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Technologies for Space
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Joint Reliability Team

WALES –
WAfer Level Encapsulation for Micro-Systems

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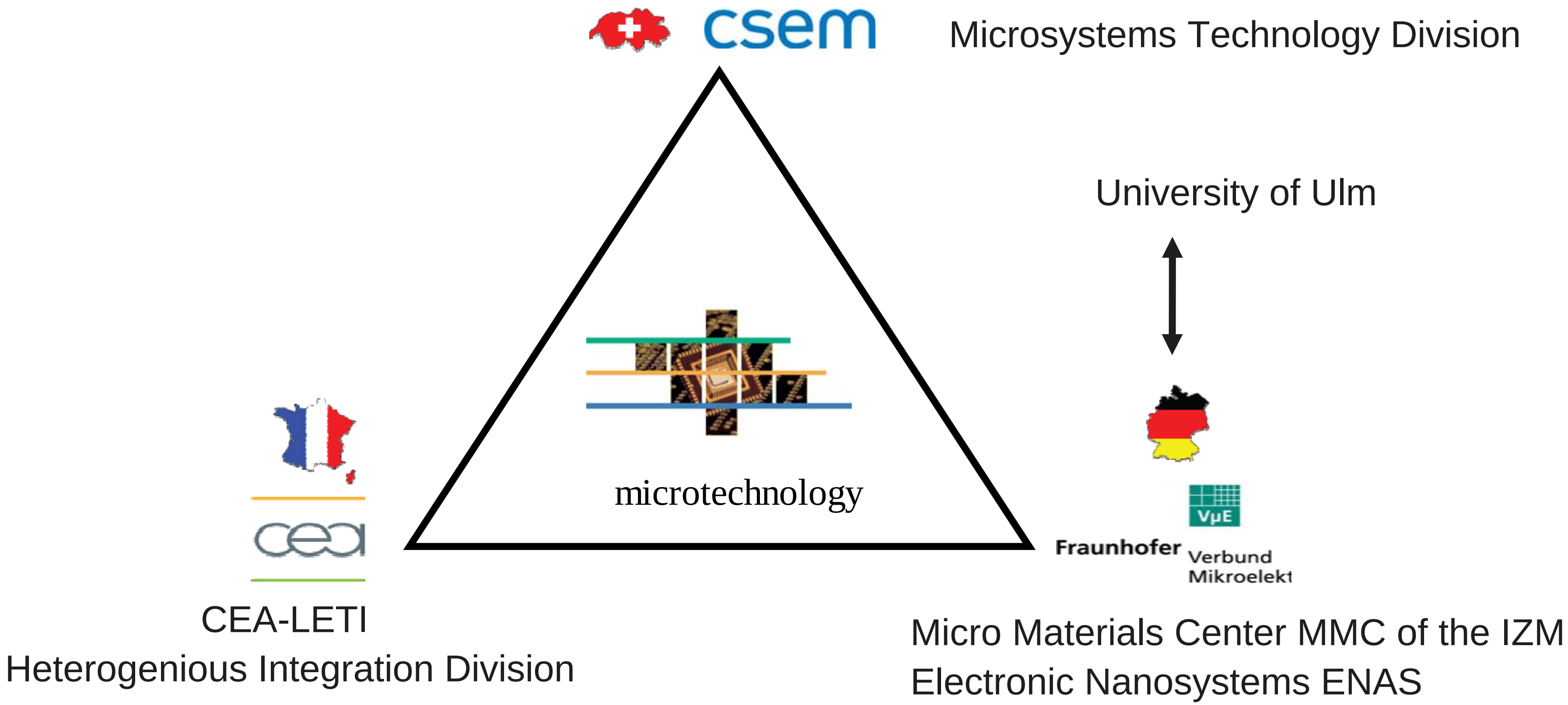
WALES Consortium

The Joint Reliability Team (JRT) has been founded in 2007 between CSEM, FHG-IZM and CEA-LETI in order to join their forces in microtechnology on reliability and related issues.



csem

Microsystems Technology Division

University of Ulm

microtechnology

Fraunhofer Verbund Mikroelekt

CEA-LETI
Heterogenious Integration Division

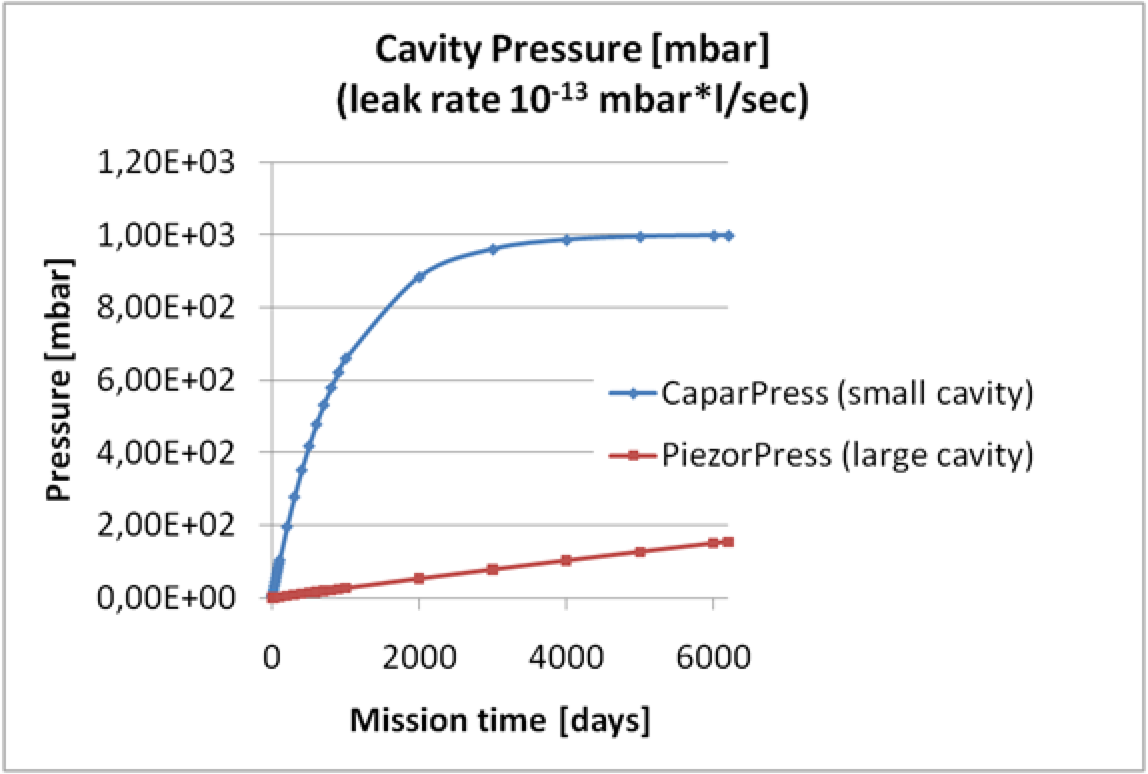
Micro Materials Center MMC of the IZM
Electronic Nanosystems ENAS

Project Objectifs: WALES

- Vacuum level detection in very small cavities
- Stress evaluation related to wafer level bonding
- Flexibility to work on different sites: Exchange of wafers

The target is to have strong consortium enabling small volume productions of MEMS for ESA space applications. This is achieved by joint activities of CSEM, CEA-LETI and Fraunhofer Gesellschaft.

Hermeticity: Challenge of extreme small cavities



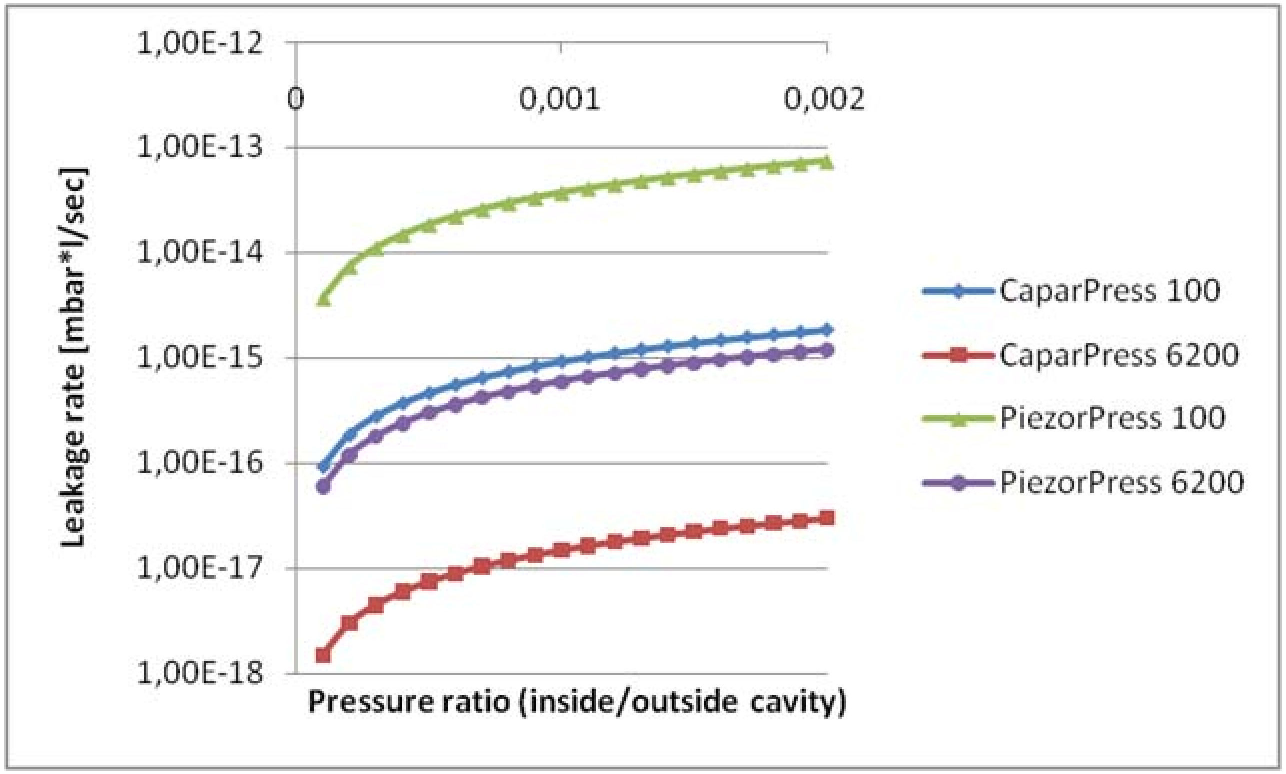
In-cavity pressure developement for a 1 bar exposure (17 years scenario)
cavity volume: 8 … 320 nl)

$$p(t) = p_0\,(1 - e^{\frac{l_r\,t}{V\,p_o}})$$

- Pre-set leakage rate of **10^{-13} mbar*l/sec** equals to the approx. **limit of He leak testing**
- final pressure after exposure time must be well below 1 mbar → dealing with extreme **high demands on admissible leakage**
- **Leakage rate measurement** itself becomes **a challenge**

Hermeticity: Challenge of extreme small cavities

- Re-calculating the maximum cavity fill-up into leakage rates to be determined on MEMS devices
- 100 day and 17 years exposure scenario



- range leakage rates not covered by hermeticity testing standards
- hermeticity testing demands specific approaches

Hermeticity testing: existing standards

Existing standards and documented references

Three standards can be referred to leakage testing on electronics and MEMS devices:

- JEDEC 22a109a

He leak testing after pressure bombing and radioisotope fine leak testing:
In WALES: range of leakage rates is in between 10^{-13} and 10^{-17} (mbar*l)/s,
which is not feasible with this method

- MIL-STD-883G
- MIL-STD-750E

Approach similar to above JEDEC standard,
but additionally metallic or ceramics lid bending pressure detection method

RGA: not applicable related to the small cavity volumes and extremly small leak rates

Hermeticity testing: solutions for small cavities

Survey of selected, original hermeticity testing procedures:

- Q-factor monitoring of resonators
- µ-Pirani measurements
- FTIR spectroscopy based measurements*,**
- Raman spectroscopy based measurements*,**
- Chemical conversion as a measure for leakage*

All listed methods have the potential to give access to small cavity volume MEMS and can access quantitatively leak rates well below 10^{-13} (mbar*l)/s. They possess different capabilities and require different development effort.

* Needs through package transparency (in visible region or for IR).

** The methods labeled with the asterisk may have the potential to be applied for validation in WALES, but are still not proven finally.

The most promising method "*Q-factor monitoring of resonators*" has been chosen as the hermeticity testing method to be applied within WALES.

Achievements of Objectives

I) Wafer Level Packaging (WLP) will be addressed to two types of resonators:

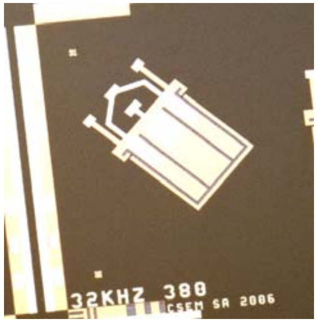
1) piezo-electric actuated resonator (CSEM)
2) capacitive actuated resonator (CEA-LETI)

II) Hermeticity

III) Testing:
- functional
- structural
- mechanical

Project Objectifs: Technology activities & exchange

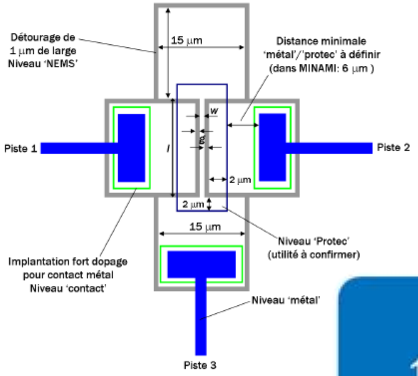
Piezoelectric Resonator
(20kHz – 1MHz)



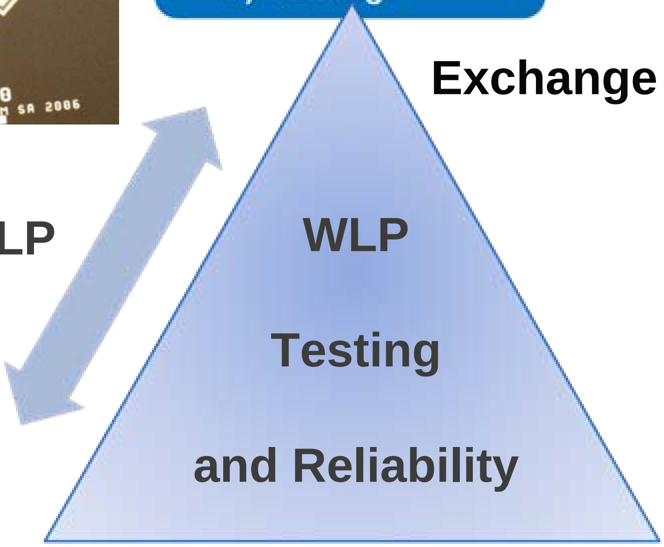
CSEM:
1) Fabrication
2) WLP
3) Testing

CEA: 200 mm
CSEM: 100 / 150 mm
Exchange of wafers for bonding.

Capacitive Resonator
(100kHz – 10MHz)



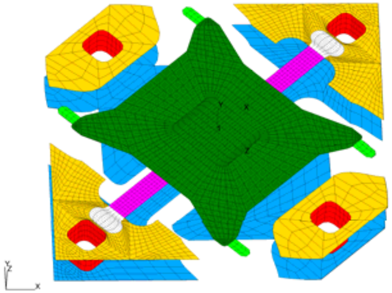
WLP



WLP

Testing

and Reliability



CEA-LETI:
1) Fabrication
2) WLP
3) Testing

Fraunhofer Gesellschaft:
1) Hermeticity
2) Testing

Survey of Packaging Methods

	Glass frit bonding	Anodic bonding	Silicon direct bonding (Fusion)	**Eutectic bonding**	Thermo-compression Au - Au	Thin film
Bonding temperature	430 – 450°C	400 – 500°C	200 – 900°C	**300 – 400°C**	320 – 400°C	NA
Bondframe width	400µm	NA	NA	**100 - 200µm**	100 - 200µm	10s of µm
Tolerance to topography	yes	No	no	**yes**	no	yes
Lowest pressure reported	10^{-3}mbar*	10^{-3}mbar*	6.10^{-4}mbar*	**10^{-3}mbar***	No result	10^{-2}mbar**

*with thin film getter **without getter

Getters: - for high vacuum a getter is needed (pumping of residual gases, maintaining of vacuum)
- Ti, Zr, SEAS getters

Electrical feedthrough: - providing of sealed and reliable interconnections
- the electrical connection should not degrade the signal quality and have low parasitics
- vertical feedthrough using holes in the cap substrate , TSV (Through Silicon Vias)

Resonator MEMS Design: piezo resonator

MEMS dimensions: 1.5 x 2 x 1.4mm.

- 4 four electrical contacts on the glass cap (contact pad dimensions: 240 x 200 µm, pitch 520 µm)

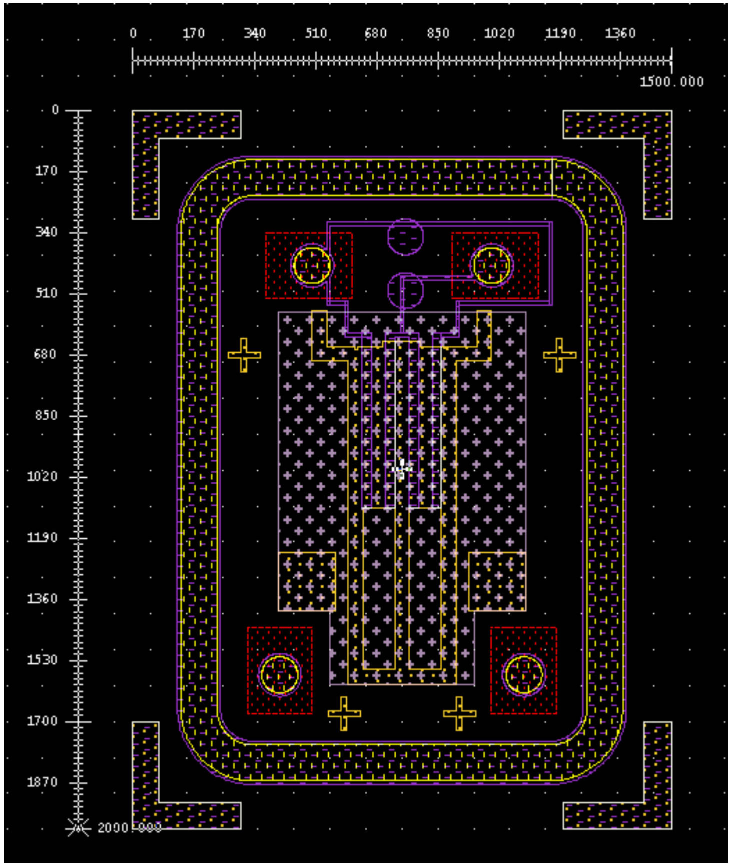
Volume of the cavity: 378 nl (0.378mm^3)

Device wafer:

- Evaporated sealing ring on device wafers : Au/Ni/Ti 100/40/10 nm OR galvanic Au (0.5 –3 mm) on sputtered UBM Au/TiW150/300 nm
- Pyrex anodic bonding on backside

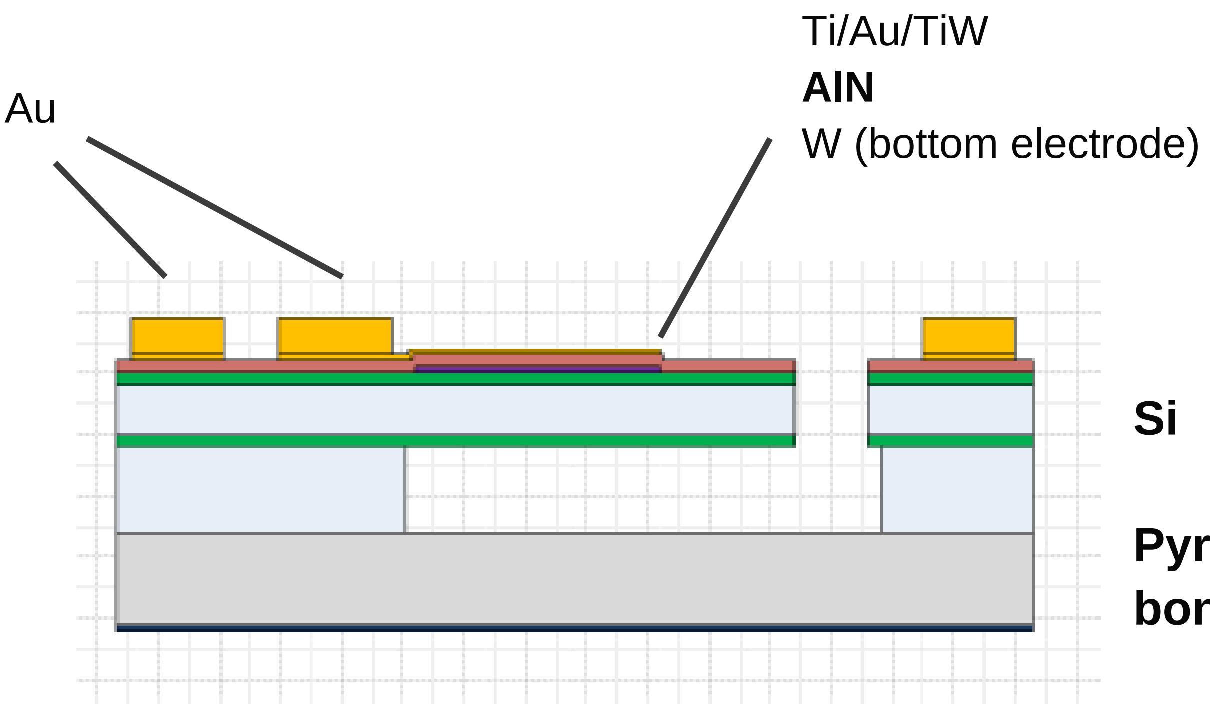
Cap wafer:

- Au vias and cavity
- Evaporated sealing ring on cap wafers : Au75/Sn25 (5.25 mm multi layers) /Cr+Pt(150 nm)



The device will work at 150 kHz (+/-20). It has a static capacitance of about 0.5 pF. It corresponds to an impedance of 2 MW at 150 kHz. However, at resonance, depending on the quality factor of the resonator and on the vacuum level inside the package, the impedance will be typically 50 kW.

Piezoelectric Resonator Fabrication: CSEM



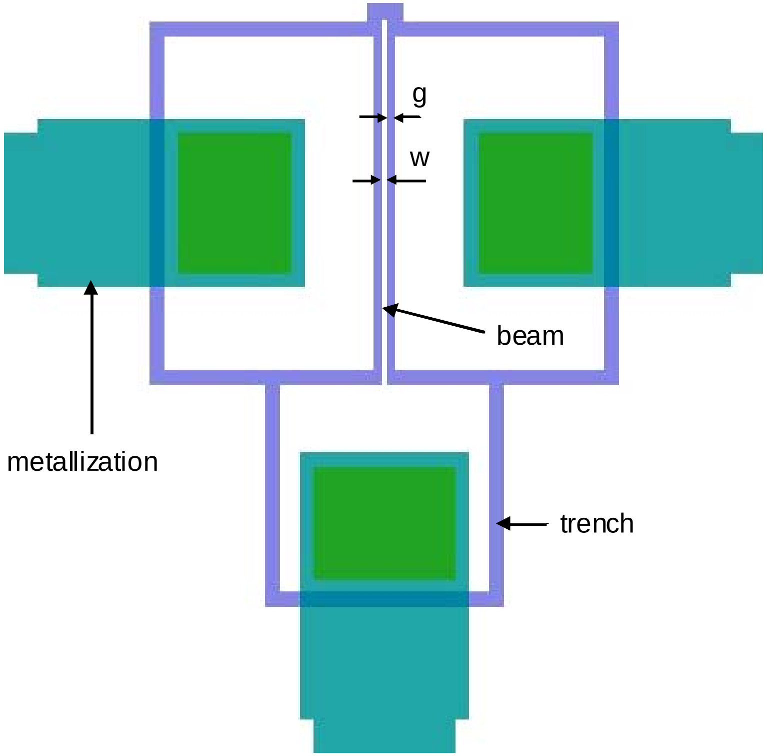
Si

Pyrex (anodic bonding)

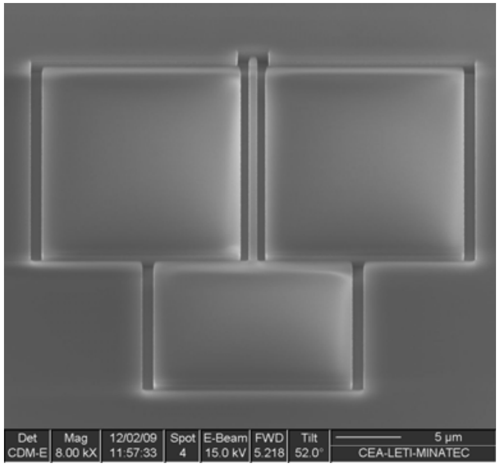
Process flow: 14 steps

Resonator MEMS Design: capacitive resonator: CEA

Beam with capacitive actuation and detection

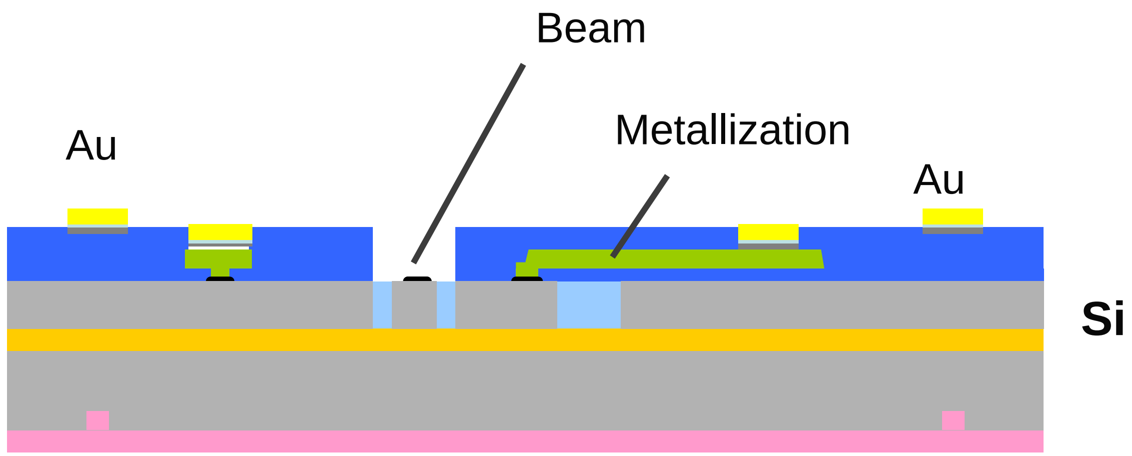


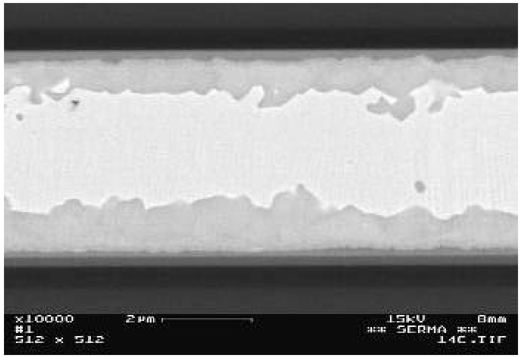
Length 18 – 100µm
Width 250 – 750µm
Gap 250 – 500nm
Resonance frequency 400 kHz – 1 MHz



Volume of the cavity: **16 nl** (0.016 mm^3)

Capacitive Resonator Fabrication: CEA





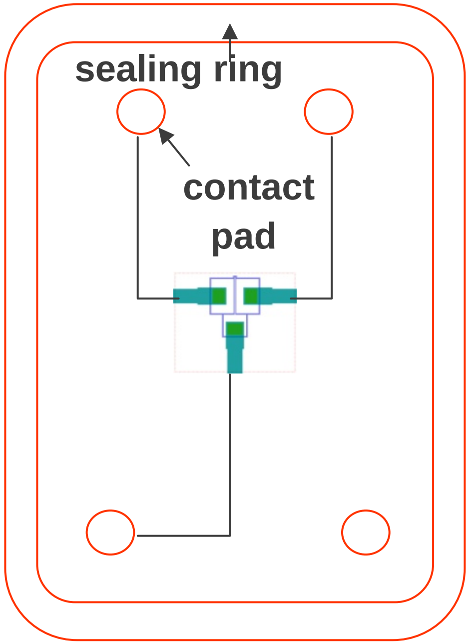
Process flow: 14 steps

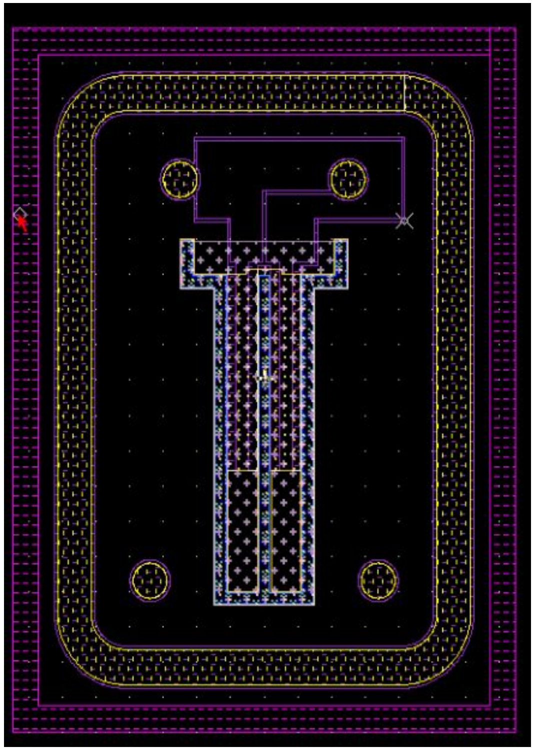
- Choice of metallization: Au and Sn electroplating
- Standoff to control the gap
- Wafer to wafer assembly: 300 – 350°C
- Under vacuum 10^{-4} – 10^{-5} mbar

Common design of the MEMS cap: CSEM + CEA

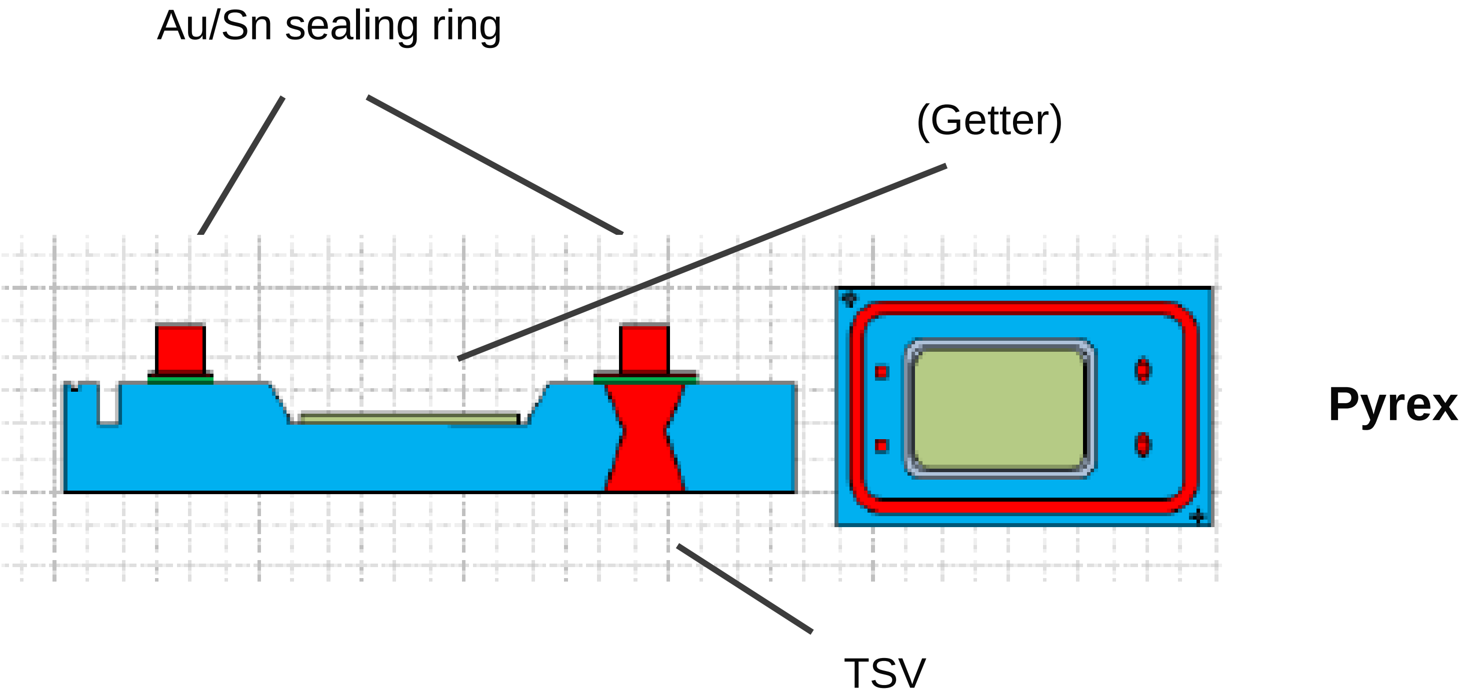
- Compatibility of CSEM and LETI packaging technology

Common layout for the cap : dimensions of chip, sealing ring, position and size of the contact pads





Cap Fabrication

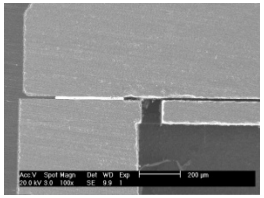


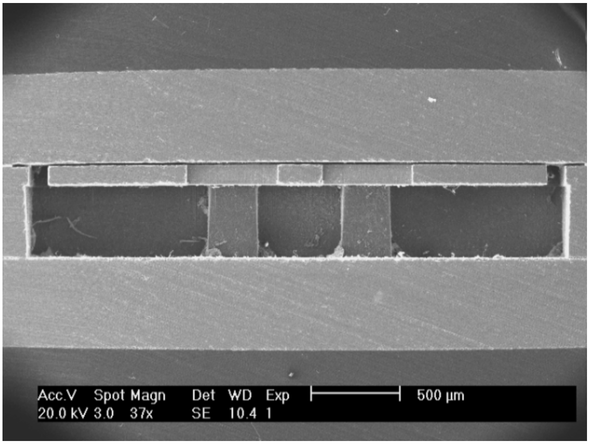
Process flow: 7 steps

Getter: used by CEA LETI for capacitive resonator

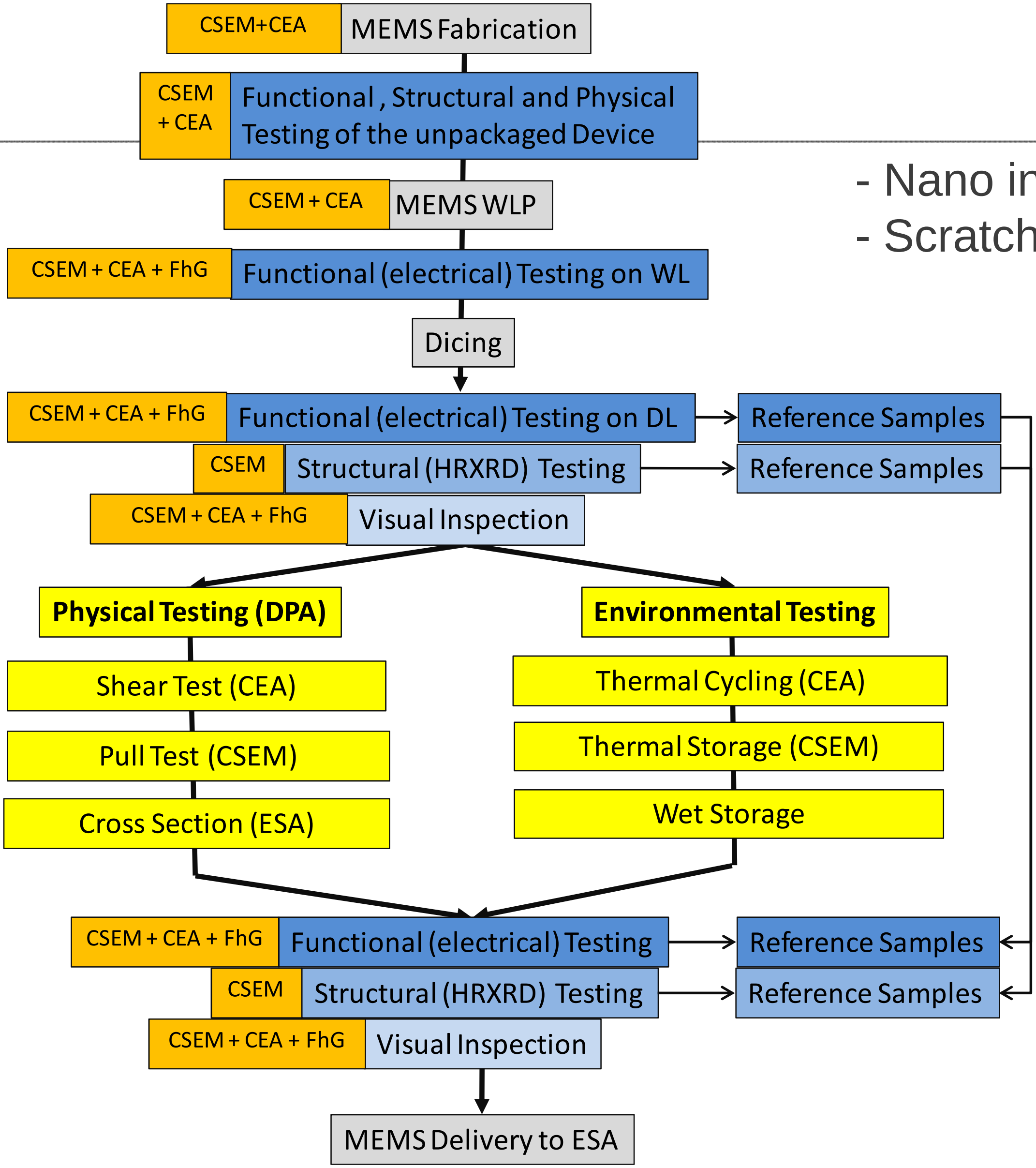
MEMS WL packaging: piezo resonator

- **Au-Sn eutectic bonding** on front side
  - tolerance to topography (-> universality)
  - narrow bond frame
  - low temperature (-> universality)
  - clean technology
- **Anodic bonding** on back side
  - mature technology
  - high vacuum and low leak rate reported (with getter)





Testing matrix:



CSEM+CEA
MEMS Fabrication

CSEM + CEA
Functional, Structural and Physical Testing of the unpackaged Device

CSEM + CEA
MEMS WLP

CSEM + CEA + FhG
Functional (electrical) Testing on WL

Dicing

CSEM + CEA + FhG
Functional (electrical) Testing on DL
Reference Samples

CSEM
Structural (HRXRD) Testing
Reference Samples

CSEM + CEA + FhG
Visual Inspection

Physical Testing (DPA)
Shear Test (CEA)
Pull Test (CSEM)
Cross Section (ESA)

Environmental Testing
Thermal Cycling (CEA)
Thermal Storage (CSEM)
Wet Storage

CSEM + CEA + FhG
Functional (electrical) Testing
Reference Samples

CSEM
Structural (HRXRD) Testing
Reference Samples

CSEM + CEA + FhG
Visual Inspection

MEMS Delivery to ESA

- Nano indentation
- Scratch test

<u>Q-factor influenced by:</u>

- packaging stress
- cavity pressure

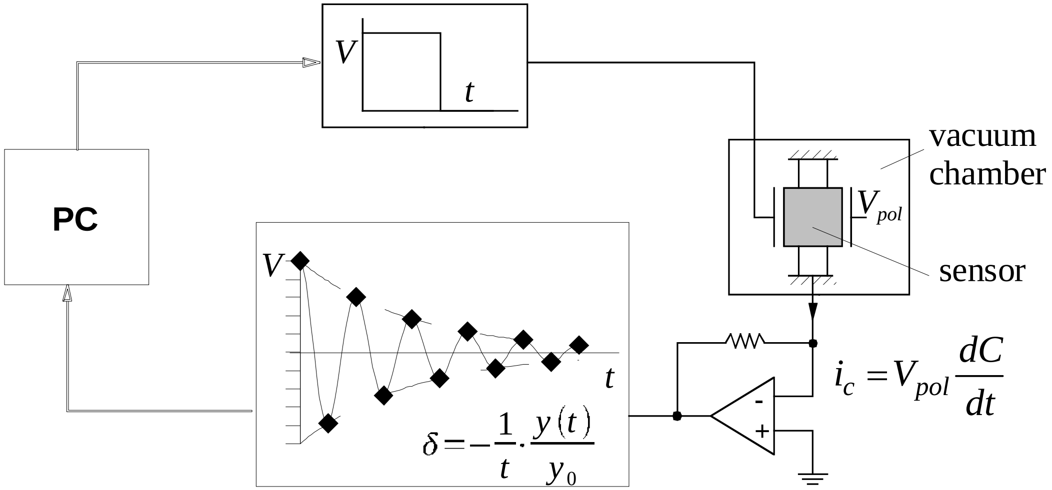
<u>WLP of:</u>

- devices with a closed sealing ring
- devices with an open sealing ring

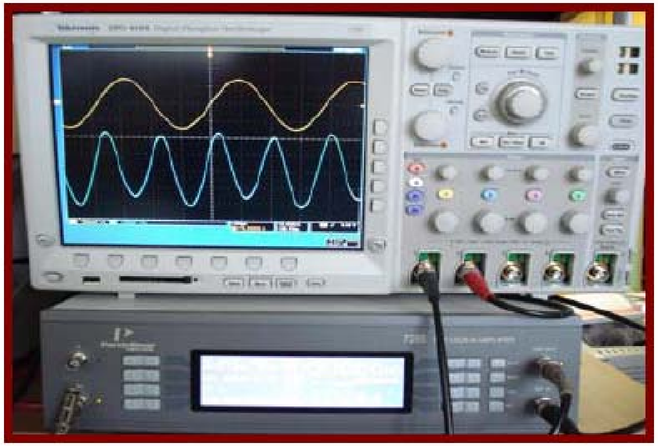
Q-factor: capacitive resonator (FhG)

Fraunhofer
ENAS

Schematic of test set-up: measurement of decay constant



Lock in amplifier
(1 mHz – 250 kHz)

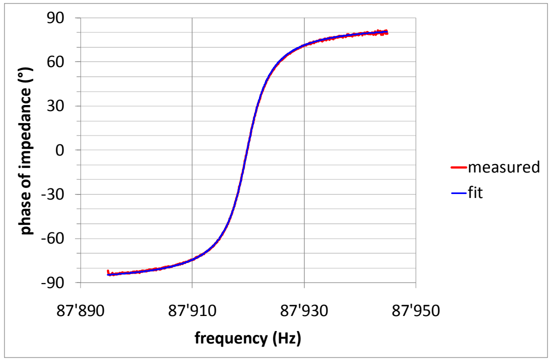


$$Q = \frac{m\omega_0}{\beta} = \frac{\omega_0}{2\delta}$$

Q – calibration curve - p

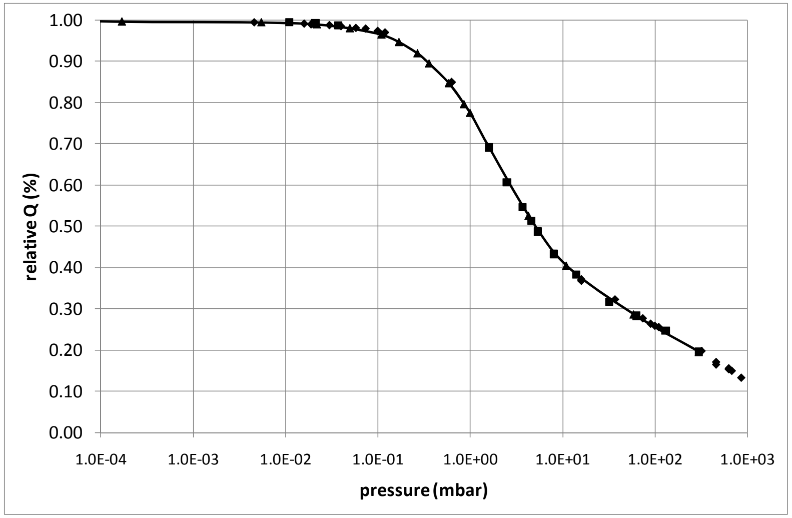
Q-factor: piezo resonator (CSEM)

- Q-factor of 80-160 devices will be measured @ 3 10^{-5} mbar
- Pass / Fail criteria : the 40-80 best resonators are selected
- The Q vs pressure curve is established for typical resonators (the number of measured curves will depend on the distribution of the Q-factor among the selected resonators)
- Measurement of the Q-factor after WLP and after thermal storage, thermal cycling and humidity testing allows to evaluate the vacuum level
- Monitoring of Q vs time allows to calculate the leak rate

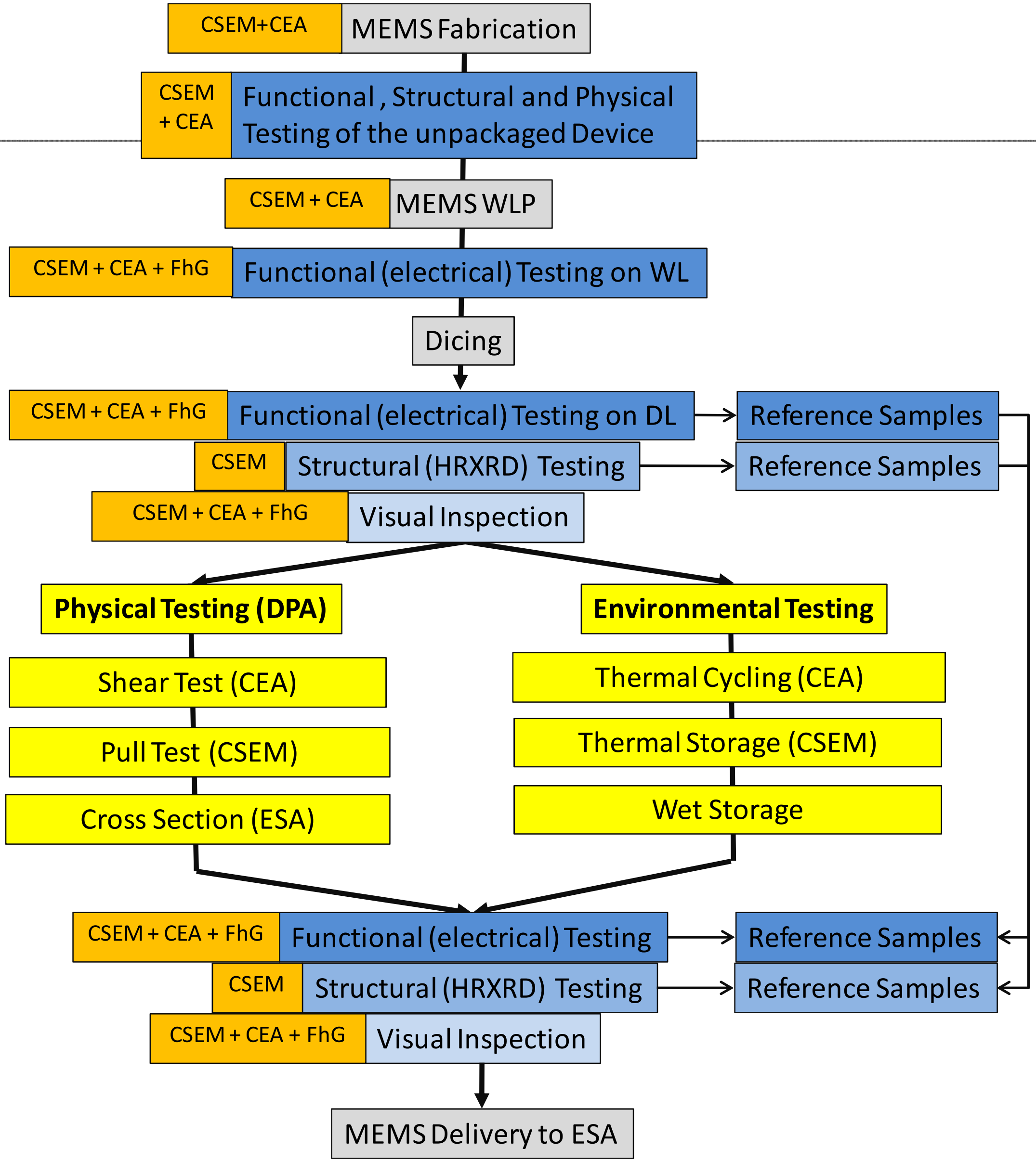


Calculation of:

$$Q = \frac{1}{R_m\, C_m\, \omega_s}$$



Testing matrix:



CSEM+CEA MEMS Fabrication

CSEM + CEA Functional , Structural and Physical Testing of the unpackaged Device

CSEM + CEA MEMS WLP

CSEM + CEA + FhG Functional (electrical) Testing on WL

Dicing

CSEM + CEA + FhG Functional (electrical) Testing on DL → Reference Samples

CSEM Structural (HRXRD) Testing → Reference Samples

CSEM + CEA + FhG Visual Inspection

Physical Testing (DPA)

- Shear Test (CEA)
- Pull Test (CSEM)
- Cross Section (ESA)

Environmental Testing

- Thermal Cycling (CEA)
- Thermal Storage (CSEM)
- Wet Storage

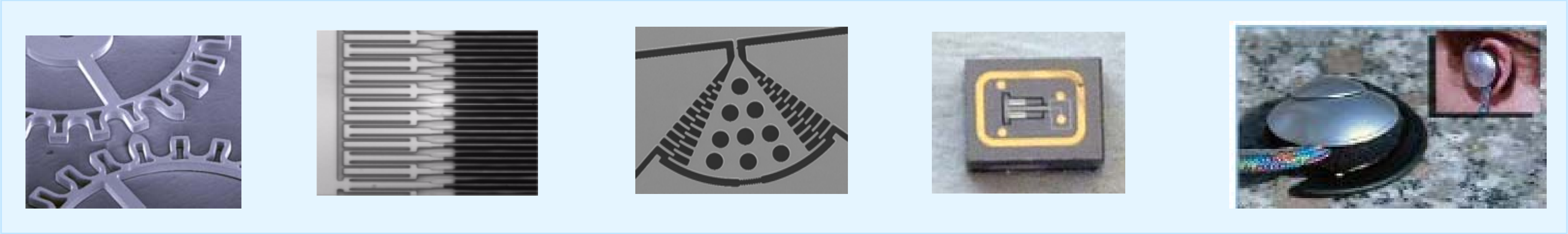
CSEM + CEA + FhG Functional (electrical) Testing → Reference Samples

CSEM Structural (HRXRD) Testing → Reference Samples

CSEM + CEA + FhG Visual Inspection

MEMS Delivery to ESA

High Resolution X-ray Diffraction (HRXRD) in MEMS reliability:



Design:
- **components**
- **device**
- **packaging level**

→ **Fabrication** → **Assembly** → **MEMS** → **Product**

Components characterization:

- structural analysis:
  phases, texture, strain, …
- defect and strain analysis related to MEMS parts in fabrication processes

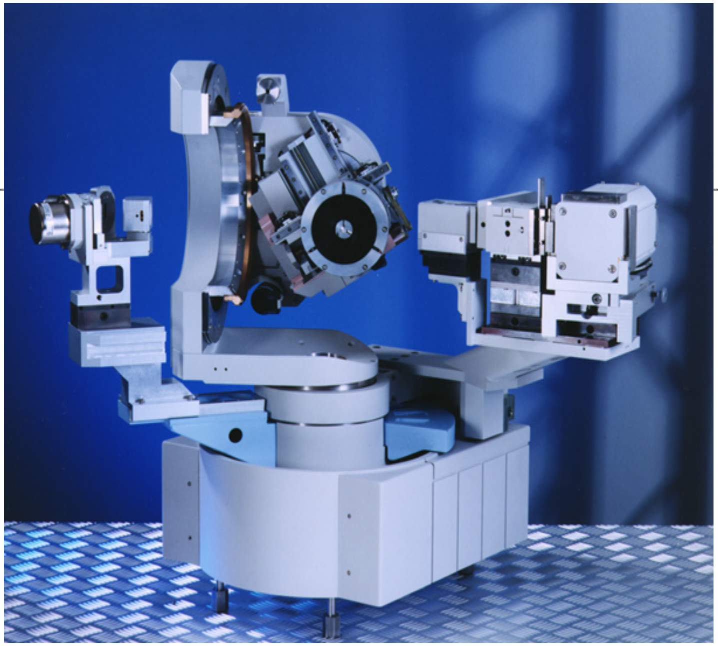
Packaging:

- defect + strain analysis

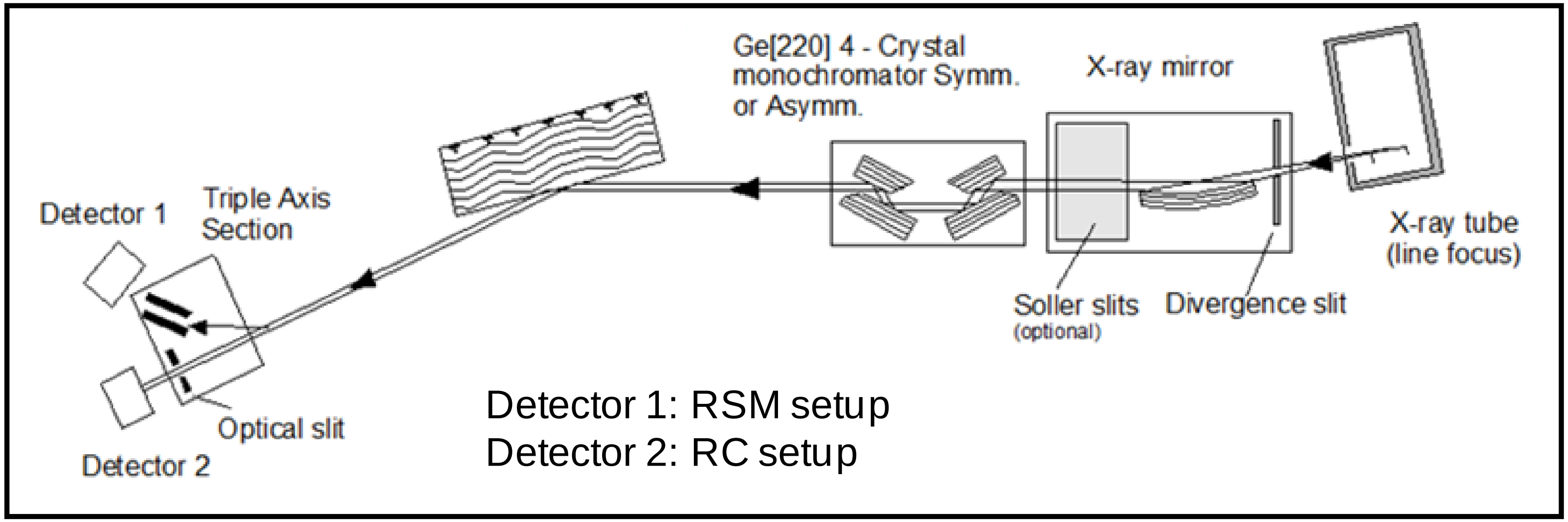
Strain dynamics and mobility of Defects by XRD:

- in-situ testing:
structural + mechanical
- aging studies:
T, radiation, high cycle fatigue

HRXRD on SCSi MEMS



PANalytical X'Pert PRO MRD



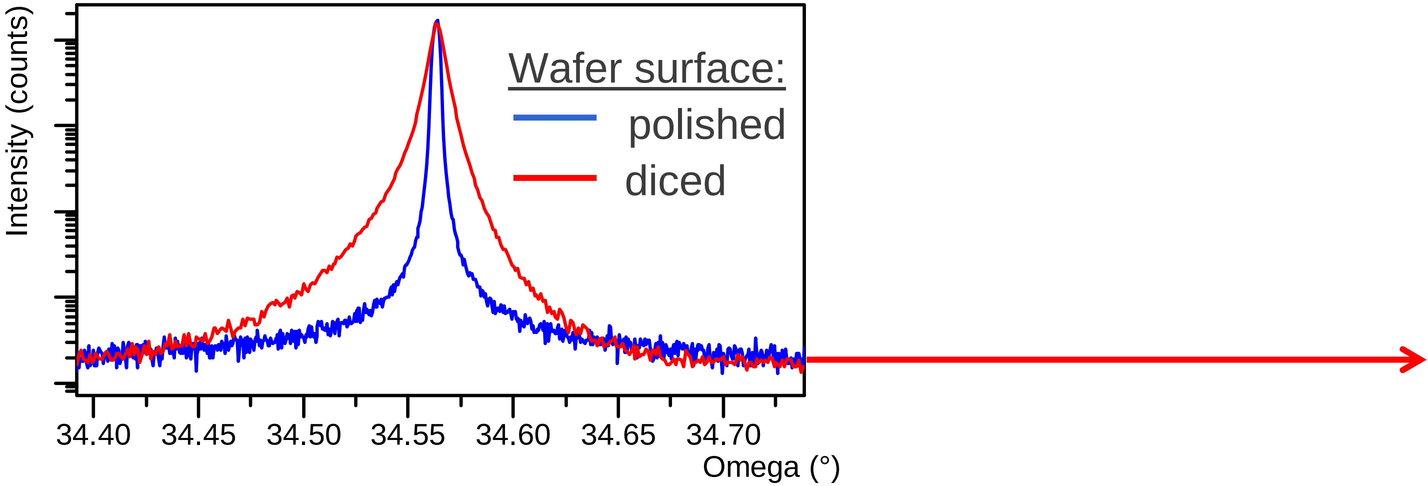
Detector 1: RSM setup
Detector 2: RC setup

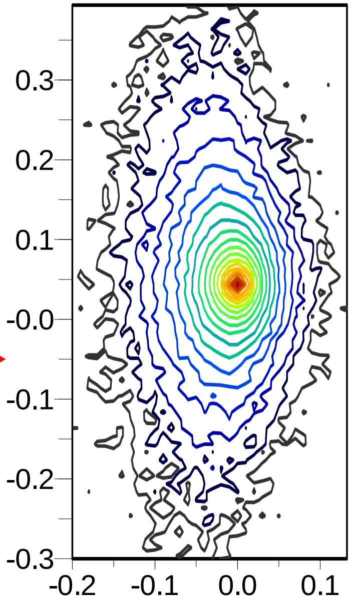
HRXRD

X-ray Rocking Curve (RC):

Reciprocal Space Mapping (RSM):

X-ray scattering can be separate into distinct features:





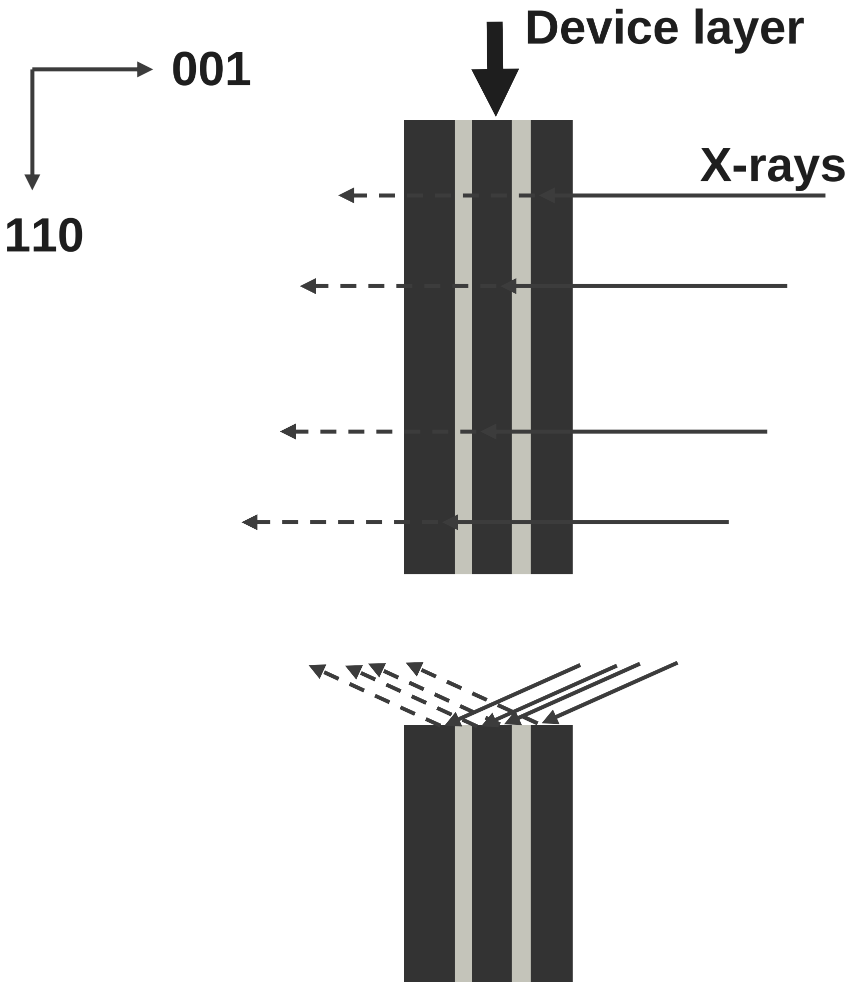
ε = strain = $\Delta d/d = -\Delta\theta/\tan\theta$

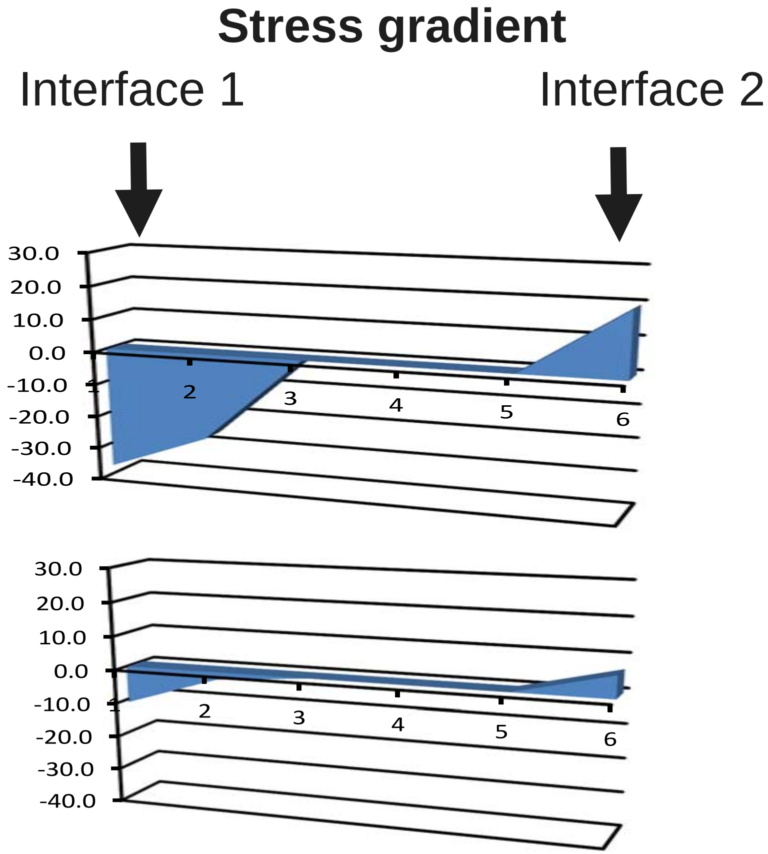
δ = stress = E ε

E = Young's Modulus

1. Strain
2. Curvature
3. Defects from diffused scattering

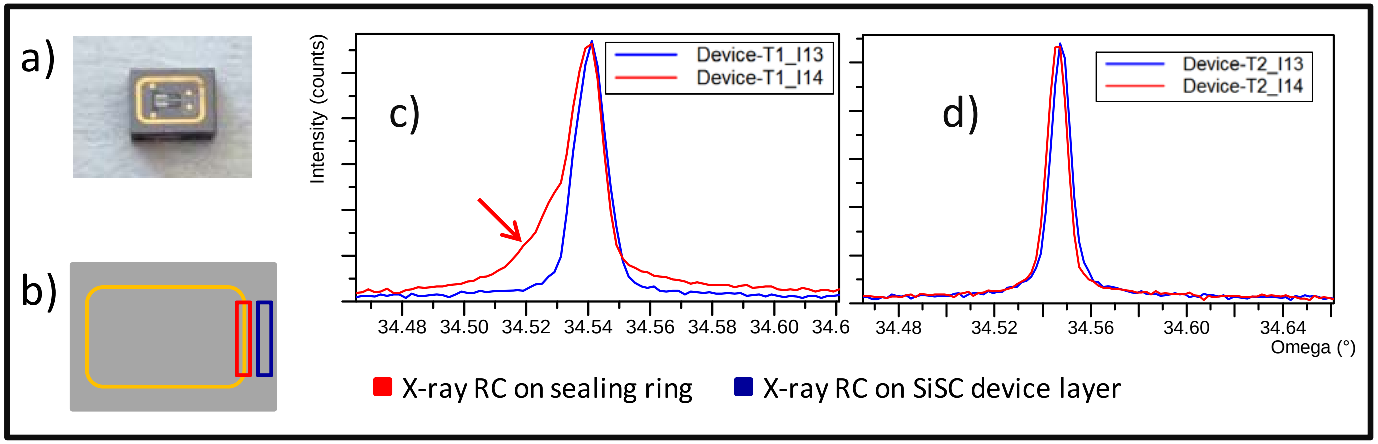
HRXRD on SCSi MEMS: Strain determination close to the interface





HRXRD strain analysis related to device fabrication.
Quality control related to sealing ring deposition process

The deposition of sealing rings for the following WLP of the MEMS.



HRXRD a) Piezor-Press unpackaged device with sealing ring; b) schematic Piezor-Press unpackaged device with sealing ring showing the areas of X-ray structural analysis; c) RC’ on two sample areas (arrow indicates strain) and c) RC’ on two sample areas (no structural modification observed).

Summary

- Vacuum level detection in very small cavities
- Stress evaluation related to wafer level bonding
- Flexibility to work on different sites: Exchange of wafers

Acknowledgements

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Thank you for your attention !