AN OVERVIEW OF SOI BASED MEMS

Jean-Philippe POLIZZI
MEMS Business Development Manager, DCOS, CEA-LETI
About Leti

1,900 researchers
250 PhD students + 40 post PhD with 85 foreign students (35%)

8500 m² clean rooms
200 and 300 mm wafer fab
Operated 24/7

318 M€ budget (80% contract R&D)
~ 40M€ CapEx

2700 patents
311 generated in 2016
40% under license

54 start-ups & 365 industrial partners

Founded in 1967

CEO
E SABONNADIERE
**WHAT ARE MEMS AND NEMS?**

- **MEMS** is the acronym of Micro Electro-Mechanical Systems.
- **MEMS** are mechanical systems with components in the micrometer scale.

**MEMS** are micron sized devices that perform mechanical, optical, chemical or fluidic functions. They are generally realized by the technology used to manufacture integrated circuits, that is thin film deposition, photolithography and etching.
MEMS MARKETS EVOLUTION

80’s

90’s

00’s

10’s
WHAT ARE THE MEMS USED FOR?

MEMS devices US$M forecasts per application market

Source: Yole Développement
30+ YEARS BACKGROUND IN MEMS SENSORS

**Thin Film Technology**
(Vac.dep. / shadow mask)

- **Key dates**
  - 1984 - Comb drive accelerometer patent

**Bulk Technology**
(Litho / wet etching)

- 1984 - Comb drive accelerometer patent

**Surface Technology**
(Litho / DRIE on SOI)

- 1996 - Startup creation

**Nano-scale Technology**
(DUV litho on thin SOI)

- 2007 - Caltech Alliance
- 2011 - Startup
- 2013 - Startup
- 2014 Startup
- 2015 Startups

**Transfers**

- **1800s**
  - Weight sensor
  - Quartz accelerometer
  - Pacemaker accelerometer
  - Geophone
  - Accelerometer

- **1980s**
  - Hygrometer
  - High perf. pressure sensor
  - Miniature pressure sensor

- **1990s**
  - Inertial platform
  - M&NEMS platform

- **2000s**
  - Above-IC GMR Technology
  - Capacitance stacking

- **2010s**
  - PZT actuator process

**30+ years background in MEMS sensors**

**Inertial platform**
Launched by Motorola
freescale semiconductor

**M&NEMS platform**

**Above-IC GMR Technology**

**Capacitance stacking**

**PZT actuator process**
Microsystems section

TECHNOLOGICAL PLATFORM

- MEMS 8” (1000 m²) + FE 8” (3000 m²) Cleanrooms
- Specific MEMS equip.: DRIE, HF-vapor, bonder...
- 5 shifts working: 7 days/week – 24h/days

Overall MEMS activities > 200 people
WHY USE SOI FOR MEMS?
HOW MEMS ARE MADE?
THE EFFECT OF STRESS GRADIENT

#1 Reason for using SOI: (almost) Stress Free Material!

#1 Reason for using SOI: Compatibility with thick structural layers
Silicon as a Mechanical Material

KURT E. PETERSEN, MEMBER, IEEE

Abstract—Single-crystal silicon is being increasingly employed in a variety of new commercial products not because of its well-established electronic properties, but rather because of its excellent mechanical properties. In addition, recent trends in the engineering literature indicate a growing interest in the use of silicon as a mechanical material with the ultimate goal of developing a broad range of inexpensive, batch-fabricated, high-performance sensors and transducers which are easily interfaced with the rapidly proliferating microprocessor. This review describes the advantages of employing silicon as a mechanical material, the relevant mechanical characteristics of silicon, and the processing techniques which are specific to micro-mechanical structures. Finally, the potentials of this new technology are illustrated by numerous detailed examples from the literature. It is clear that silicon will continue to be aggressively exploited in a wide variety of mechanical applications complementary to its traditional role as an electronic material. Furthermore, these multidisciplinary uses of silicon will significantly alter the way we think about all types of miniature mechanical devices and components.

I. INTRODUCTION

In the same way that silicon has already revolutionized miniaturized mechanical devices and components must be integrated or interfaced with electronics such as the examples given above. The continuing development of silicon micromechanical applications is only one aspect of the current technical drive toward miniaturization which is being pursued over a wide front in many diverse engineering disciplines. Certainly silicon microelectronics continues to be the most obvious success in the ongoing pursuit of miniaturization. Four factors have played crucial roles in this phenomenal success story: 1) the active material, silicon, is abundant, inexpensive, and can now be produced and processed controllably to unparalleled standards of purity and perfection; 2) silicon processing itself is based on very thin deposited films which are highly amenable to miniaturization; 3) definition and reproduction of the device shapes and patterns are performed using photographic techniques which have also, historically, been capable of high precision and are amenable to miniaturization; finally and most

Silicon is an excellent mechanical material!
E=169 GPa

#2 Reason for using SOI: Single Crystal Silicon is an excellent structural material
WHY USE SOI FOR MEMS?

#3 Reason for using SOI: No CTE mismatch with underlying support

Buckling happens
WHY USE SOI FOR MEMS?

#4 Reason for using SOI: Built-in sacrificial layer
WHY USE SOI FOR MEMS?

#5 Reason for using SOI: Precise thickness control of structural layer
Inertial Sensors

Accelerometer

3D Gyro

Geophone
Example of technology transfer to industrial company

- Development and transfer of the HARMEMS technology to Freescale
- HARMEMS accelerometer shipments: 350+ million units
Membrane based Sensors

Pressure

3D Force sensor

cMUT and pMUT
NEMS RESONATORS CO-INTEGRATED WITH CMOS

Capacitive resonators with STMicro 0.35µm CMOS (IEDM 2012)

Monolithic integration with CMOS

MOS circuit
NEMS

100 MHz / Q=40 000

Piezoresistive resonators with LETI FDSOI CMOS (ISSCC 2012)

MEMS for time reference (nano-gaps)
NEMS-BASED SENSORS PLATFORM FOR GAS AND BIO-SENSING

Mass loading

Effect of mass loading

Final spectrum

Initial spectrum

Magnitude (a.u.)

Frequency (Hz)

Responsivity

Resolution

\[ \delta m = -2M \frac{\delta \omega}{\omega_0} \propto f^3 \]

- High resolution
- Very short response time
- High integration

Gas detection

Mass-spec for Bio applications

\( \mu \)bolometer

Cellular force sensor
M&NEMS "Generic" Platform

- **Miniaturized** sensors
- **Generic** platform
- Well known and **robust** piezoresisitive detection
- Not sensitive to parasitics
- **Strongly differentiated** approach (20+ patents)

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

---

3-axis **Accelero**

3-axis **Gyroscope**

3-axis **Magneto**

**Pressure sensor**

**Microphone**
M&NEMS 6-AXIS COMPASS/ACCELEROMETER

- 6-axis mechanical footprint ≈ 1,1mm²
- Low power consumption (30µW/axis in DC)
- Robust to external field (x10 compare to Hall, GMR, TMR)
- 1 electronic common for each of the 6 axis
- High linearity

To our knowledge
World’s Smallest Integrated 6-axis compass
3-AXES M&NEMS GYROSCOPE

- Mechanical footprint ≈ 2 mm²
- Cross-axis rejection > 59 dB
- ARW 1.8 mdps/√Hz
- Bias Instability = 1.2°/hr
- Linearity error is < 0.25% of the FSR

To our knowledge
World’s Smallest 3-axis High Perf. Gyroscope
M&NEMS PRESSURE SENSOR

- Mechanical footprint ≈ 0.1mm²
- High linearity
- Auto-test electrode

- Reliability:
  - Protected gauge from external environment
  - Over-pressure protection (stops)
- Compatible with high temperature

To our knowledge
World’s Smallest high performance Pressure sensor
CONCLUSION

- 30 years experience in MEMS
- 200 people involved in MEMS
  (sensor, actuator, RF, packaging, process, characterization)
- All 8” MEMS/NEMS technologies in-house

- 80% of the MEMS sensors developed in Leti are based on SOI wafers
  - Accelerometers, gyrometers, pressure, force sensors
  - Microphones, MUTs
  - Mass sensors based on vibrating beams

1. Stress free structural layer
2. Single Crystal Silicon shows superior mechanical properties
3. No CTE mismatch with support
4. Built-in sacrificial layer
5. Precise control of structural layer thickness
Thank you for your attention