Joint Reliability Team

WALES –
WAfer Level Encapsulation for Micro-Systems

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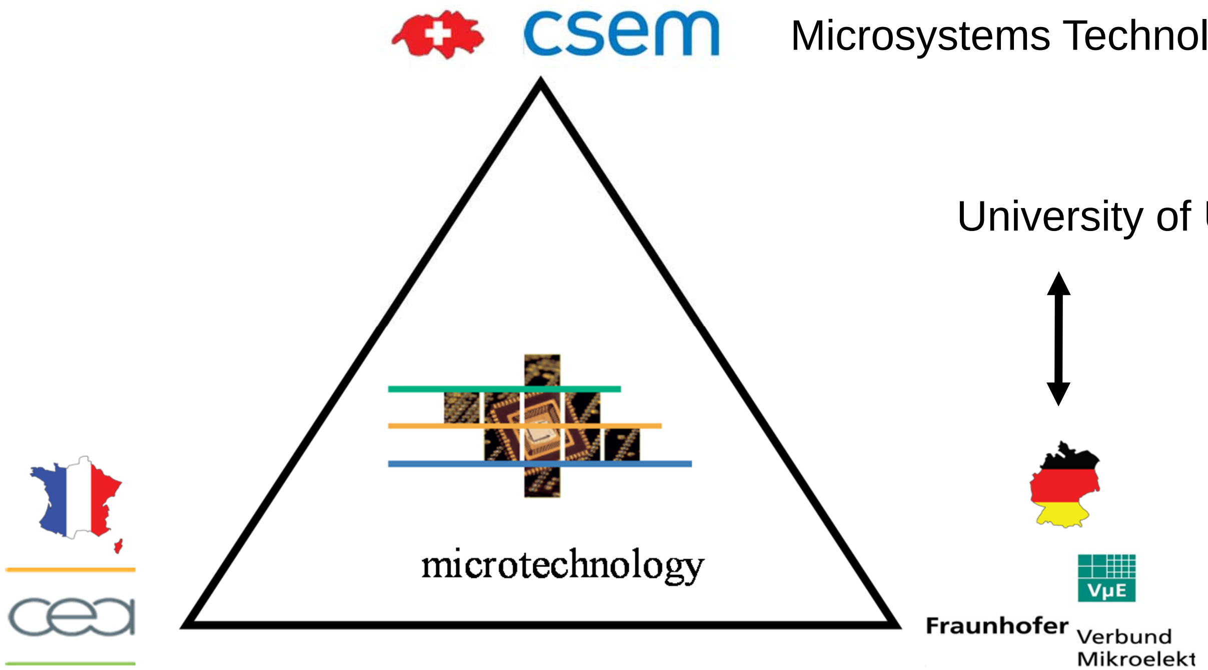
WALES Consortium



Microsystems Technology Division

University of Ulm

CEA-LETI
Heterogenious Integration Division

Micro Materials Center MMC of the IZM
Electronic Nanosystems ENAS

Project Objectives: Technology activities

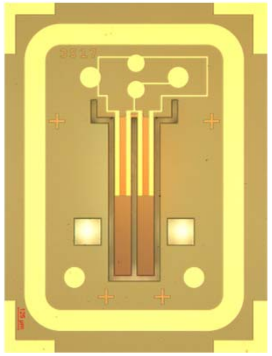
1. MEMS Fabrication
   - Resonator fabrication
   - Resonator electrical testing
   - Cap wafer fabrication

2. MEMS Packaging
   - Wafer level packaging

3. MEMS Testing

Project Objectives: Technology activities & exchange

Piezoelectric Resonator
(20kHz – 1MHz)

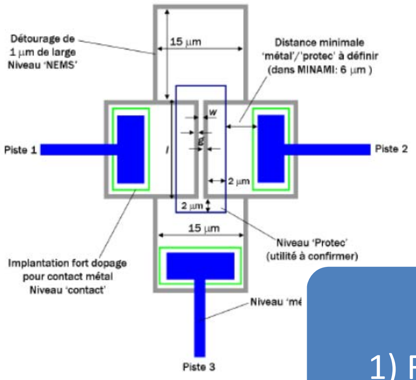


CSEM:

1) Fabrication
2) WLP
3) Testing

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

Capacitive Resonator
(100kHz – 10MHz)

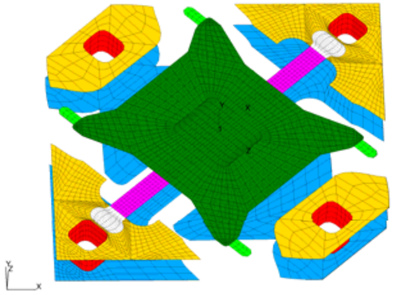


WLP

WLP

Testing

and Reliability



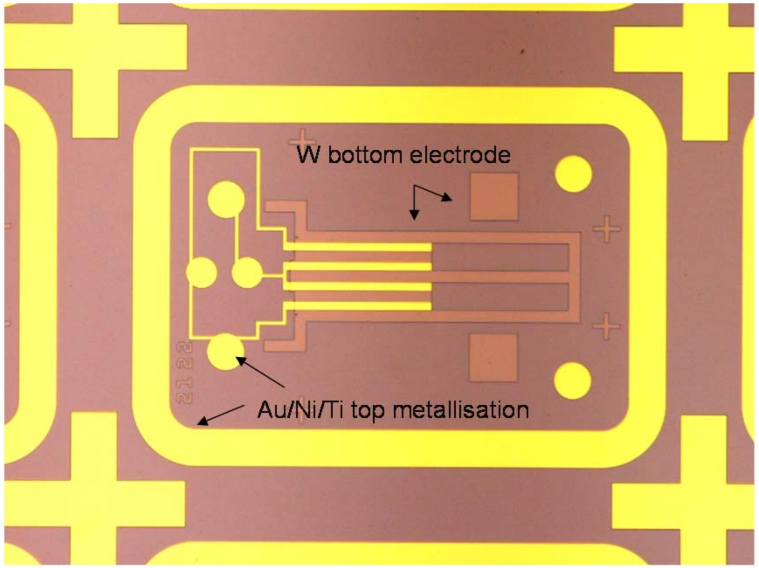
CEA-LETI:

1) Fabrication
2) WLP
3) Testing

Fraunhofer Gesellschaft:

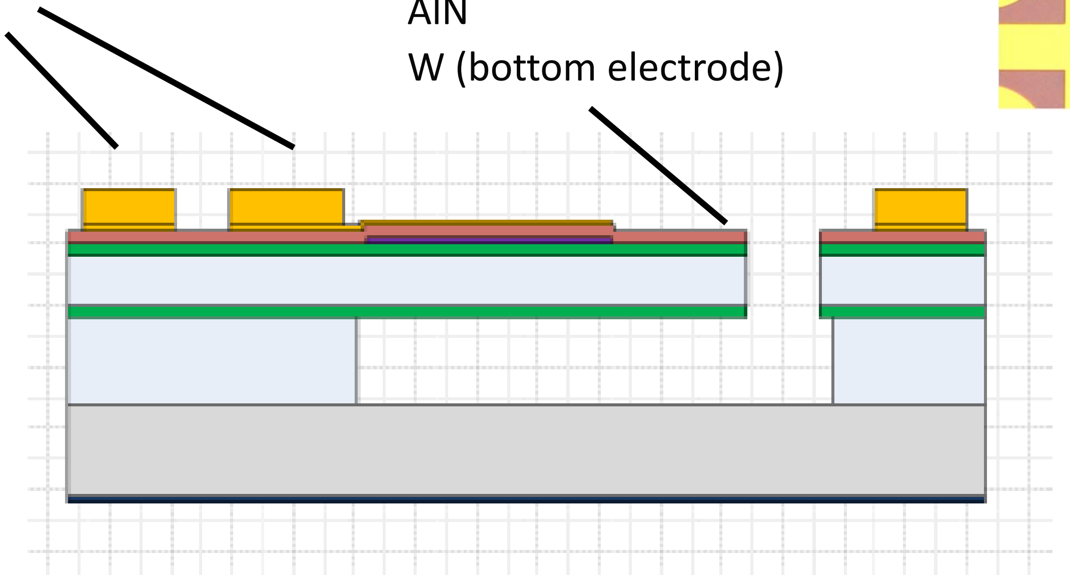
1) Hermeticity
2) Testing

Piezoelectric resonator fabrication



Design:

- MEMS dimensions: 1.5 x 2 x 1.4mm
- 4 four electrical contacts on the glass cap
  (contact pad dimensions: 240 x 200 µm
- Volume of the cavity: 378 nl (0.378mm^3)



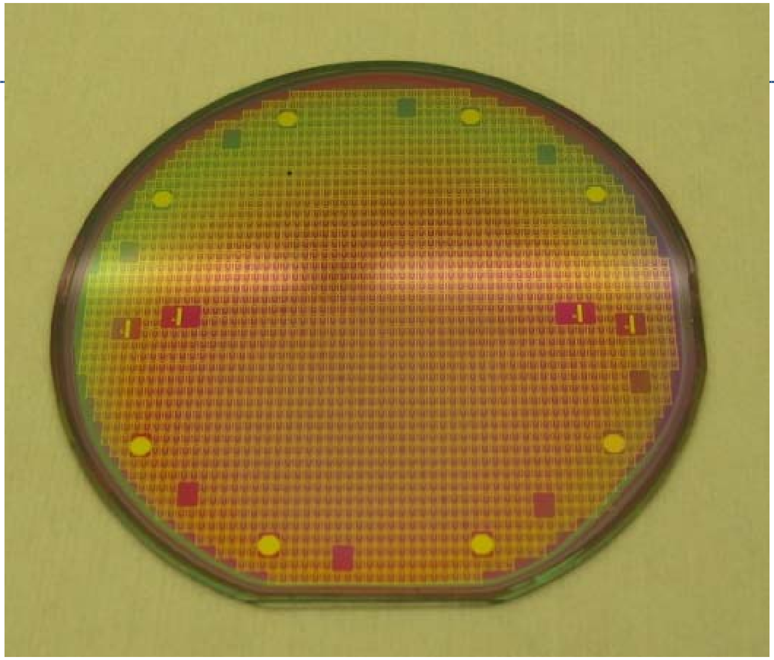
Au/Ni/Ti

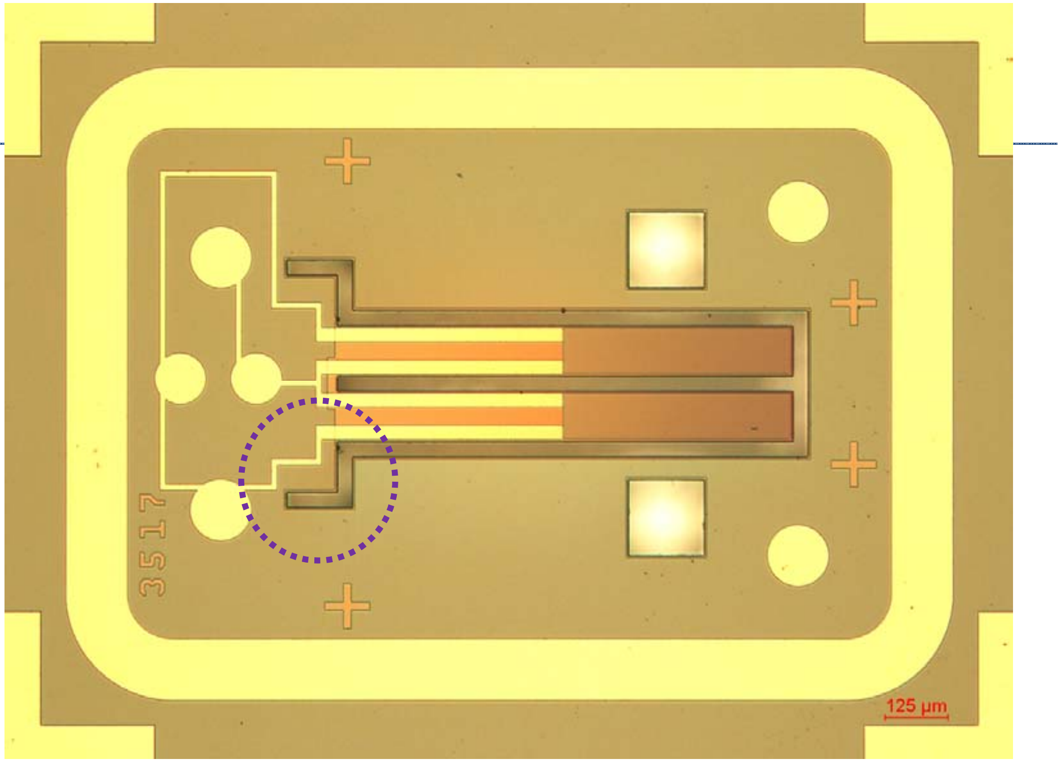
AlN

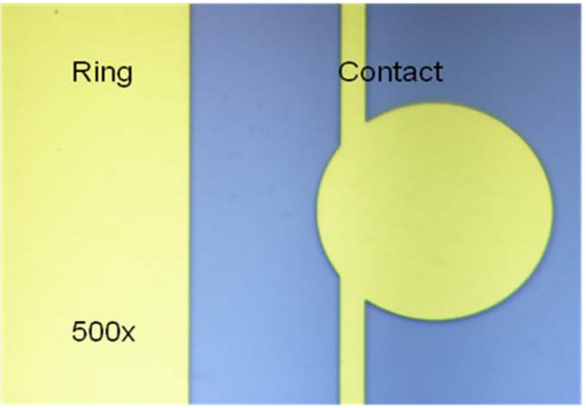
W (bottom electrode)

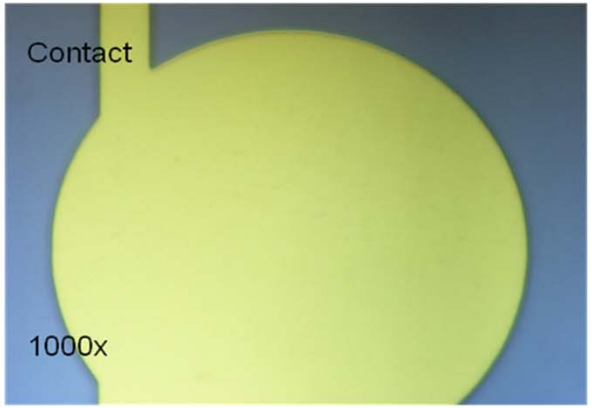
Si

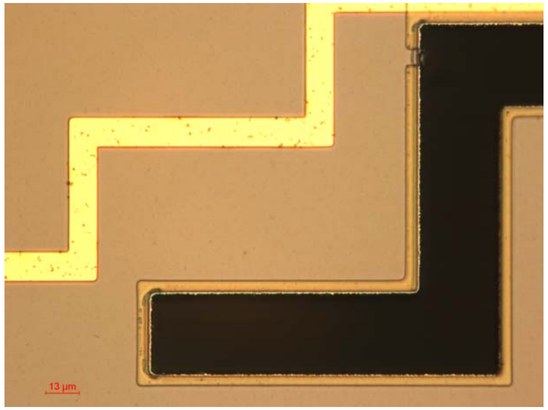
Pyrex (anodic bonding)




3517
125 µm

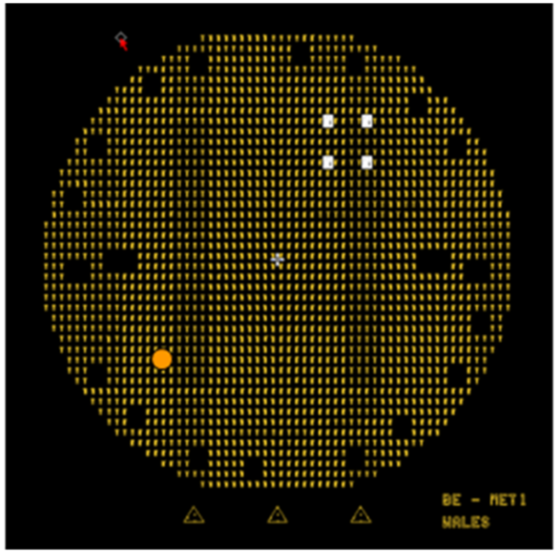

Ring
Contact
500x

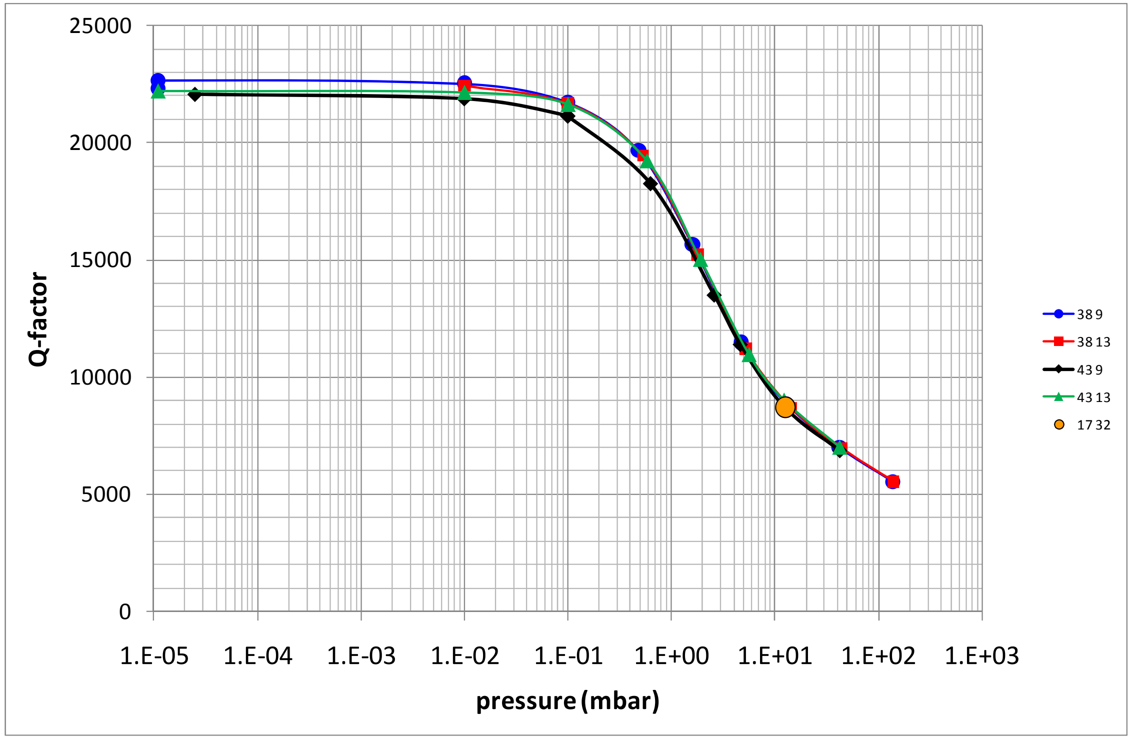

Contact
1000x


13 µm

Resonator electrical testing

Position of measured resonators:

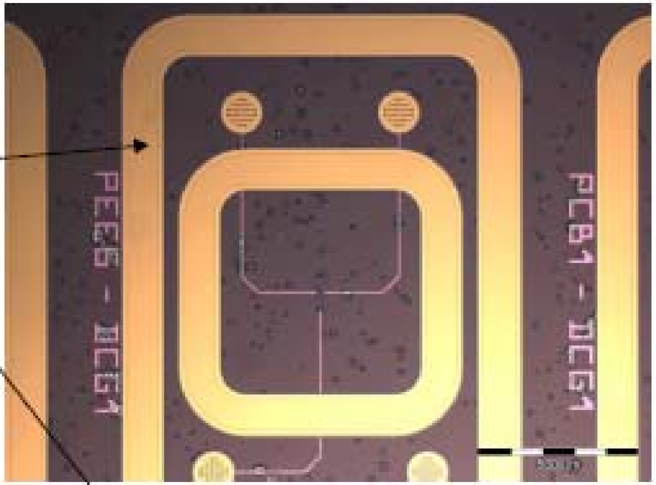


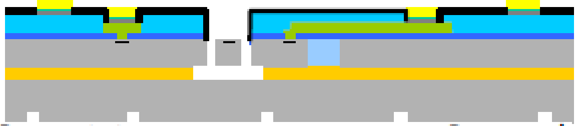


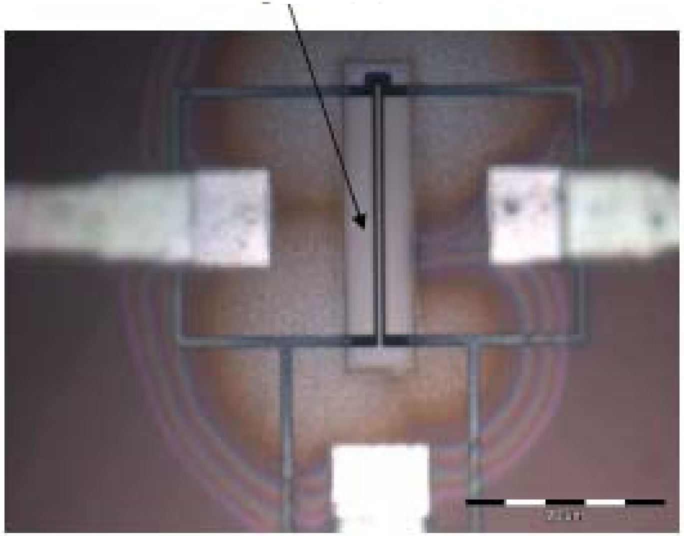
The good reproducibility allows the use of a single Q vs pressure curve for all resonators. A calibration for each resonator in an individually manner is not necessary.

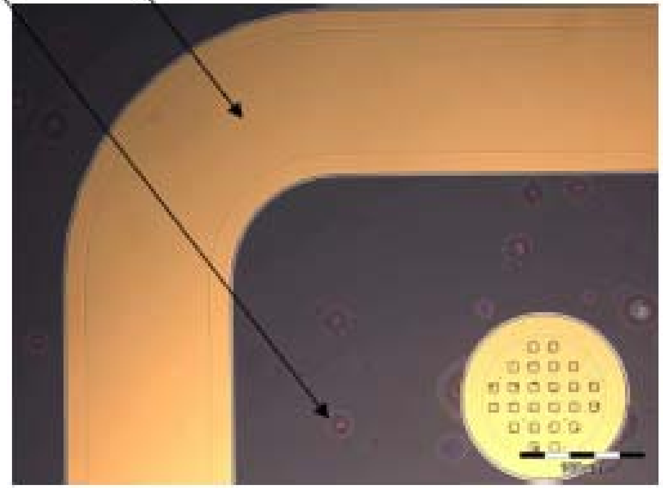
Capacitive resonator fabrication

- Visual aspect after beam release
  - No defect on UBM rings
  - Micro defects on the SiO2 surface
  - Beam release OK



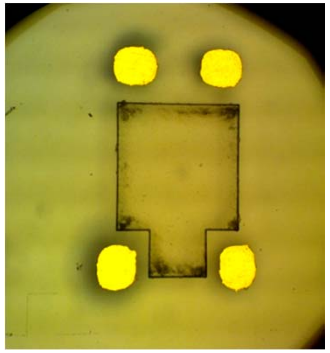
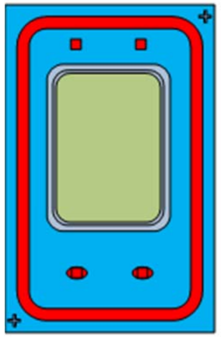






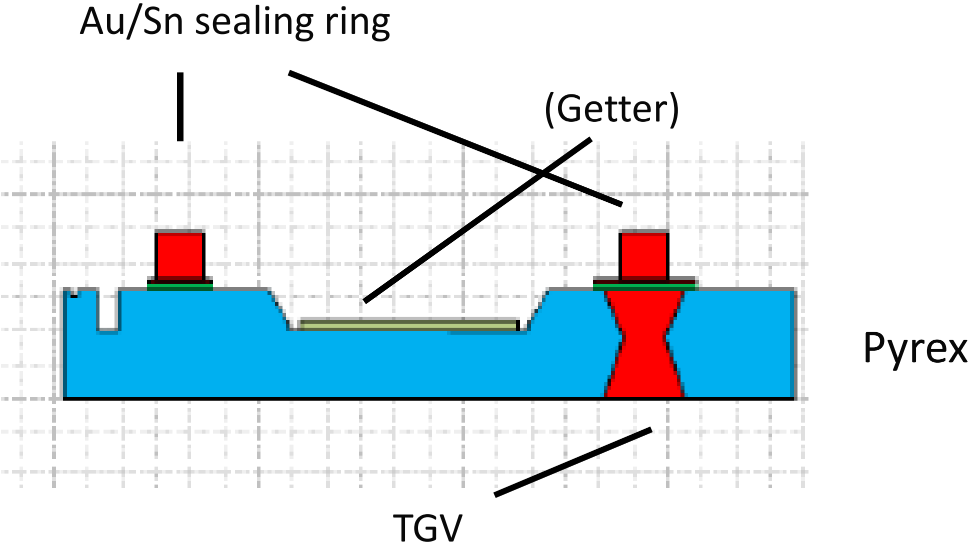
Cap wafer fabrication

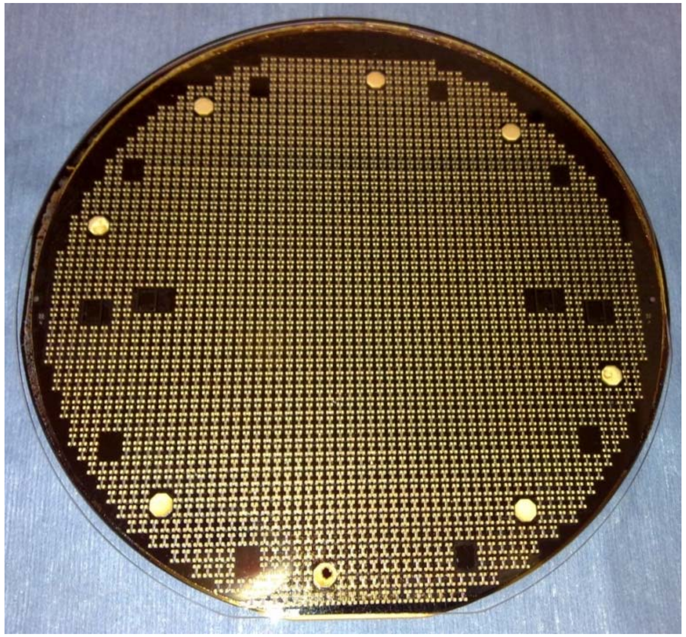
Design:

View of a cap after wafer polishing.

- Cavities and vias by sandblasting
- Au via filling by galvanic
- Wafer polishing



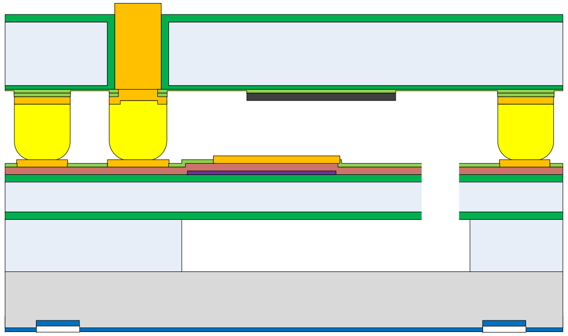


Choice of WLP method

	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

Assembly and soldering:

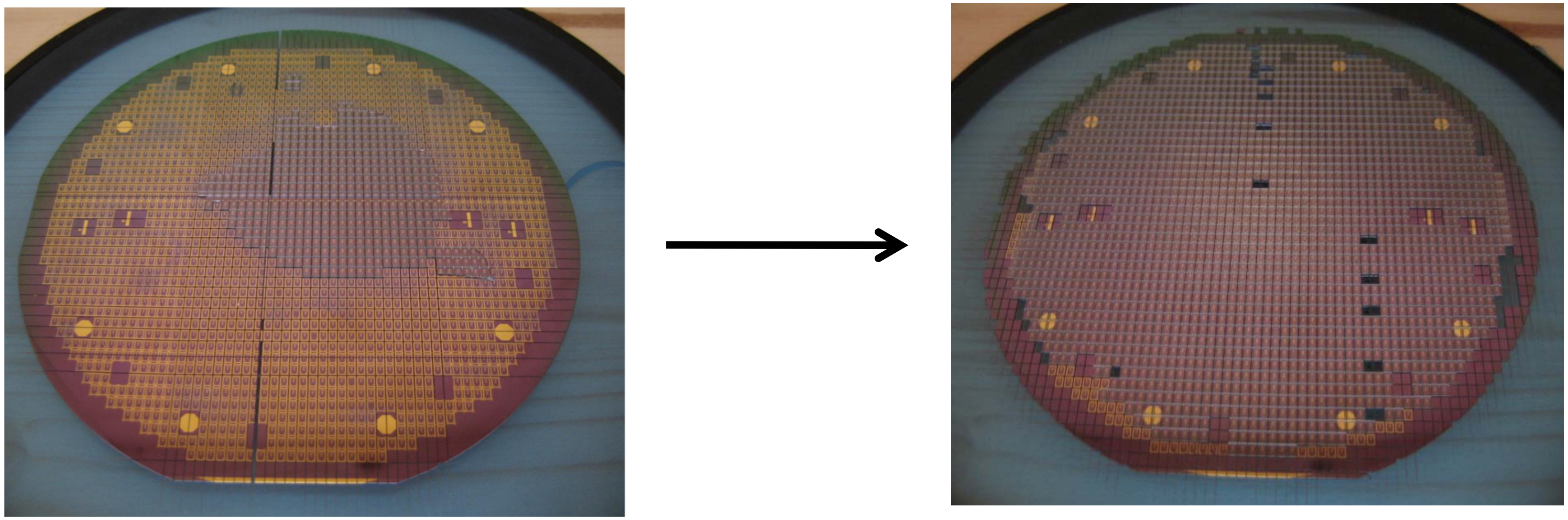


Wafer level packaging strategy

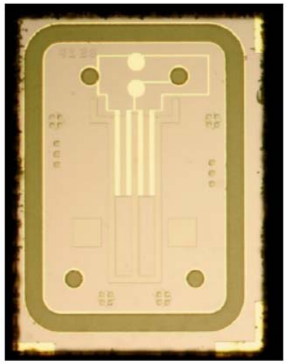
- Mechanical caps and devices
    - start from the conditions established for die to die bonding (different equipments with different T reading and cooling rates)
    - optimization of the conditions (shear strength, uniformity, yield)

- Final caps and devices (with resonators, backside bonding, vias and cavities)
    - start from the conditions established for wafer level bonding of mechanical wafers and from the results of the die to die bonding of final caps and devices.
    - optimization of the conditions (vacuum level, leak rate, uniformity, yield)

Wafer level packaging at CSEM

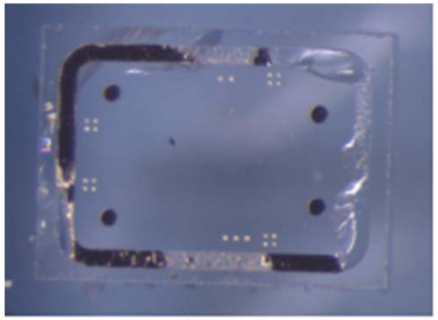


Optical Inspection:



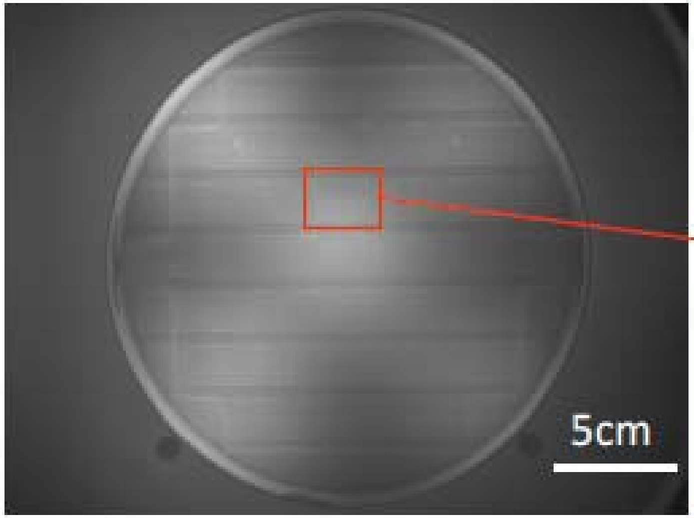
Shear test:

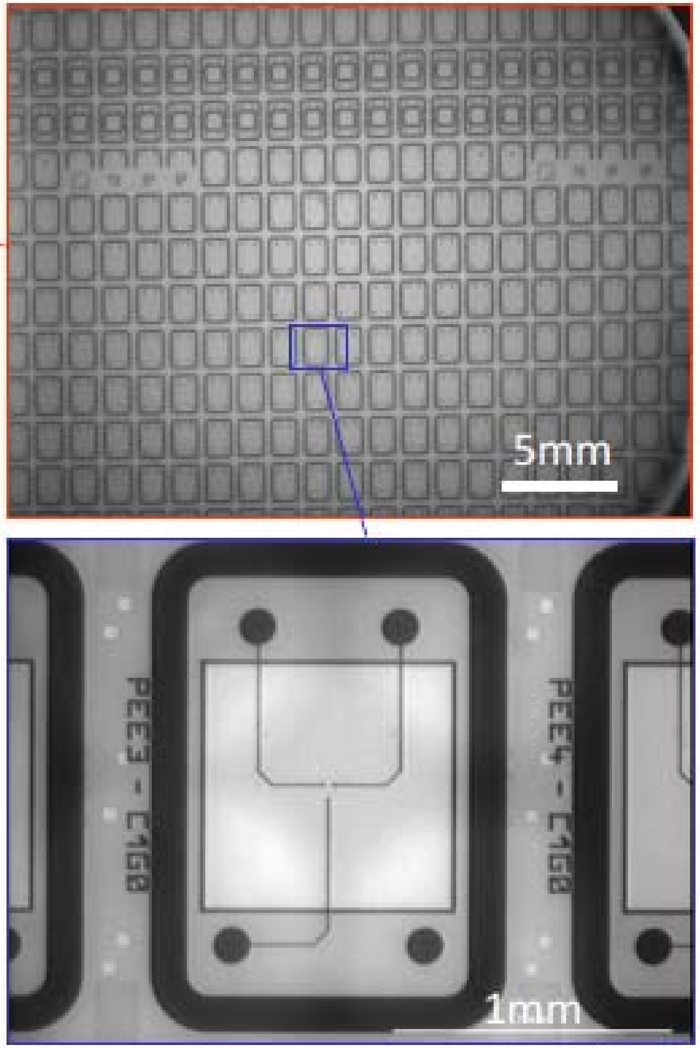
-assessment of the mechanical bonding strength being a prerequisite to hermeticity.



Shear force of up to 7 kg was measured, which correspond to a shear pressure of 125 MPa.

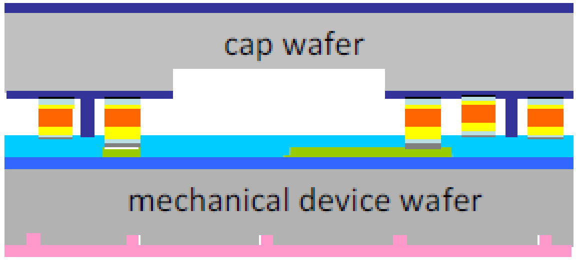
Wafer level packaging at CEA-LETI



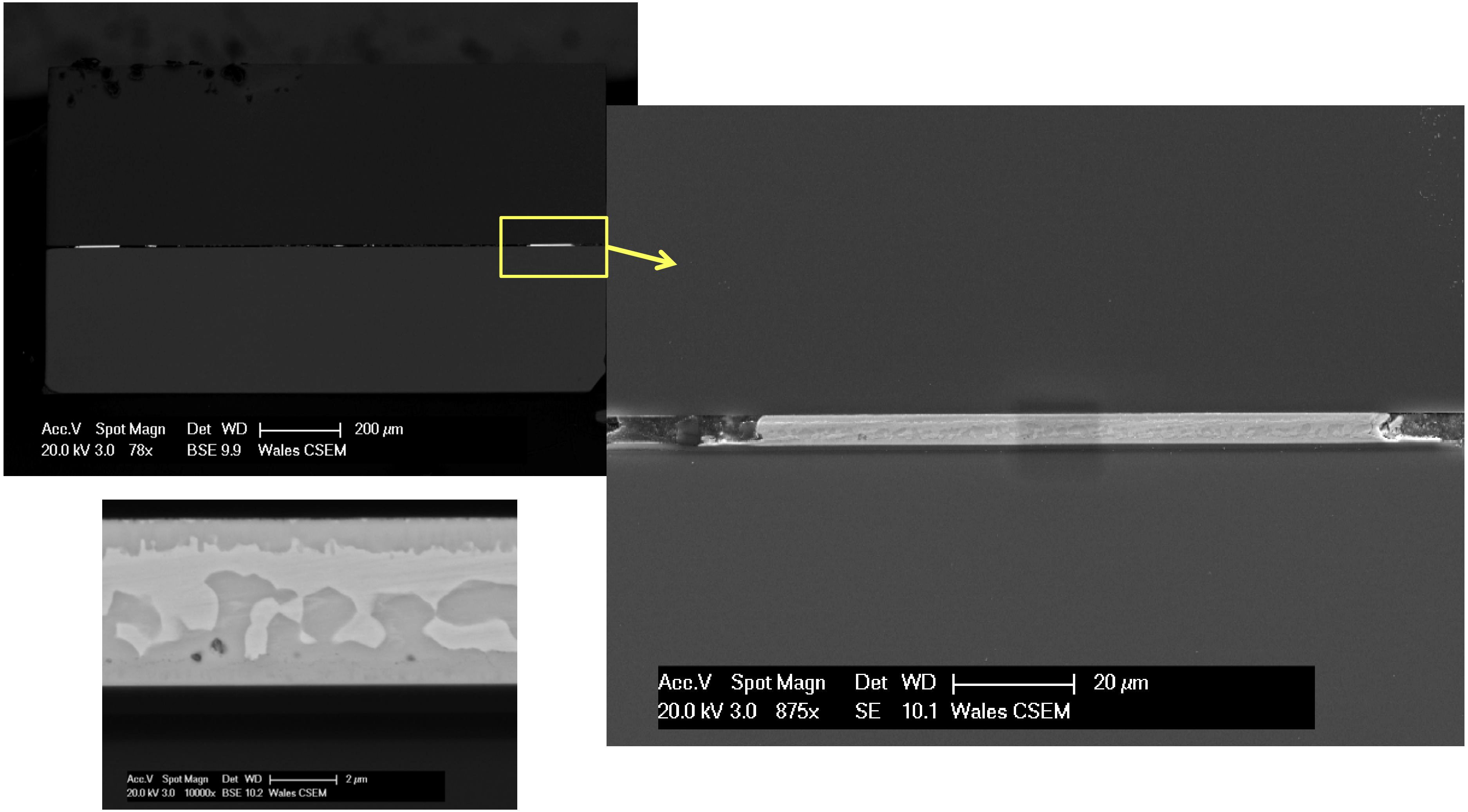


IR results

- Limited AuSn overflow
- No obvious defects

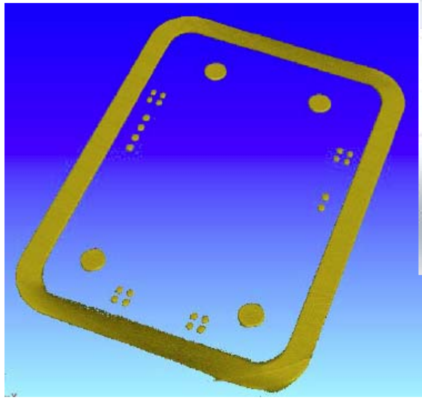


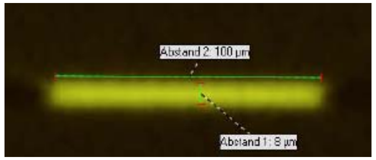
Micrographs presenting cross section of the sample

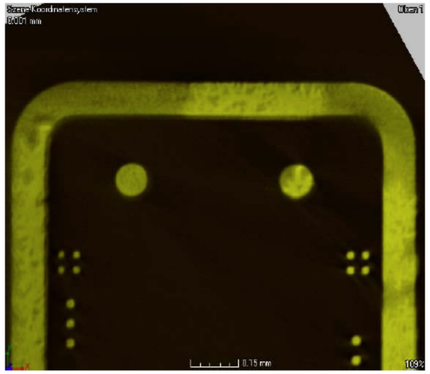


X-ray Tomography & Die Penetration

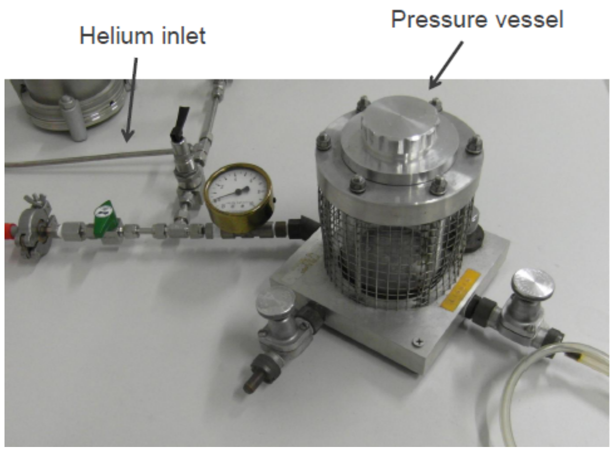
3D

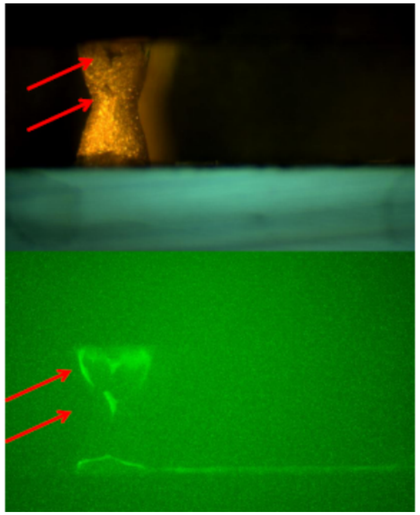


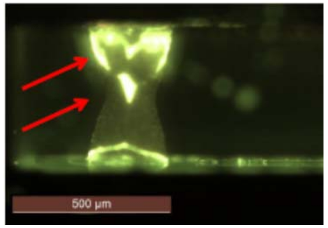




Fraunhofer
ENAS

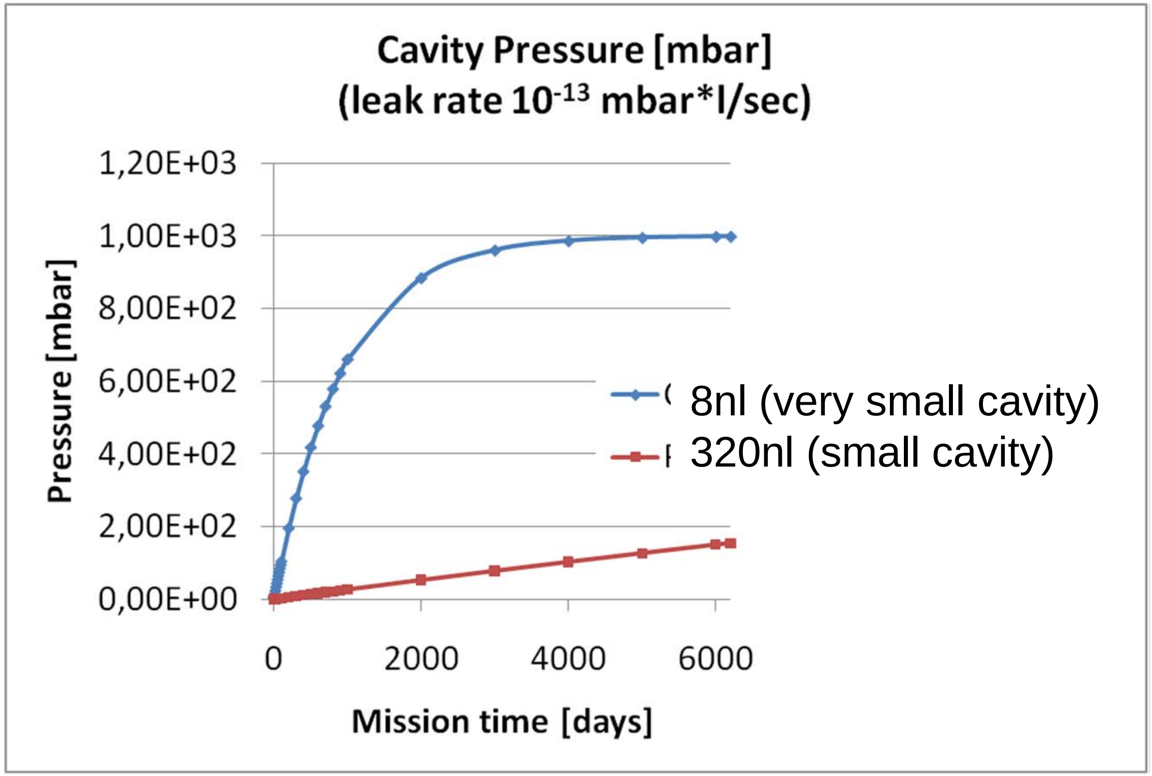






esa

Hermeticity: Challenge of extreme small cavities



In-cavity pressure development for a 1 bar exposure (17 years scenario)

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

- 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 testing: solutions for small cavities

Survey of 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 methods can access quantitatively leak rates well $< 10^{-13}$ (mbar*l)/s.

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

Most promising method: ***"Q-factor monitoring of resonators"***

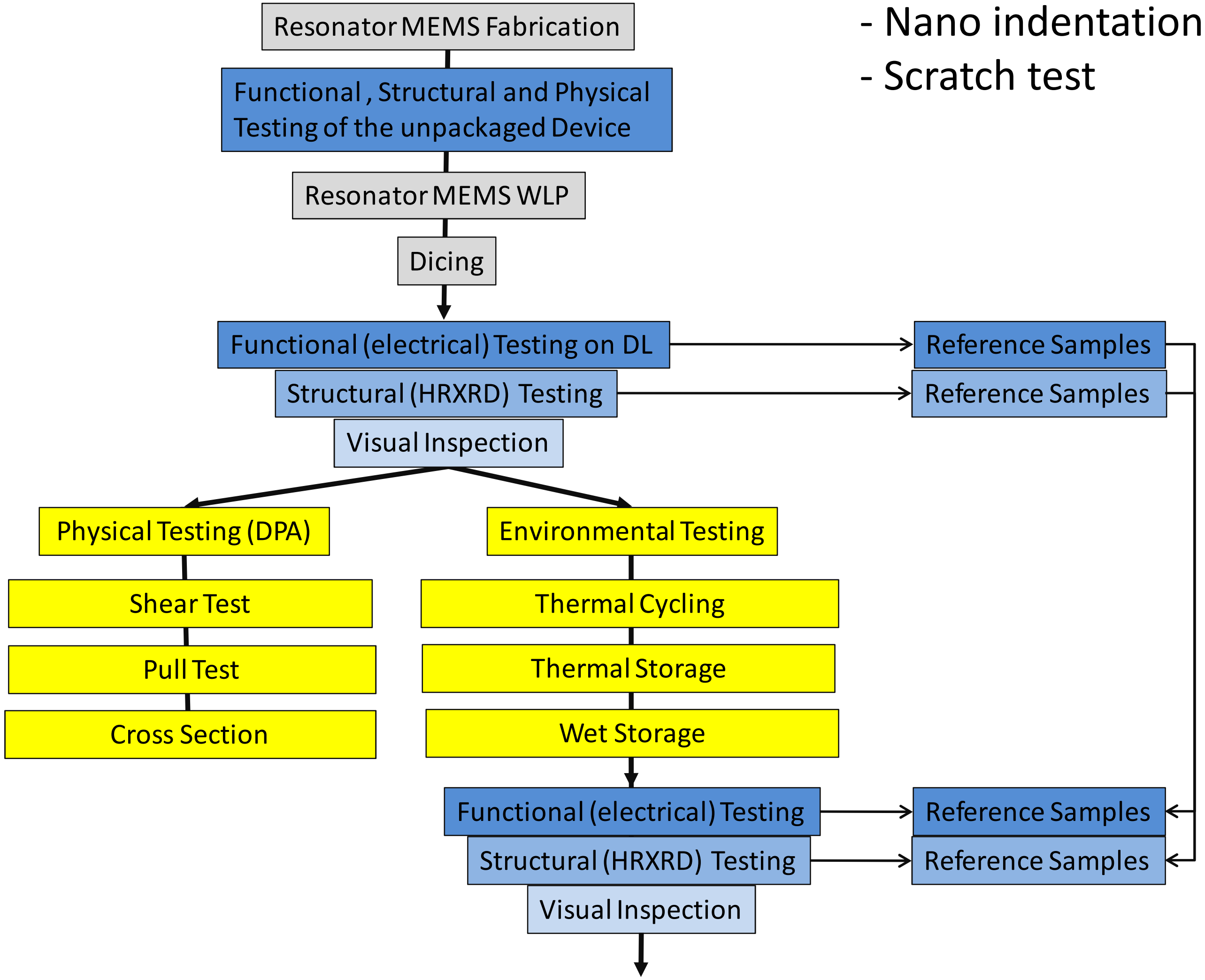
MEMS testing

<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



Resonator MEMS Fabrication

Functional , Structural and Physical Testing of the unpackaged Device

Resonator MEMS WLP

Dicing

Functional (electrical) Testing on DL → Reference Samples

Structural (HRXRD) Testing → Reference Samples

Visual Inspection

Physical Testing (DPA)

Shear Test

Pull Test

Cross Section

Environmental Testing

Thermal Cycling

Thermal Storage

Wet Storage

Functional (electrical) Testing → Reference Samples

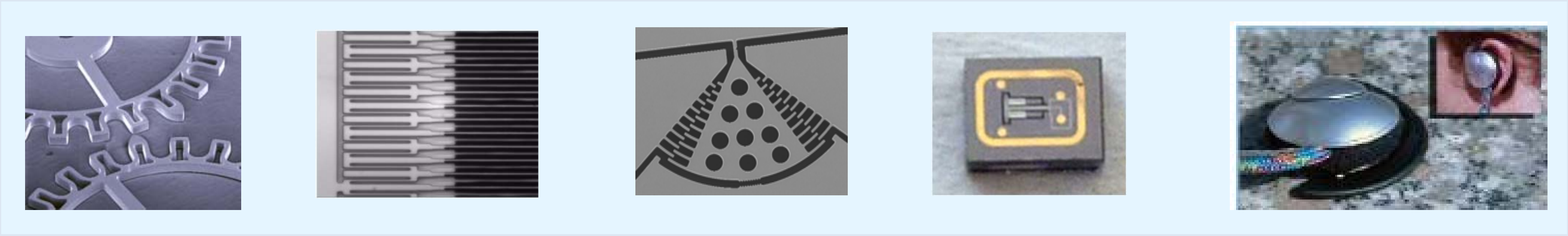
Structural (HRXRD) Testing → Reference Samples

Visual Inspection

- Nano indentation
- Scratch test

Structural testing (HRXRD)

High Resolution X-ray Diffraction in MEMS reliability:



Design:
- components
- device
- packaging level

→ Fabrication → Assembly → MEMS → Product

<u>Components characterization:</u>

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

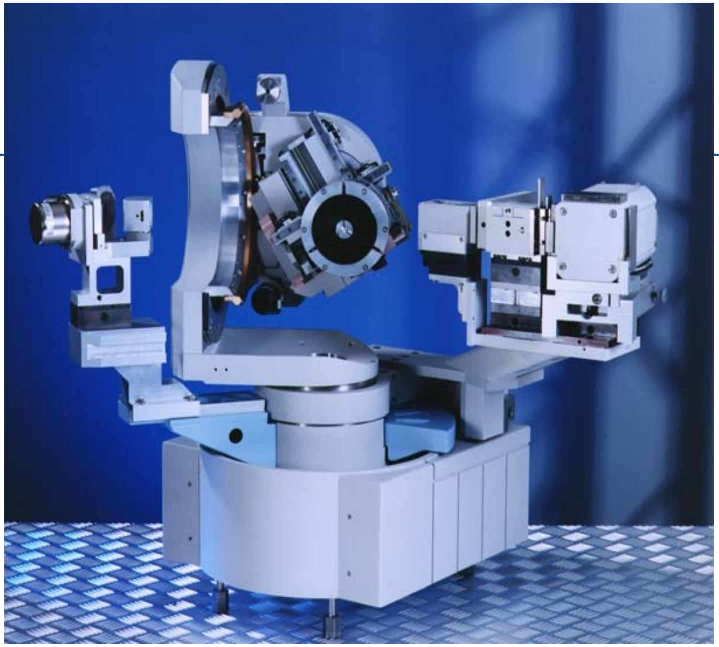
<u>Packaging:</u>

- defect + strain analysis

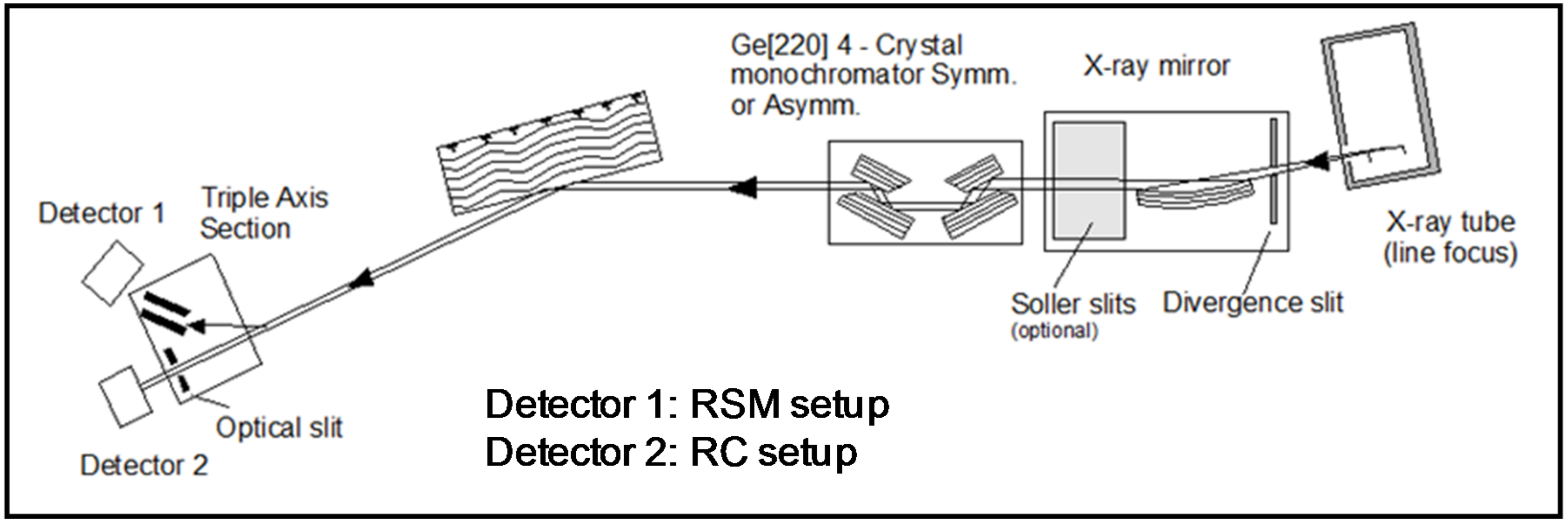
<u>Strain dynamics and mobility of Defects by XRD:</u>

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

HRXRD on SCSi MEMS



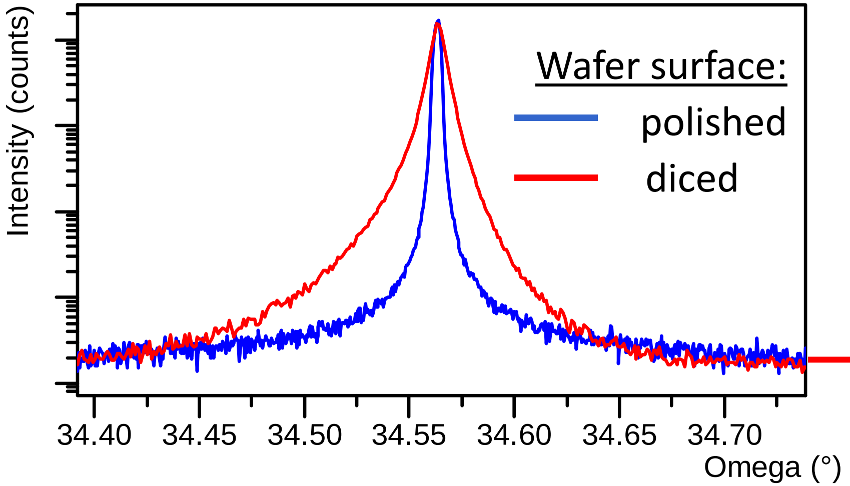
PANalytical X'Pert PRO MRD

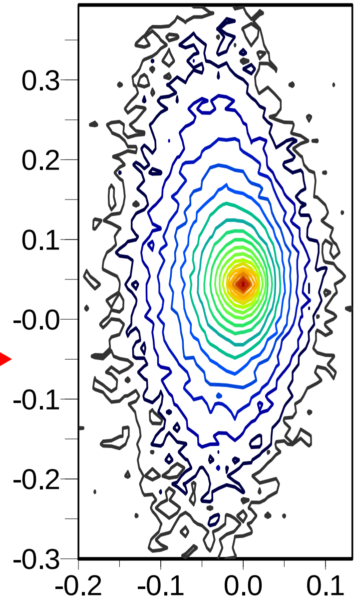


Detector 1: RSM setup
Detector 2: RC setup

X-ray Rocking Curve (RC): Reciprocal Space Mapping (RSM):

X-ray scattering can be separate into distinct features:



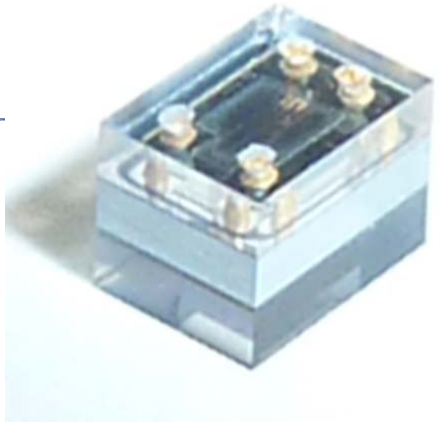


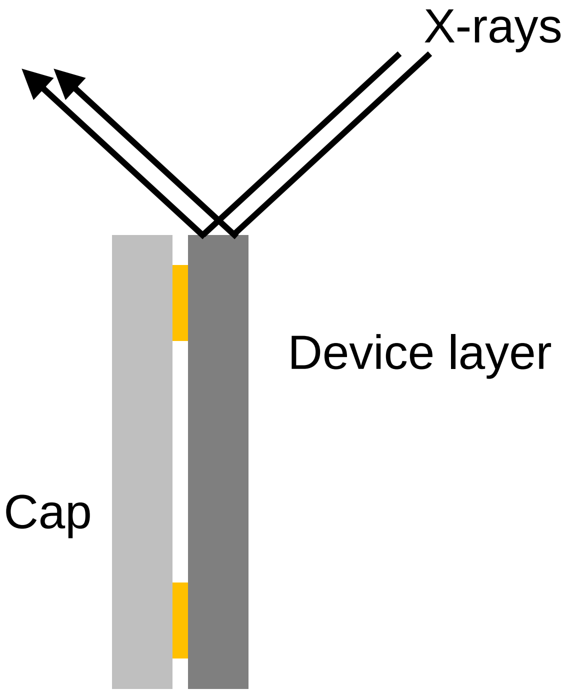
ε = strain = $\Delta d/d = -\Delta\theta/\tan\theta$

δ = stress = E ε

E = Young's Modulus

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

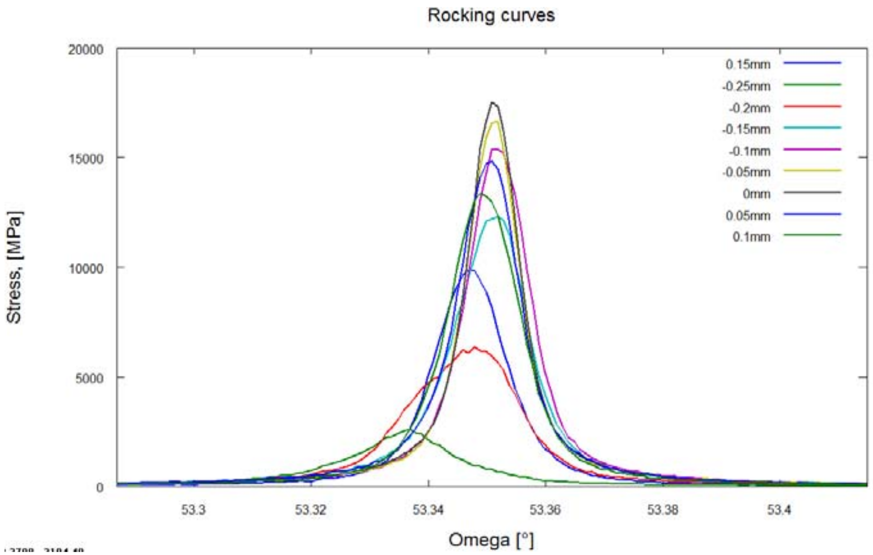


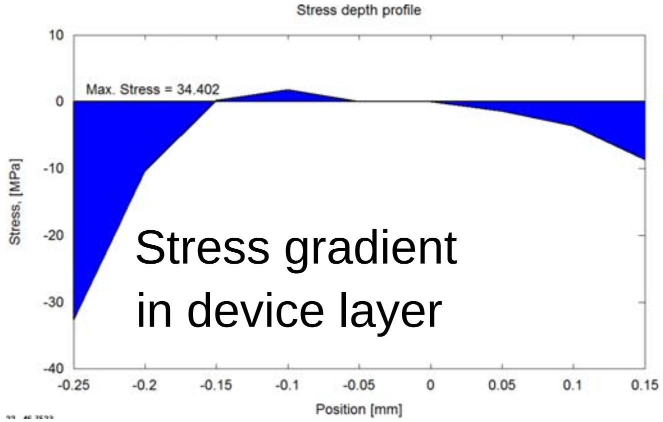


X-rays

Device layer

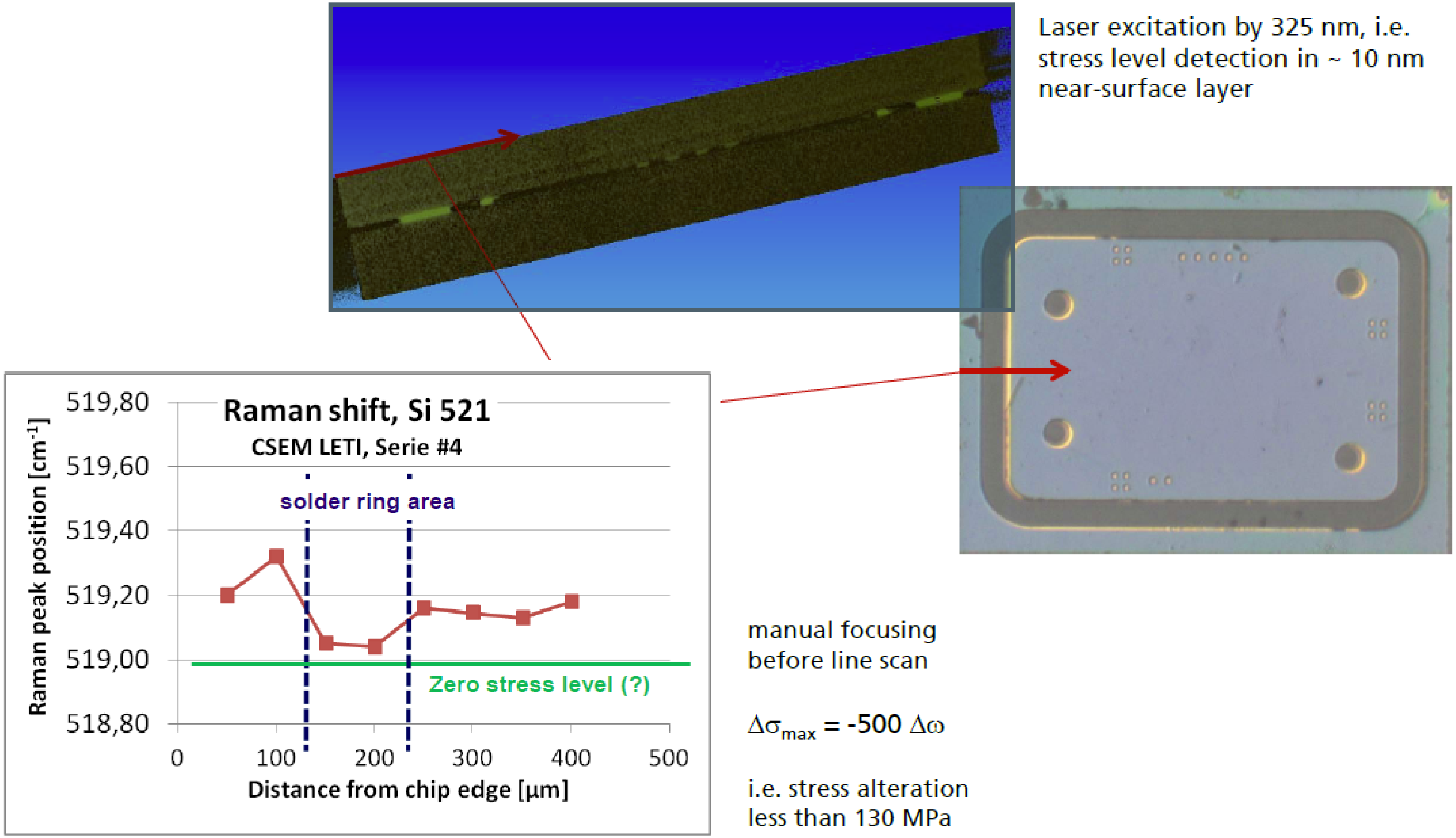
Cap





Stress gradient
in device layer

Raman stress determination

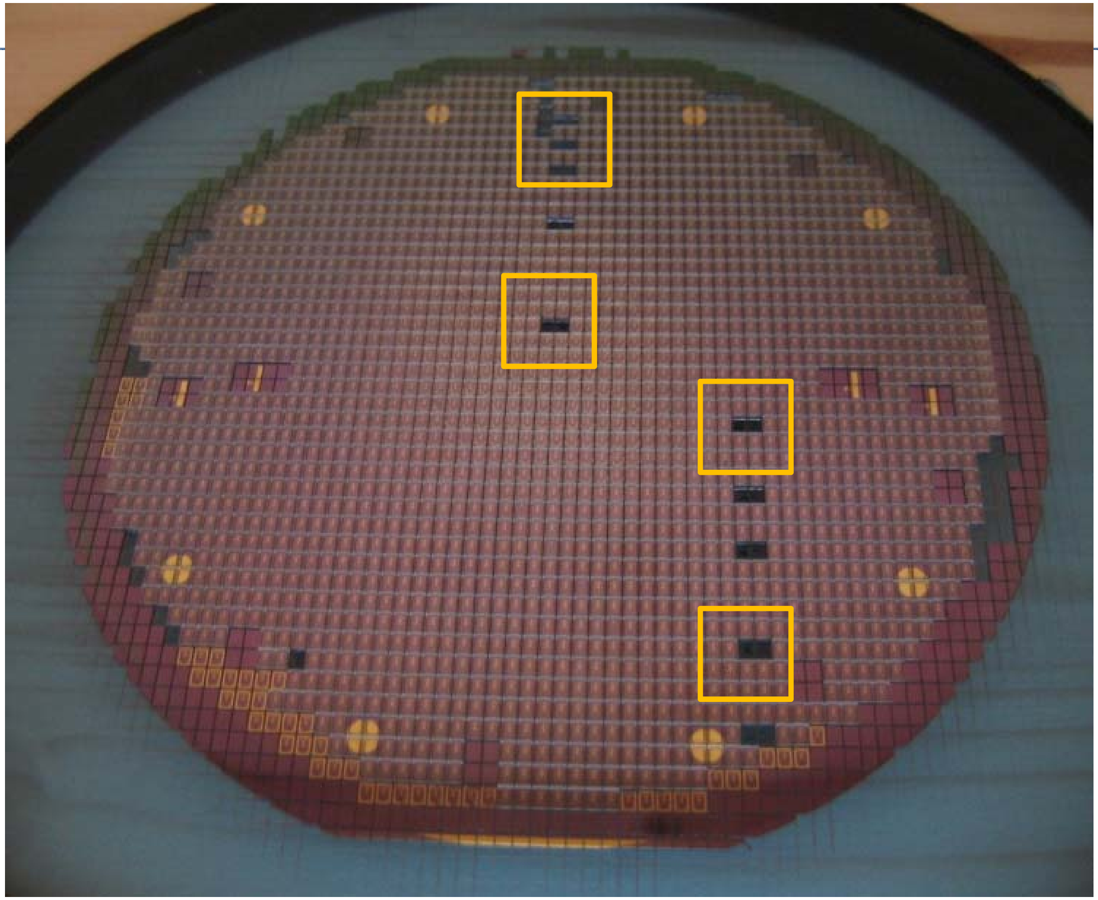


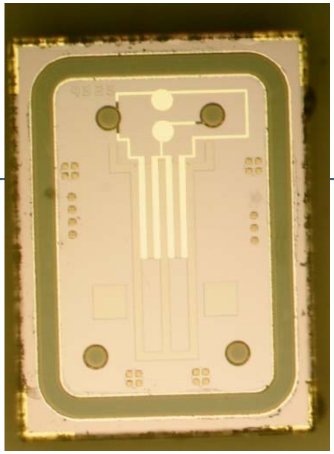
Laser excitation by 325 nm, i.e. stress level detection in ~ 10 nm near-surface layer

manual focusing before line scan

$\Delta\sigma_{max} = -500\ \Delta\omega$

i.e. stress alteration less than 130 MPa





Strain in device layer:

- Very small
- homogeneous within the wafer

Tests in parallel:

- Shear tests
- X-ray Tomography
- Cross section

On functional devices and caps:

- Electrical tests to evaluate pressure level and leakage rate

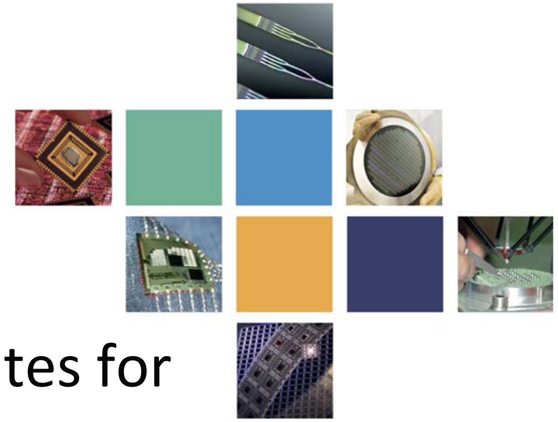
Summary

- Successful wafer level packaging
- Possibility of vacuum level detection in very small cavities
- Stress evaluation related to wafer level bonding :

  - possibility to decuple the influence of packaging strain and pressure on the Q-factor determination of resonators

Integration of VTT :

- Support on wafer level packaging of CSEM's mechanical and functional resonator wafers with VTT's cap wafers by VTT
- VTTs MEMS packaging by VTT with having partially fabrication steps at CSEM



Aim of WALES:

- Showing the flexibility of work on different sites for fabrication and WLP
- Presenting a consortium to ESA for MEMS fabrication and qualification

Thank you for your attention !

esa

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csem

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Antonia Neels
Claude Muller
Jacek Baborowski
Viron Teodoridis

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