OPEN ENGINEERING
General Presentation

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Open Engineering s.a.

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Bee-Pitron

Open Engineering Background

- **OE develops and sells simulation software**
  - OE solutions are for the multiphysics market
  - OE solutions are based on OOFELIE

- **OE provides services**
  - Customization (Flexibility)
  - Engineering

- **OE participates to projects**
  - EC
  - ESA
  - BELSPO
  - WR

World Wide Representation

Distribution Channels

AbleMAX (Korea)

Bee Pitron (Russia)

SHAMA Technologies (Singapore)

SOFTMEMS Europe

SOFTMEMS Noth America

TATA ELXSI LIMITED (India)

VINAS (Japan)

DAG Technologies Sdn Bhd (Malaysia)

EMAX-EASTERN MAX TECHNOLOGY (Republic of China)

K.P.R. ENGINEERING s.r.o. (Czech Republic)

KSIMETRO (Bulgaria)

NUMECA International - Corp. OFFICE

NUMECA USA Inc.

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Reference Partners

Business partners

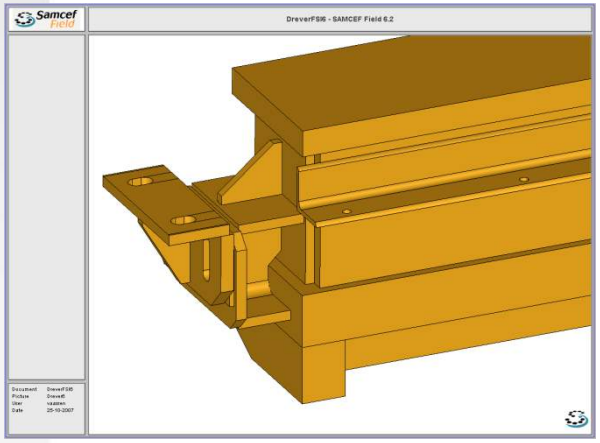
Universities and research centers partners

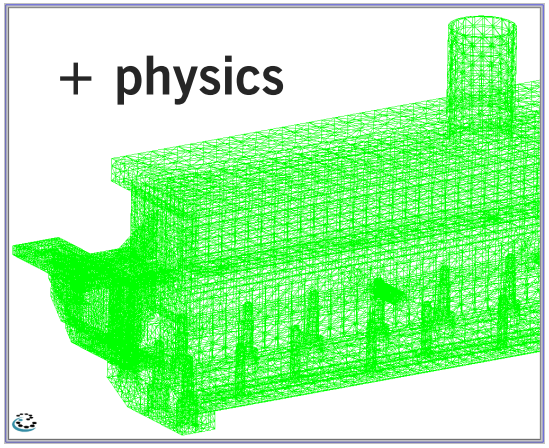
What is numerical simulation in engineering ?

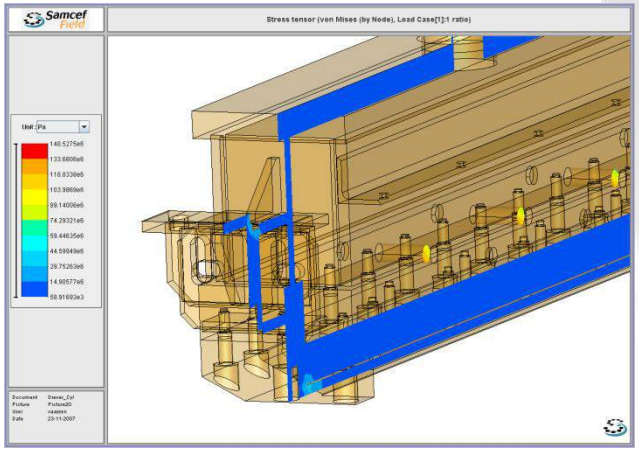
Why using numerical simulation ? ➔ To reduce the cost of prototypes

- ❑ **Once created, what will be the behaviours ?** → **Design**
- ❑ **If I change this parameter, is it better?** → **Optimization**
- ❑ **It does not work! Why, and How fixing the problem ?** → **Understanding**

CAD **CAE** **Results**







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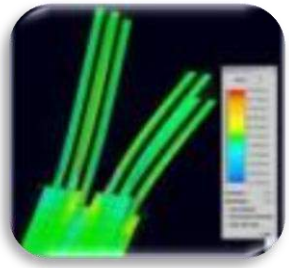
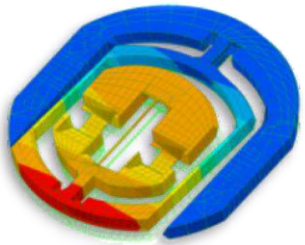
Why Multiphysics?

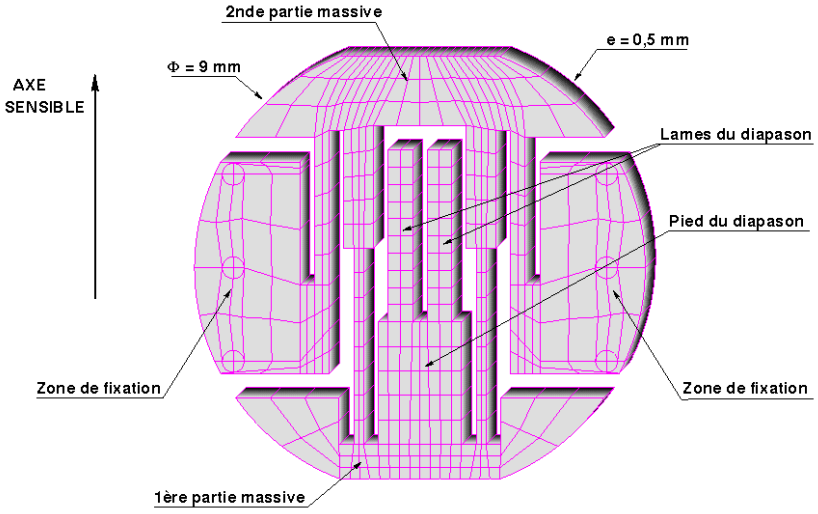




- Size reduction & new manufacturing technologies
- Needs strongly coupled piezo-thermomeca

ONERA
THE FRENCH AEROSPACE LAB

Active device : 60 μm x 30 μm x 2.2 mm



DGA

Sagem
Défense Sécurité
Groupe SAFRAN

THALES

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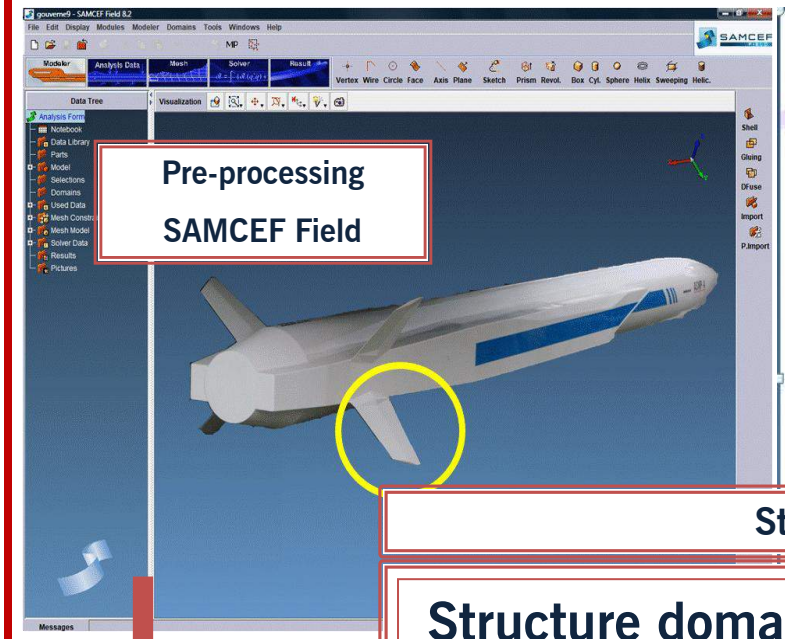
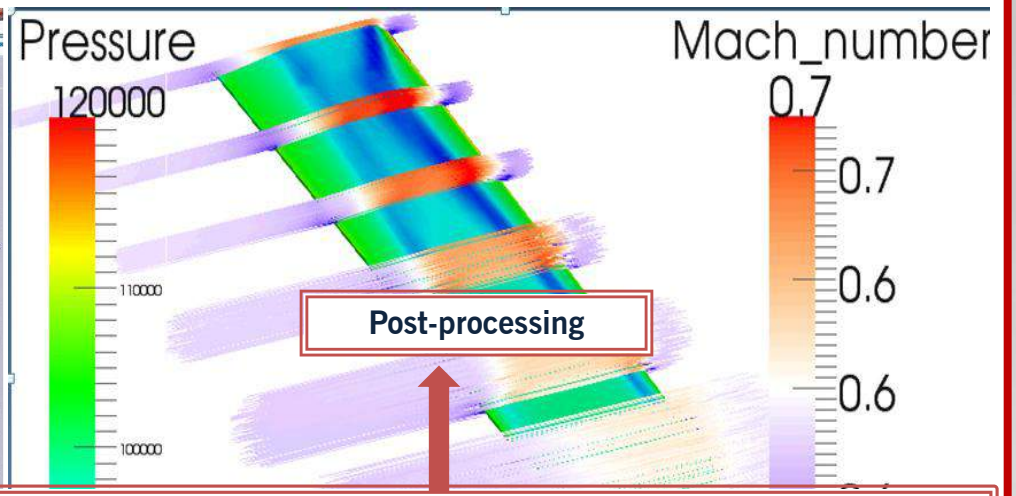
F.S.I. Design Flow

Fully integrated F.S.I. or Fluid – Multiphysics solution





Strongly coupled F.S.I. staggered solver

F.S.I. solver piloting

OOFELIE®

Structure domain

C.S.M. solver
OOFELIE®
(Open-Engineering S.A.)

+ **other fields of physics** (piezo, acoustics, optics…)

Transfer at interfaces
Non-conform meshes
M.P.I. protocol
OOFELIE®

Interface displacements
Interface velocity
Interface temperature

Pressure loads
Viscous stresses loads
Thermal fluxes

Fluid domain

NUMECA

C.F.D. solver

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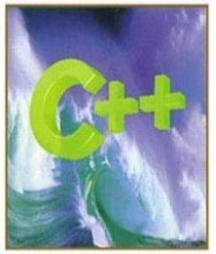
OOFELIE – TECHNOLOGICAL PLATFORM

- **Designed around a multiphysics database**
  - One single database for all numerical methods
  - ✓ Mechanical, thermal, electrical, acoustical, fluids



- **Designed for couplings**
  - Coupling of more than 2 physical fields
  - ✓ Thermomechanical, Piezoelctrical, Pyropiezoelectrical, Electomagnetical, FSI, Electrostatical, Electro-thermomechanic, Piezovibroacoustics

- **Open to other solutions**
  - ✓ Management of the interaction
    - Data transfer & Mesh mapping
  - ✓ Chainings

Effort (1991-2013)
150-200 man year

- **Adaptable to new methods**
  - ✓ FEM-BEM-FDM (X-FEM)

- **SDK for advanced users**

Oofelie SDK
Oofelie Software Development Kit

- **Access to the source code for key partners**

Oofelie Community
Object Oriented Finite Elements Led by Interactive Executor

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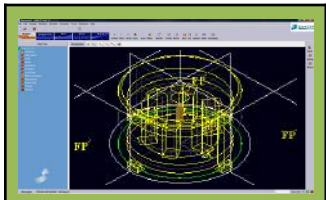
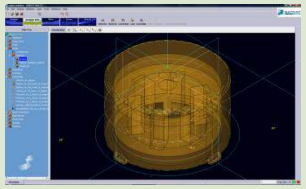
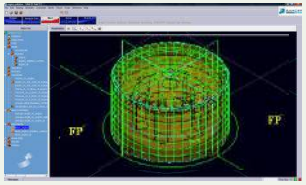
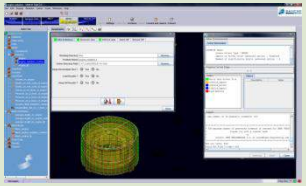
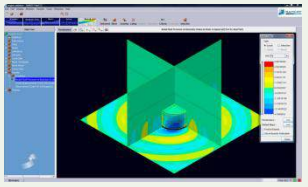
OOFELIE User Interface

Industry Standard Design Flow – 5 Intuitive Steps

	Use the full CAD interface for parameterized modelling of your structures. Link into the mechanical design flow by importing and manipulating files from various vendors (STEP, IGES, CATIA..)
	Use the hierarchical UI to assign the different multi physical data's to each component. Make use of a pre-defined material data base to increase your efficiency.
	Define the mesh of your structure. Take the most accurate and efficient approach by using the full spectrum of mesh shapes (tetrahedron, pentahedron, hexahedron,...), mesh orders (linear, quadratic) and mesh generation (Delaunay-Voronoi, Frontal, ...) methods.
	In the vibroacoustics domain, you solve for the modal & harmonic response of your parameterized system. Combination with piezoelectric analysis will lead to linear, static & transient methods. Move from verification to design by linking to optimization scripts or to Boss quatro for parametric analyses, design of experiments, multidisciplinary optimization, sensitivity & statistic analysis.
	After simulation, you will find the results in the solution tree of the hierarchical UI. The results can be 3D plots as well as animations and sound files ! Finally results are easily exported to other tools for further postprocessing.

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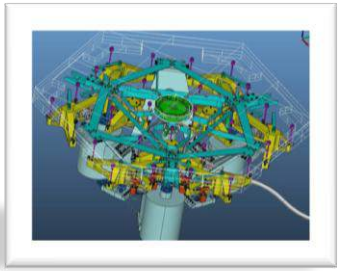
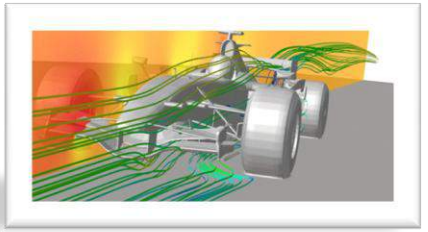
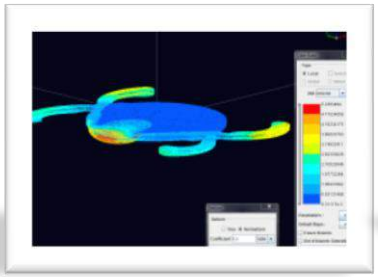
OOFELIE::Multiphysics 3D CAE

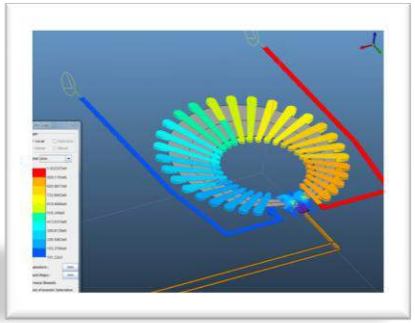
OOFELIE::Multiphysics

- Mechanics
- Thermics
- Electric
- Acoustic
- Fluid
- Electro-Magnetic
- Thermo-Mechanic
- Piezo-Electric
- Pyro-Piezo-Electric
- Vibro-Acoustic
- Electro-Static actuation
- Electro-Thermom-Mechanic
- F.S.I.









Moldex3D True 3D CAE for Injection Molding

ZEMAX Development Corporation

NUMECA International

SoftMEMS Bringing MEMS to the Mainstream

- Injection Analysis and Coupling
- Optics Analysis and Coupling
- CFD Analysis and Coupling
- EDA link and coupling

OOFELIE::Multiphysics

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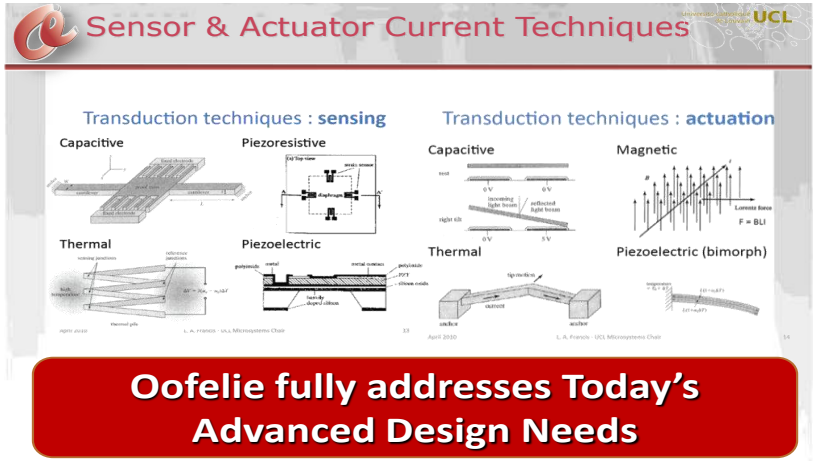
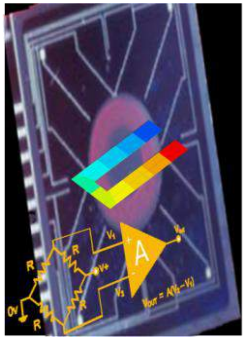
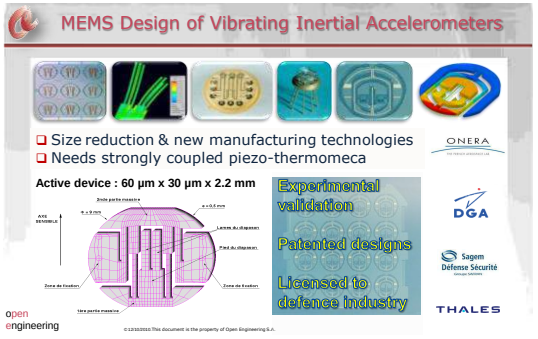
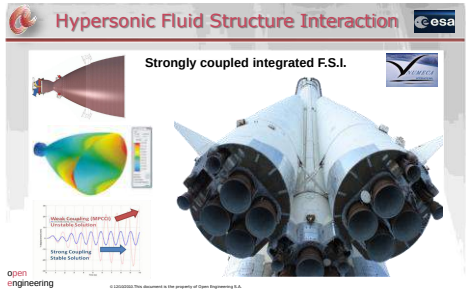
Sensors And Actuators

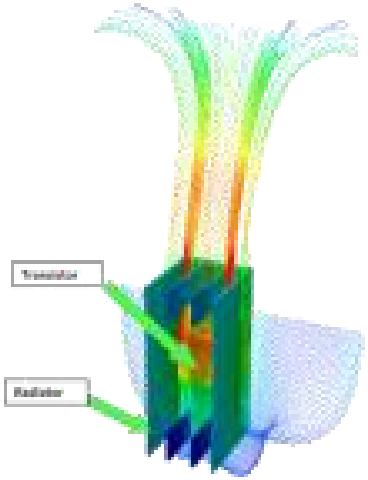


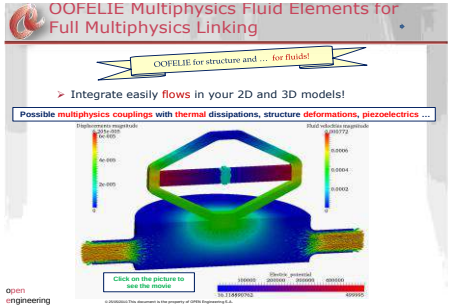




Multiphysics F.S.I.



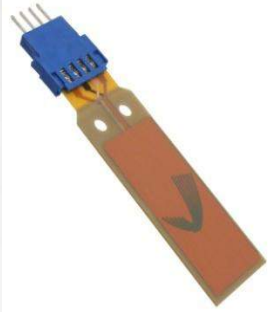




Open Engineering - Service Activities

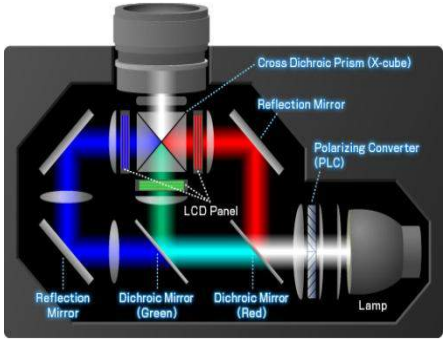
Multiphysics experts to support your innovation processes

- **Vibro Acoustics:** Piezo loudspeaker, noise prediction of muffler, acoustic response
- **Electro Technics:** Joule heating, EM devices, Piezo actuators
- **FSI-CFD:** Convection, Cooling
- **Opto-Thermo Mechanics:** Thermal, mechanical optic's deformation
- **MEMS Design:** Accelerometer, Piezo microphones, Sensors, RFMems, piezo energy harvesting
- **Thermo Mechanics:** Package/Board Heat Mgmnt, Deformation, Stresses

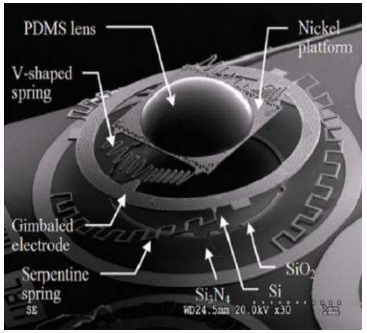


Piezo energy harvesting

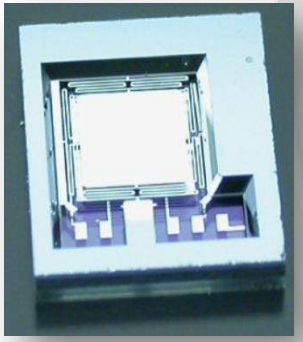
LED



LCD projector



Endoscope



Head Up Display

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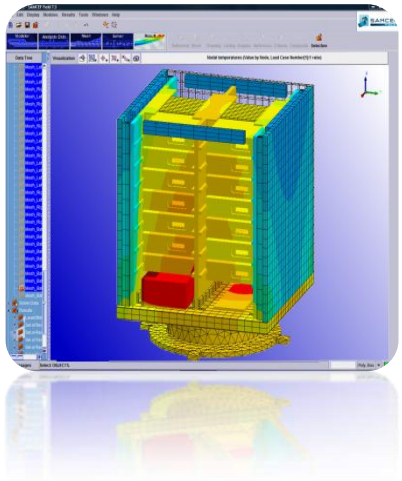
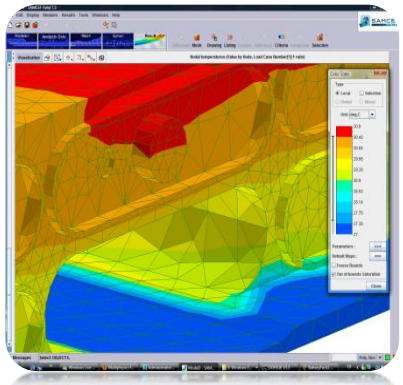
Small Satellite Thermal Control & Positioning

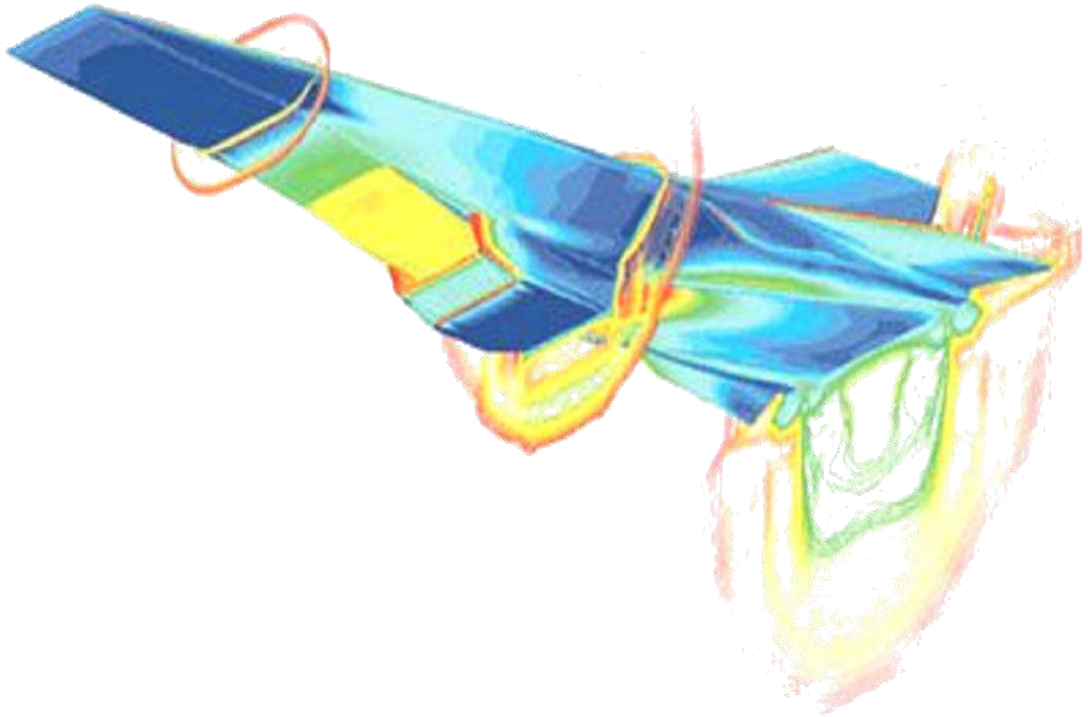
- **Microsatellite**
  - Provide Automatic Identification System (AIS)
  - 30x30x30 cm
- **Robust design**
  - **Component reliability**
    - Low temperatures
  - **Sensitivity of detectors and units**
    - Narrow temperature ranges
  - **Pointing of instruments**
    - Small temperature gradients
- **Multiphysics modeling taking into account**
  - Magneto-Torque
  - Satellite orbit, satellite rotation
  - Solar radiation, earth albedo & IR deep space IR, active cooling
  - Electronic component dynamic power dissipation
- **One year from concept to operational microsatellite**





Work performed under contract for LUXSPACE

Multiphysics F.S.I. (MP-FSI)



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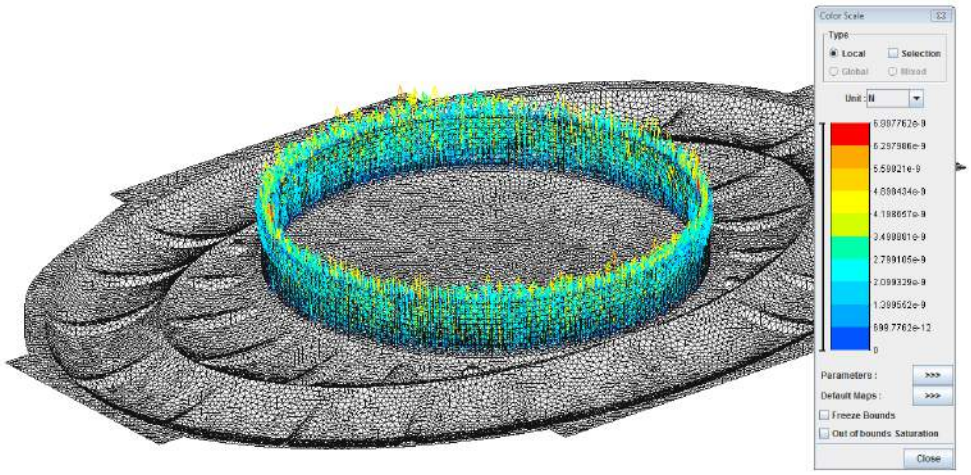
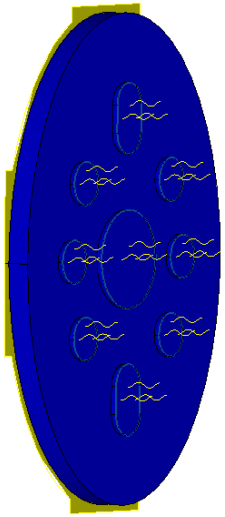
Vibro-Acoustics - Targeted application areas

- Reduction of noise (with passive or active components)
  - Noise prediction in passengers enclosures
    - cars
    - aircrafts
    - helicopters
    - ...
  - Acoustic radiation prediction (engines, gearboxes, ...)
  - ...
- Improvement of high fidelity devices:
  - Loudspeakers
  - Microphones, ...
- Prediction of vibroacoustic behavior of tanks (strong coupling)
- Acoustic signature detection equipments, sonars, ...

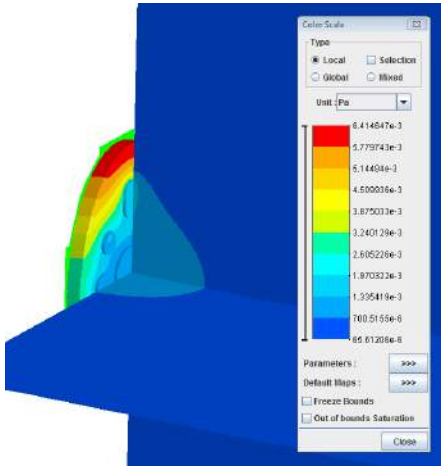
VibAc – EM Loudspeaker

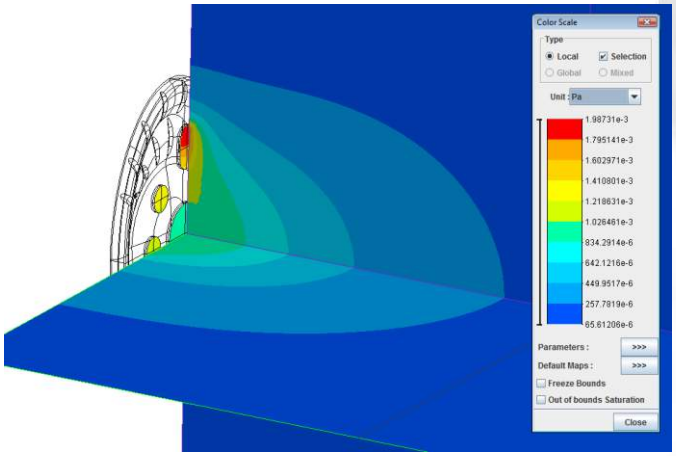


Nodal force distribution related to unit current density in the coil and computed magnetic field (F=J^B)



The opened acoustic cavity on the vibrating plate





Pressure field amplitude at 20kHz

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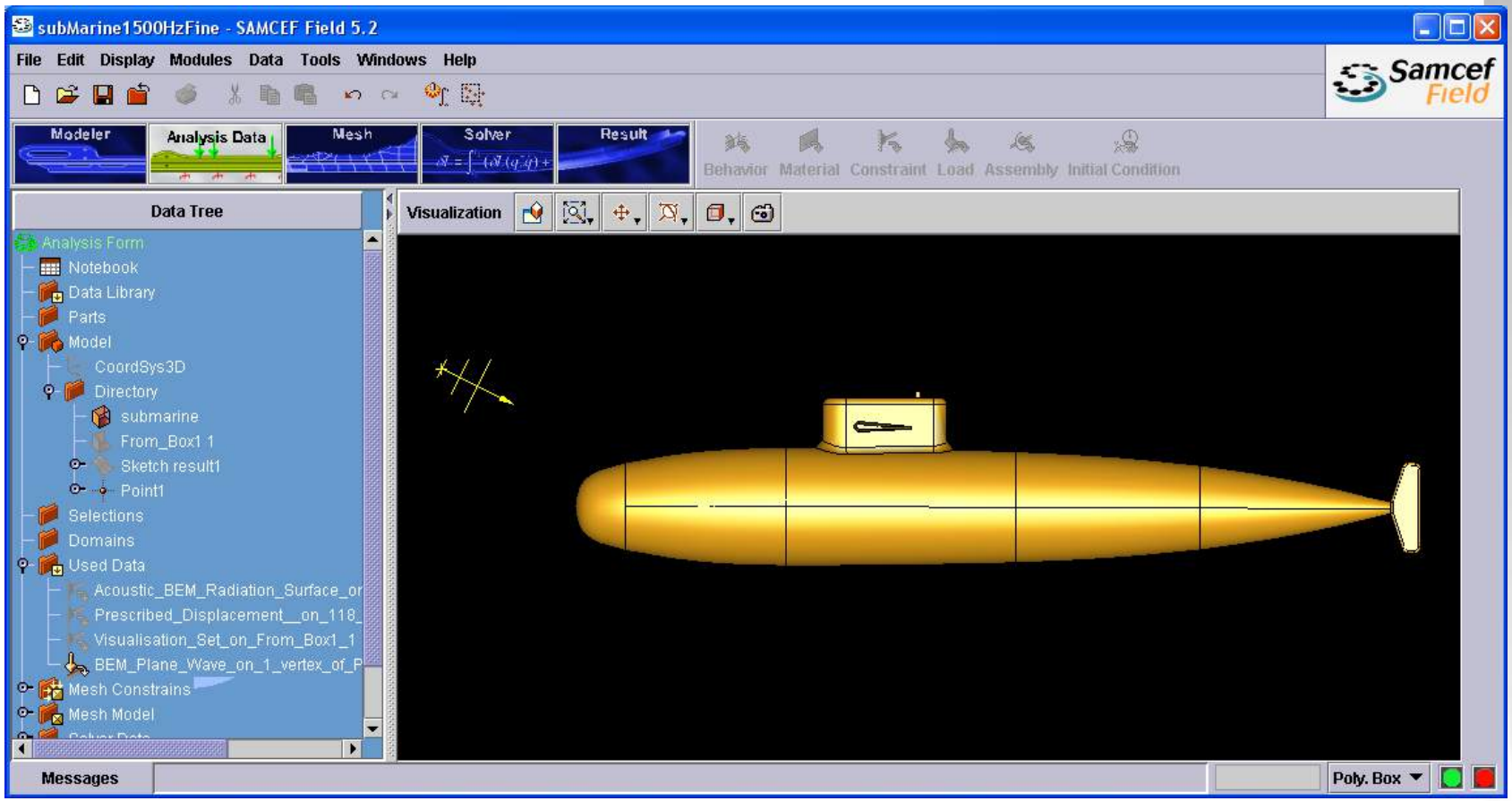
VibAc - Submarine



Plane wave diffraction by a submarine
submarine length : 37 meters
excitation frequency : 1500 Hz

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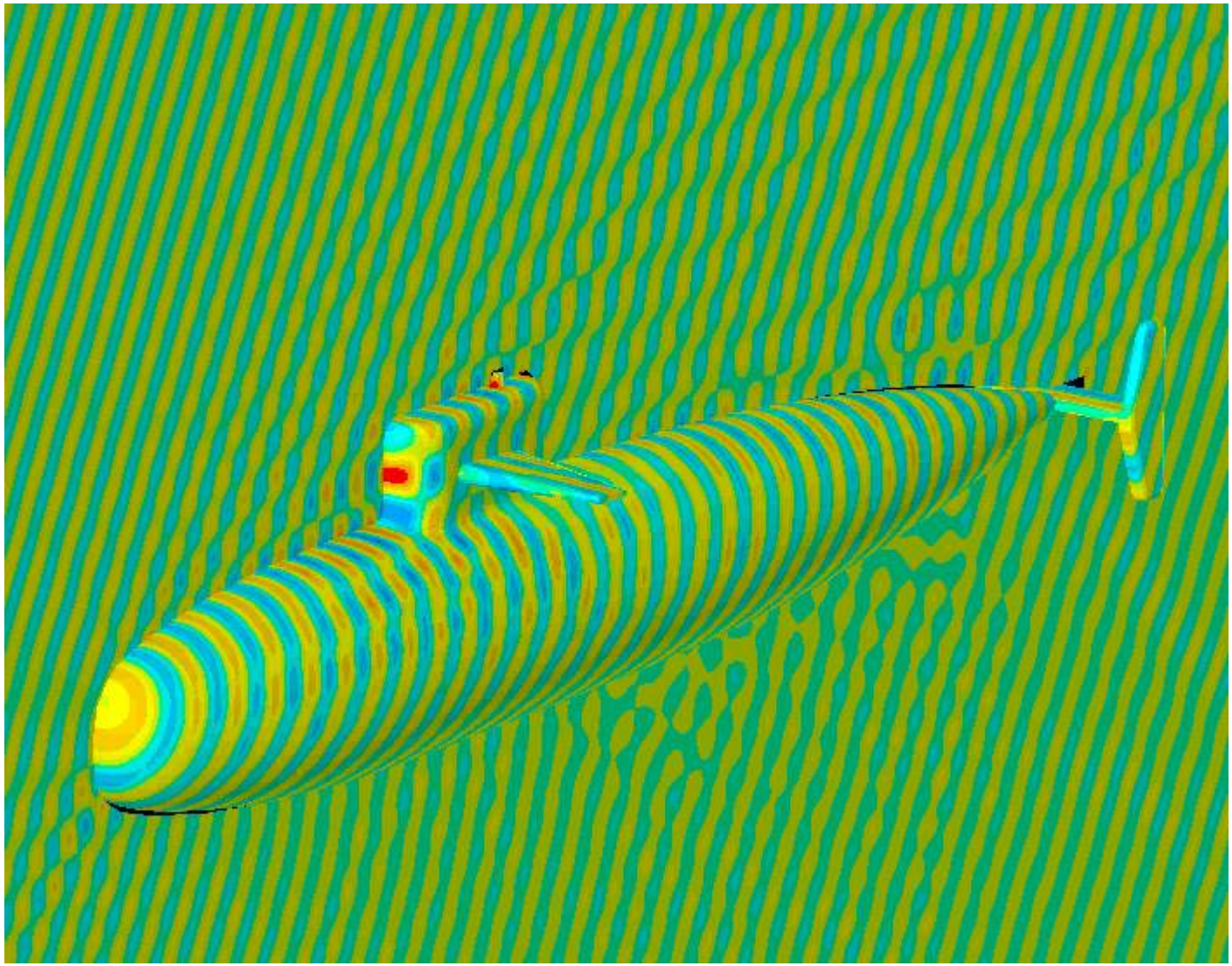
VibAc - Submarine



External pressure field on radiation surface and in external domain

VibAc - Submarine

… on Intel P4 3GHz with 2 GB RAM

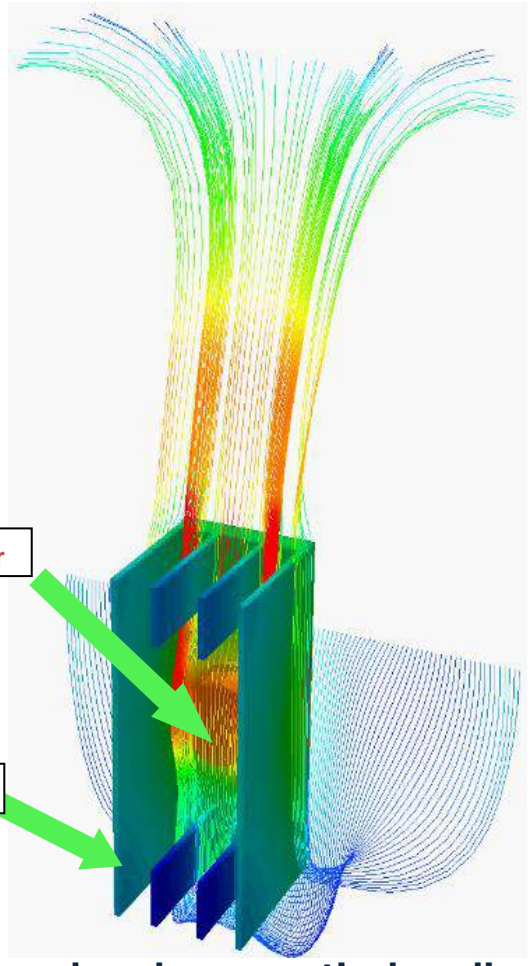
FMM algorithm: 42 iterations
Total time: 58 minutes

Direct resolution technique:

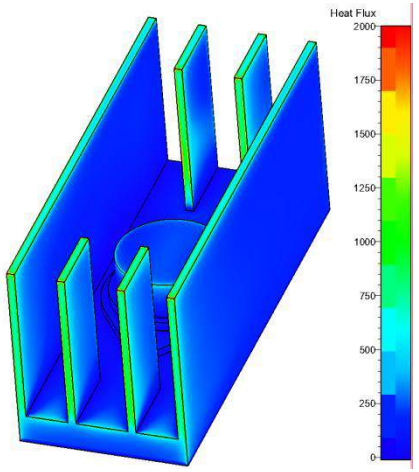
Construction of A : 8 hours + 41 GB RAM
LU decomposition of A: 36 hours
Total time: 44 hours

Package Heat Modeling
Natural Convection using Strong Coupled FEM-FSI

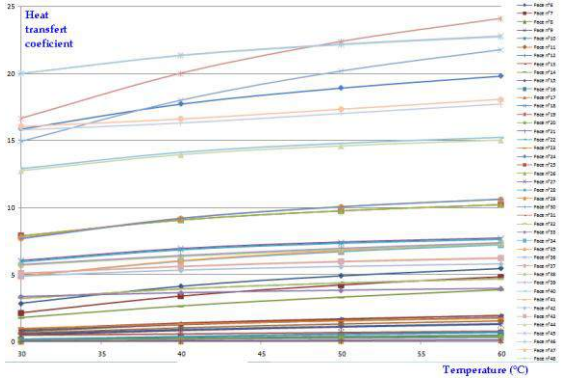
- **Incompressible Convective Flow**
- **Mutual radiation included**



Transistor placed on a vertical cooling device



Interface heat fluxes



Heat transfert coef. Vs Temperature

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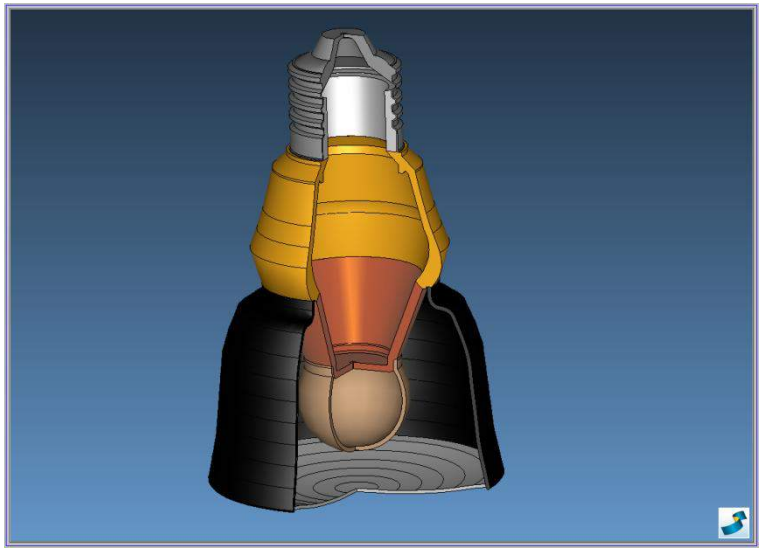
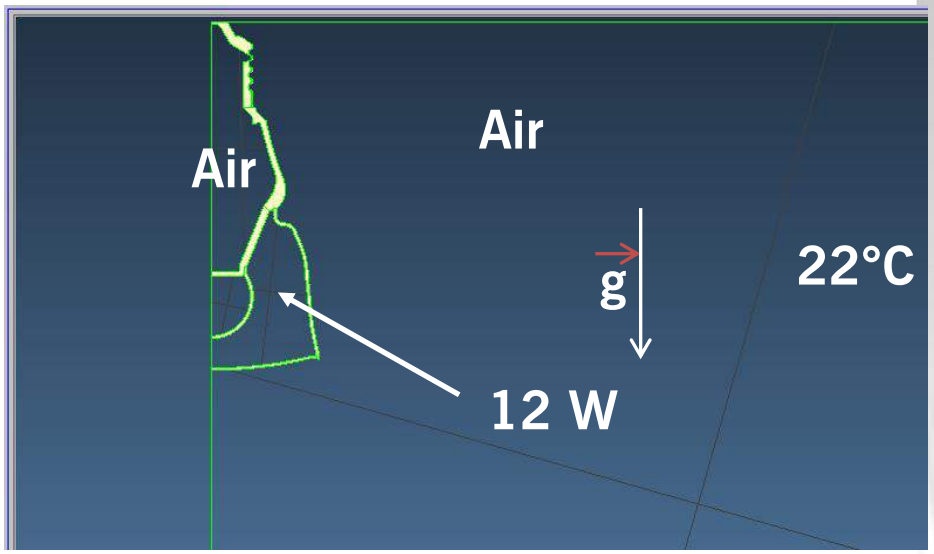
LED thermal analysis

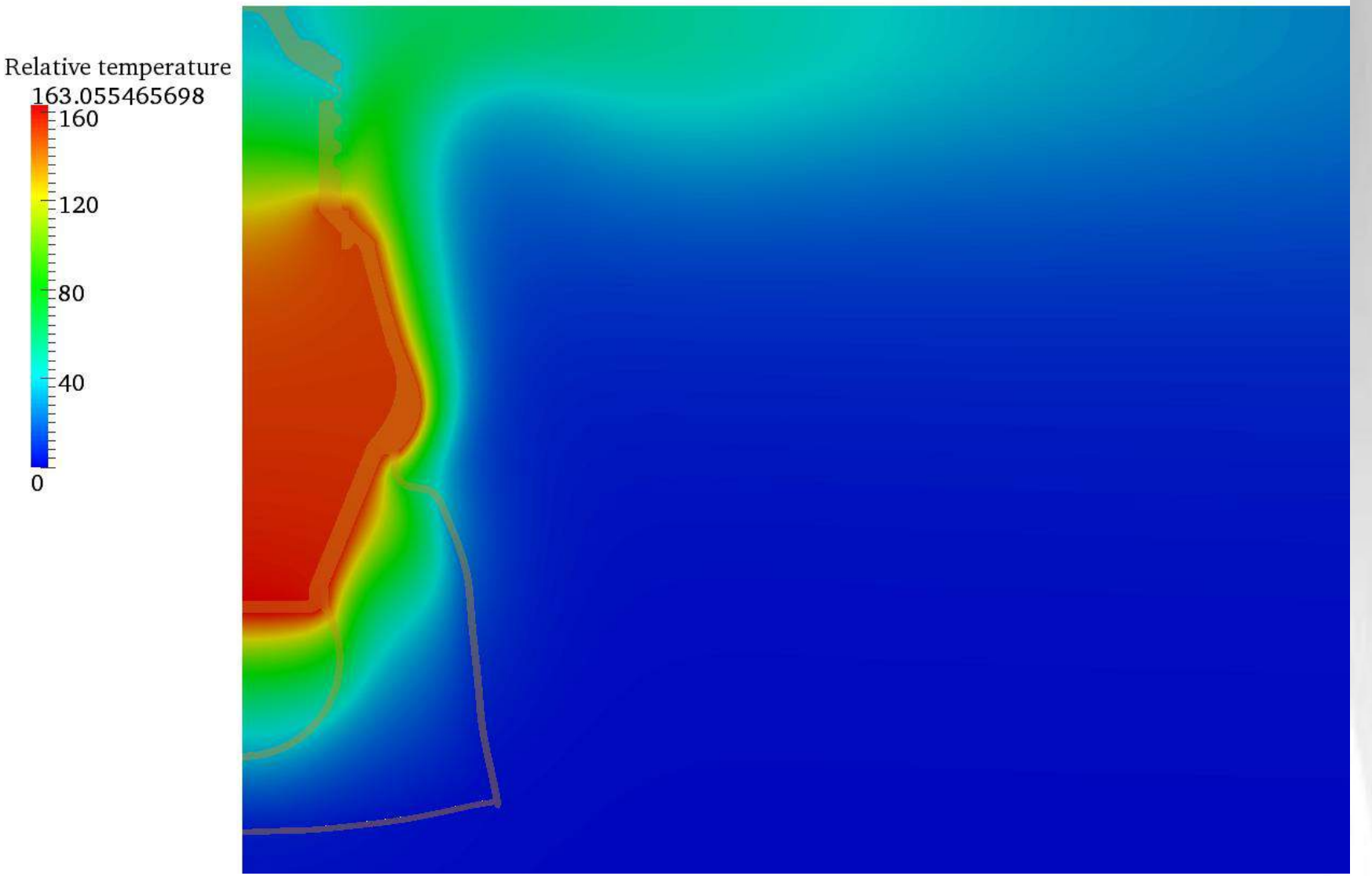




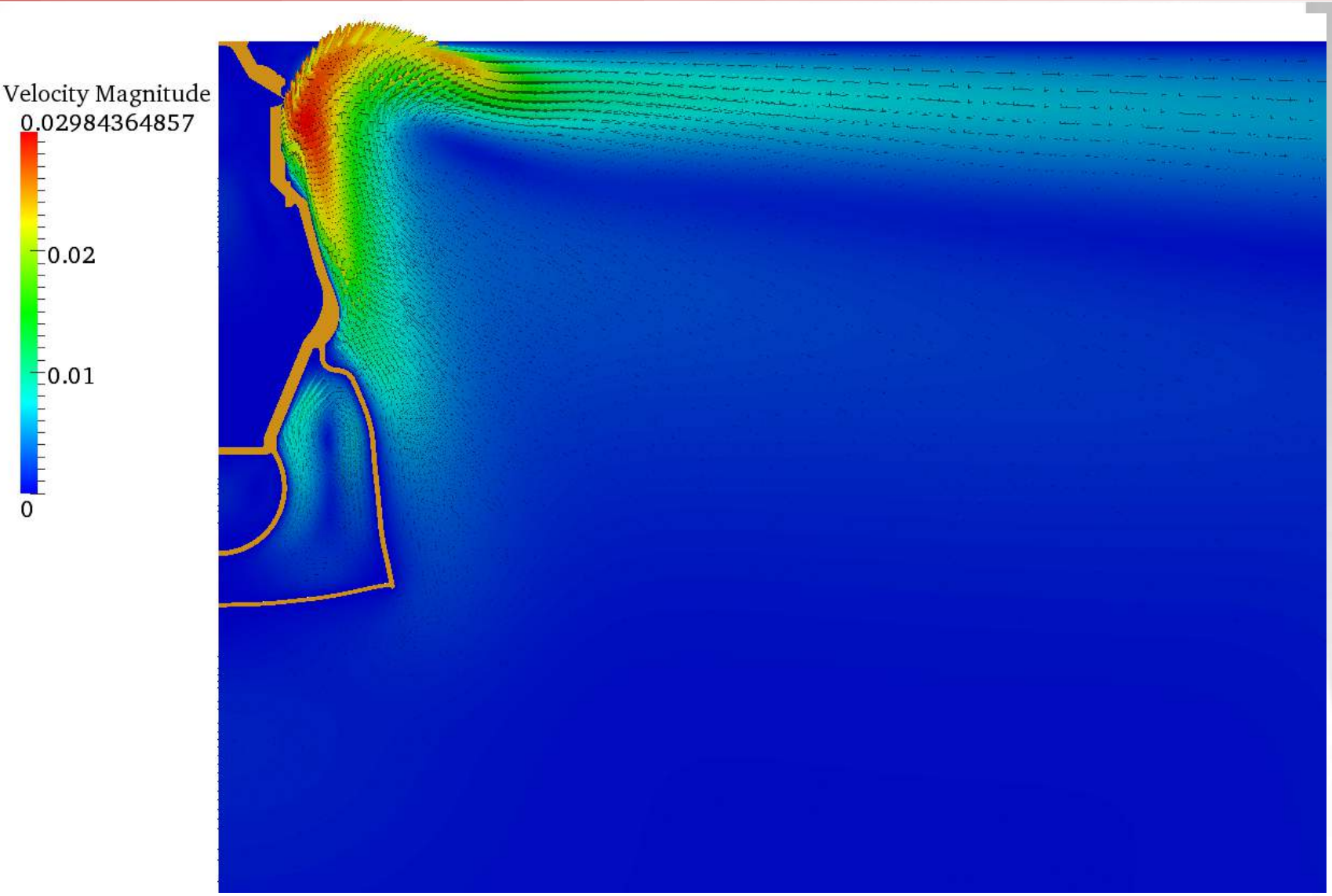
3D model

2D axisymmetric model

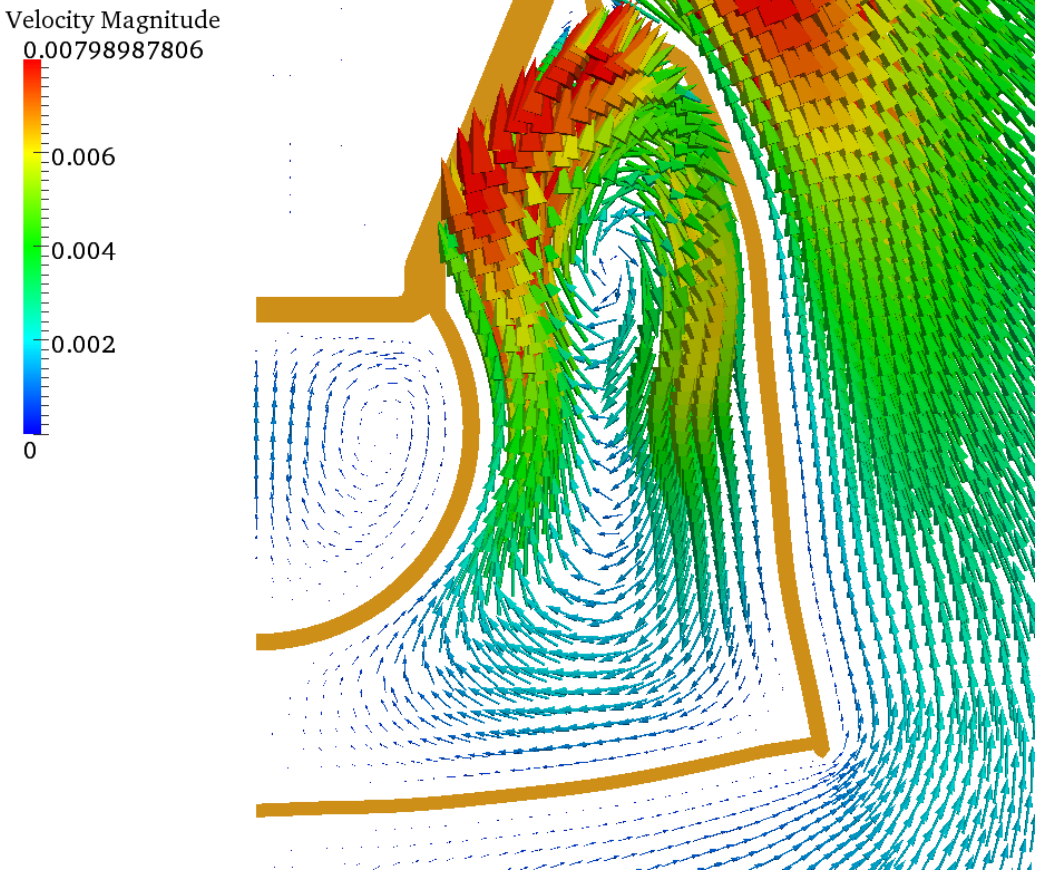
Temperature distribution

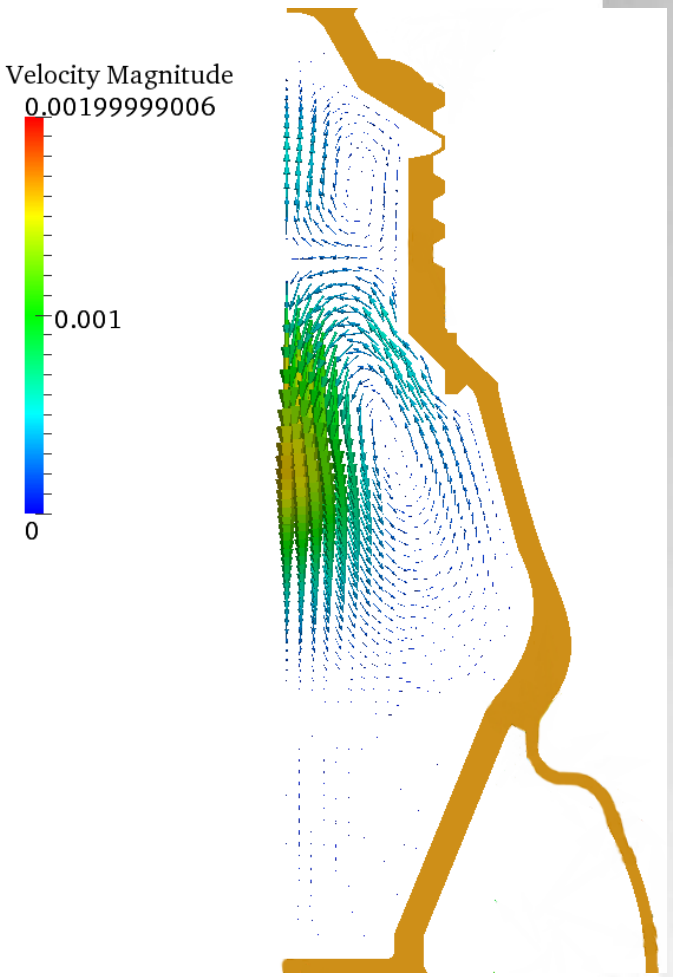


Velocity



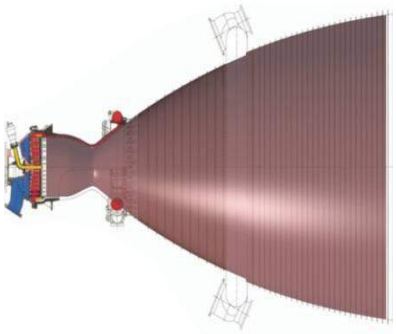
Steady solution: velocity in cavities

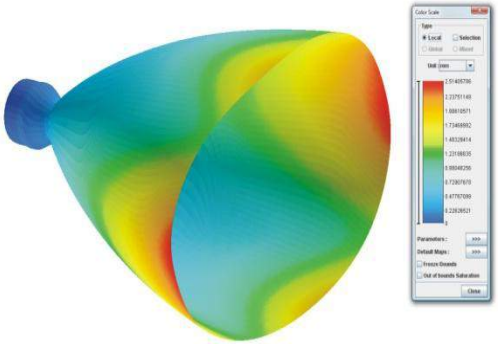




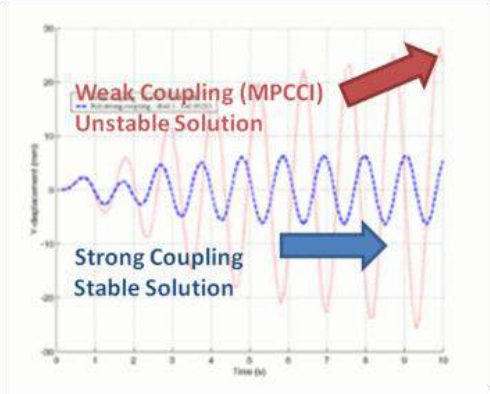
Fluid Multiphyiscs Interaction

Strongly coupled integrated F.S.I.



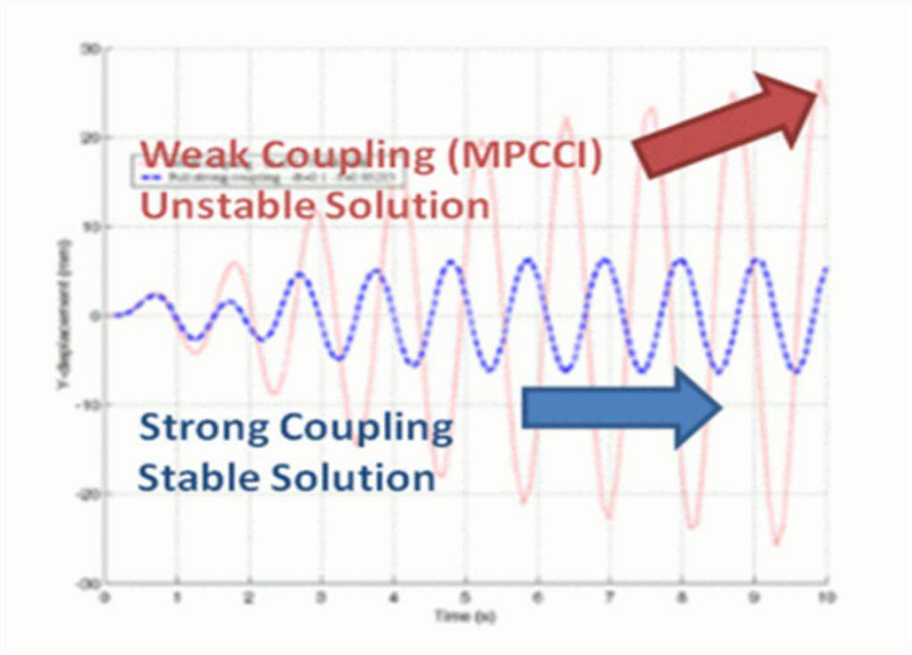


Supersonic FSI

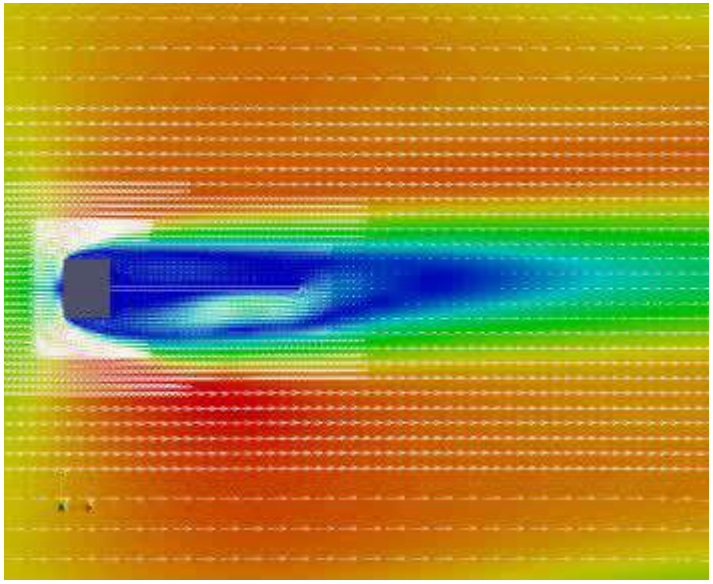


Wing Flutter

The Advantages of OOFELIE 's Strong Coupled FSI

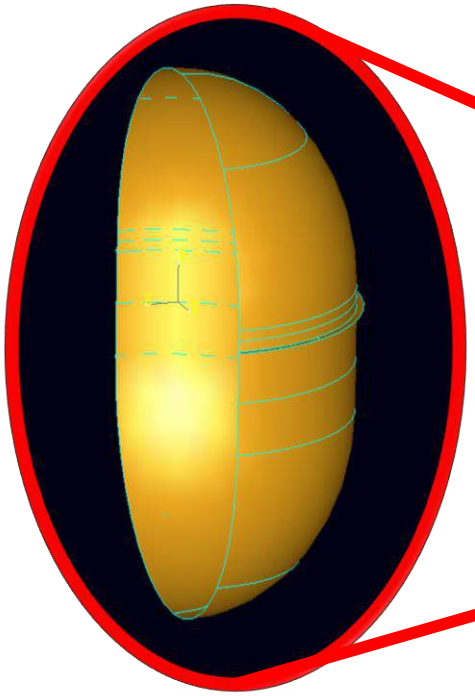


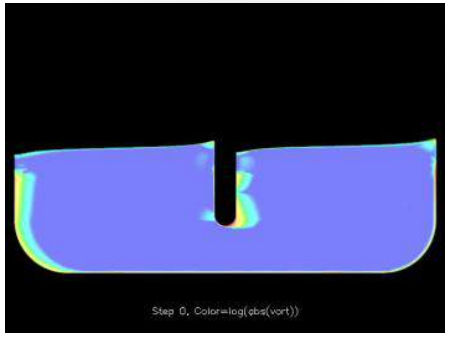
Displacement amplitude vs time

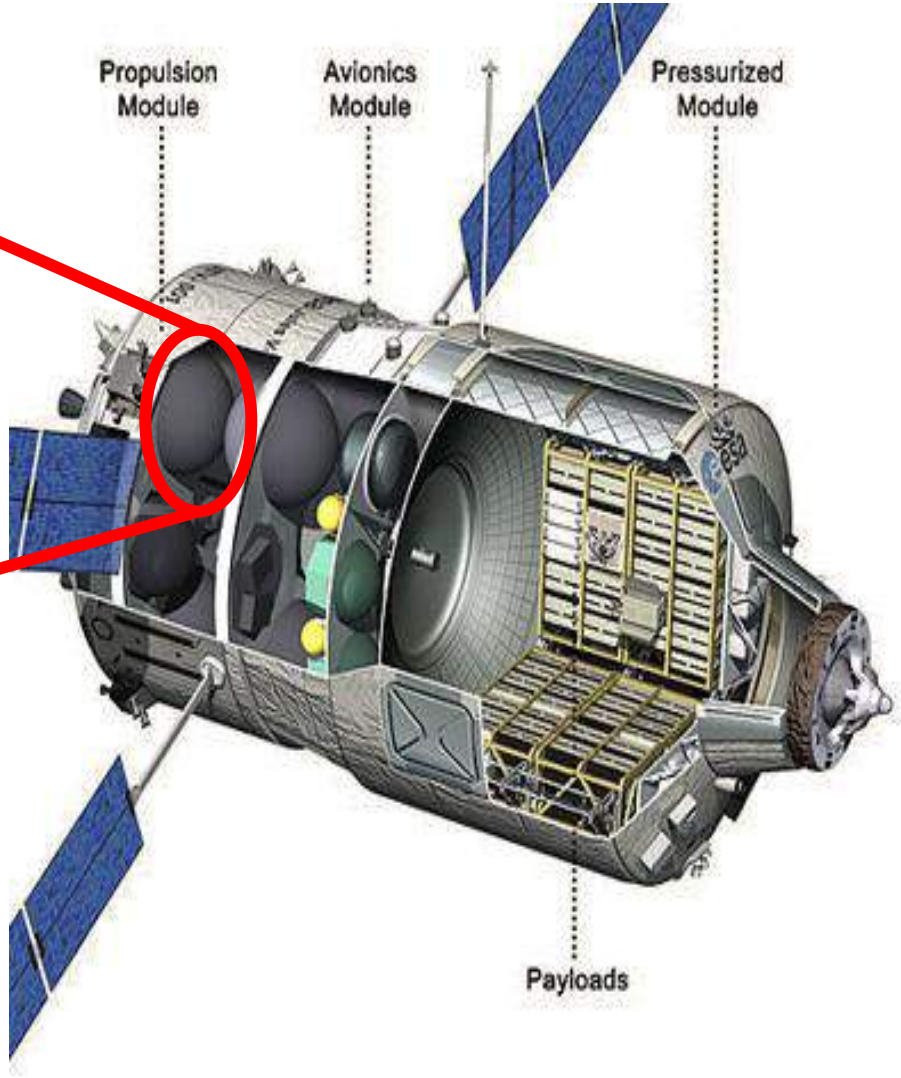


- Real model is stable in time
- Weak coupling introduces spurious energy
  - Artificial increase of energy
  - Amplification of the movement

Cryogenic Sloshing







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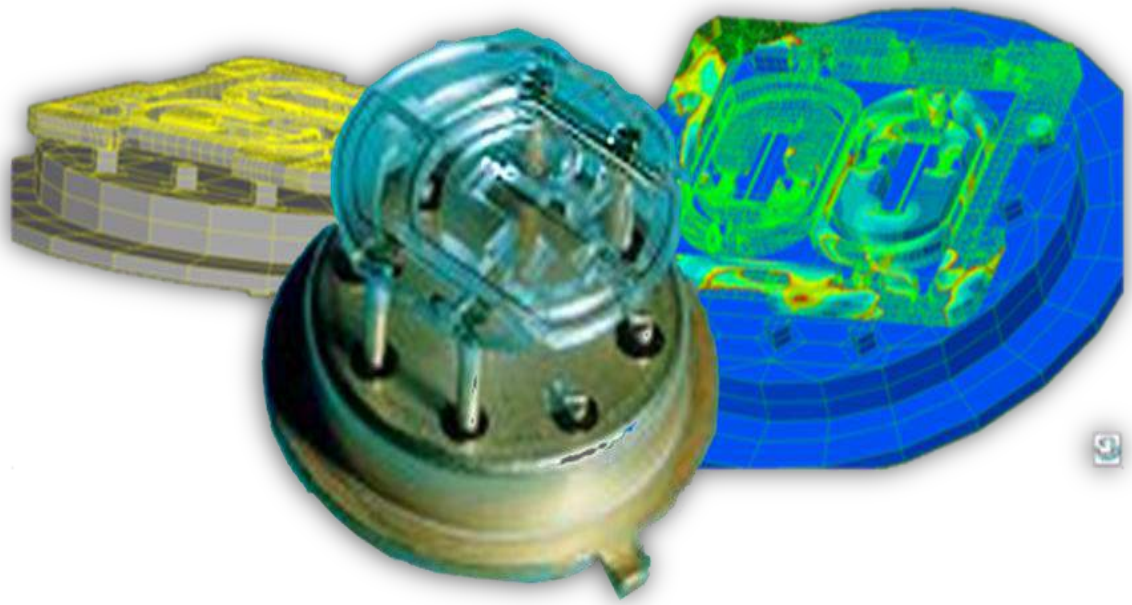
Sensors & Actuators (S&A)



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The importance of MEMS-based microsystems for automotive, user electronics, medical and aeronautic design.

Opportunities and Challenges

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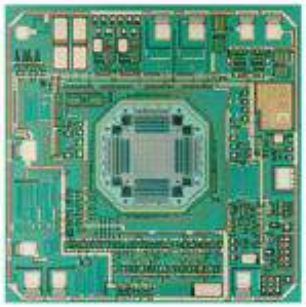
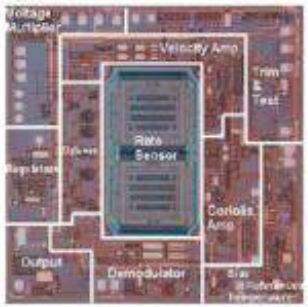
The MEMS Market & Applications

Commercial examples of MEMS



< Accelerometers

Analog Devices, Bosch, ...

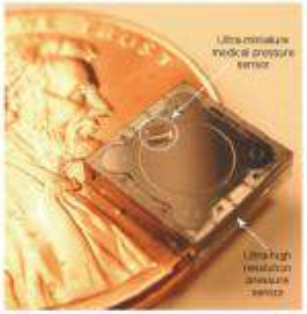


Gyroscopes >

iMEMS ADXRS (Analog Devices)

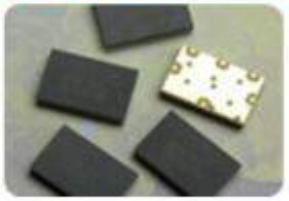
< Optical displays and MOEMS

TI, Samsung, ...



Pressure sensors and microphones >

ISSYS, Freescale, Sensata, ...



RF oscillators, filters, relays, switches, ... >

Si Time, Agilent, Murata, NXP, Avago Technologies, ...

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Université catholique de Louvain

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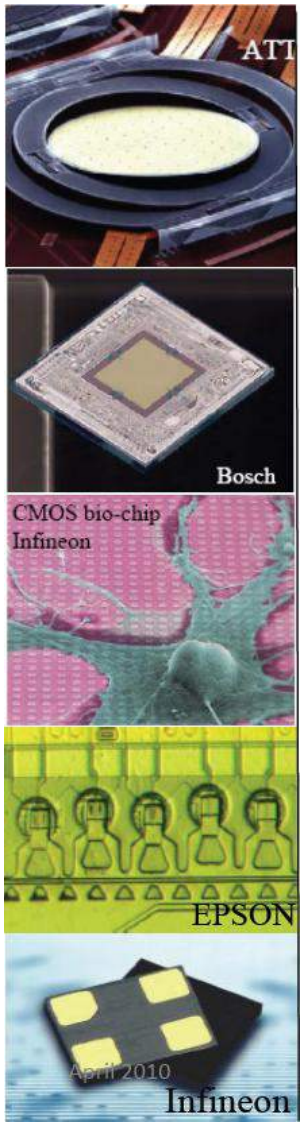
MEMS are (yet) found in …



Automotive: airbags, accelerometers, tyre pressure sensors, stability gyroscopes, exhaust sensors, …

Aeronautics/space: health monitoring, altimeter, compass, … Less weight, more human---machine interfacing.

Telecoms: RF---MEMS switches, acoustic resonators and filters, optical switches (MOEMS), …

Optical displays: micro mirrors in beamers, television.

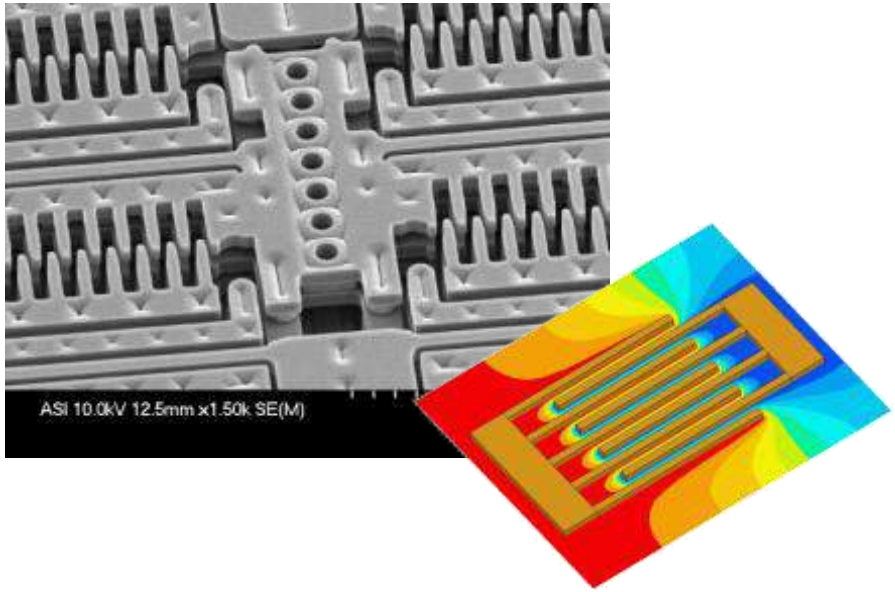
Biomedical: implantable electrodes, cochlear implants, drug delivery micropumps, pressure sensors for surgery, point---of---care biosensors,

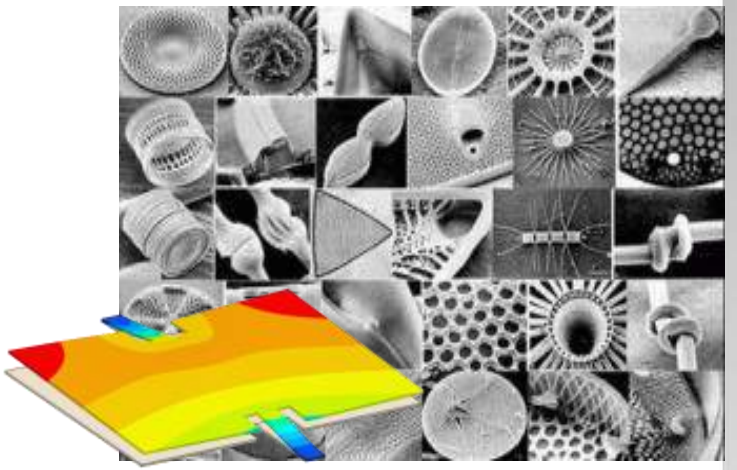
Environmental monitoring: gas and fluid sensors, humidity sensors,

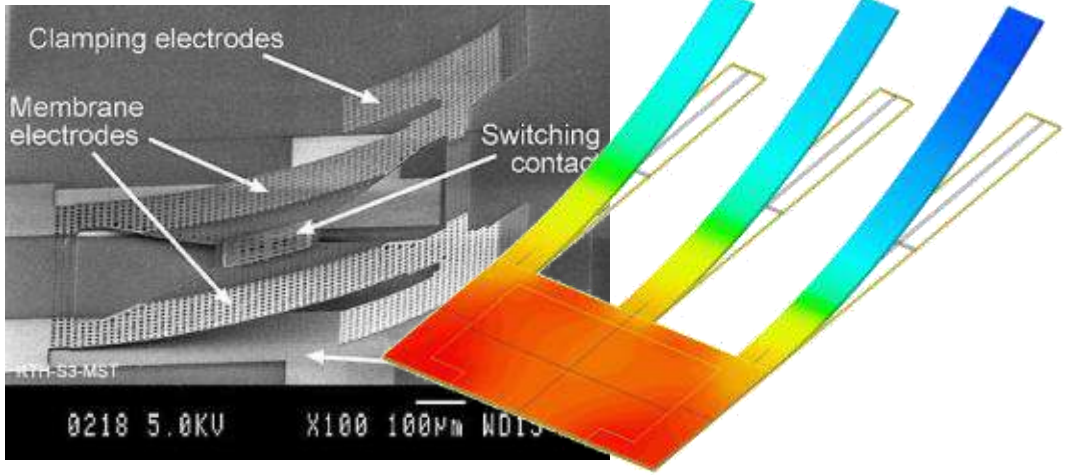
Industrial monitoring: flow, temperature, vibrations,

Consumers electronics and **leisure**

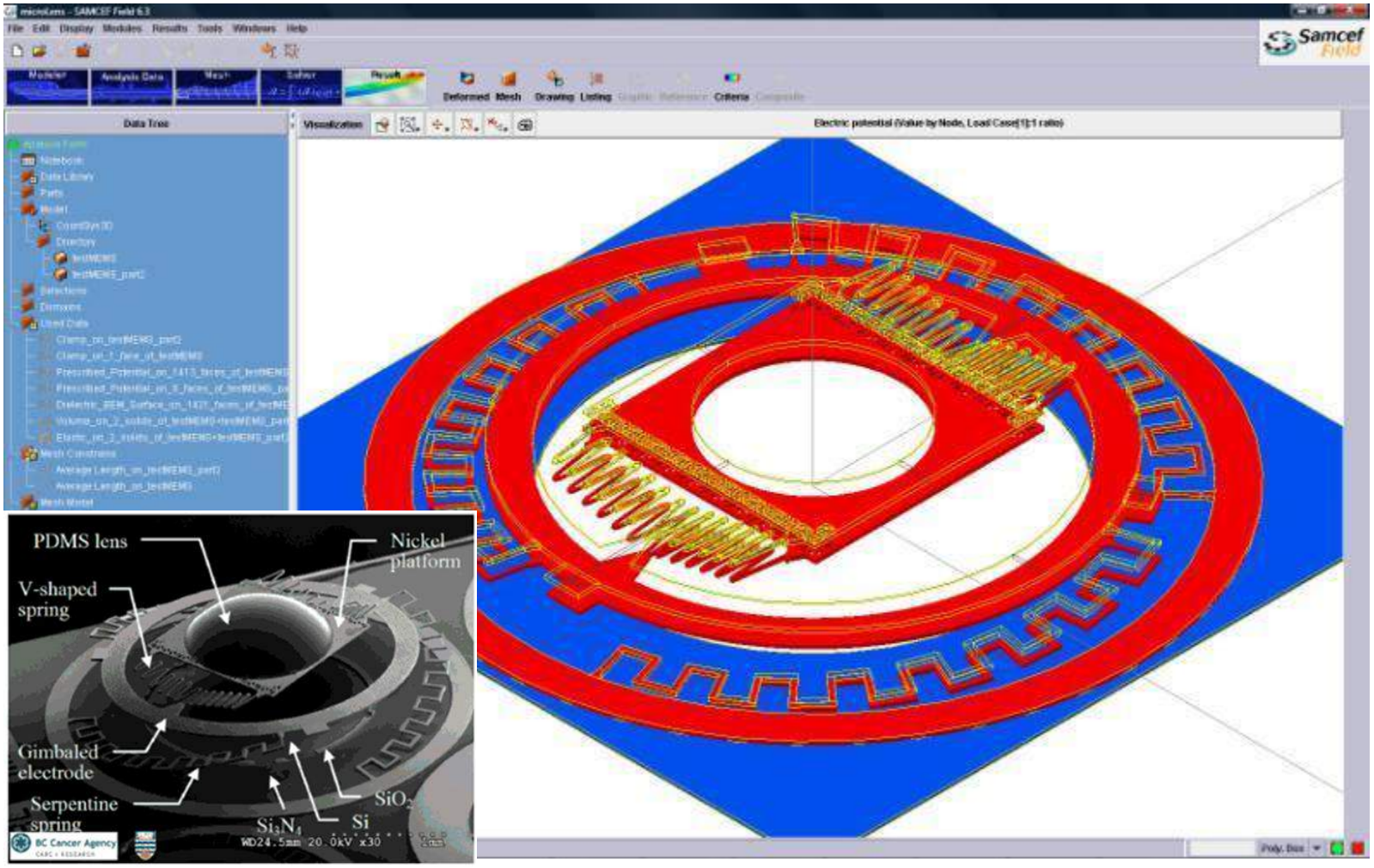
Examples







BEM electrostatic example using FMM



Electrostatically actuated micro-lens for biomedical application

(With courtesy of University of British of Columbia and British Columbia Cancer Research Centre, CANADA)

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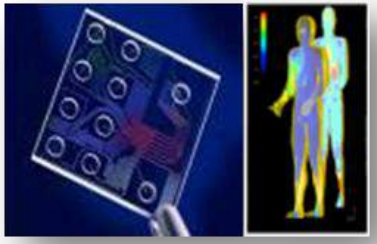
Market Growth Drivers

Immediate growth comes from different angles

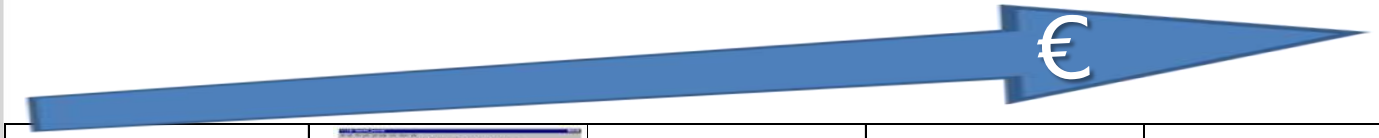
- The replacement of classic systems in the industrial sensors and actuators market (machinery, automotive, A&D).

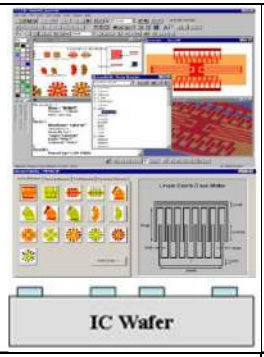
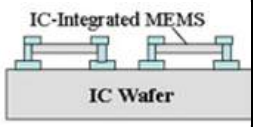
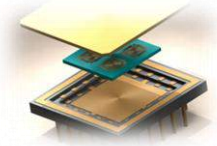
- New human interaction interfaces for smartphones, mobile applications, gaming etc.

- Biomedical applications such as lab-on-chip.



MEMS Based Smart Systems – Value Chain



					
Design Step	**1.** MEMS & IC designed in separate tools. Using separate technologies **2.** MEMS designed in same tool/ same technology as IC with additional interface to mulitphysics	3D stacked Microsystem created	Package for microsystem is chosen	Packaged microsystem put on board	Board included in end-application

Great adventures await… but …

What's going on in *Lilliput*'s world ?

- Inertial forces are taking over gravitational forces
- Surface forces are predominant over body forces
- Heat dissipates quickly
- Stiffness decreases slower than mass: increased resonant frequencies
- In microchannels :
  - laminar flows (low Reynolds number)
  - high pressure required to move fluids
  - gas flow in the slip regime
- Electrical breakdown happens at higher voltages
- Breakdown in the classical continuum !

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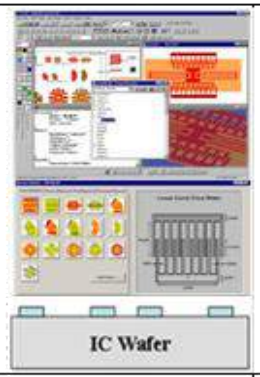
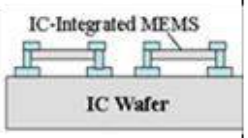
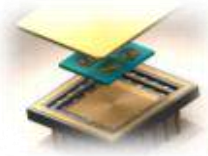
What's going on in the industry?

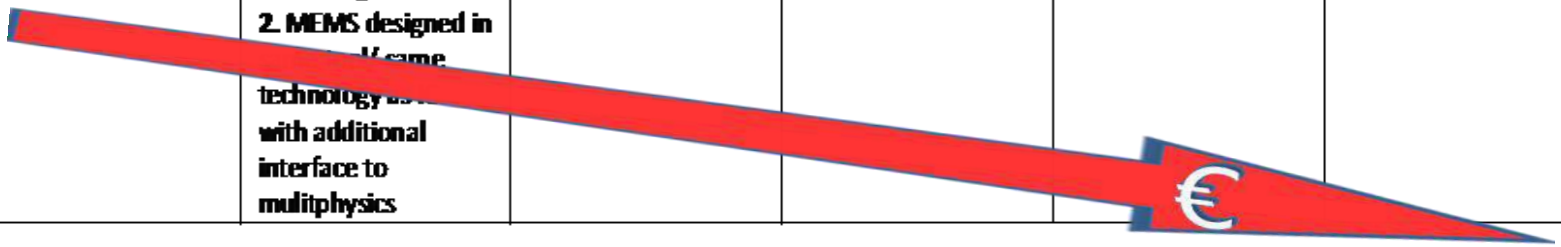
Optimization of the global innovation process

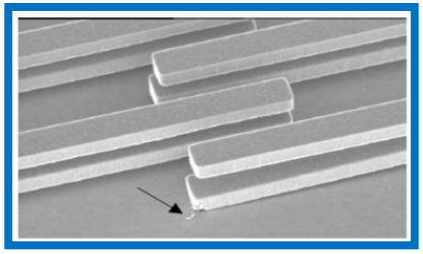
- Microsystem reliability problems in automotive
  Recalls Toyota, Chevrolet: Innovation at the expense of profit
- Devices in consumer electronics such as microphones and accelerometers, used in mobile phones, are under a tremendous price pressure
  Since 2004, prices have dropped by 50%
- FAB process variability still requires extensive testing.
  Over 40% of total costs generated by production line tests.
- To exact high value, on highly competitive markets it is important to increase the life span for end-products with add-on sales (ink, gaming, mobile communication, ...).

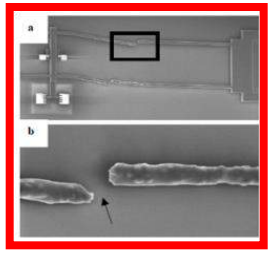
"Design for Reliability and Robustness" including simulation and measurements emerges as a strong need

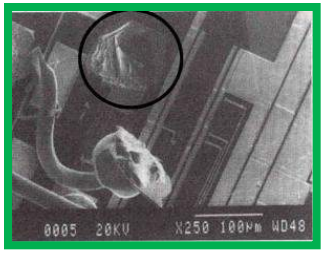
Value Chain Revisited

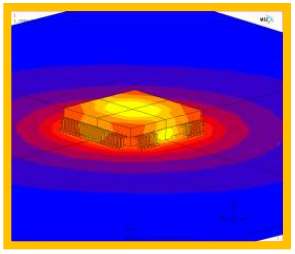
					
Design Step	**1. MEMS & IC designed in separate tools. Using separate technologies** **2. MEMS designed in [illegible] same technology [illegible] with additional interface to multiphysics**	**3D stacked Microsystem created**	**Package for microsystem is chosen**	**Packaged microsystem put on board**	**Board included in end-application**











Electro-static Discharge – burn-in, Electro-thermal heating & Failure, bondwire disconnect, solder cracks, package heat & vibration fatigue effects

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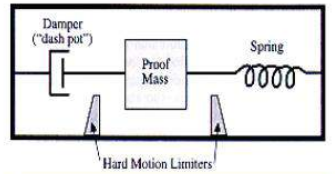
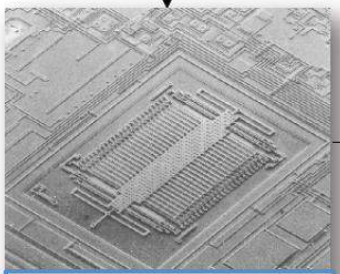
Technology needed to cover & close the MEMS value chain

How *industrial* MEMS are conceived ?

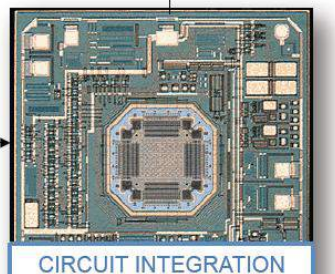


CONCEPTS & MODELS

PACKAGING



PROCESS DEVELOPMENT



CIRCUIT INTEGRATION
& TESTING

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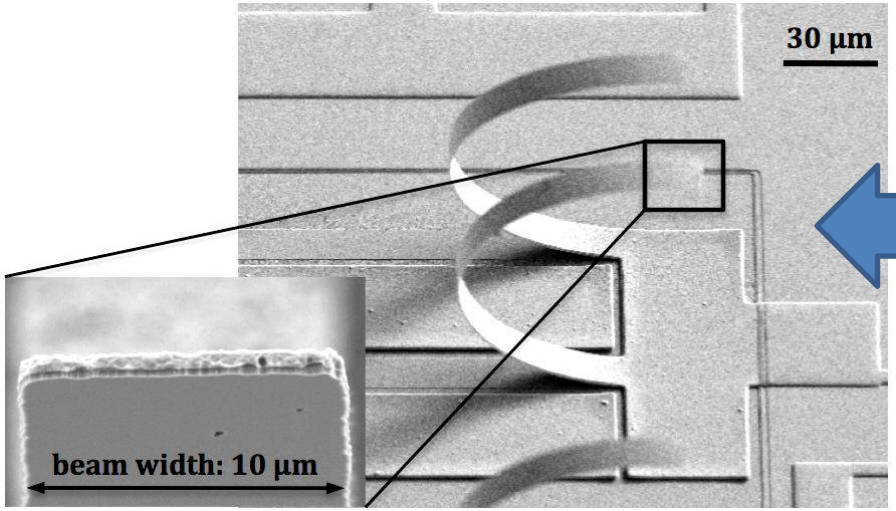
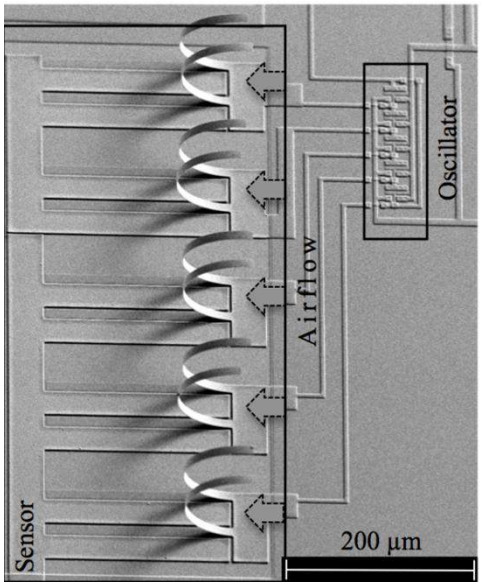
The Integrated Design of a MEMS-based Flow-Sensor System

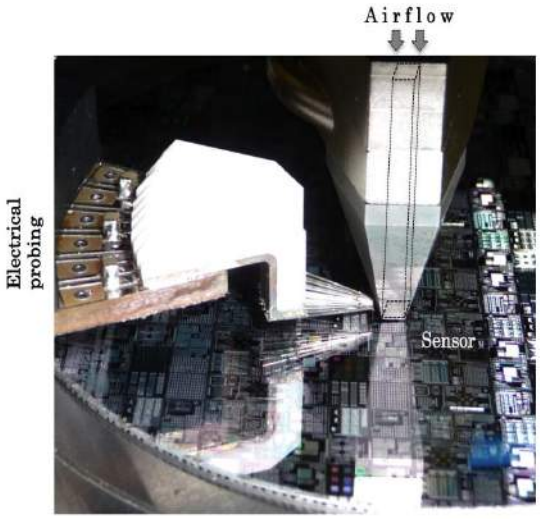
MEMS shear stress flow sensor based on capacitive effects

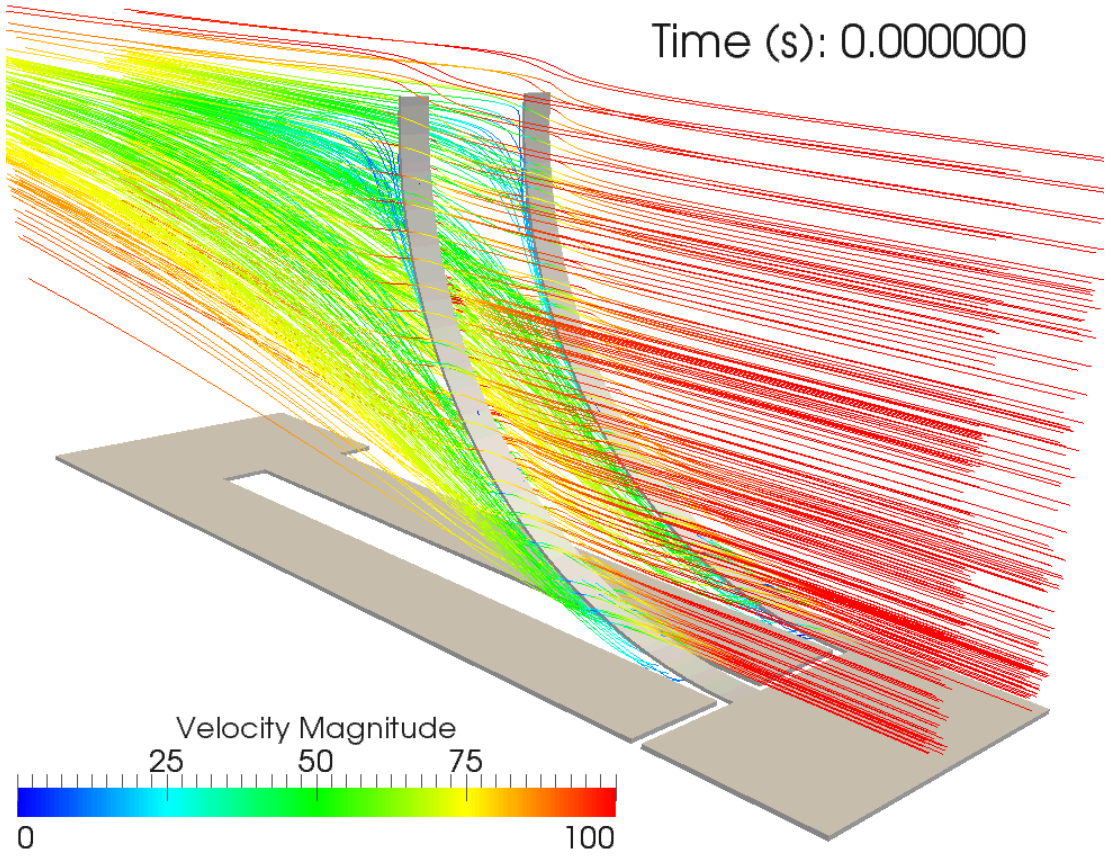
- A high level of functional integration is critical for successfully building smart systems.
  - Capture all multiphysics interactions and optimize the sensitivity
  - simulate the fluid-structure interactions (FSI) together with the electronics circuitry.



Multiphyisics FSI Flow Sensor Behavior







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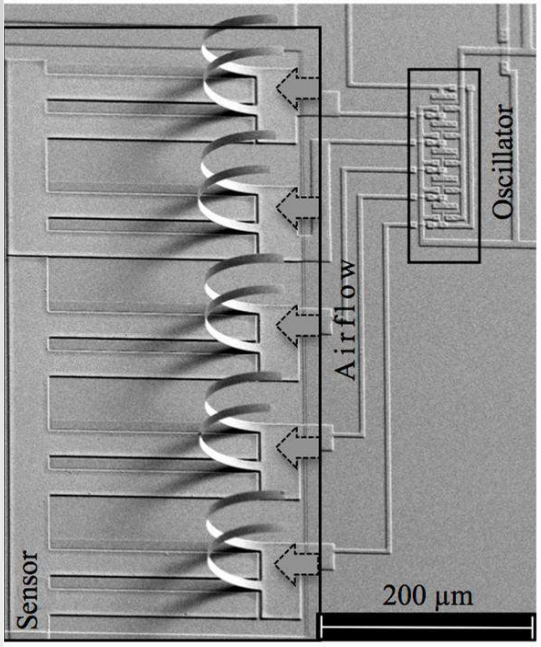
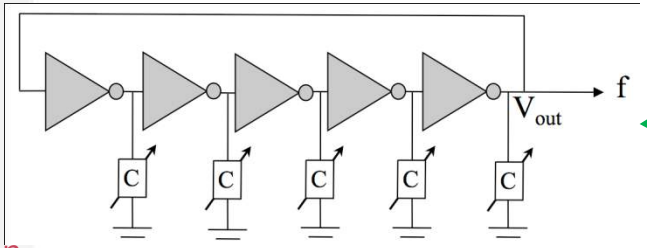
Micro Mechanical And Electrostatic Analysis

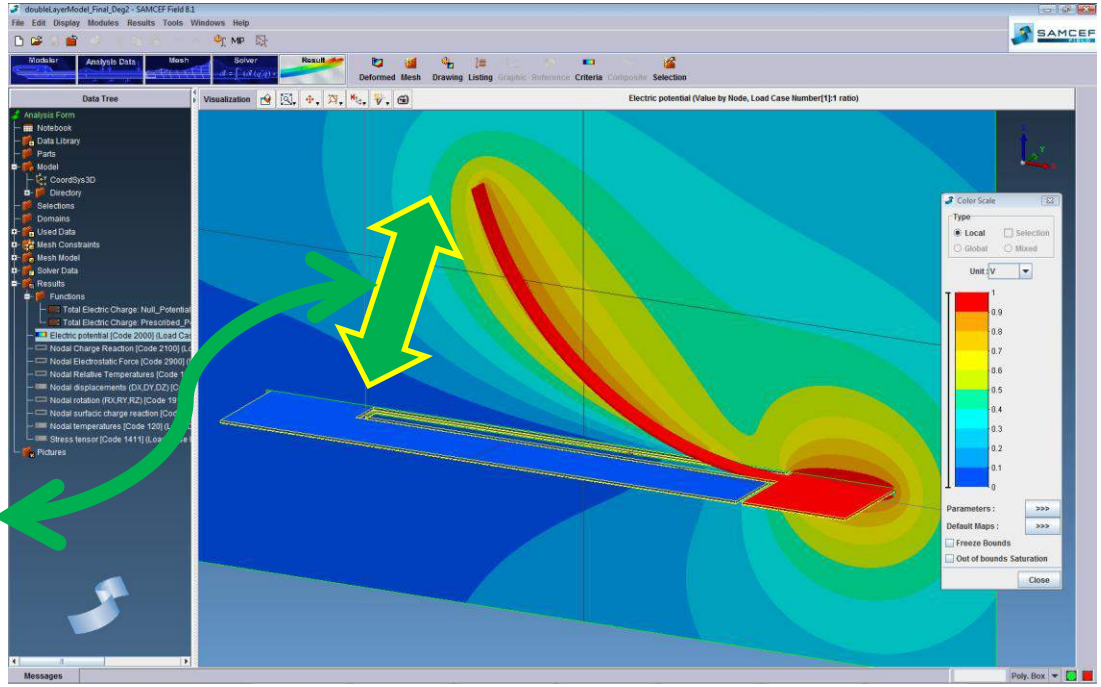


Shape relies precisely on

- The control of the **internal stresses** in multilayered structures originating from thermal expansion mismatch
- **Plastic yielding** of a metallic layer

Capacitive Effect between 2 electrodes





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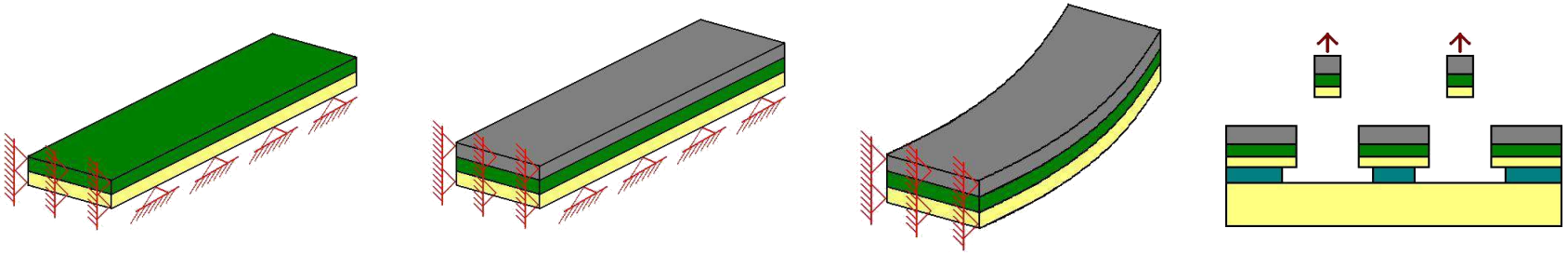
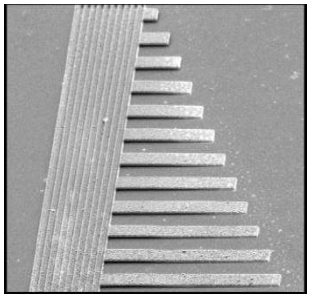
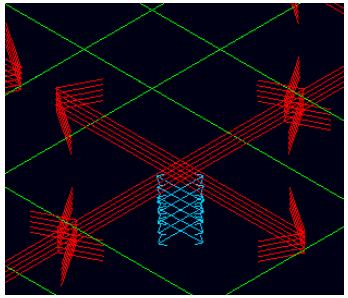
FAB Process STEP BY STEP SIMULATION

Residual Stresses

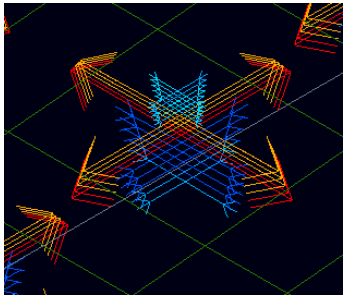
$T_{Si} = T_{SiN} = 800$ C → $T_{all} = 150$ C → $T_{all} = 20$ C



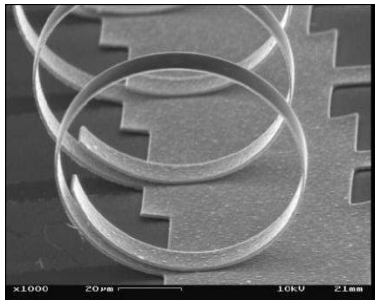




Stress Si ≠ Stress Si_3N_4,
Stress Al = 0

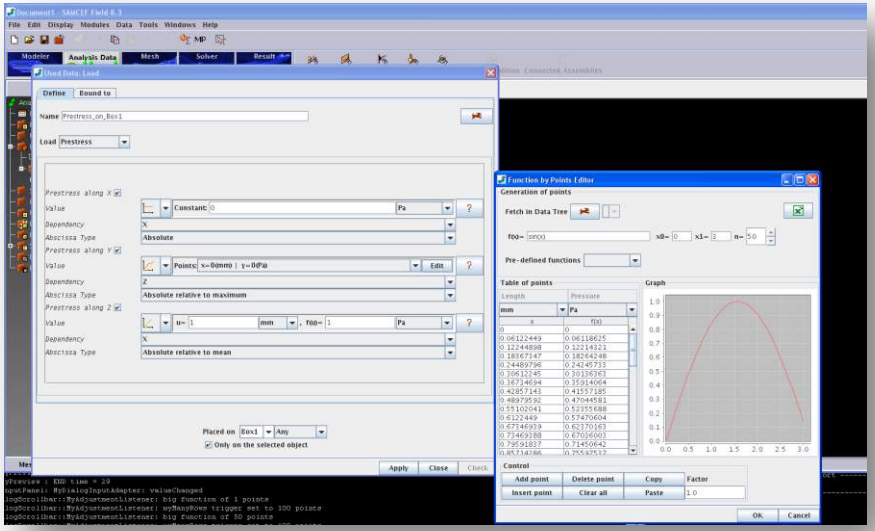


All stresses ≠

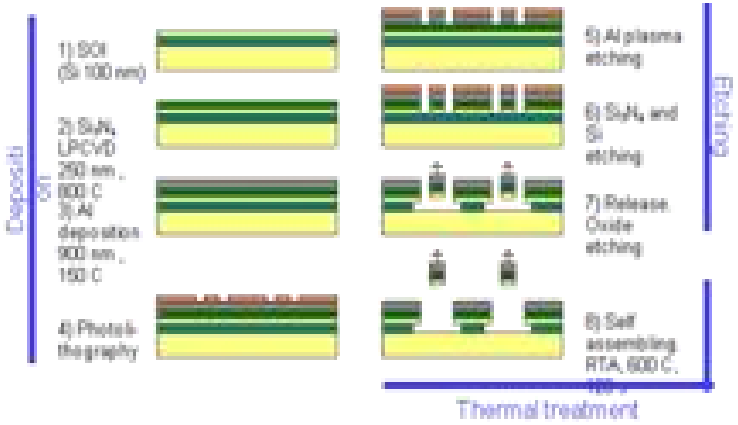


Dealing With FAB Process Pre-stress

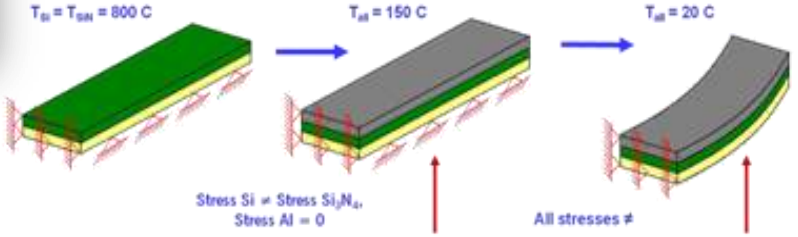
Pres – Stress Formula based Input



Full FAB-process Simulation

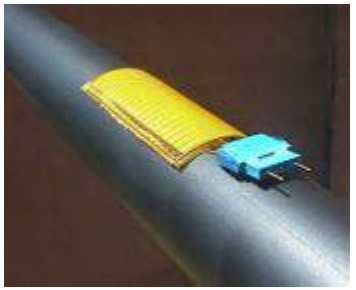


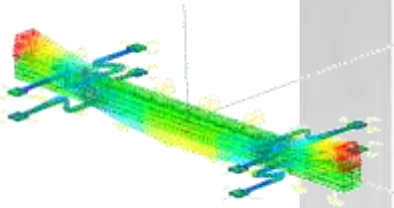
❑ Step by step simulation : residual stress



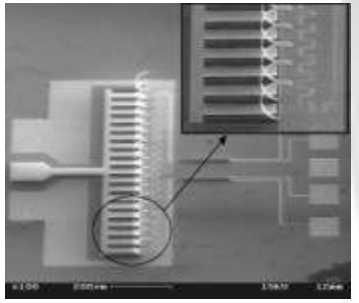
Actuators & sensors modeling: What's Happening Today?

- **Multiple Physical phenomena often involved**
  - Capacitive – Electrostatics
  - Piezoresistivity
  - Piezoelectrity
  - Thermal
  - Magnetics

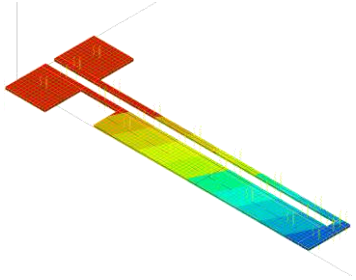




- **Components Scale Down**
  - Time-constants of physical effects have similar orders of magnitude.
  - Strong coupling is requested for best accuracy and covergence



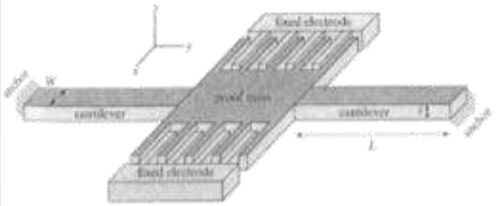
- **Complexity increases**



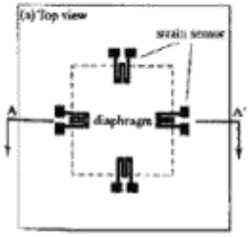
Sensor & Actuator Current Techniques

Transduction techniques : **sensing**

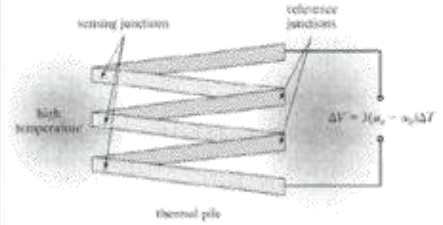
Capacitive



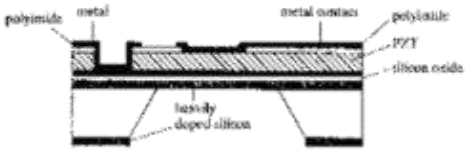
Piezoresistive



Thermal

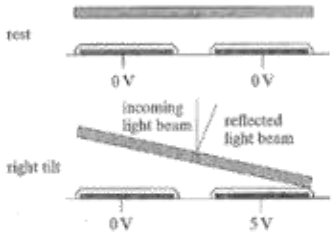


Piezoelectric

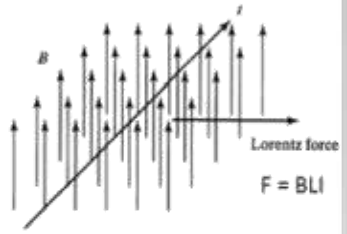


Transduction techniques : **actuation**

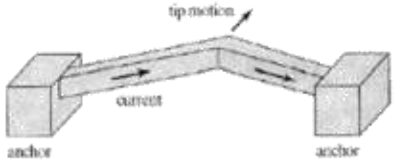
Capacitive



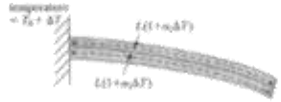
Magnetic



Thermal



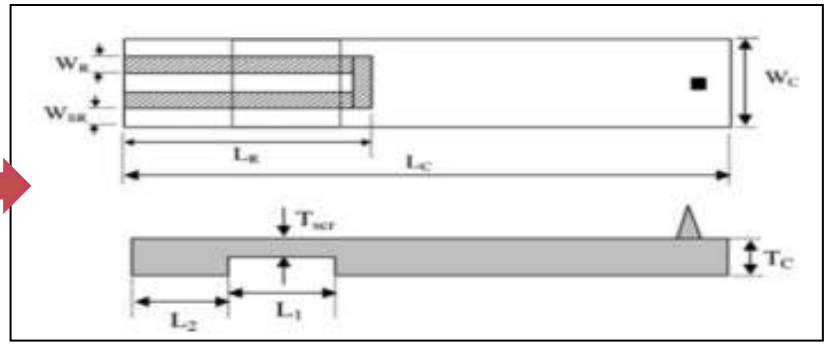
Piezoelectric (bimorph)

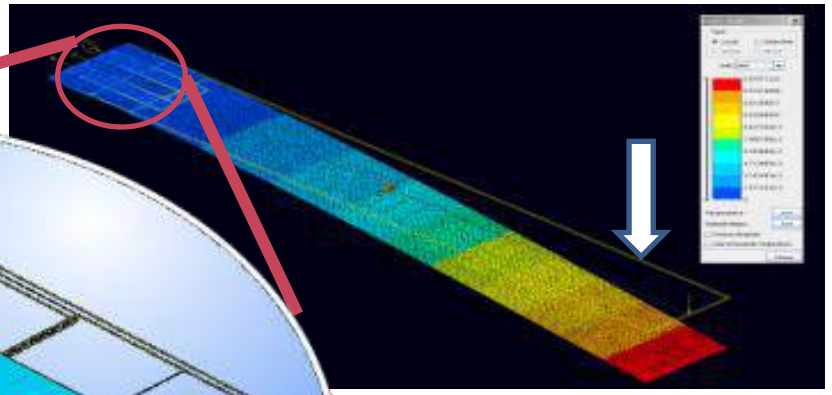


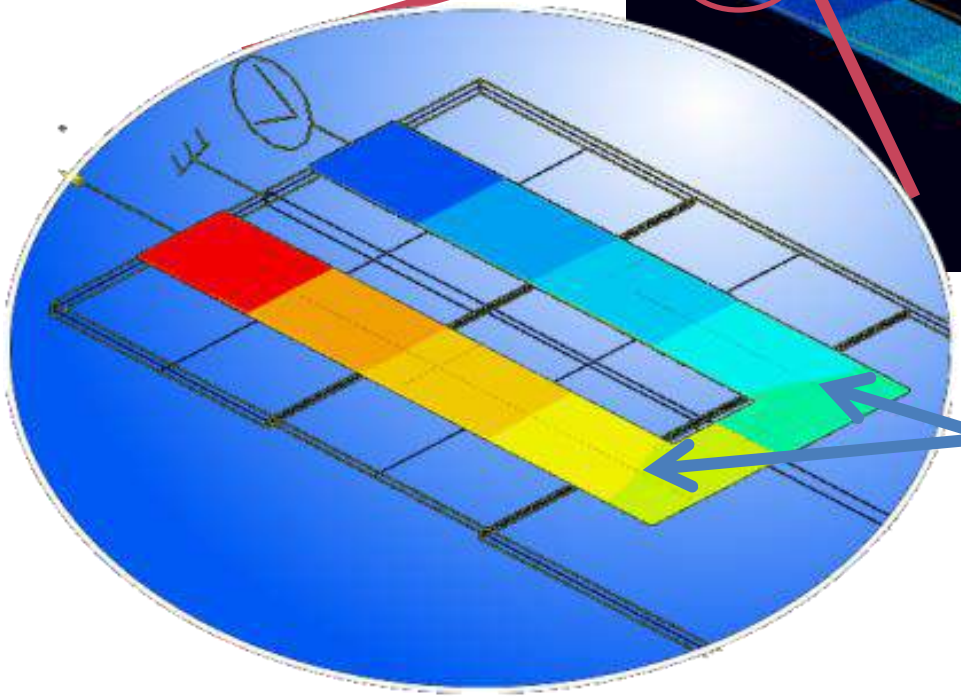
OOFELIE::Multiphysics fully addresses Today's Advanced Design Needs

Pressure Sensor Test Case

Piezoresistive semiconductor layer on a bending beam







Resisitivity Change At Highest Deformation Region

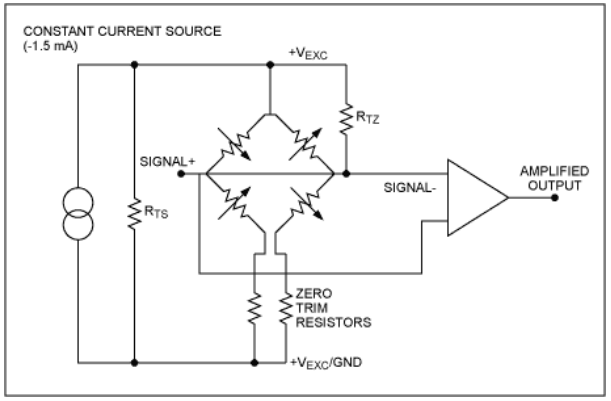
Piezoresistive Pressure sensor

Typical applications

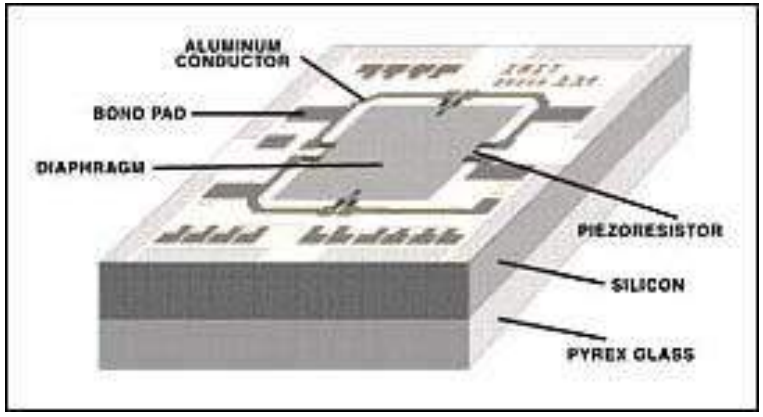
- microphones,
- biomedical instrumentation (*e.g.*, blood and fluid pressure)
- vacuum sensing
- wind-tunnel model instrumentation
- automobile power and acceleration measurement
- household electronics

Parametric optimization

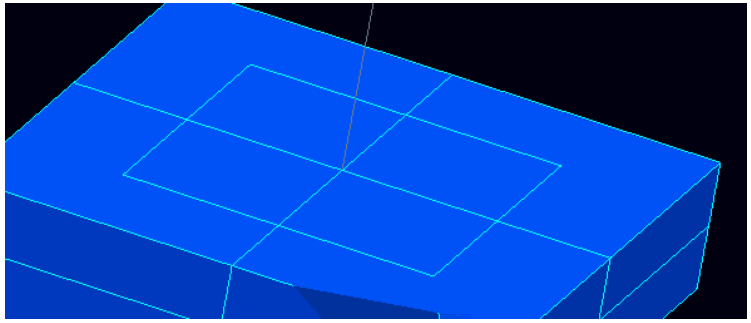
- chained analysis (mechanical & piezoresistive)
- mesh mapping in 3D



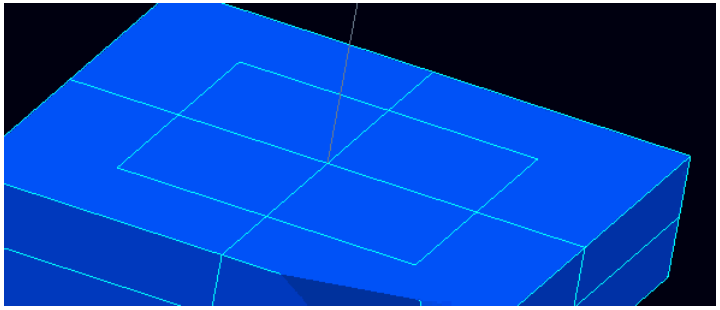
Wheatstone bridge



Piezoresistors are placed on the diaphragm



Displacement



Stress

Energy harvester

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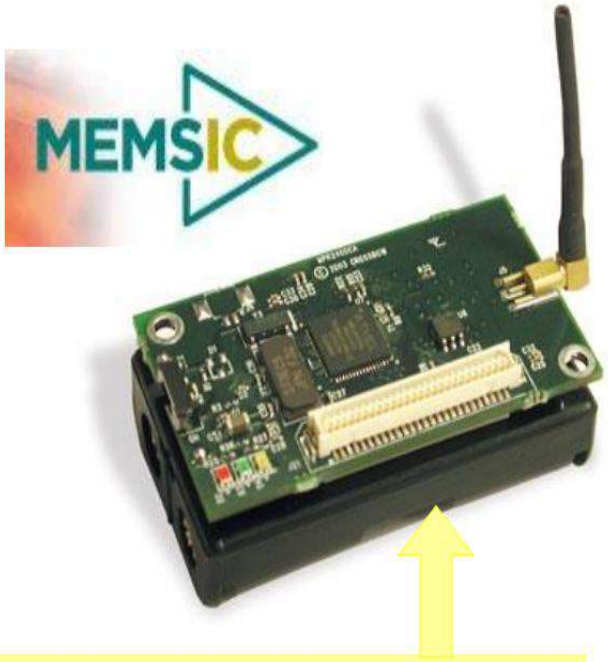

two (2) AA batteries

Significant cost associated with the labor cost of changing batteries!

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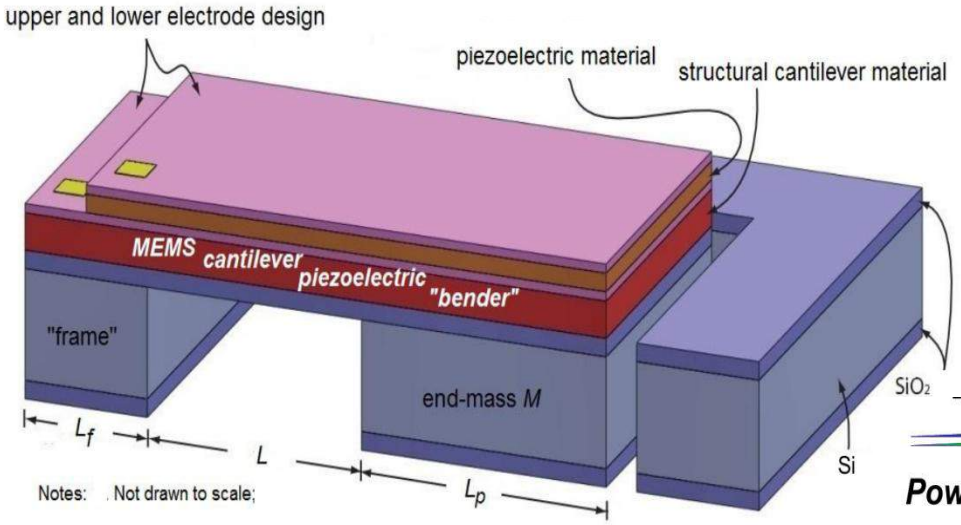
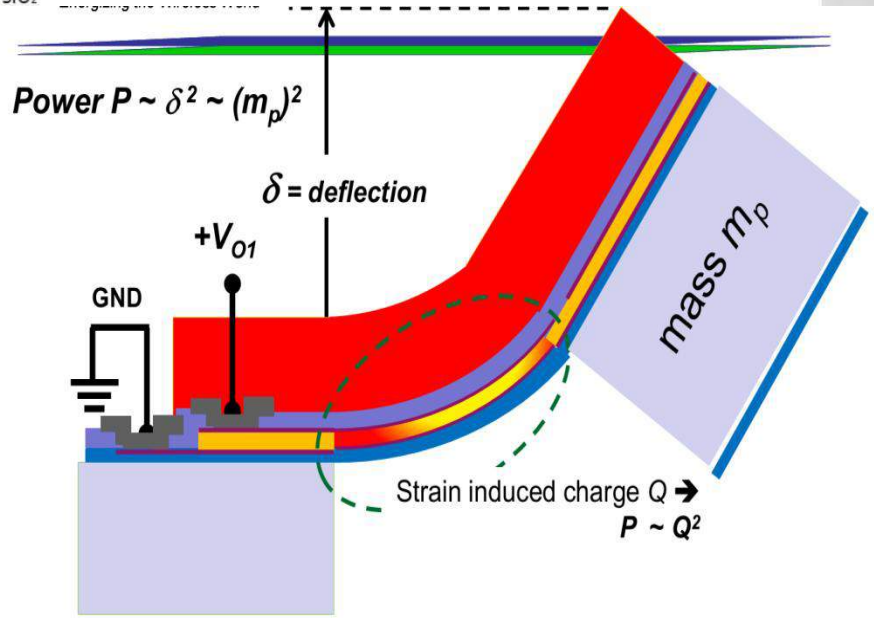
Basic BOLT™-R design





Energy harvester

microGen
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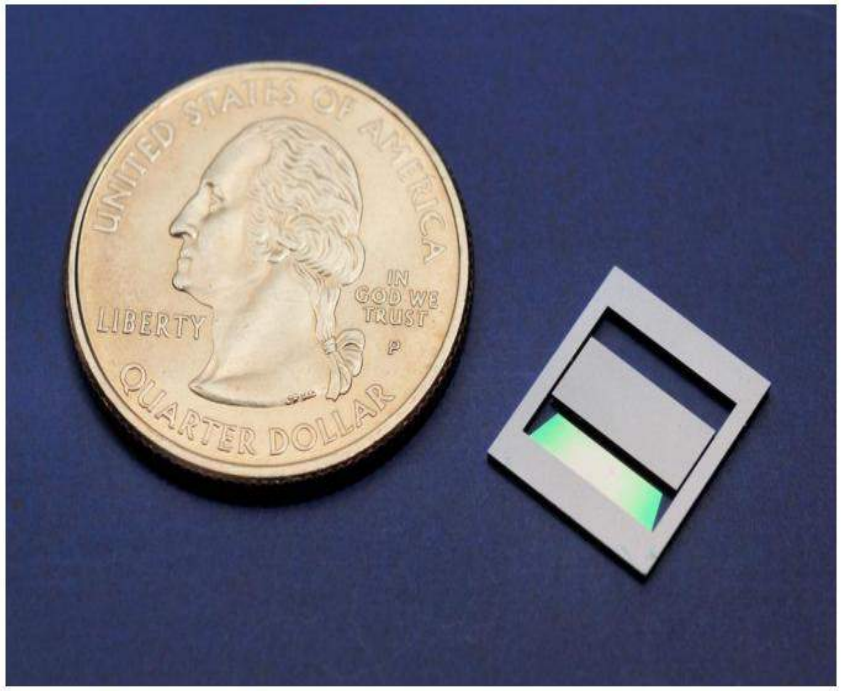
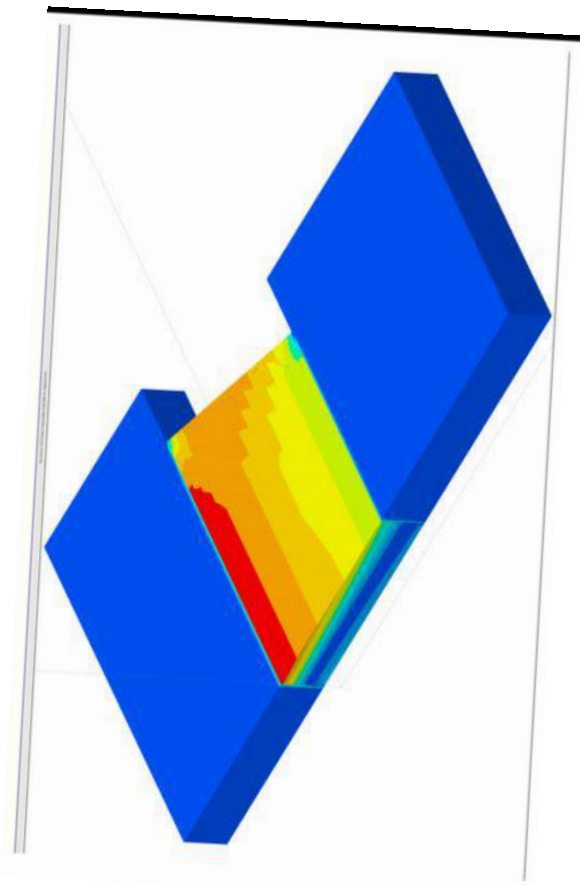
Optimized design with OOFELIE

Single MPG die

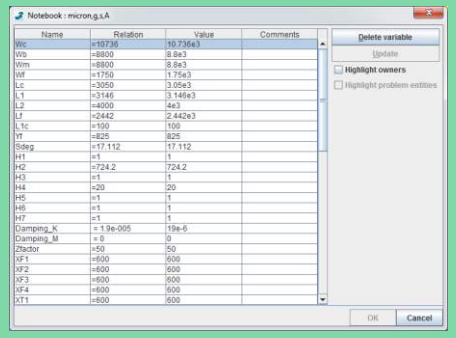


MPGs from X-FAB

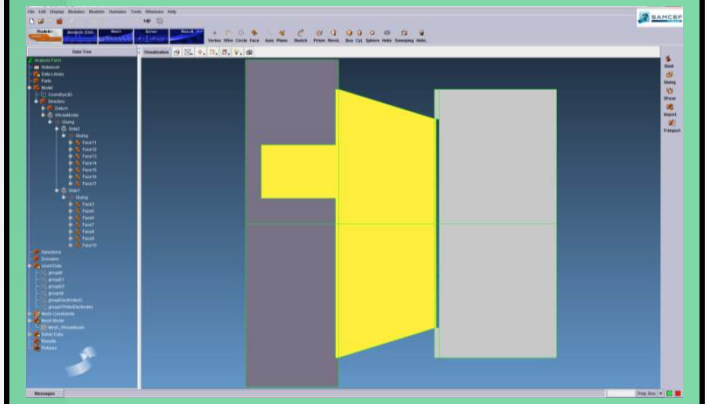
Available in Q2 2013



Piezo Energy Harvesting Design Flow

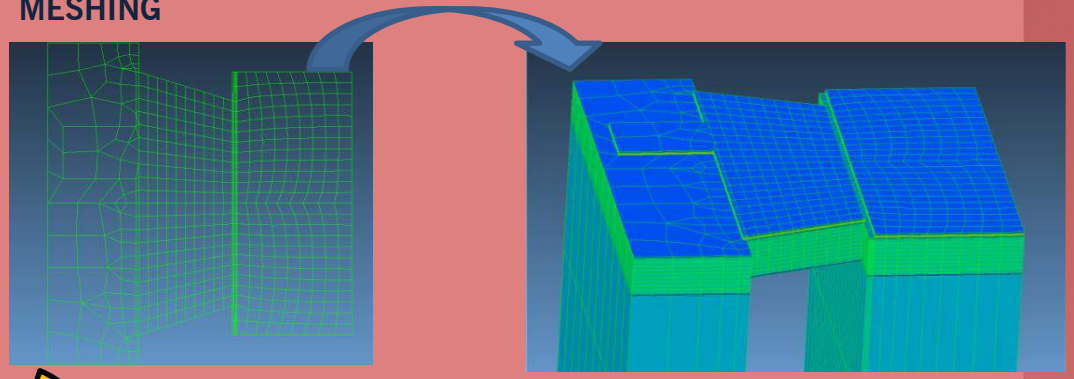


PARAMETRIC MODEL



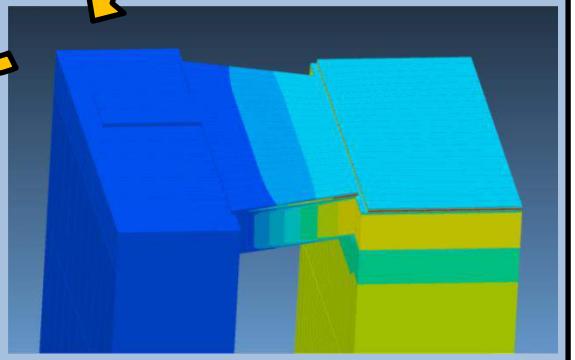
OPTIMIZATION

MESHING

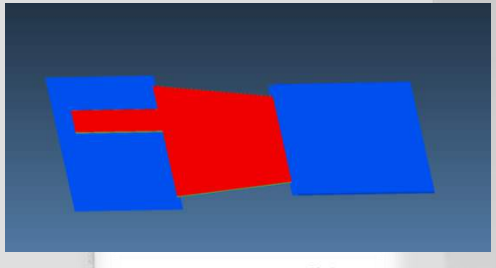


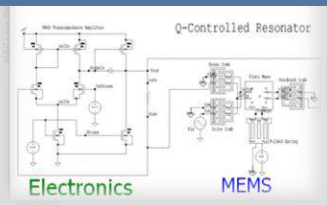
BASE

3D EXTRUDED MESH



- Modal analysis
- Harmonic response
- Results
  - Stresses
  - Strains
  - Elec. potentials
  - Displacements





- Capacitance analysis
- Reduced Order Modeling
  - Co-simulation

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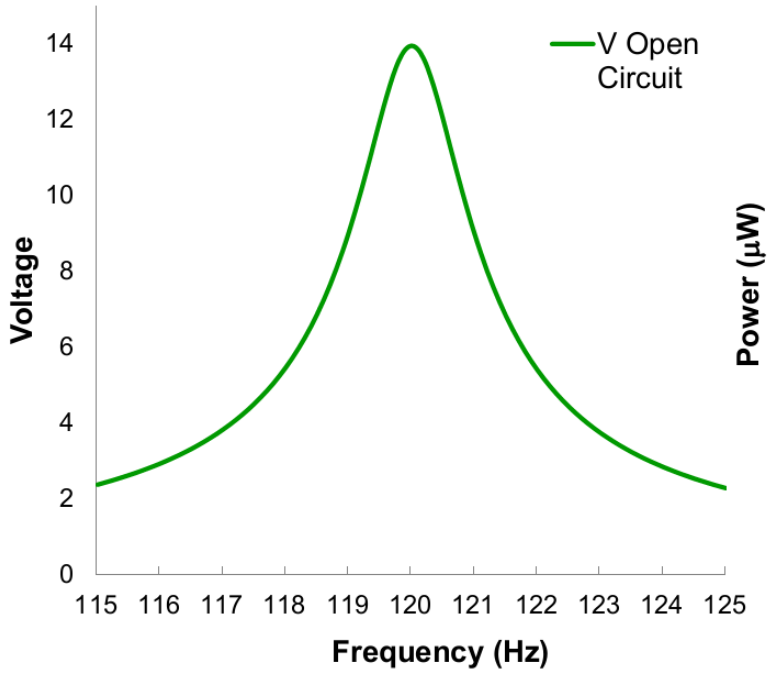
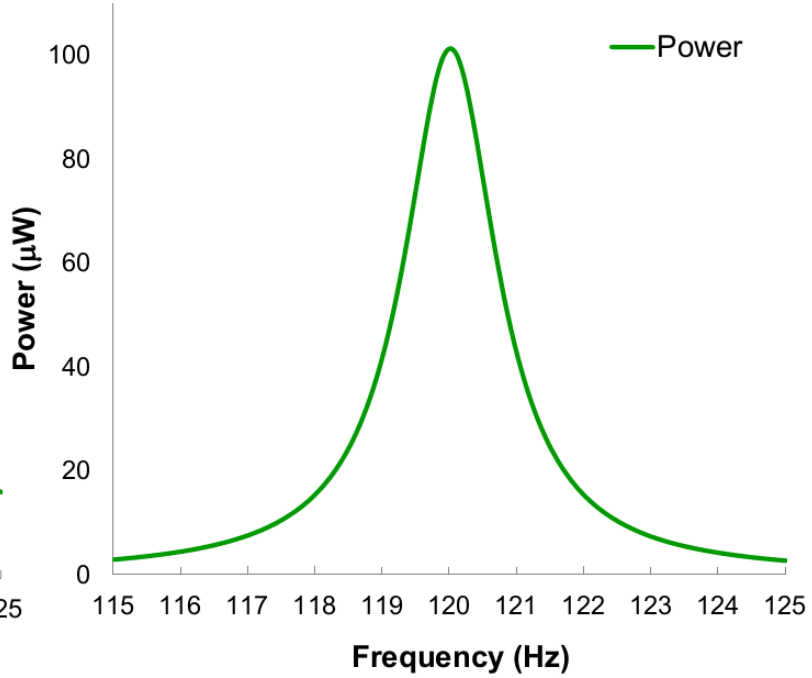
Sample Performance: BOLT™-R0120

Voltage



Power



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International attention

New York's Creative Core $200,000 Emerging Business Competition

2012 Winner

Silicon 60

2012 EE Times' 'Hot' Emerging Start-up

ENERGY HARVESTING & STORAGE USA

2012 Silver sponsor and Exhibitor

Solid State TECHNOLOGY
Insights for Electronics Manufacturing

X-FAB to Manufacture MEMS Energy Harvesters for MicroGen Systems, June 8, 2012

MEMS' Trends

"MicroGen to ship MEMS energy harvester samples in wireless sensor node subsystems", Sept 16, 2011.

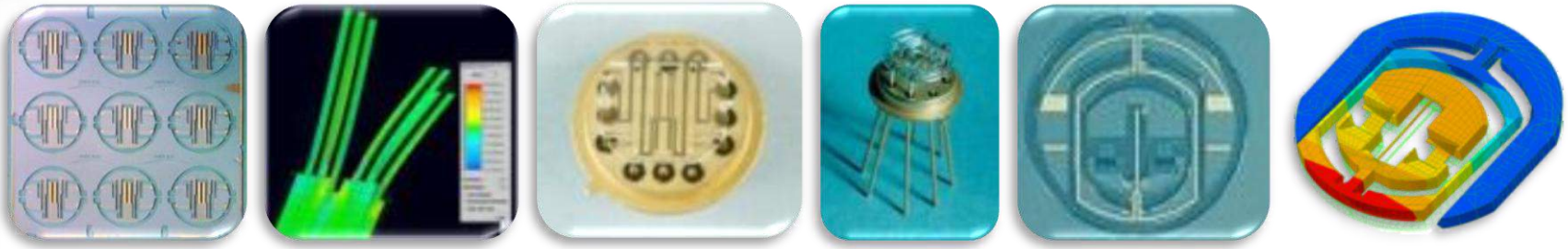
MIT technology review

"Power Scavenging Batteries", August 25, 2011

VLAB
MIT/Stanford Venture Lab

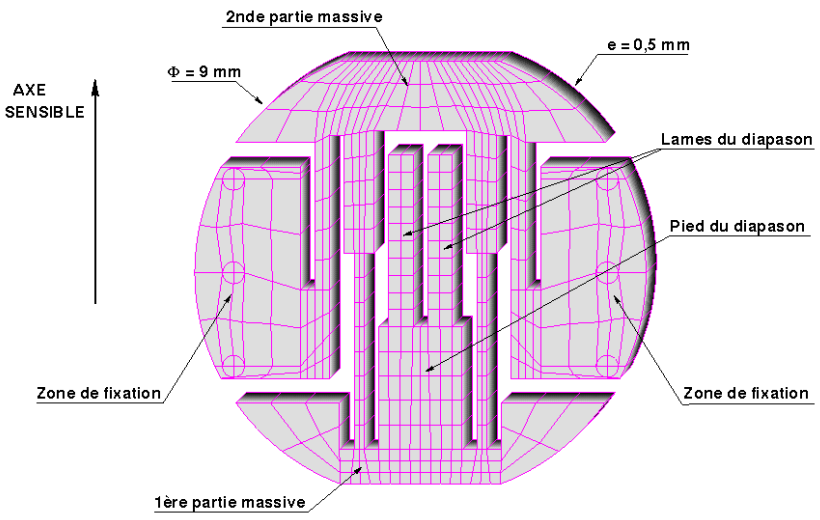
"Energy Harvesting – Power Everywhere", April 19, 2011

MEMS Design of Vibrating Inertial Accelerometers



- Size reduction & new manufacturing technologies
- Needs strongly coupled piezo-thermomeca

ONERA
THE FRENCH AEROSPACE LAB



Experimental validation

Patented designs

Licensed to defence industry

DGA

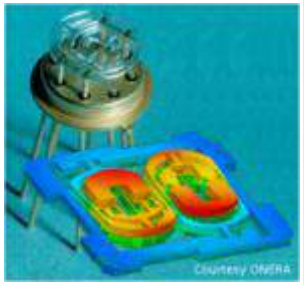
Sagem
Défense Sécurité
Groupe SAFRAN

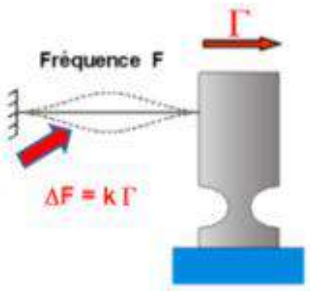
THALES

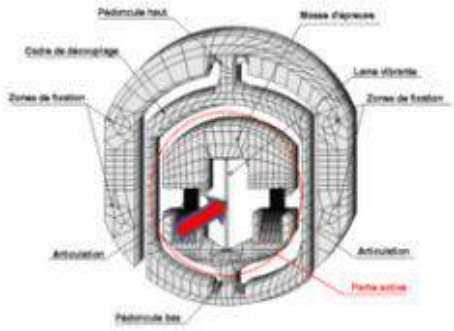
open
engineering

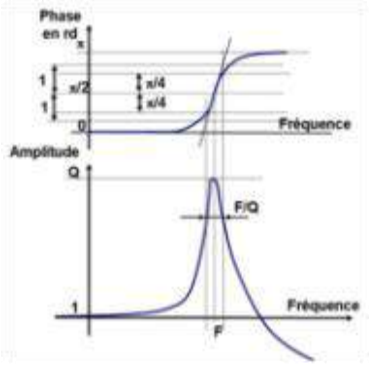
Vibrating Inertial Accelerometer Design by Onera

- Monolithic quartz sensor. Sensitive to orthogonal acceleration.
- Efficiently decouple the vibrating beam from the outside case
- Maximize the vibration quality factor









	Q factor
Zener theory	16 580
Oofelie : thermo-elastic	13 700
Oofelie : piezo-thermo-elastic	13 090
Experimental characterisation	~13 000

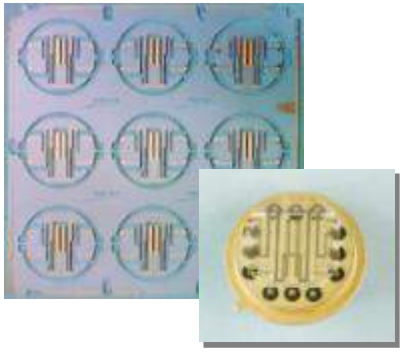
$$\Delta F = \frac{F}{2.Q}\Delta\varphi$$

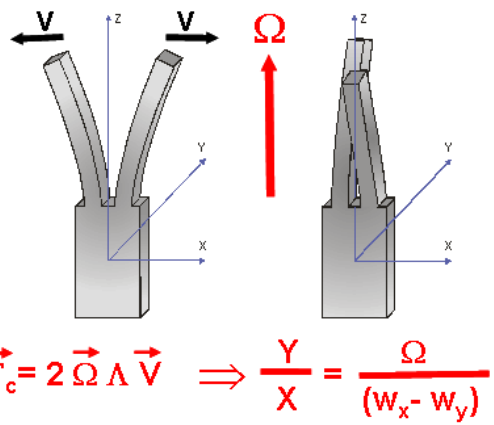
piezoelectric actuation of a beam
measurement of the frequency shift due to axial stresses

The whole device - including the sensor's package is simulated using Oofelie because of the need of strongly coupled Piezo-thermo-elastic modeling.

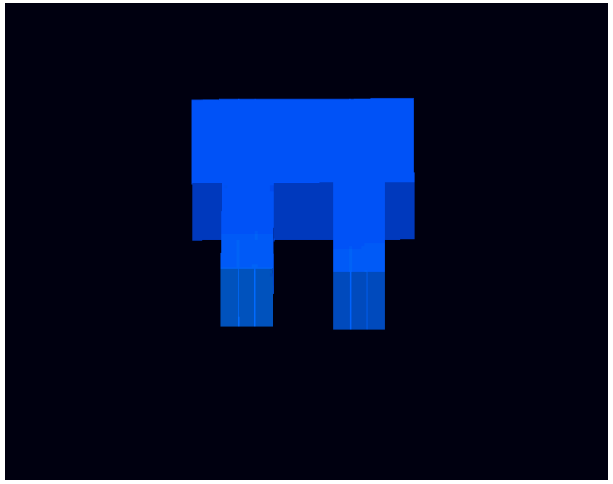
Vibrating Inertial Accelerometer (courtesy of ONERA)

Vibrating gyrometers based on Coriolis effect

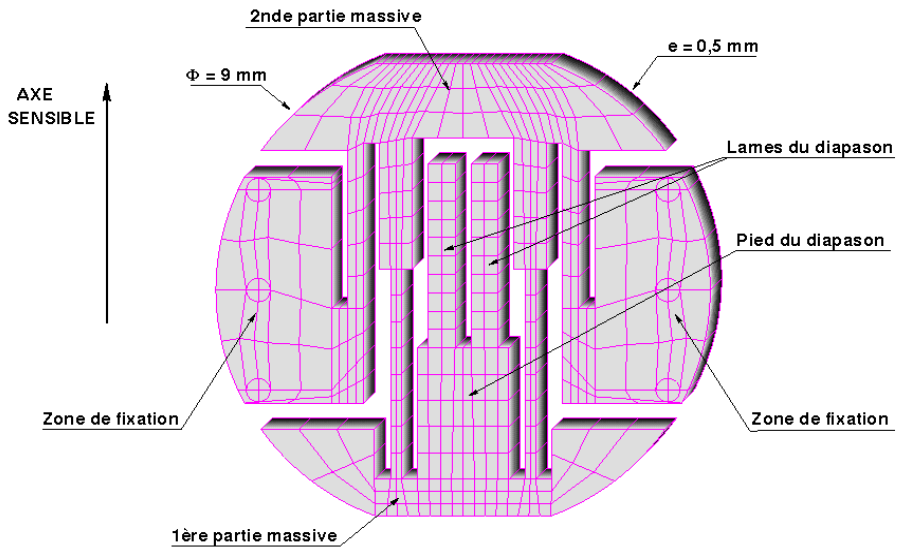


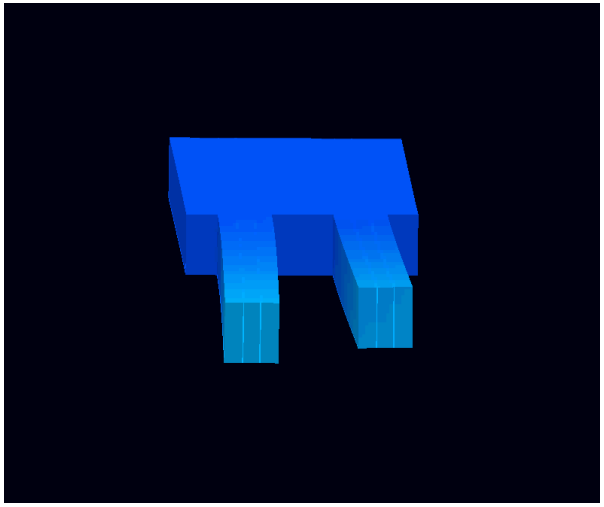


$$\vec{\Gamma}_c = 2\,\vec{\Omega} \wedge \vec{V} \Rightarrow \frac{Y}{X} = \frac{\Omega}{(w_x - w_y)}$$



Driving mode

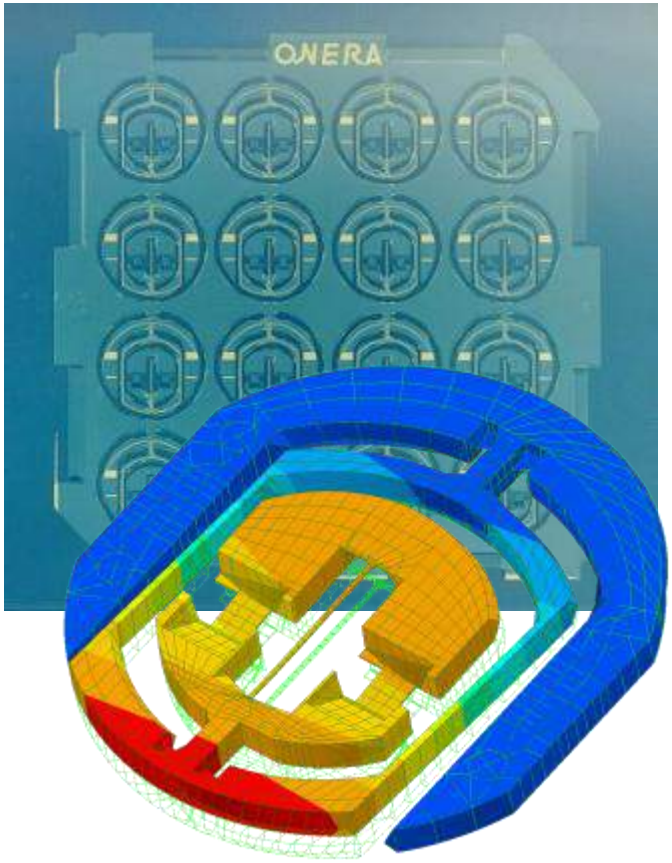




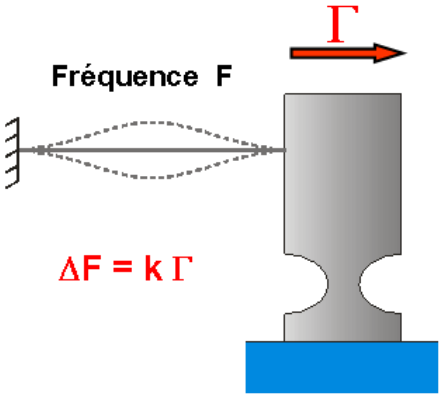
With coriolis effect

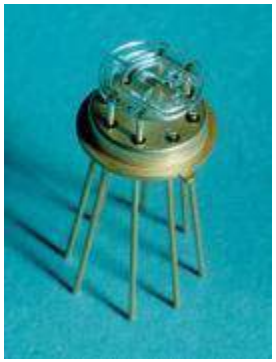
Example PyroPiezoElectric (courtesy of ONERA)

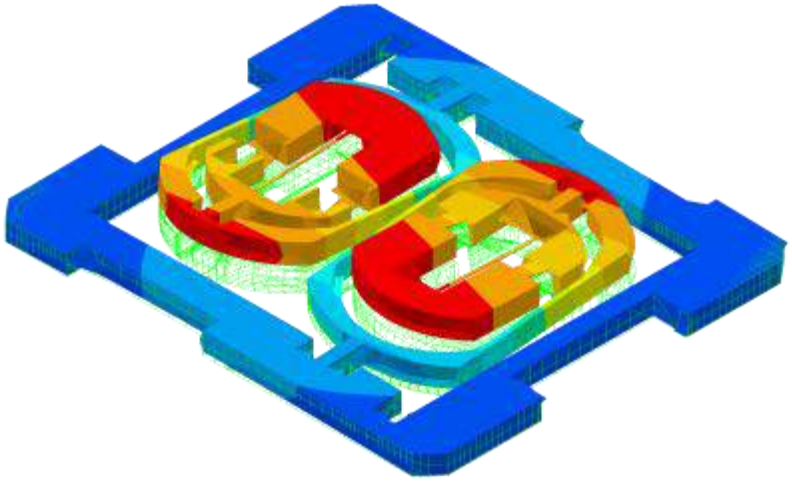
Vibrating inertial accelerometers



VIA

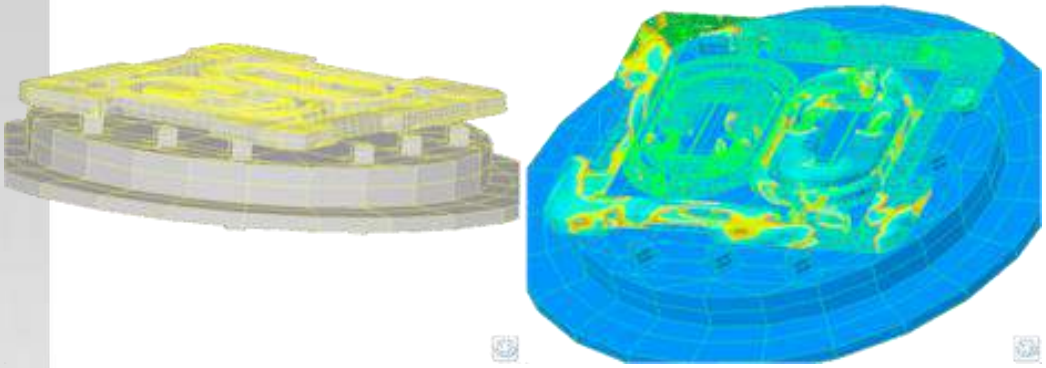






DIVA

Optimize For Packaging Effects

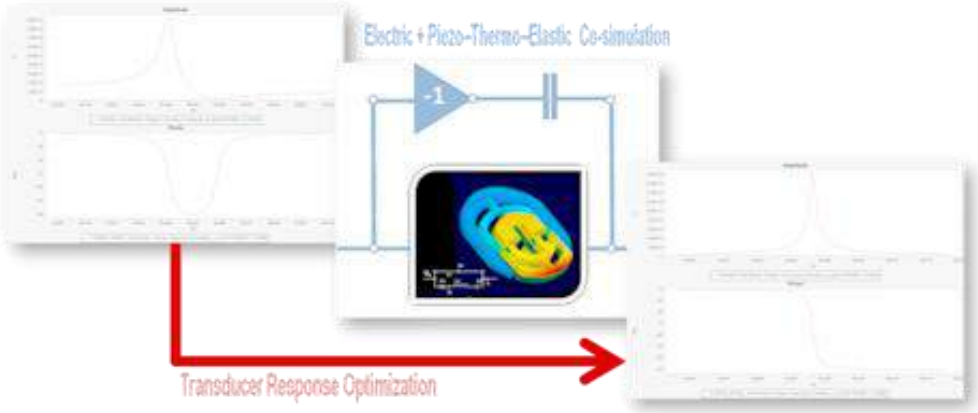


Simulate with To8 package

- Study the energy losses through the mounting parts
- Optimize the resonance quality
- Minimize the effect of thermal stresses on the resonance frequency.

Circuit Co-simulation Inside Oofelie

The electric compensation circuit and optimization of the electric parameters improves the total system performance



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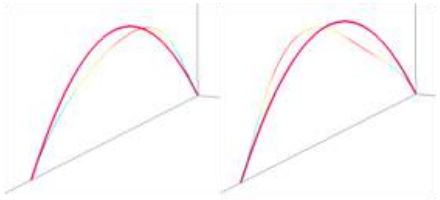
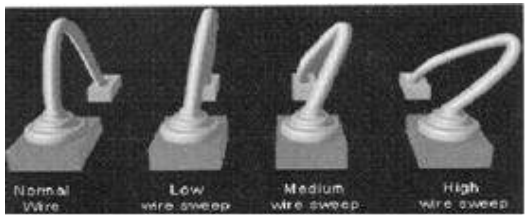
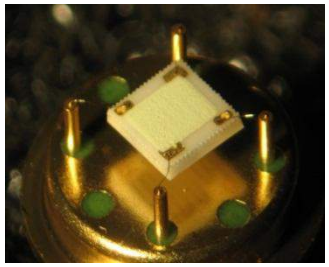
Packaging & Bonding Challenges

- Identify most appropriate package for harsh environments
- Understand and master
  - Size, length and shape of bondwiring
  - The influence of gluing
  - The influence of the package on the functionality
  - Limit induced stresses caused by assembly process

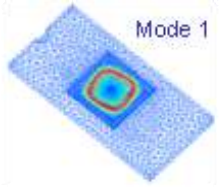


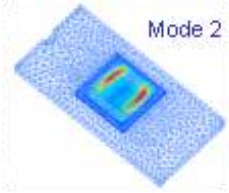


Simulation vibration bondwire 25µm to exclude short-circuits

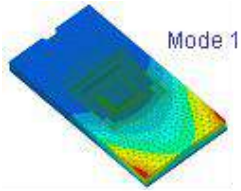


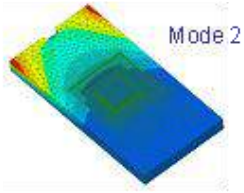
Sensor suspended by 4 25µm bondwires to withstand a 4m drop





Vibration modes glued chip (without package)





Vibration modes glued chip (with package)

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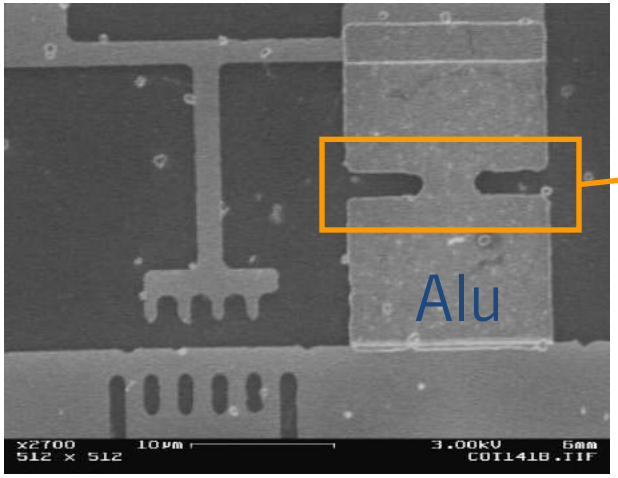
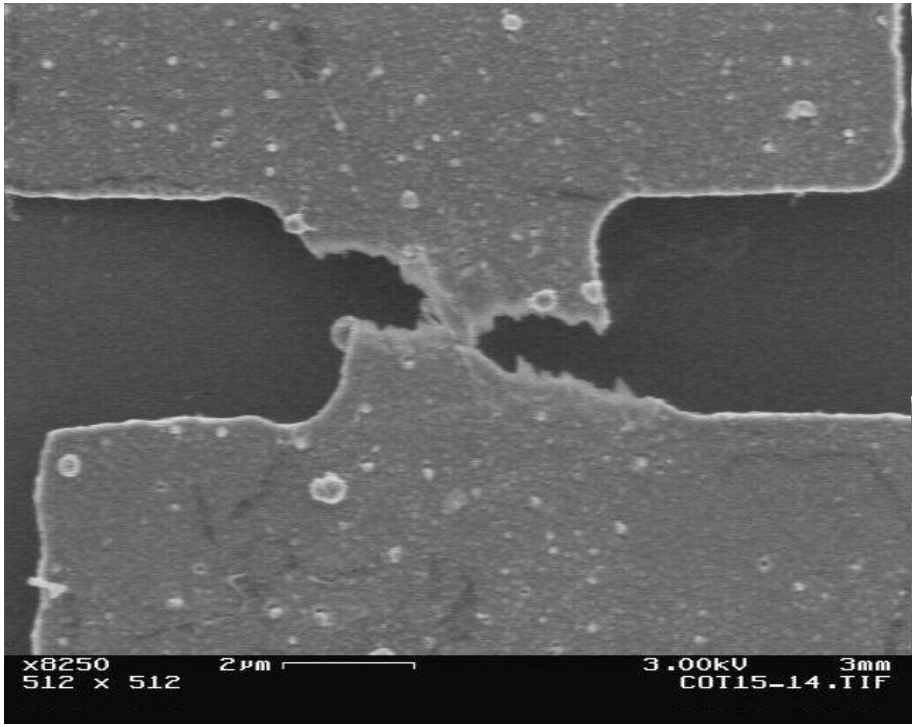
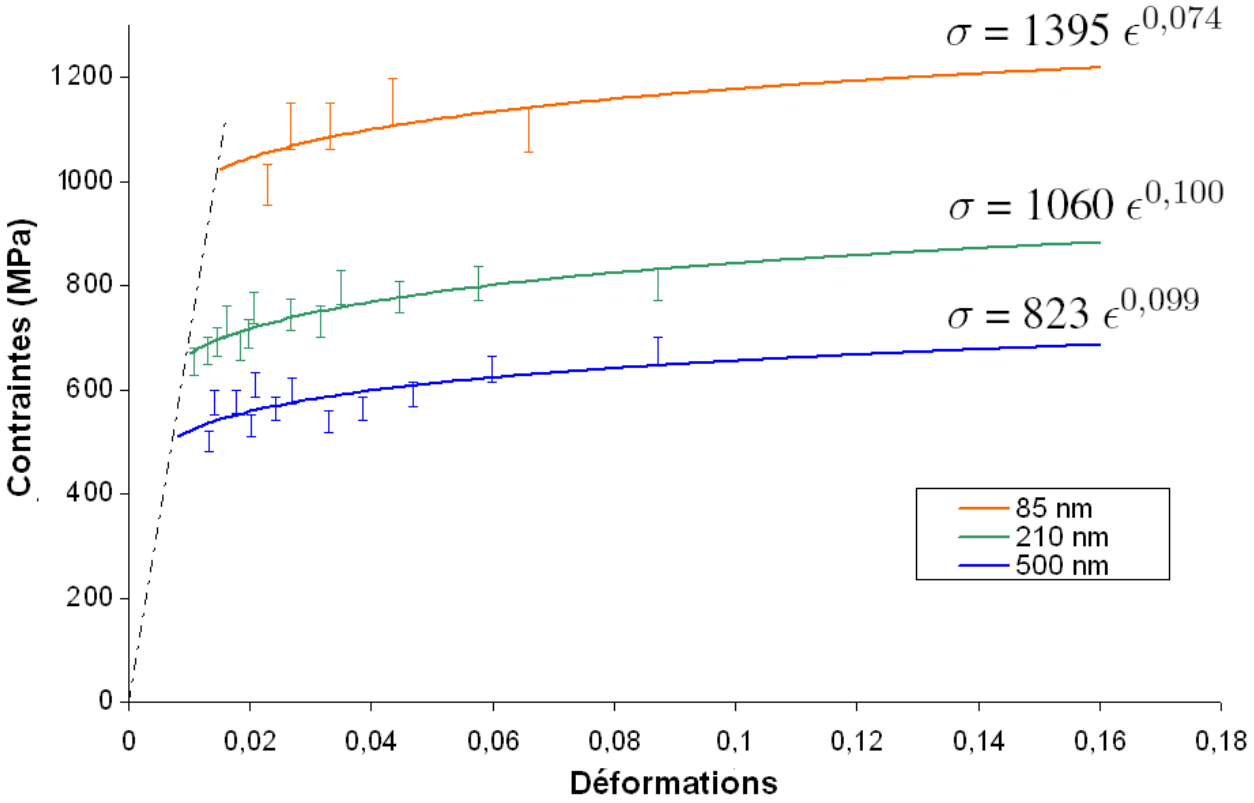
Increased Downscaling: Material Properties?

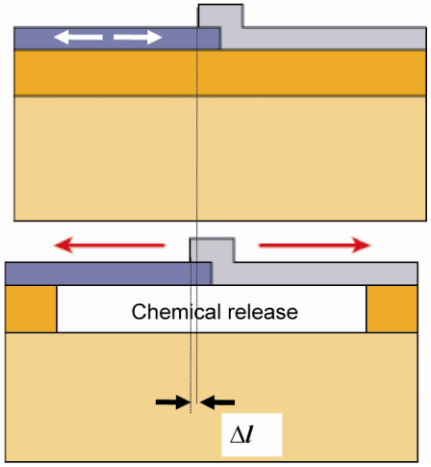
Uniaxial traction test





Uniaxial tensile test on aluminum thin films

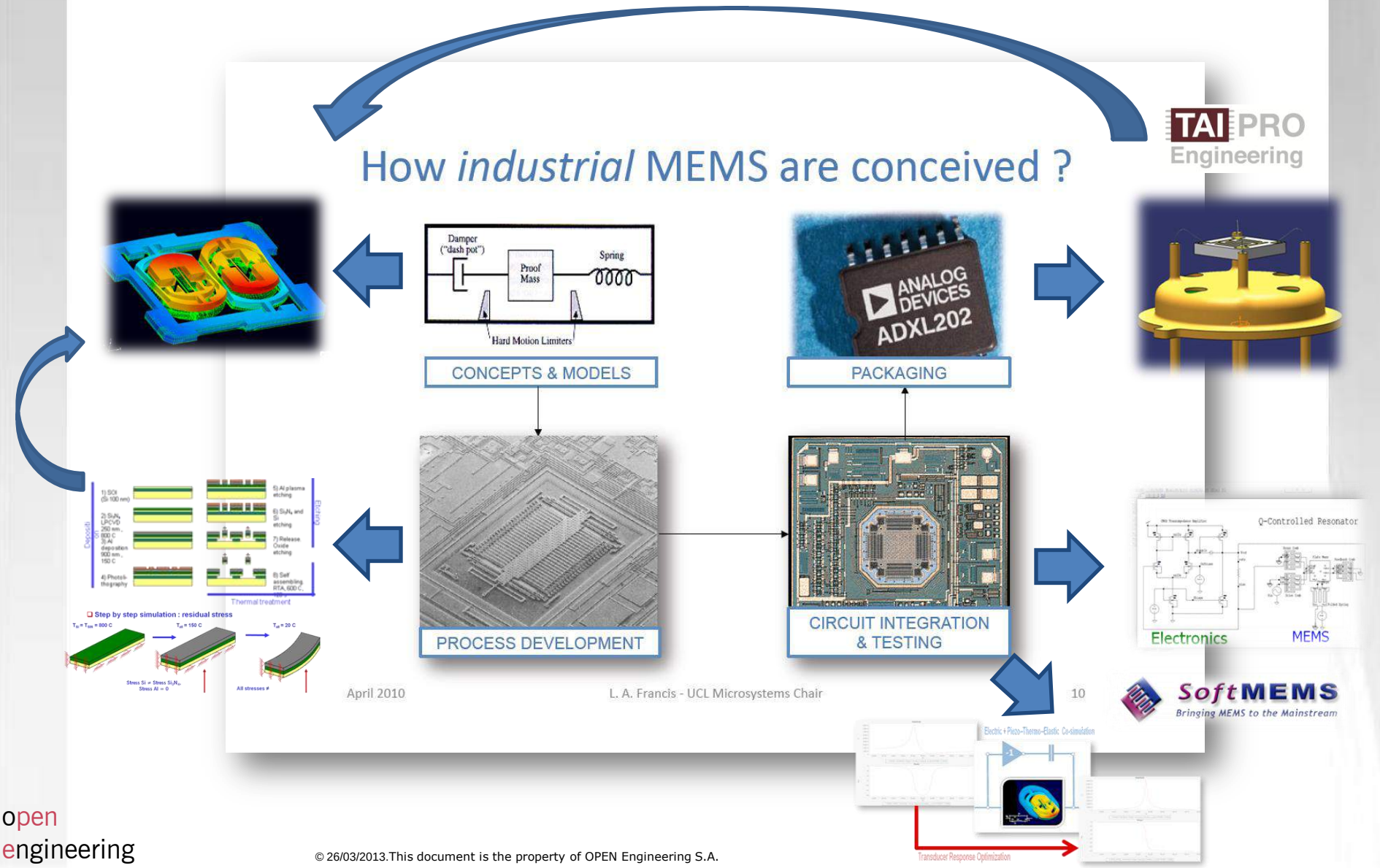




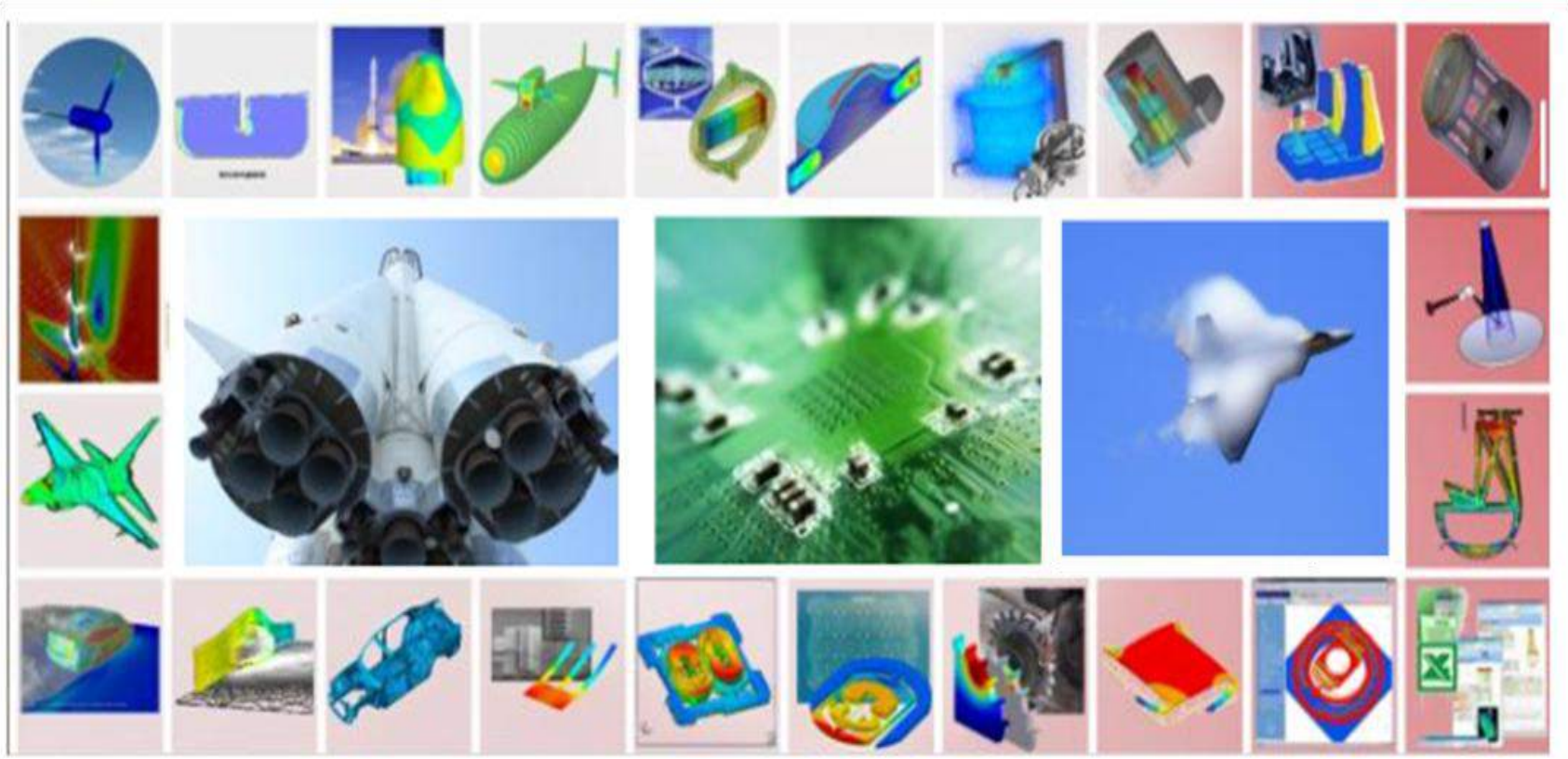
Yield strength of **85 nm-thick Al = 1,100 MPa** compared to a **bulk value for Al = 40-70 MPa**

[M. Coulombier et al., MNL'07]
[N. André et al., Micro. Eng.'07]

Technology needed to cover & close the MEMS value chain



Engineering Standard Multiphysics Solutions When *You* Need To Get The Job Done!



Спасибо за внимание!

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