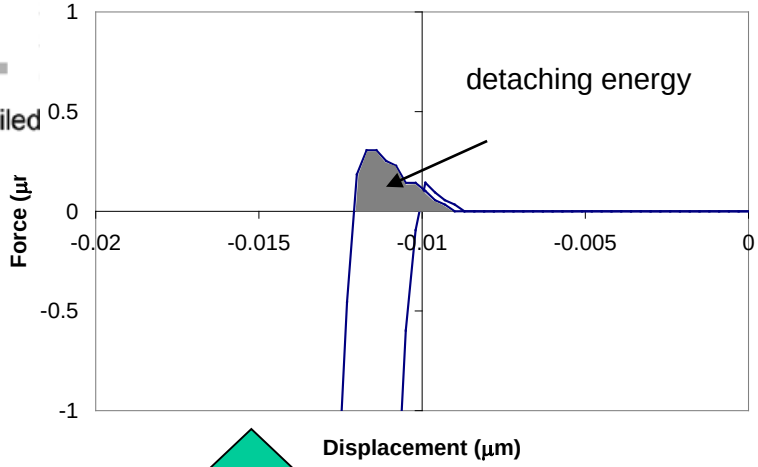


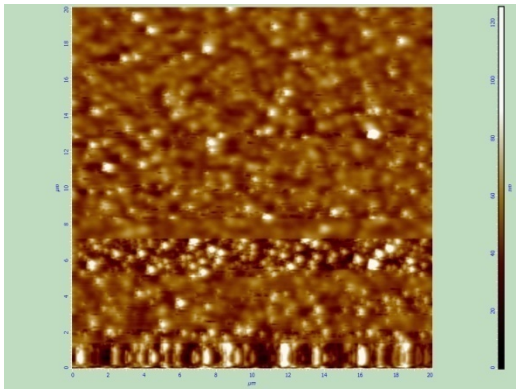


1.3 Reliability - Theoretical, experimental and numerical study of spontaneous adhesion phenomena in MEMS (stiction)









AFM measurements of surface roughness

meso-scale model for computing the detaching energy

results

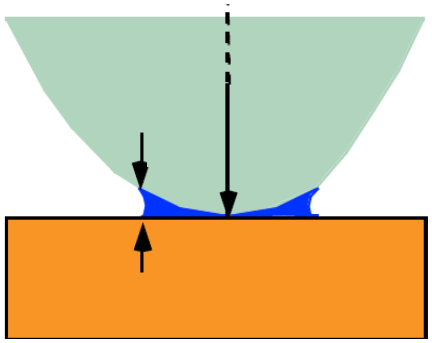
FEM elastic-plastic analyses with adhesive contact

the adhesive contact model includes:

capillary attraction

depends on:

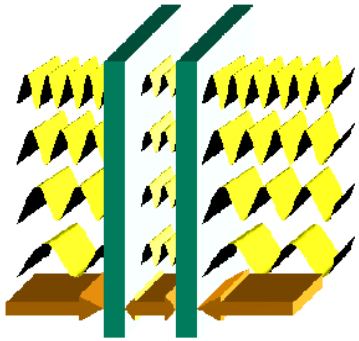
- relative humidity
- temperature
- surface gap
- shape of asperities



“dispersion” forces (Van der Waals, Casimir)

depend on:

- material features
- surface gap
- surface geometry



2. MEMS modelling & simulation

Objective: To perform specific modelling & simulation activities for MEMS

Main achievements:

2.1 Numerical modelling and simulation of fluid damping in MEMS at varying pressure

2.2 Numerical simulation of electrostatic problems: precise evaluation of capacitance and electrostatic force for complex geometries

2.3 Numerical modelling and simulation of accidental drop impacts

2.4 Numerical modelling and simulation of 3D fracture processes in polycrystals

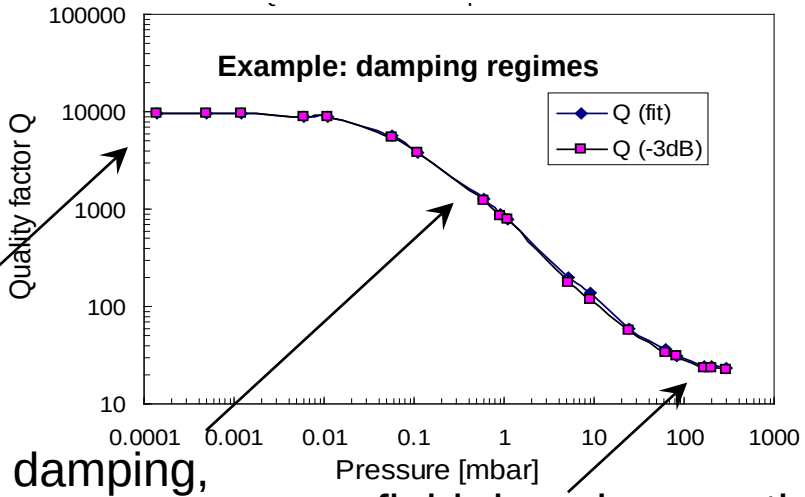
2.5 Numerical modelling and simulation of multi-physics problems in MEMS

- Collaboration with state of the art international computational mechanics groups

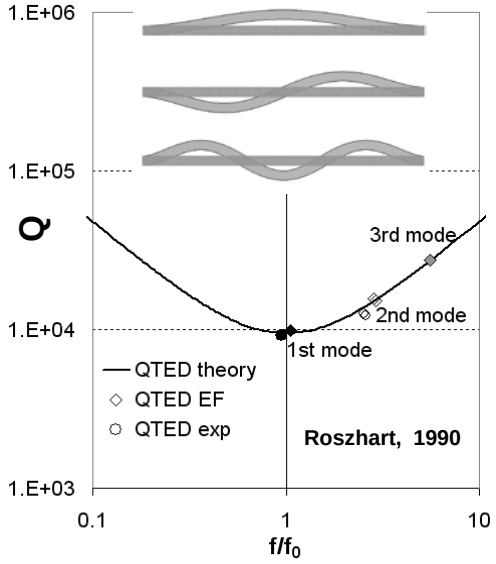
2.1 MEMS modelling - Numerical modelling and simulation of fluid damping in MEMS at varying pressure

Precise evaluation of quality factor Q at varying pressure.

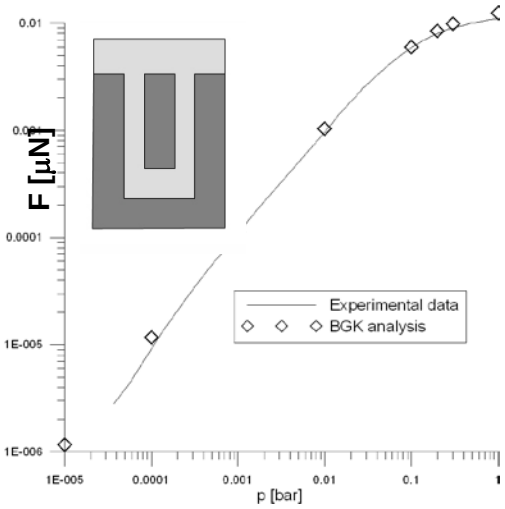
Applied to microphone and gyroscope



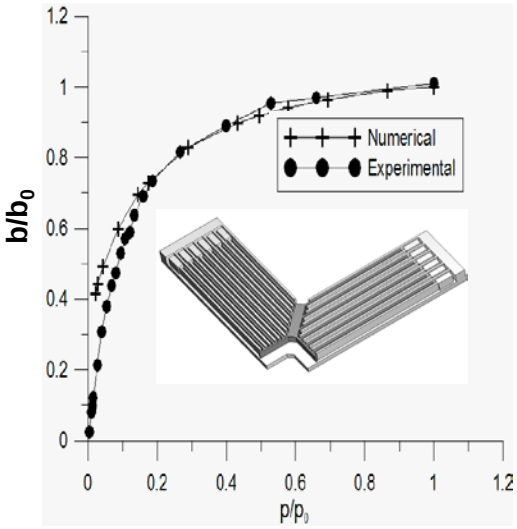
solid/surface damping: e.g. thermoelasticity



fluid damping, rarefied regime: BGK model



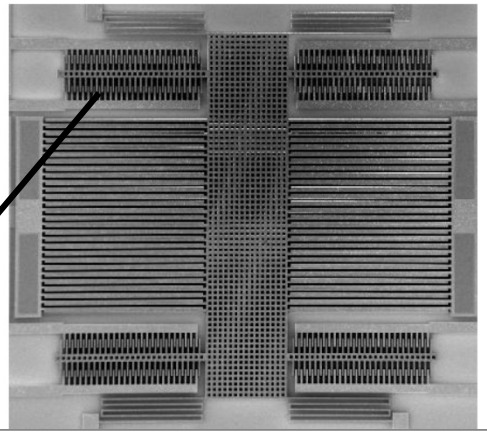
fluid damping, continuum regime: Navier-Stokes

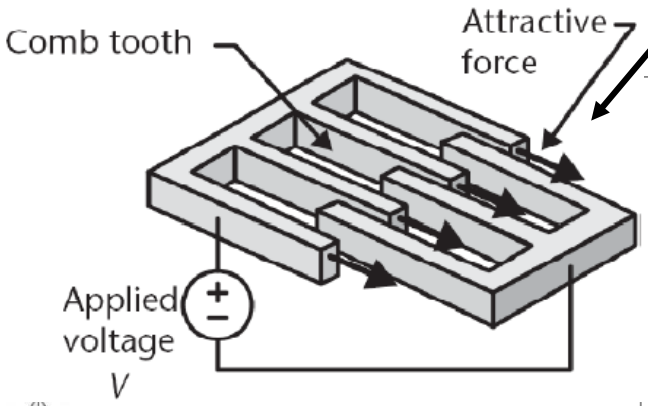


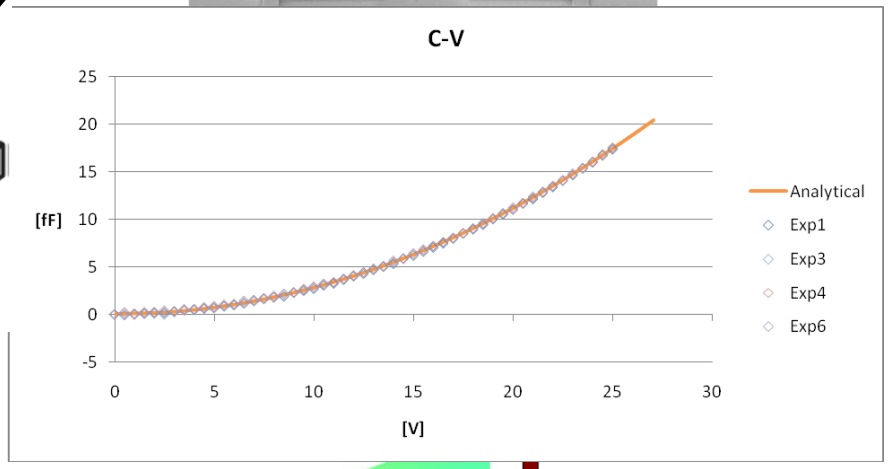
2.2 MEMS modelling - -Numerical simulation of electrostatic problems

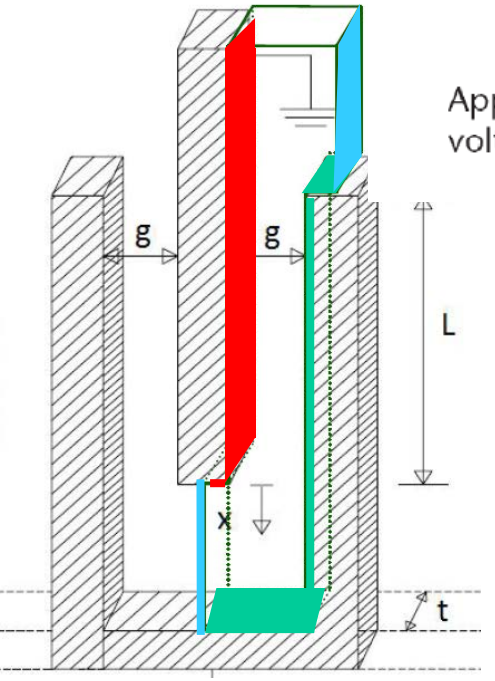
Precise evaluation of capacitance and electrostatic force for complex geometries

Applied to design of accelerometers and test device for stiction problems





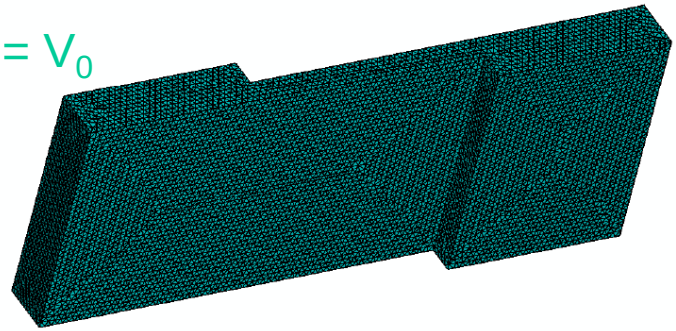


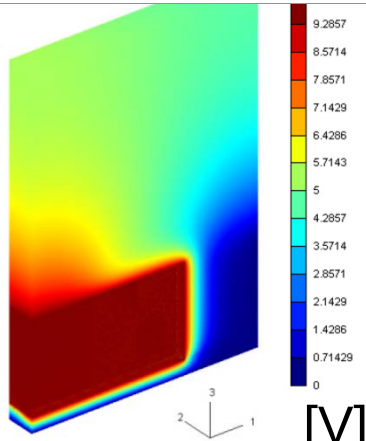


symmetry

$V = 0$

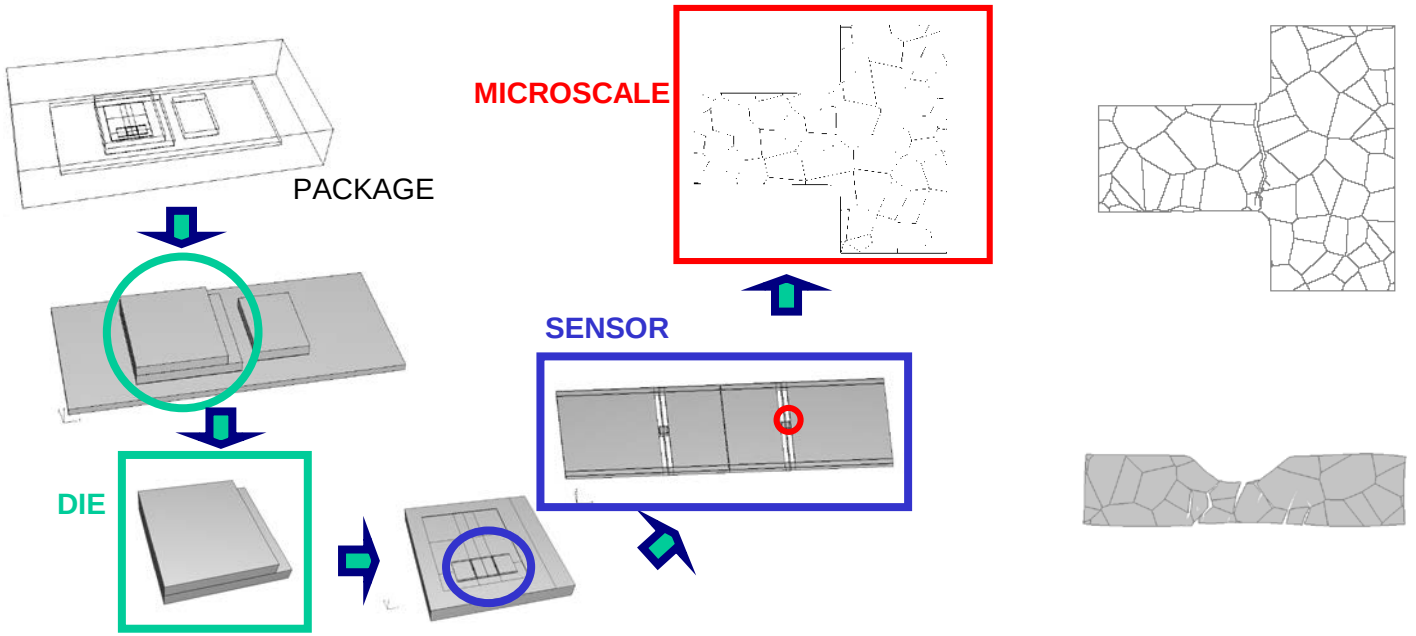
$V = V_0$





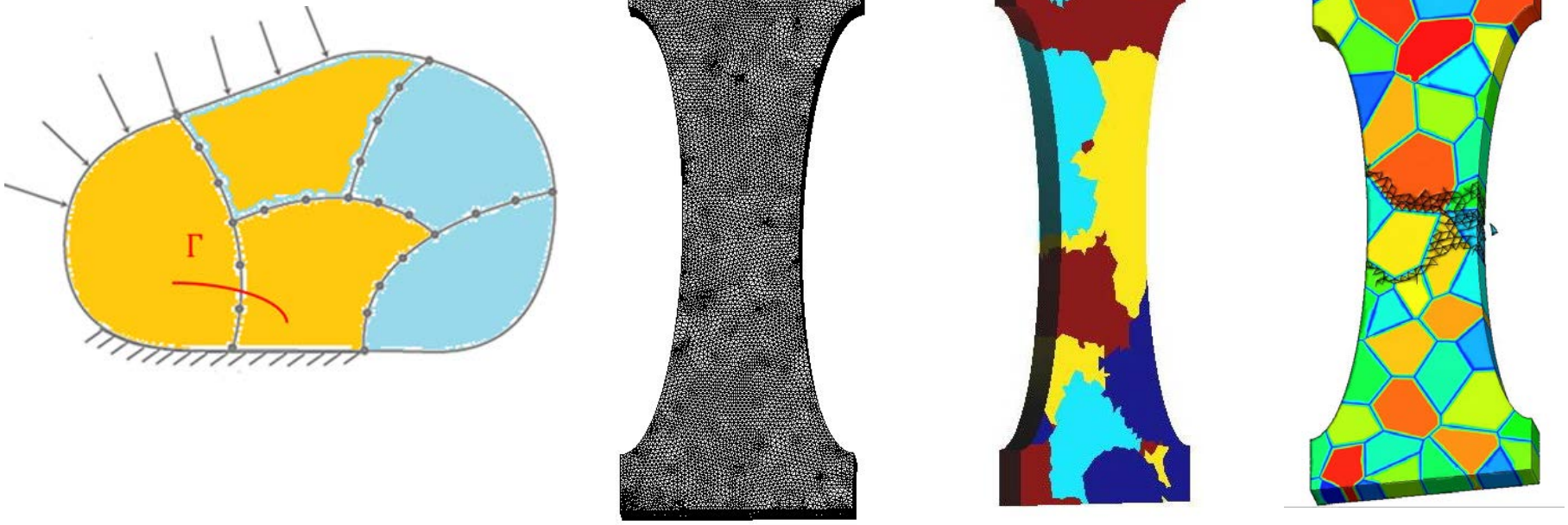
2.3 MEMS modelling - Numerical modeling and simulation of accidental drop impacts

- Large scale FE numerical simulations
- Simplified procedure for a top-down approach with decoupled responses.
- Assessment of safety against accidental drop
- Simulation of fracture processes in polycrystals
- Applied to design of accelerometers and microphone



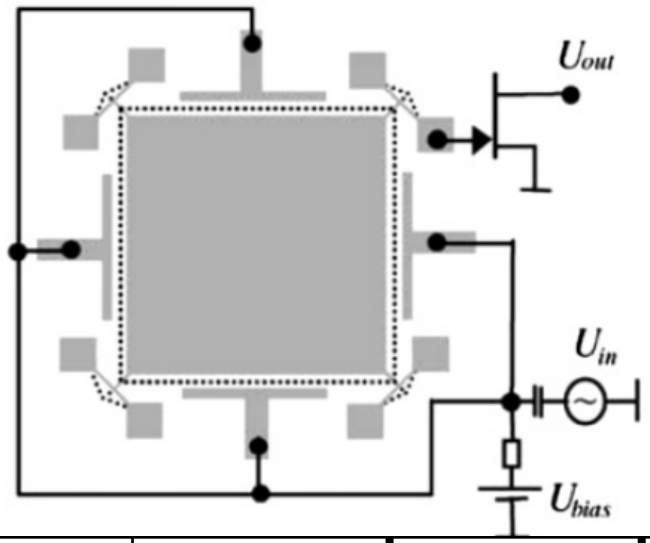
2.4 MEMS modelling – 3D Numerical modelling and simulation of fracture processes in polycrystals

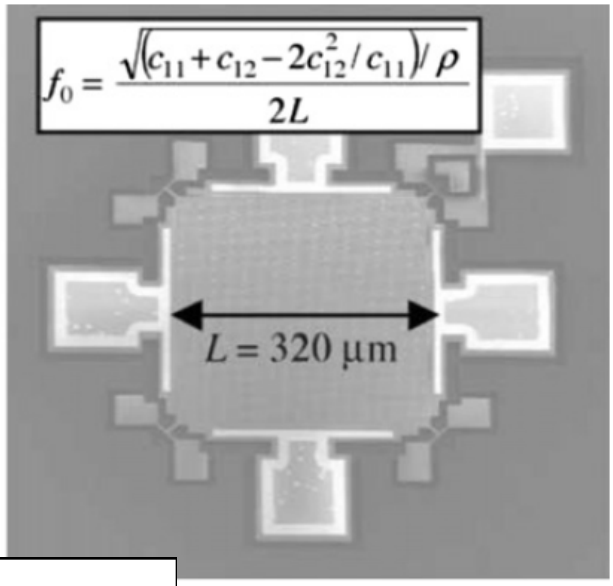
Domain decomposition techniques applied to the 3D FE simulation of fracture processes in polycrystalline MEMS.



2.5 MEMS modelling –Numerical modelling and simulation of multi-physics problems in MEMS

Application of the POD Model Order Reduction technique to the simulation of electro-mechanical vibration of a MEMS plane resonator. Computing time reduced of 90%.



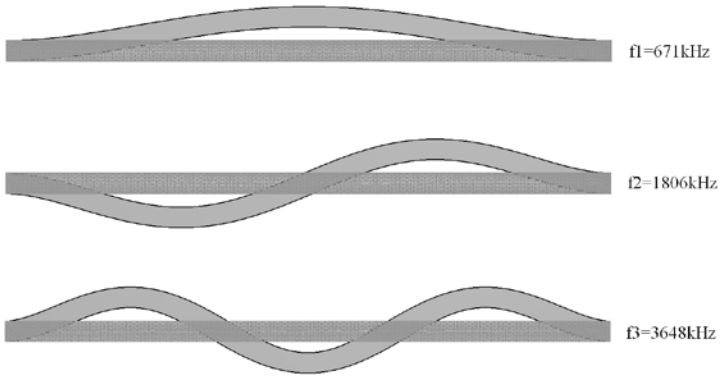


	Total time	**error** w.r.t. stag.	**gain** w.r.t. Stag. (%)	n° POM
S ($t_{tot}=4\cdot10^{-5}$)	**24370**	-	-	--
S-POD ($t_{snap}=3\cdot10^{-7}$)	7121	$8{,}32\cdot10^{-2}$	-70,8	35
SD-POD ($t_{snap}=3\cdot10^{-7}$)	5587	$7{,}02\cdot10^{-2}$	-77,1	35
S-POD ($t_{snap}=2\cdot10^{-7}$)	4705	$8{,}33\cdot10^{-2}$	-80,7	38
SD-POD ($t_{snap}=2\cdot10^{-7}$)	3793	$8{,}32\cdot10^{-2}$	-84,4	38
S-POD ($t_{snap}=1.5\cdot10^{-7}$)	3639	$7{,}25\cdot10^{-2}$	-85,1	34
SD-POD ($t_{snap}=1.5\cdot10^{-7}$)	2826	$5{,}86\cdot10^{-2}$	-88,4	34
SD-POD updated	**2664**	$9{,}98\ 10^{-2}$	**-89,1**	**31**

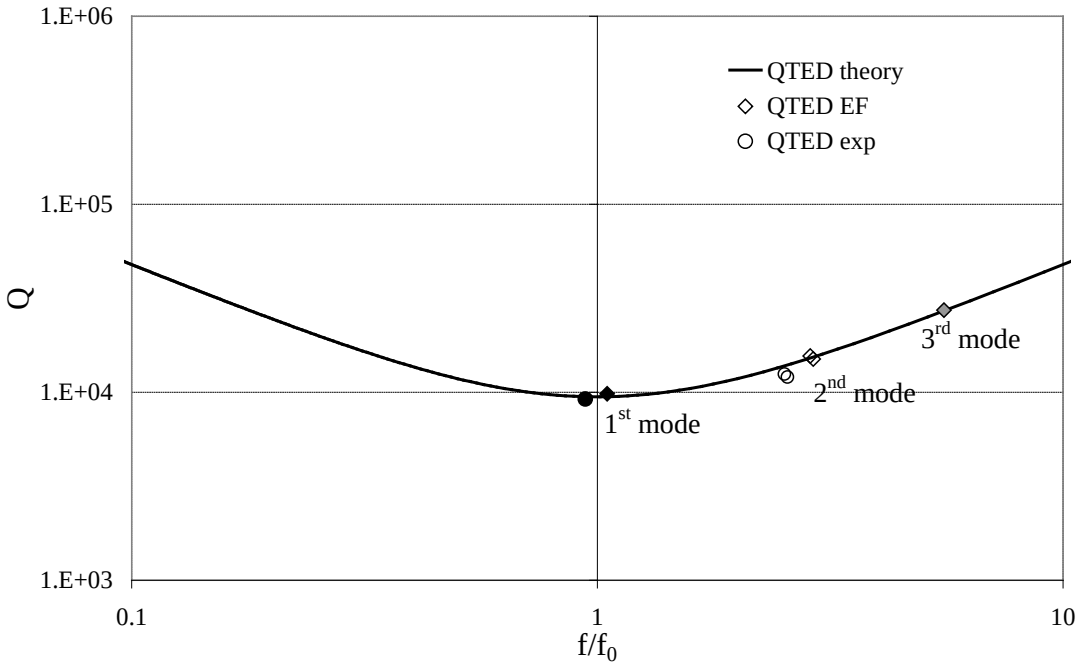
3. Theoretical study and numerical modelling of damping (fluid, solid thermoelastic damping, anchor losses…)

Theoretical study and computational models for the correct evaluation of solid damping in MEMS. Possible applications to resonators, resonant accelerometers, gyroscopes, magnetometers…

FEM-based discretization of thermoelastic problem



E	150GPa	ρ	2330 kg/m^3
ν	0.2	C	700 J/(kg · K)
α	2.6·10^{-6} 1/K	k	148 W/(m · K)



- Collaboration with STM and electronics and material science groups in Polimi

4. Resonators

Objective: to develop resonant devices which keep a very stable frequency in a wide range of temperatures, i.e. limited thermal drift.

Main achievements:

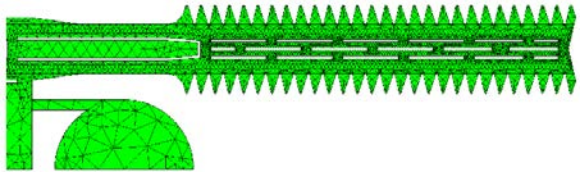
4.1 Modelling and simulation of resonators

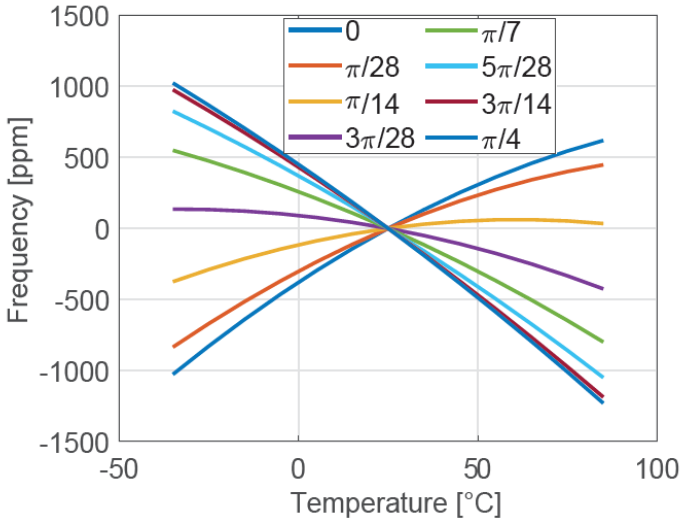
4.2 In progress: experimental activity, design of new devices.

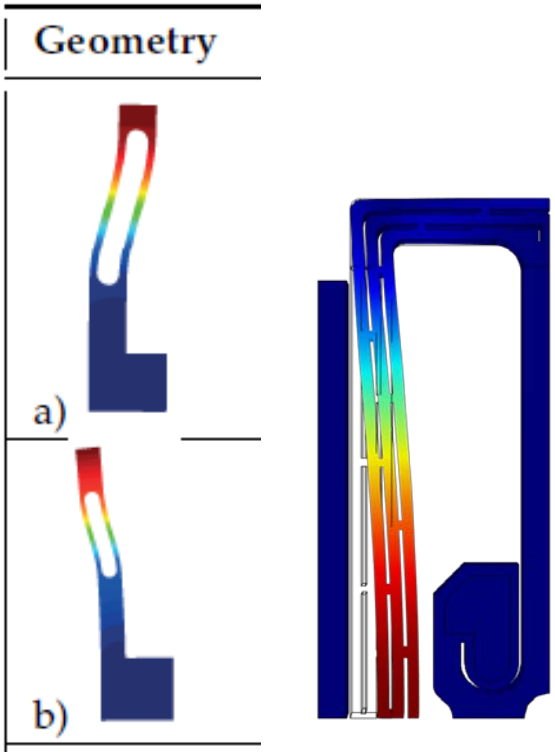
- Collaboration with STM and electronics Polimi group

4. Resonators

- Modelling and simulation of damping
- Modelling and simulation of thermo-elastic response
- Shape optimization







5. Micro-mirrors

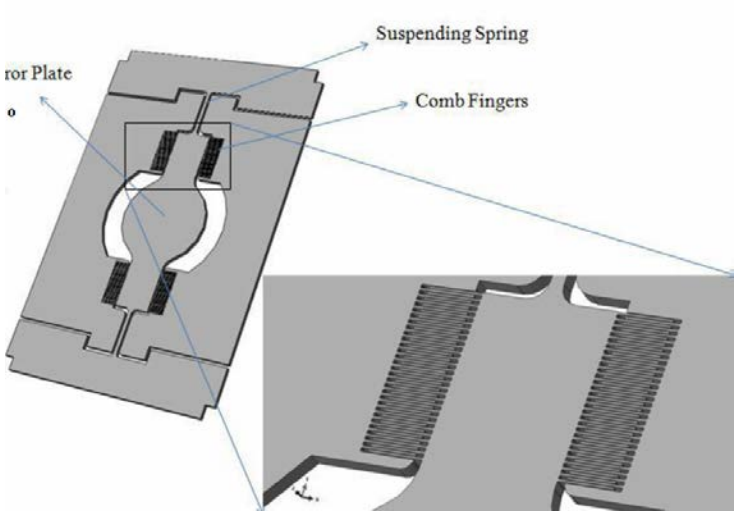
•Objective: to develop efficient micro-mirrors for video projection applications and solve damping and mechanical reliability issues

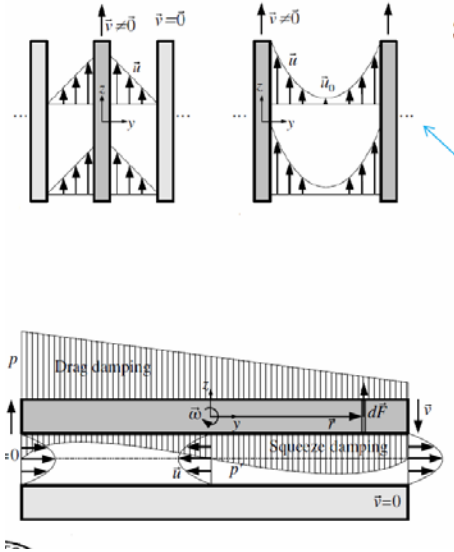
•Main achievements:

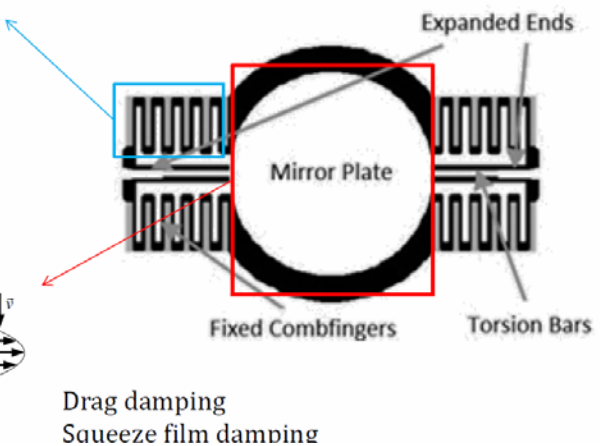
Fluid damping studies of torsional micro-mirrors

Study and modelling of non-linear mechanical behaviour

- Collaboration with STM
- EU funded project LAb4MEMS II: http://www.lab4mems2.ite.waw.pl/

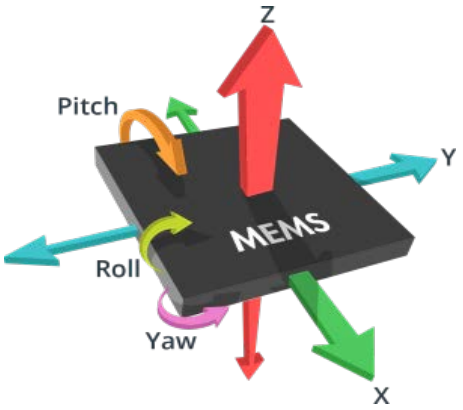


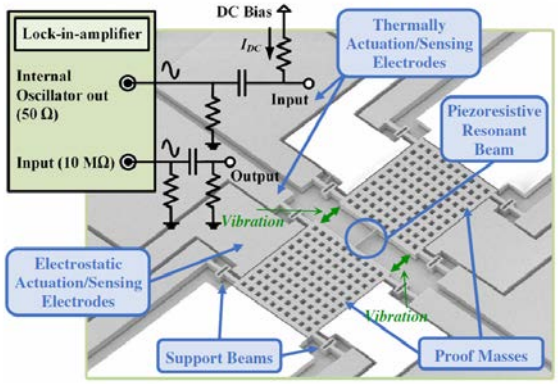


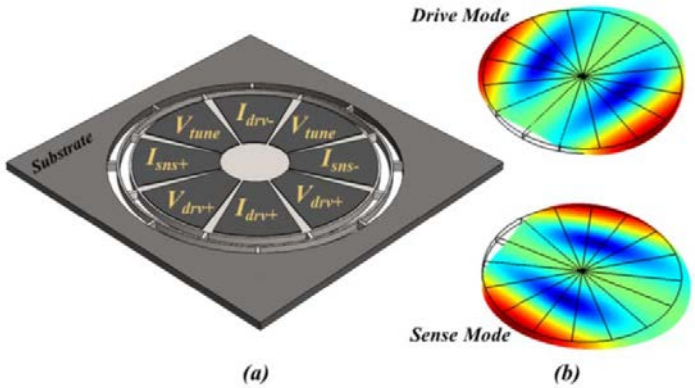


6. Micro-gyroscopes

- New gyroscope configurations
- AM, FM, LFM gyroscopes
- Modelling and simulation
- Collaboration with STM, electronics group and USA teams
- Study of piezoelectric gyroscopes

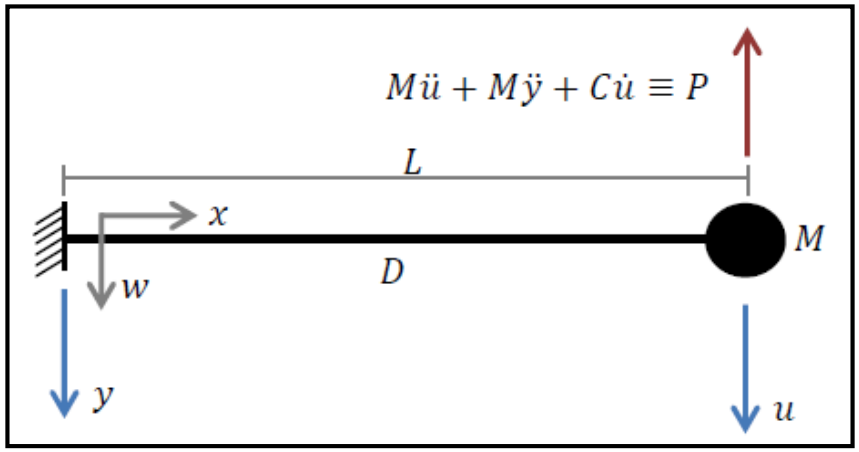






From IEEE MEMS 2015

7. Piezoelectric energy harvesters



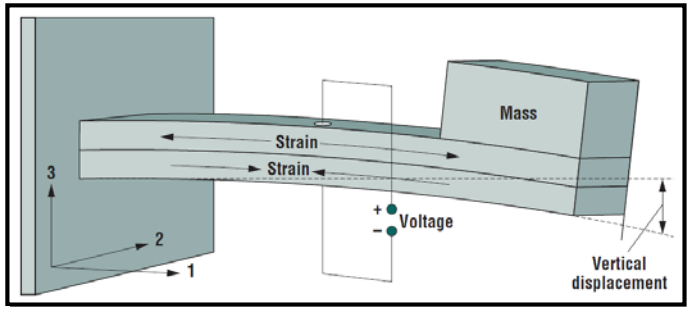
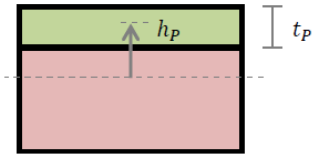
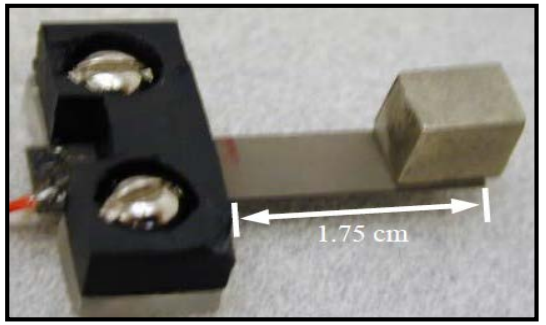
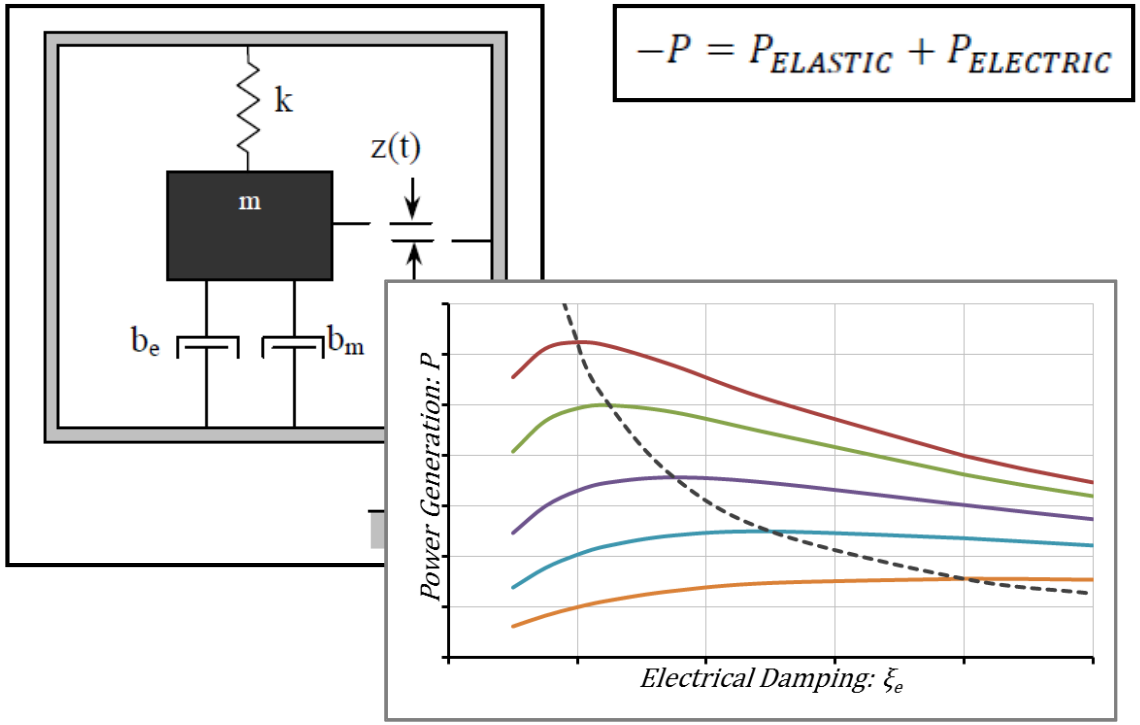


Figure from Roundy et al. (2005)



$$-P = P_{ELASTIC} + P_{ELECTRIC}$$

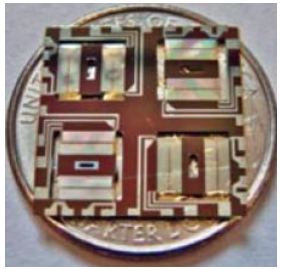


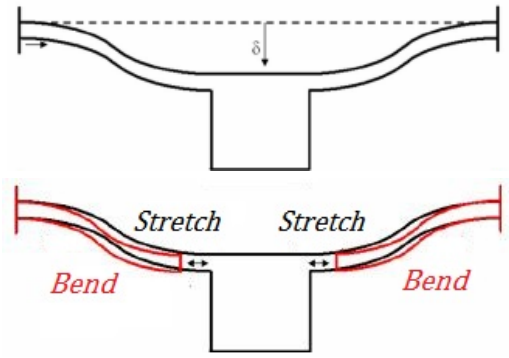


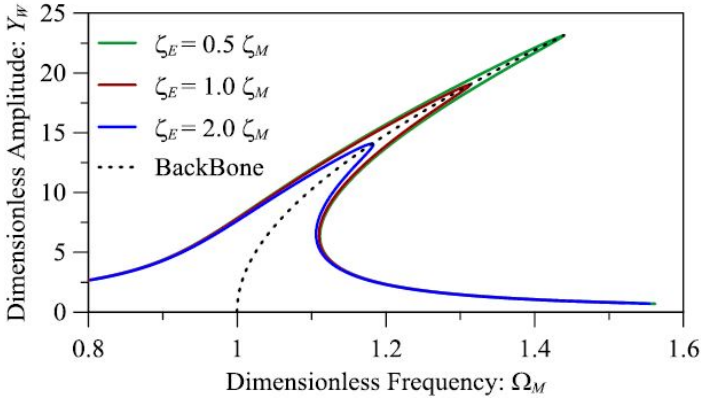
- Study of various configurations and possible applications
- Collaboration with mechanics group and MIT

7. Ultra wide bandwidth Energy Harvester

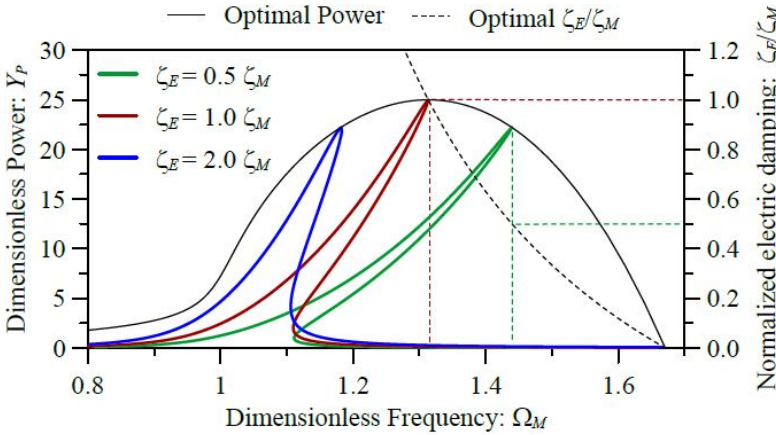
- Nonlinear Resonance







- Hardening effect at high amplitudes due to stretching mode
  - Smaller device
  - High frequencies
  - Lower amplitudes
  - **Wider Bandwidth**
  - Reliability issues



Increase of the natural frequency

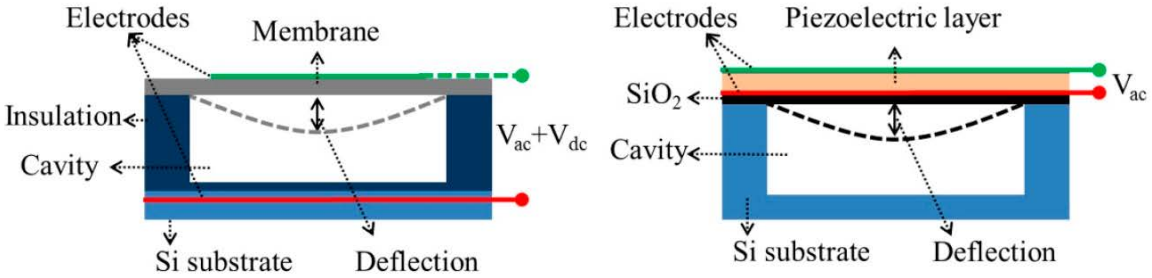
Optimal power generation

G. Gafforelli, R. Xu, A. Corigliano, S.G. Kim. J. of Physics, Conf. Series, 2013.

8. PMUT

Piezoelectric Micromachined Ultrasound Transducer (PMUT) for Integrated Sensing, Actuation and Imaging

- Collaboration with STM
- Study of piezo-actuated vibrating membranes
- Study of acoustice waves
- Study of multi-physics behaviour

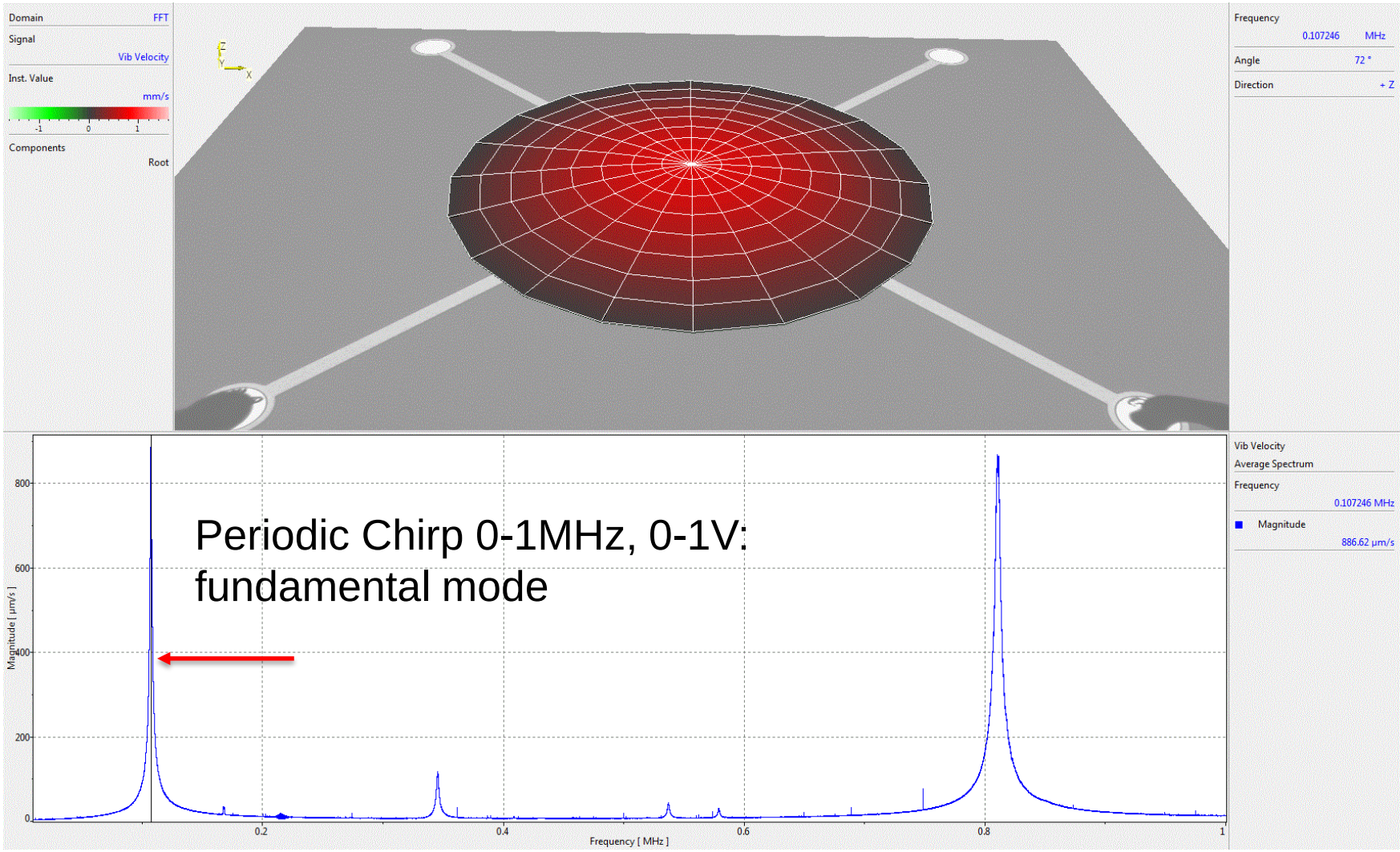


Sensors **2015**, *15*, 8020-8041; doi:10.3390/s150408020

Experimental modes

Polytec MSA-500 Laser Doppler Vibrometer

107 kHz



9. Technology related activities:

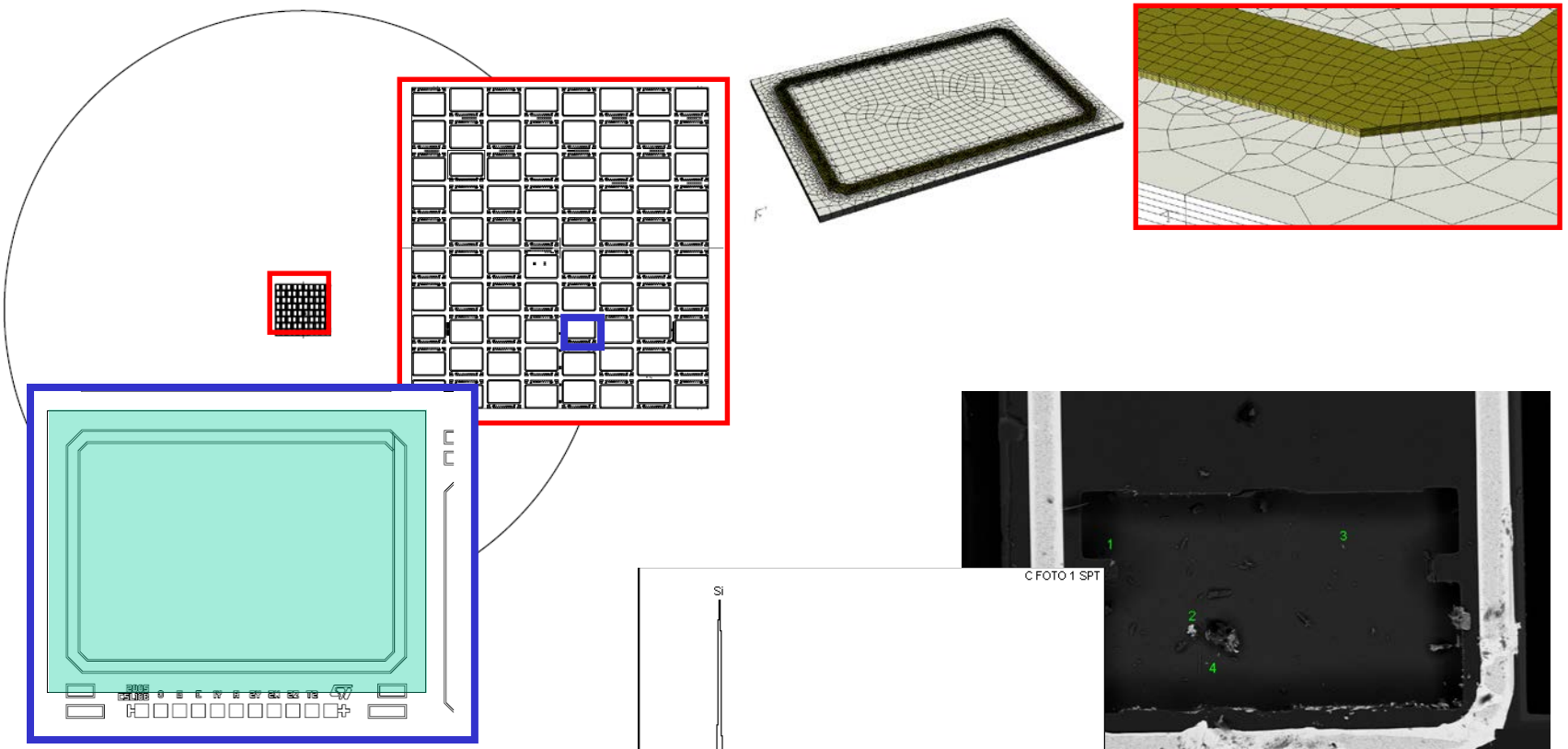
Objective: to help new technology development with dedicated simulation activity

Main expected achievements *(new, in progress):*

5.1 Study and modelling of the moulding process
5.2 Study and modelling of the wafer bonding process
5.3 Improvement of the etching process

- Collaboration with STM and material science groups

9.2 Technology related activities - Study and modelling of the bonding process



Finite Element modelling of the thermo-compression phase, shape optimization

AFM and spectral examination of metal-bonded surfaces

10. Additive manufacturing applied to MEMS

In the framework of the inter-departmental lab MEMS&3D

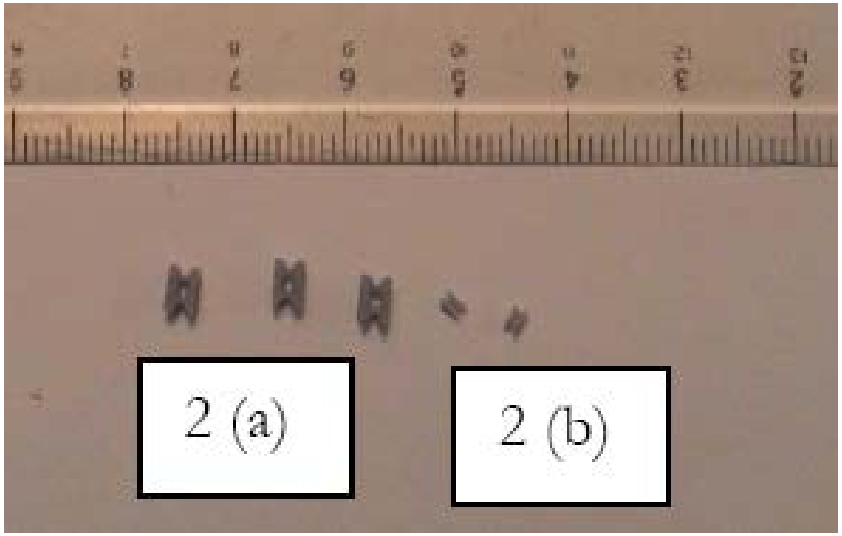
Use of 3D and ink-jet printing for the fabrication of low-cost and 3D MEMS

Possible collaboration with Physics Department for two-photon polymerization and fabrication of micro 3D devices

High resolution printing of 3D auxetic structures with different scales

Prototype designing

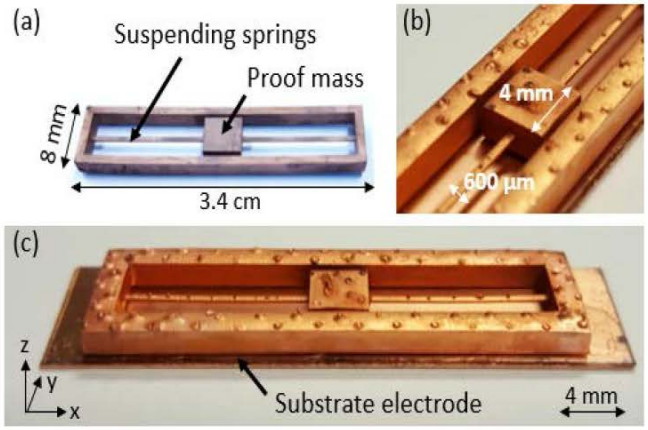
Prototype printing

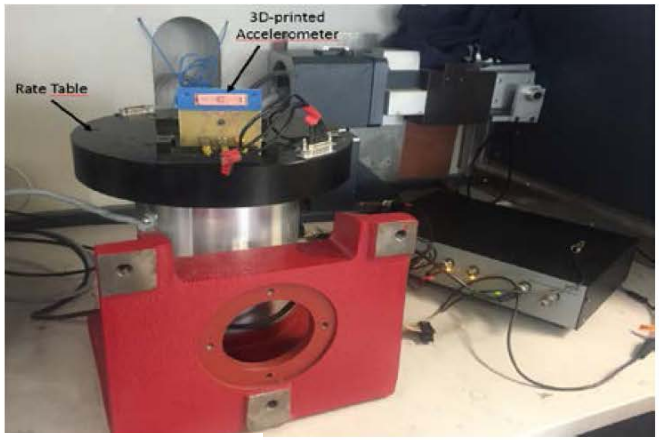


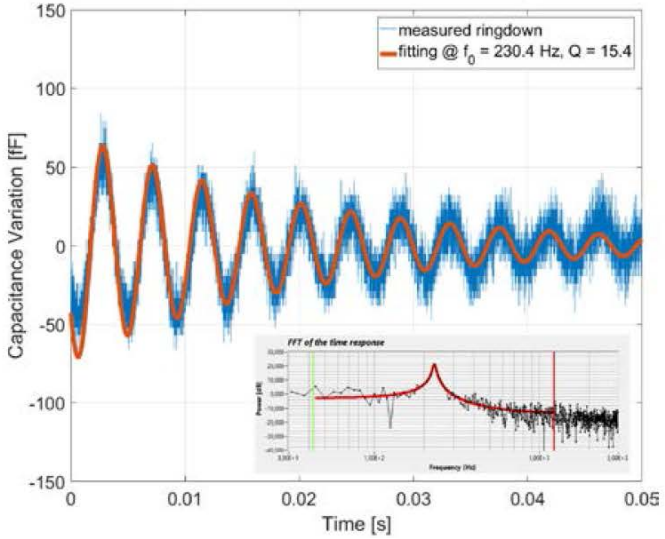
SL printed 3D prototypes

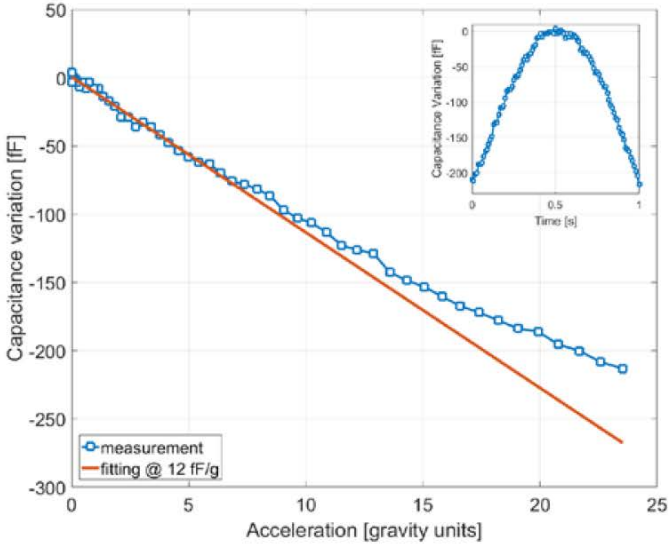
10. Additive manufacturing applied to MEMS

New!









Design, fabrication and testing of the first 3D-printed and wet metallized z-axis accelerometer

C. Credi[1], V. Zega[2], G. Langfelder[3], R. Bernasconi[1], A. Cigada[4], L. Magagnin[1,*], M. Levi[1], A. Corigliano[2]

Eurosensors2017