MEMS devices and applications

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Outline |

I. Introduction: LETI, a major player in MEMS R&D

II. Activities on MEMS actuators

III. Activities on RF MEMS

IV. Activities on MEMS sensors

V. Key accomplishments and vision for the future
MEMS activities at LETI: missions & scope

**Missions**
- Designing new MEMS components and/or developing fabrication processes of MEMS devices with Si-based technologies
- In strong partnership with international industrial companies
- Focusing on single process steps or full development cycle including device concept and prototyping

**MEMS at LETI**

**R&D domains**
- MEMS actuators
- MEMS (NEMS) sensors
- RF MEMS & passives
- + packaging and associated design kits

**Market areas**
- Very broad range
  - Consumer applications, mobile phones
  - Automotive & Space
  - Health
  - Defense
MEMS activities at LETI: main figures

- Some statistics: the largest R&D MEMS lab in Europe
  
  More than 150 persons including research engineers and technicians, PhD students and Post-docs
  
  ~30 patents and more than 150 publications every year
  
  5 common labs with industrial companies

- Covering the whole chain: from MEMS design to system integration

  - MEMS design (modeling and simulation) and prototyping
  - Fabrication and packaging
  - Electrical and functional characterization
  - Integration with analog and digital electronics

- Main industrial partners

Leti Day in Nagoya, October 4th 2012 – MEMS devices and applications (J.Arcamone)
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MEMS actuators

- **Research Focus**
  Materials and process development (PZT,...)
  Piezoelectric and Electrostatic actuators

- **Applications**
  Inkjet technology
  Imaging: adaptive focus lens
  Acoustic: MEMS loudspeakers
  Medical: energy harvesting, micro-pump
Development of PZT as MEMS material

Material development and 200mm integration
- Specific deposition techniques (Sol-Gel, epitaxial) for gradient-free layers
- In-depth characterization → extracted parameters: $e_{31,eff} \approx -16 \text{ C/m}^2$, $d_{31} \approx 155 \text{pm/V}$, $\varepsilon \approx 1500$

Implementation as piezoelectric actuator
- Applied voltage on PZT → in-plane stress → membrane deflection
- Application: inkjet and switch
Acoustic application
MEMS digital loudspeaker

Acoustic digital MEMS for portable electronic devices
- Sound Level Pressure at 1m: 50 dB/cm²
- Actuation voltage < 30 V
- Thickness < 1mm, size 1 x 1 cm²
Electrostatic or piezoelectric actuator for portable electronic devices

- Focal distance: $\infty \rightarrow 10\,\text{cm}$
- Actuation voltage $< 10\,\text{V}$
- Thickness $< 500\,\mu\text{m}$
- Start-up creation: Wavelens
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RF MEMS

- **Research Focus**
  - Materials and process development (AlN,...)
  - High-Performance RF Passive Components
  - High-Q and Tunable Magnetic Inductors
  - Acoustic Resonators and Filters
  - RF MEMS Switches

- **Applications**
  - Impedance Matching Networks
  - Tunable Antennas
  - Filtering, Time Reference, RF Circuits

- **Market areas**
  - Space & Defense, Telecom, Low-Power Radio, Medical, Entertainment
RF MEMS switch

Electrostatic switch

- SPST dc-contact series switch
- Ultra-compact design → 800x800µm²
- High maturity 200mm process
- Highly reliable Ruthenium metal contact
- Dielectric free electrostatic actuation → no charging effects
- DC to 40 GHz operation band
- Insertion Loss < 0.6 dB, Isolation > 20dB
- Low actuation voltage (35 V)
Lamb waves filters

- Basis: strong know-how on BAW devices
- Use of laterally-propagating waves
- Frequency and other resonator properties **fixed by layout** (and not only by layer thicknesses)
- Frequencies ranging from 100 MHz to 2.5 GHz depending on the exploited acoustic mode
- Suitable for **narrow-band** filtering

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**RF filters**

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**RF MEMS realizations 2/2**

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**Resonant cavity**

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**Waveguide**

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**Air gap**

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**Impedance (Ω)**

![Graph showing impedance as a function of frequency.](image)

- $f_0 = 280$ MHz
- $k_{t2} = 1\%$
- $Q_{shunt} = 400$
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MEMS sensors

- **Research Focus**
  
  Process integration  
  Inertial sensors (accelerometer, gyroscope, magnetometer)  
  Pressure and force sensors  
  NEMS-based chemical and biosensors  
  Magnetic sensors

- **Applications**
  
  Motion capture (11 axis platform)  
  Haptics  
  Gas analysis and point-of-care

- **Market areas**
  
  Space & Defense, Automotive, Entertainment, Industrial Safety, Health monitoring
Multi-axis M&NEMS platform

M&NEMS: a multi-sensor, multi-axis generic platform
- Sensors fusion with one common electronics, protected by more than 20 patents
- Not sensitive to parasitic, **x3 area gain**, low-power

**MEMS-size inertial mass** + **Nano-size piezoresistive gauge**

3D accelerometer 3D gyroscope 3D magnetometer Microphone & Pressure sens.

*To be published*
NEMS-based sensors

NEMS-based resonant sensors address other domains than MEMS: eg, chemical and bio-sensing

- High-efficiency generic (patented) design of NEMS resonator based on electrostatic actuation and piezoresistive detection (high SNR, high frequency)
- Unique and robust NEMS technology

Multi-gas sensor coupling gas chromatography and NEMS detectors Start-up creation 2012 APIX tech.

NEMS-based mass spectrometry for biodetection (proteins, viruses and bacteria)
Magnetic sensors

Above-IC GMR current sensors

Magnetic Tunnel Junction (TMR, MRAM)

MEMS sensors realizations 3/3
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Key accomplishments

Examples of technological transfers to industrial companies

- MEMS accelerometers and gyroscopes
- High-value capacitors

Recent start-ups

- APIX Multi-gas analyzers coupling gas chromatography and NEMS
- Wavelens MEMS-actuator–based varifocal lens (autofocus) for mobile phone camera
Future perspectives

- **MEMS actuators**
  MEMS using low-cost piezoelectric polymer as structural layer
  Energy harvesters

- **RF MEMS**
  Tunable, reconfigurable and low-power components
  Ultra-high frequency (60-100GHz) filters and switches
  Complex SoC (DC-DC converters, decoupling capacitors)

- **MEMS sensors**
  Extension of M&NEMS platform to other kinds of sensors
  MEMS / NEMS for biosensing
  Current sensors based on magnetic components
**LETI’s MEMS activities in summary**

- **Support to industry** either on **technological steps** (new materials, technology consulting) or **full development cycle** (new device concept demonstrator including design and process of prototypes)

- **Investigating new materials** for improved performance, reliability, lower production cost, and new applications

  **Investigating breakthrough devices architectures**

- **Keep industrialization in mind** at all times, ensure quick demonstration for design feedback

- **Deliver**
Original approach on energy harvesting

Multi-ferroic Composites coupled to shape-memory/PiezoE Composites

- Magnetization changes with stress
- PZT actuator to obtain a voltage controlled of the uniaxial anisotropy
- New concept for thermal harvesting based on combination of shape memory effect and direct piezoelectric effect ($\Delta T \approx 2 - 20^\circ C$)

Voltage response of the piezo/magnetic composite vs time with natural T variations in a room (open window)

Net uniaxial anisotropy field of the composite vs applied stress