IMES Institut für Mechanische Systeme

ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

EPFL École Polytechnique Fédérale de Lausanne

EPFL LMTS Microsystems for Space Technology Laboratory

Failure Mode Discussion on Irradiated MEMS Structures

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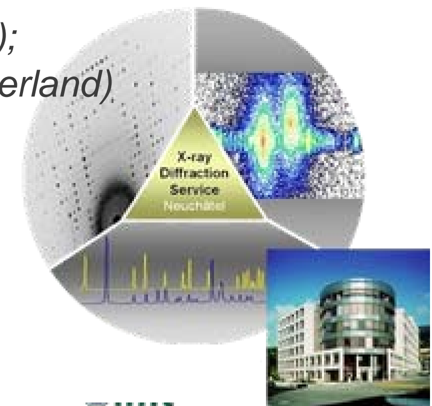
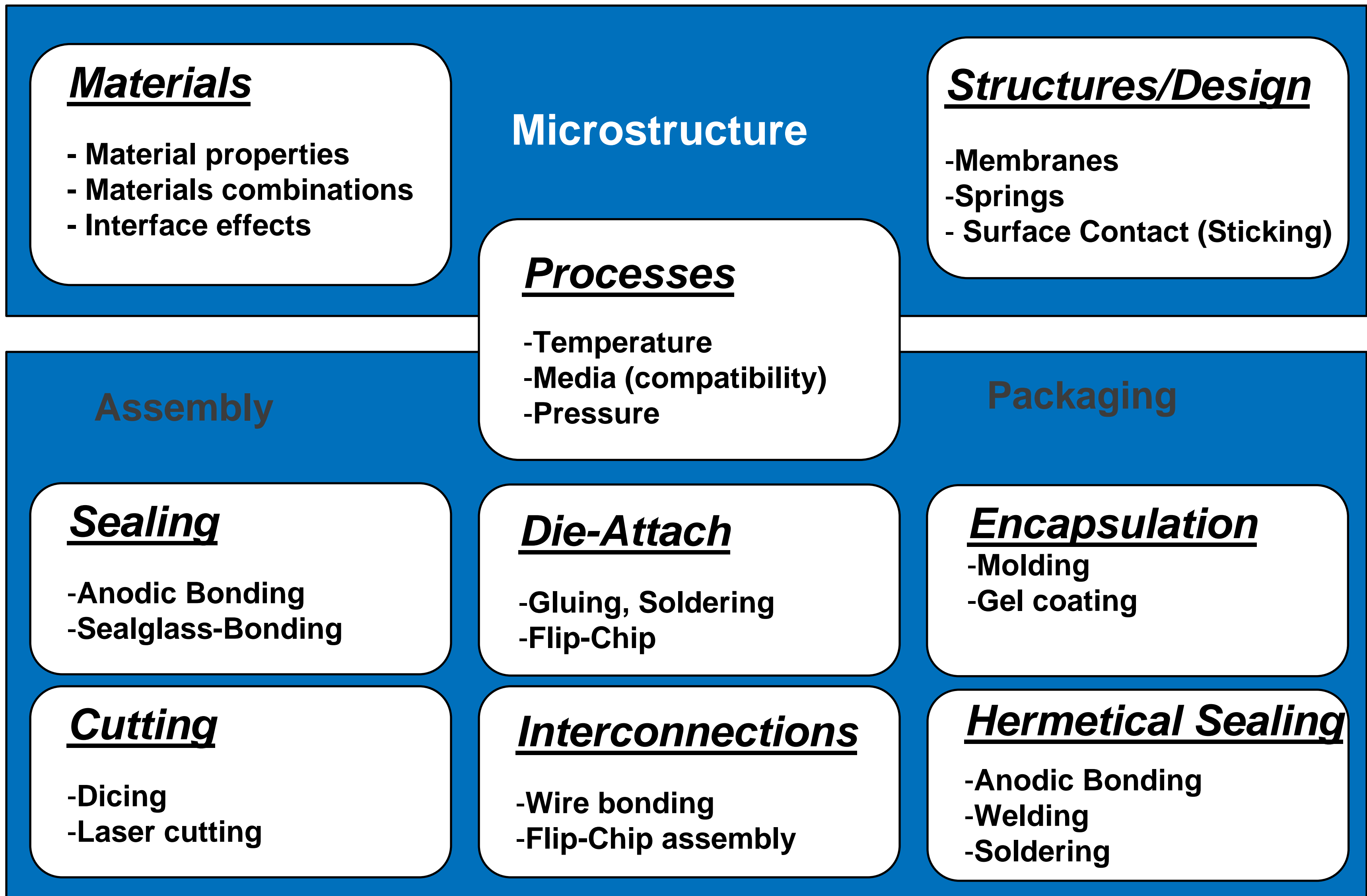
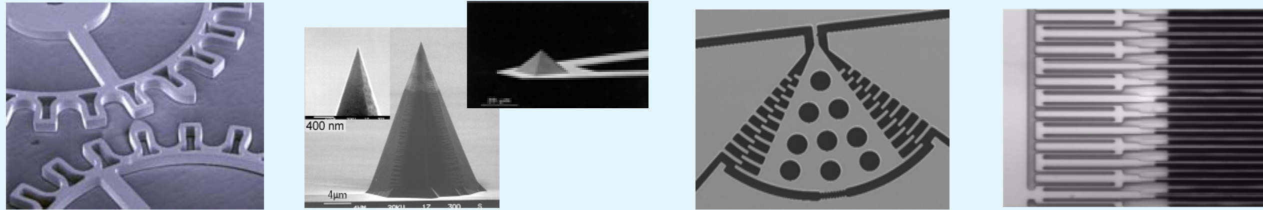
[1]CSEM, Microsystems Technology (Switzerland);
[2]EPFL, Microsystems for Space Technologies Laboratory, (Switzerland)
[3]ETHZ, Institut für Mechanisch Systeme, (Switzerland)

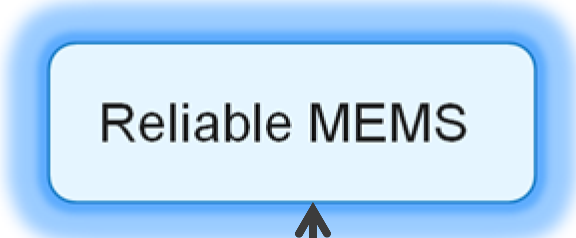


Quality Control & Reliability of MEMS



Reliable MEMS





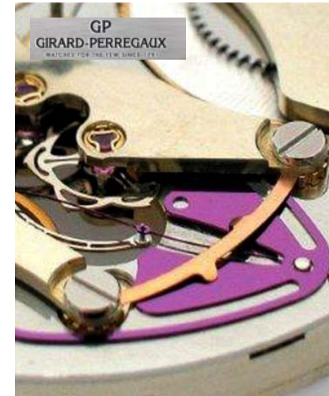
<u>Components characterization:</u>
- structural analysis:
  phases, texture, strain, …
- defect and strain analysis related to MEMS parts in fabrication processes

<u>Packaging:</u>
- defect + strain analysis

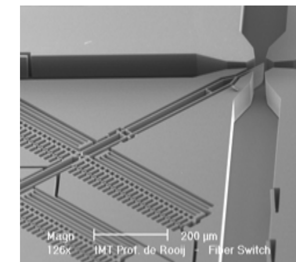
<u>Mobility of Defects:</u>
in-situ testing:
structural + mechanical
-aging studies:
T, radiation, high cycle fatigue

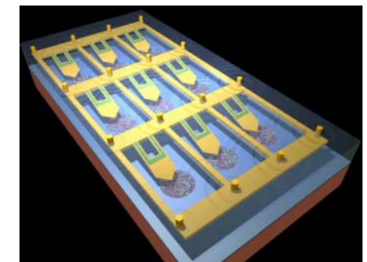
Foundry Services

- **Watch Parts**

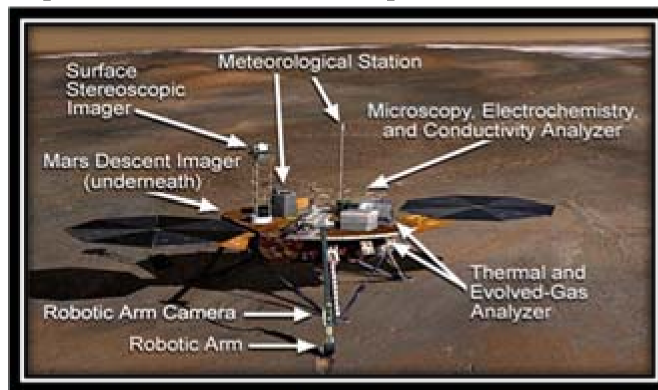


- **Optical MEMS Switches and Nanotools**

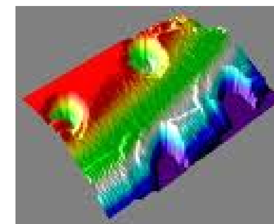


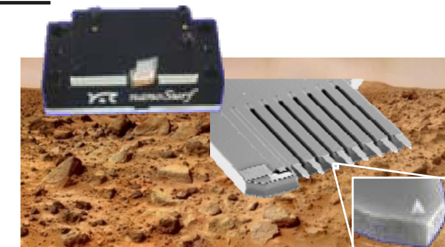


- **Components for Space Research**



Phoenix Mars Mission





Multiple sensors on the AFM probe various samples of the Martian soil.

Some examples

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Study of functional (mechanical) properties related to defect dynamics in MEMS:

Dynamical Studies

Testing / Aging

Temperature Influence

Radiation Damage

Mechanical Testing

In-situ Tensile and Bending Tests

High Cycle Fatigue on MEMS

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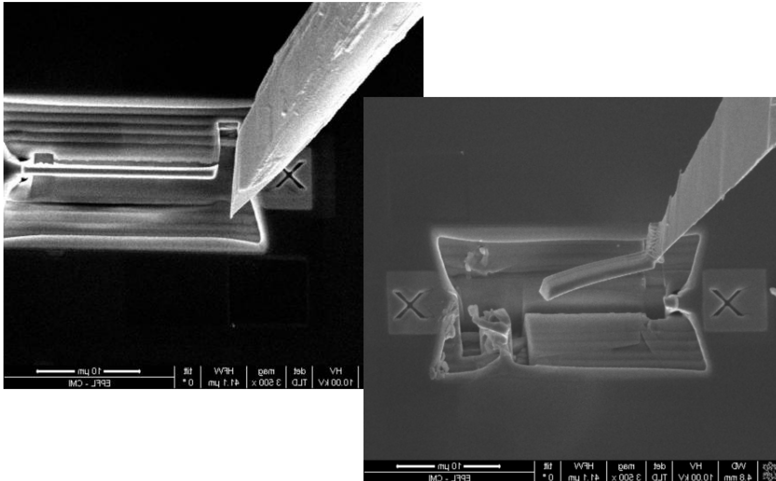
Defect Analysis in SiSC MEMS

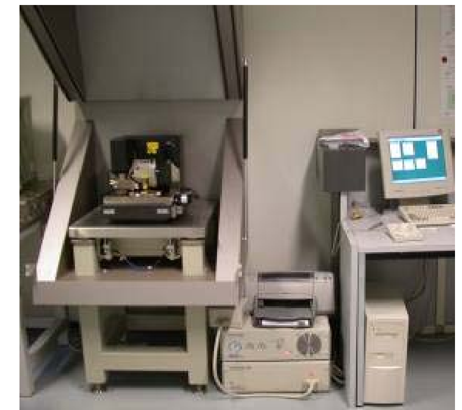
X-ray Diffraction

- HRXRD (global defect analysis)

Microscopy

- AFM (surface defects)
- FIB + TEM (defect profile in cross section)





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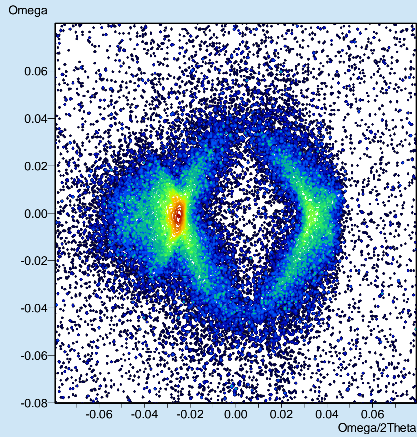
Characterization

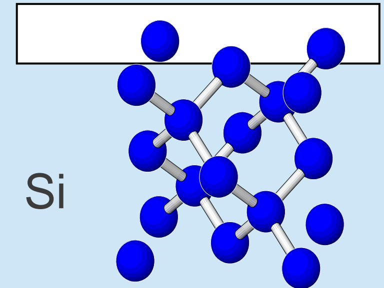
Functional: electrical, mechanical

Structural

HRXRD

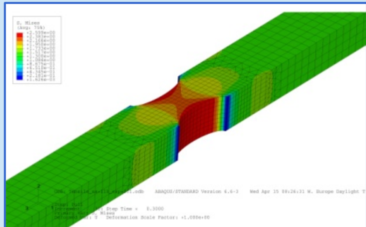


Si



+

Reliability in MEMS



Mechanical:
Bending + tensile tests

Simulations

Testing

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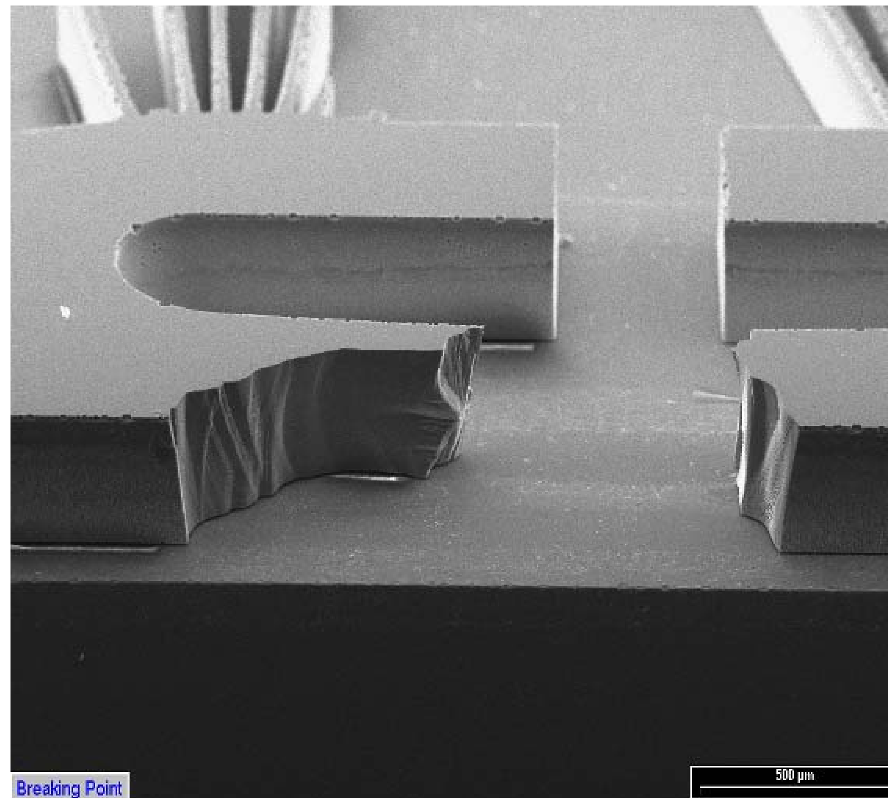
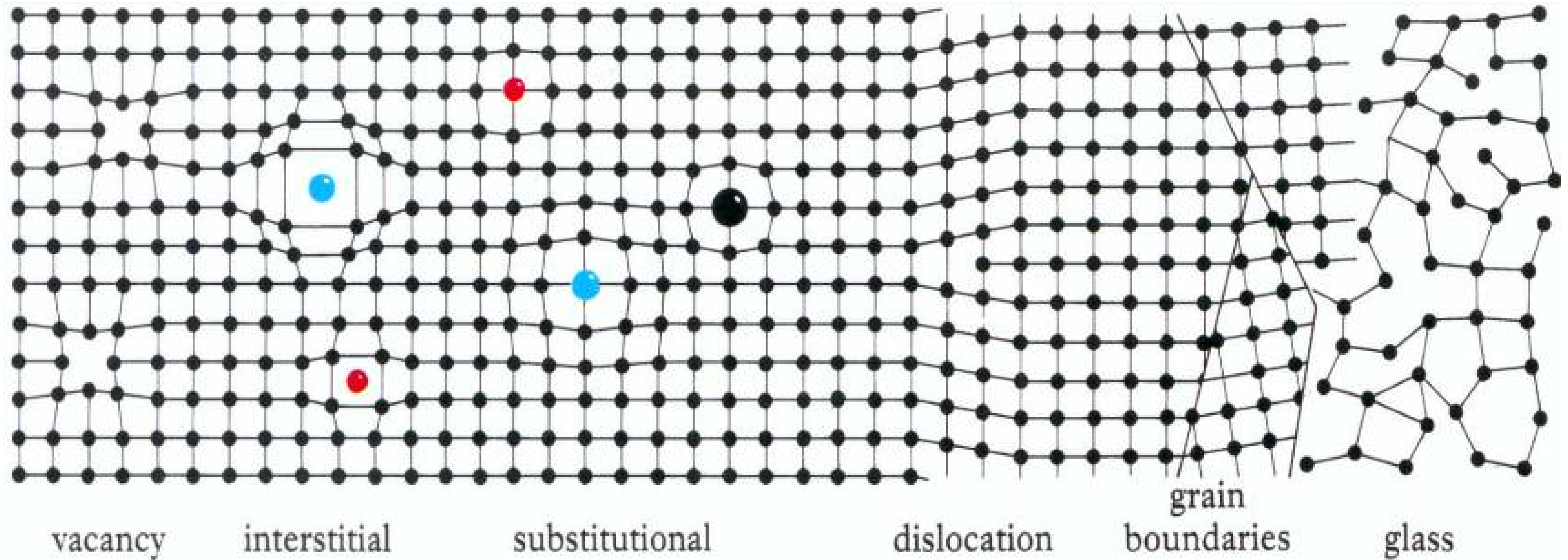
Study of materials properties: fracture toughness



When SiSC structures break ?
Why SCSi structures break ?

Defects in a Crystal



from: I.F. Mercer: "Crystals", The Natural History Museum, London 1994

+ surface defects (roughness, …)

+ sample size effect

Analysis Infrastructure at CSEM

AFM

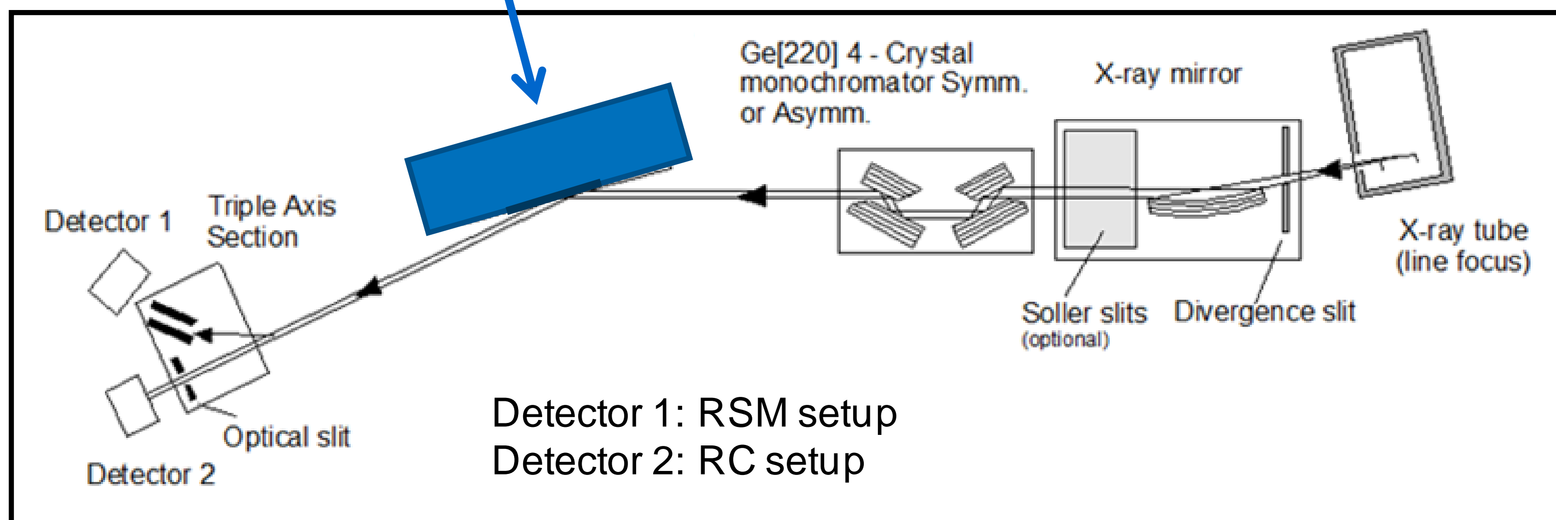
ESEM

RBS

HRXRD

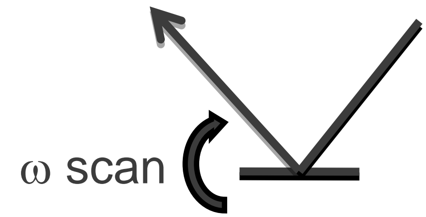
HRXRD on SCSi MEMS

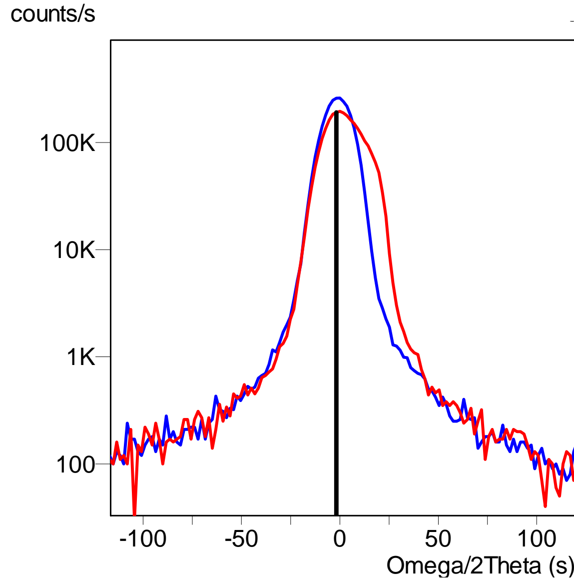
Mechanical Test Instrument with the sample also positioned with respect to the diffractometer setup:

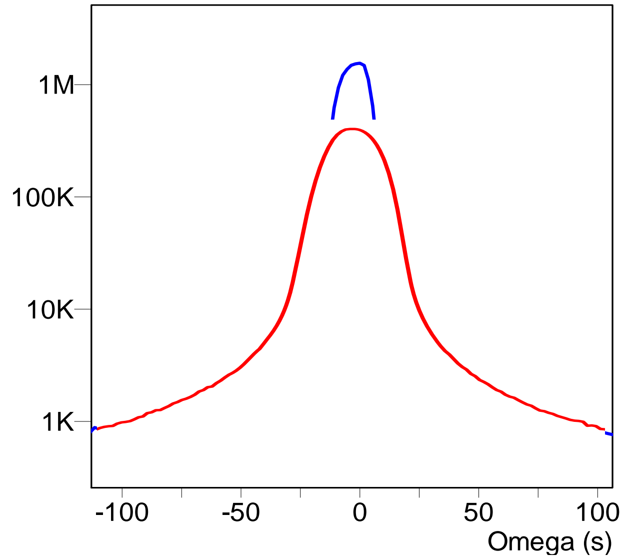


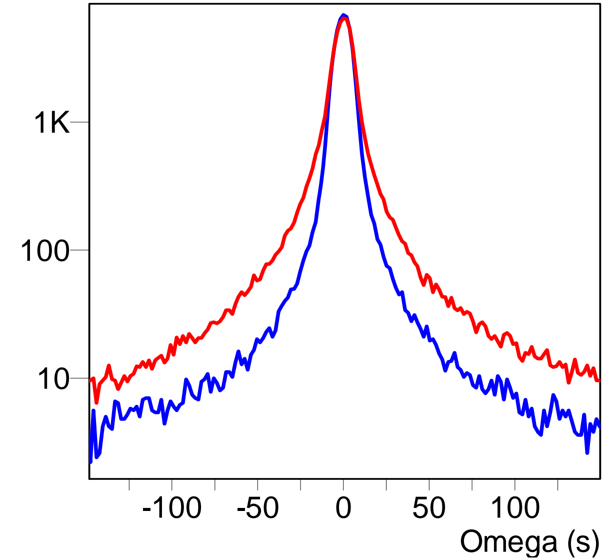
PANalytical X'Pert PRO MRD

X-ray Rocking Curve (RC) measurements









1. Strain

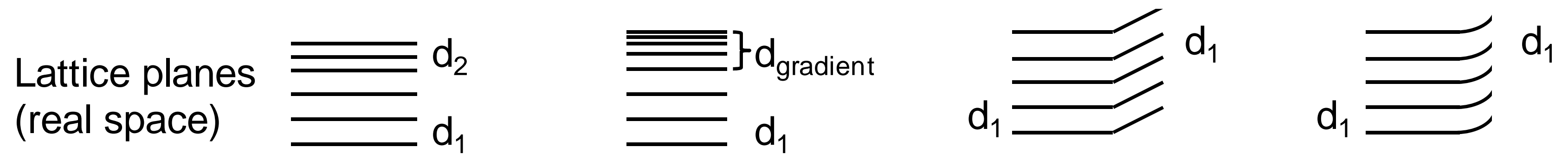
$\varepsilon = \Delta d/d = -\Delta\theta/\tan\theta$
$\delta = E\ \varepsilon$

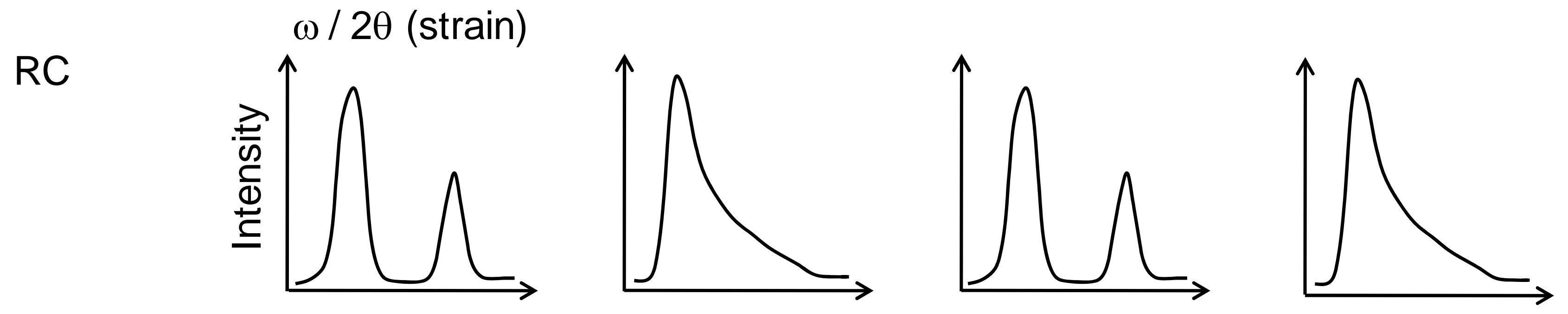
2. Curvature

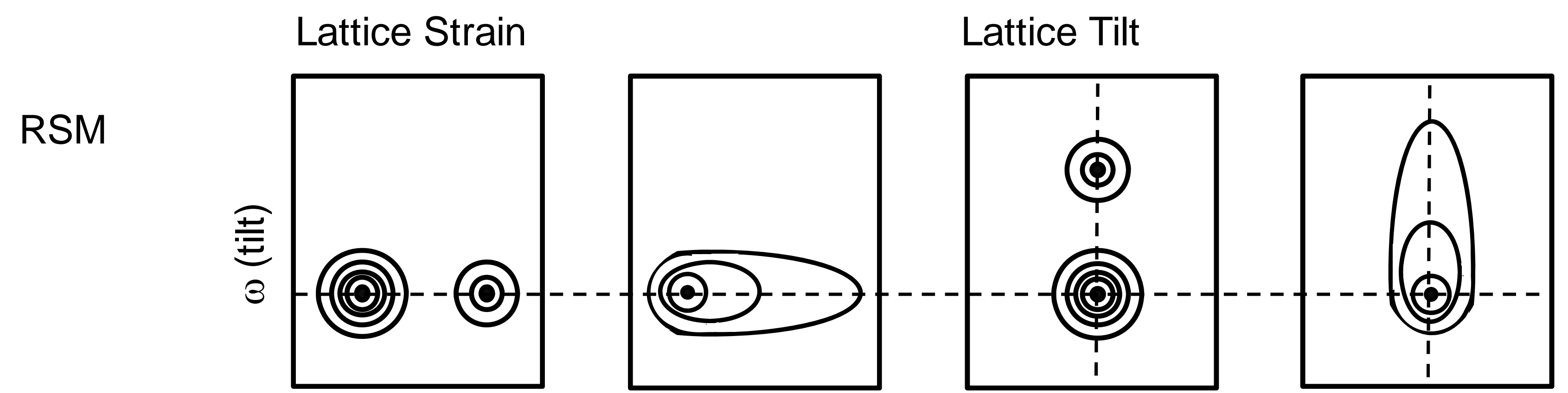
3. Defects from diffused scattering

■ reference

HRXRD for strained layers





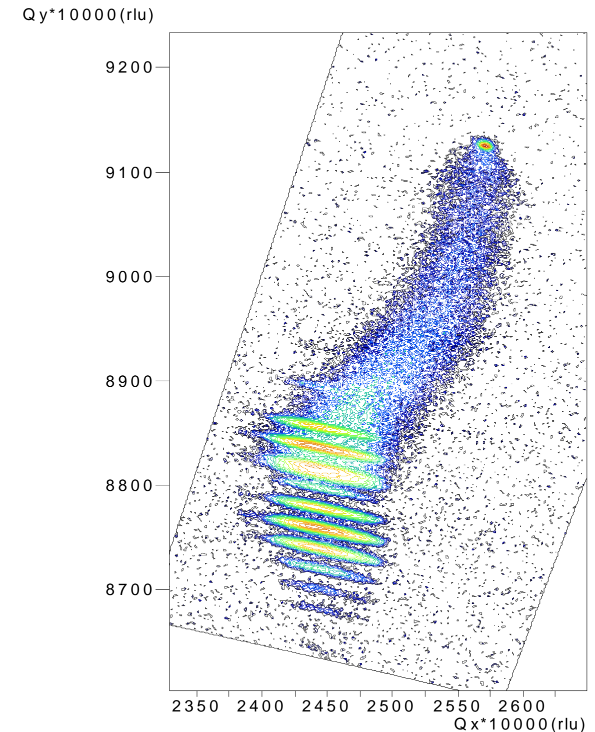


Reciprocal Space Mapping (RSM)

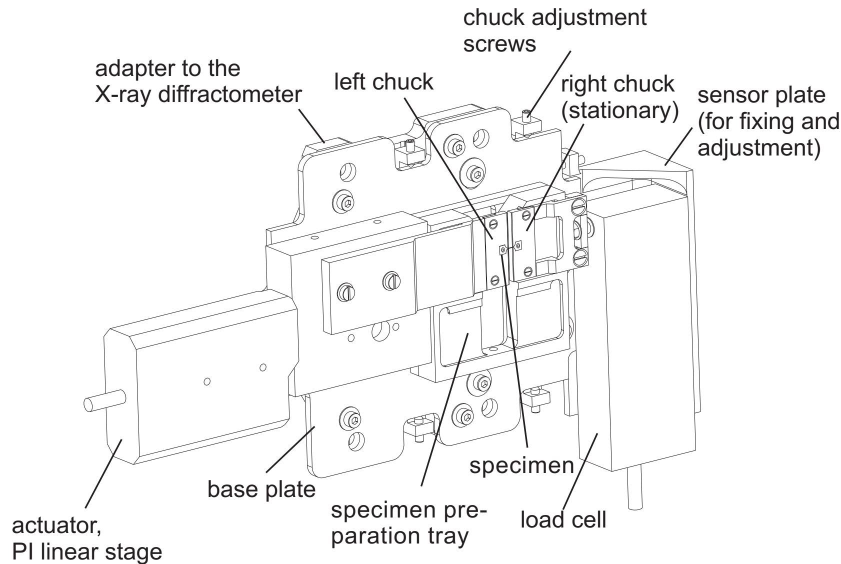
Scattering close to the maximum of a nearly perfect sample can be separate into distinct features:

-Bragg scattering
-surface truncation
-dynamical streak
-diffused scattering (defects in material)

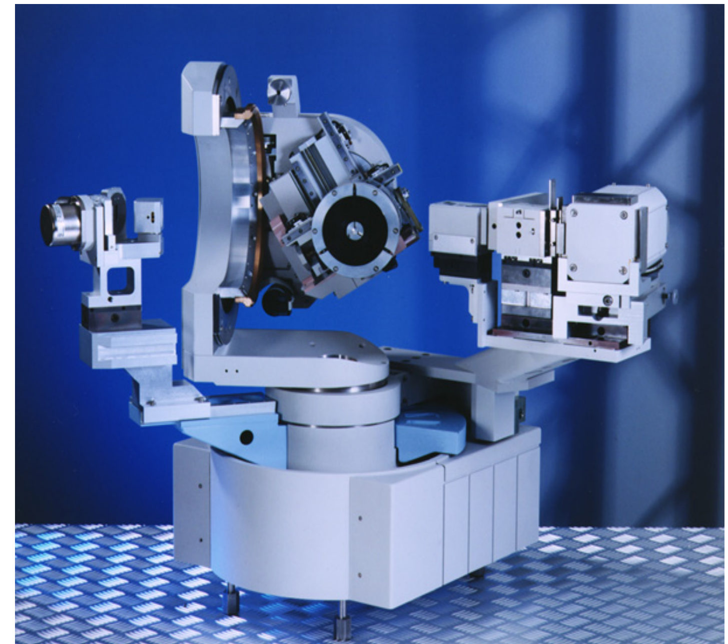
The information of the sum of defects is found.



Bending Test + Tensile Test Instrument: easily adjustable



Structural Analysis by HRXRD

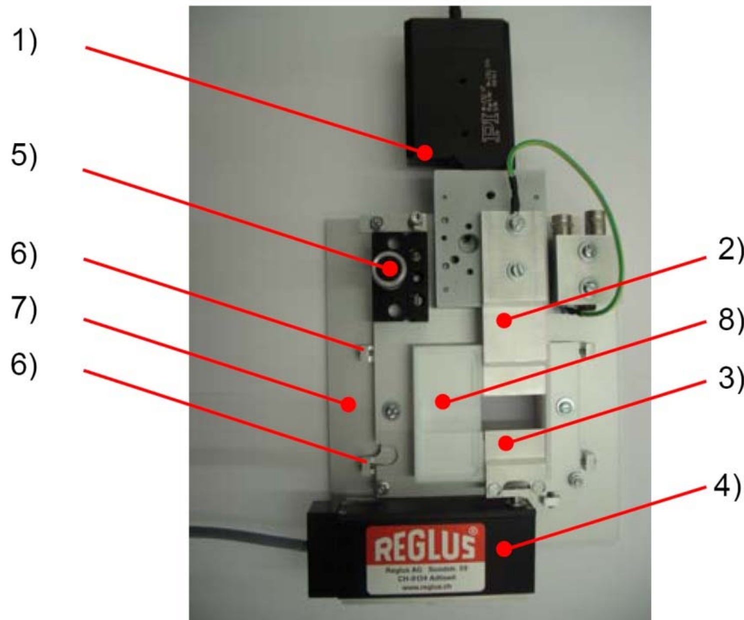


Mounting for In-situ Testing

Development for in-situ testing:

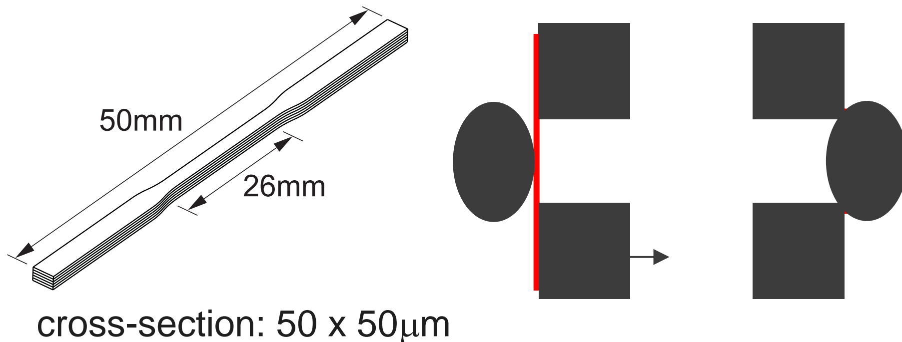
IMES Institut für Mechanische Systeme

ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich



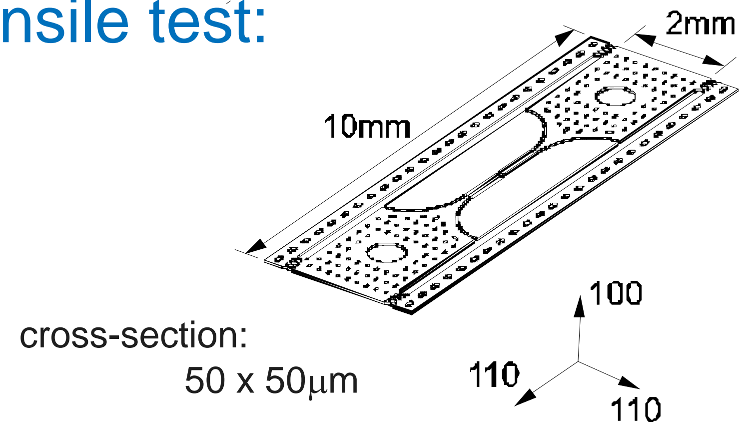
1) Actuator motor
2) Moving support (16 mm)
3) Static support
4) Force sensor (2 N)
5) Manual position adjustment
6) Fixation force sensor
7) Support frame
8) Probe holder

Two point bending test:



cross-section: 50 x 50µm

Tensile test:



cross-section:
50 x 50µm

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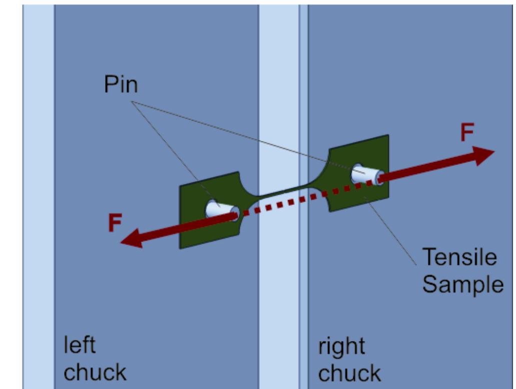
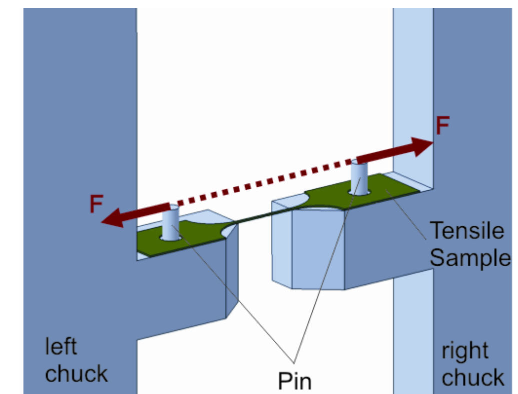
Tensile test: set-up

In-situ mechanical testing :
strain and defect analysis





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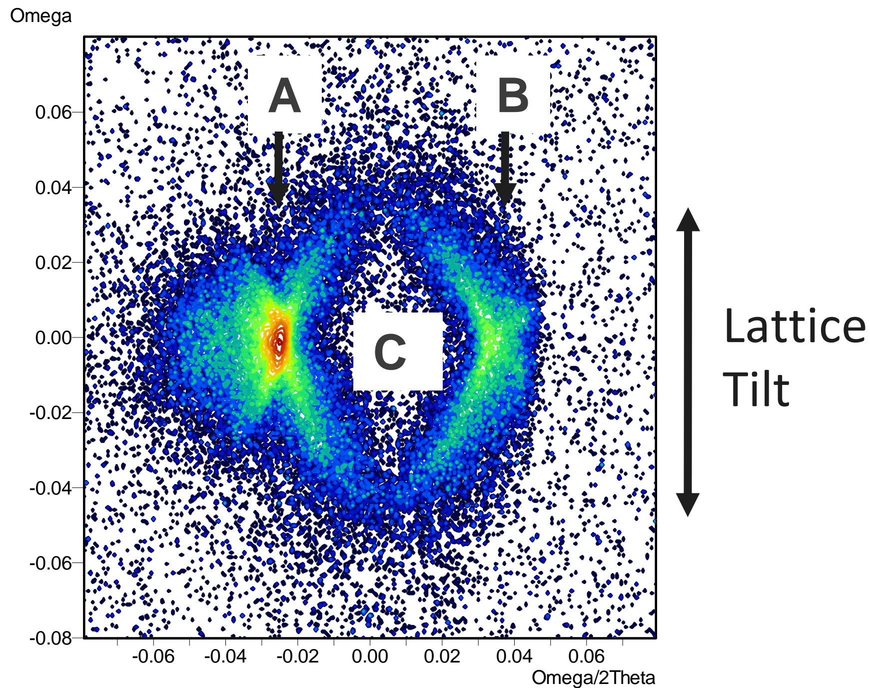
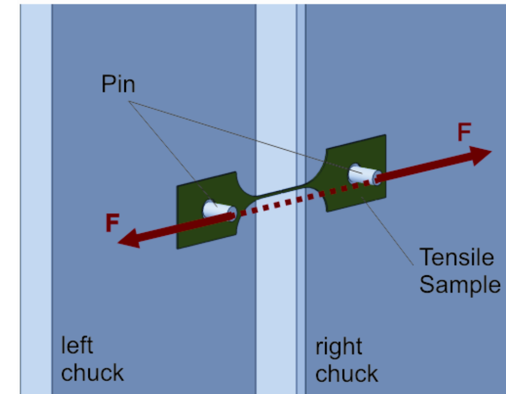
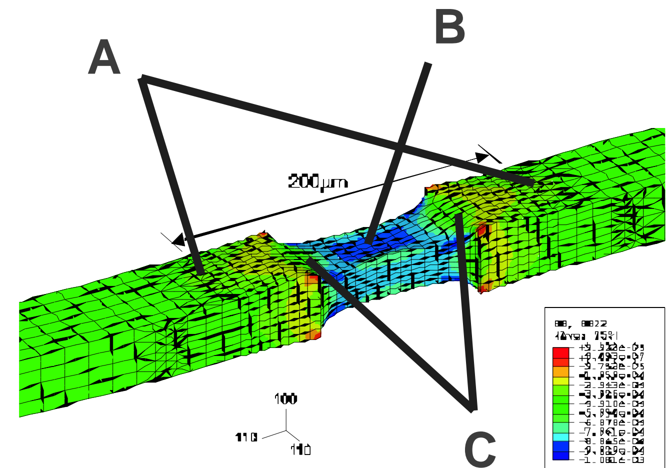
Mechanical Testing: In-situ Tensile Tests on SiSC micro-beams

Example of a tensile test
on SCSi (single crystal, 50μm beam)



Lattice
Tilt





ε= strain = Δd/d

σ = stress = ε x E

Mechanical Testing: In-situ Tensile Tests

Omega

0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06

-0.06 -0.04 -0.02 0.00 0.02 0.04 0.06

Omega/2Theta

Omega

0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08

-0.06 -0.04 -0.02 0.00 0.02 0.04 0.06

Omega/2Theta

Omega

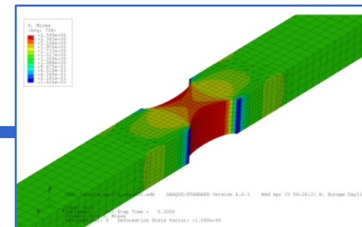
0.10
0.05
0.00
-0.05
-0.10

-0.10 -0.08 -0.06 -0.04 -0.02 0.00 0.02 0.04 0.06 0.08

Omega/2Theta

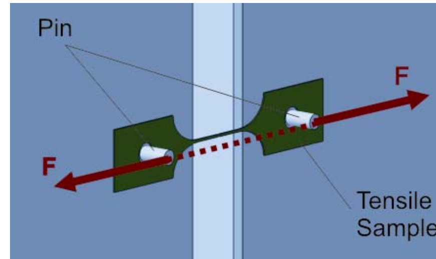
0N

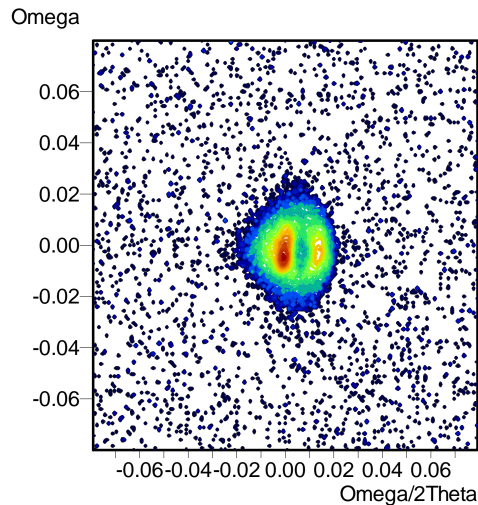
4N



6N

Mechanical Testing: In-situ Tensile Tests

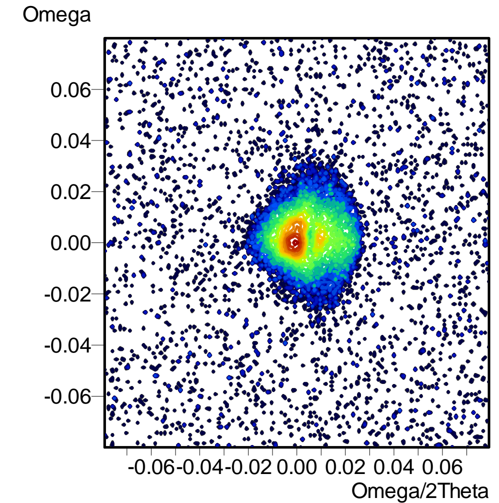




Initial load: 1N

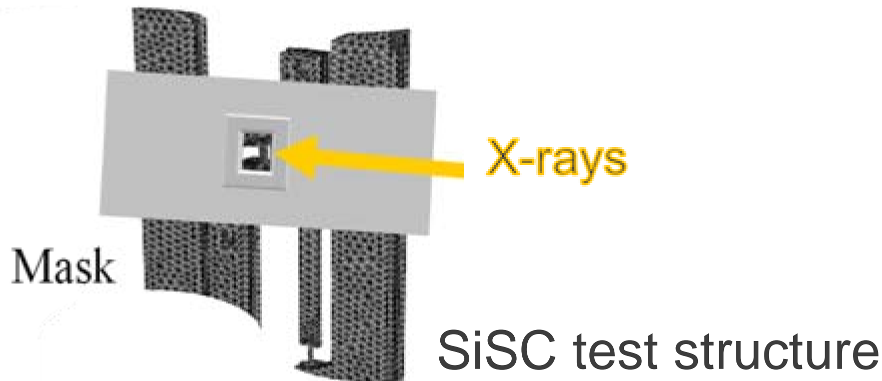
Loading to 6N

+ Relaxation

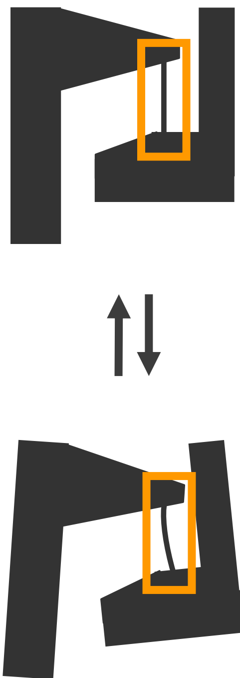


Final load: 1N

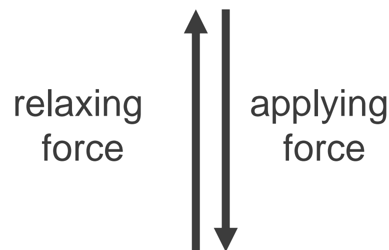
Bending Tests on SiSC beams
HRXRD investigations and simulations



SiSC test structure



1. Relaxed structure (low strain)

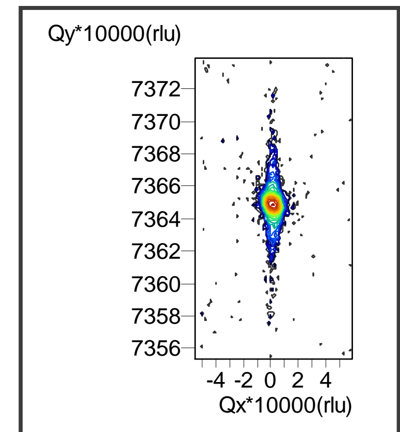


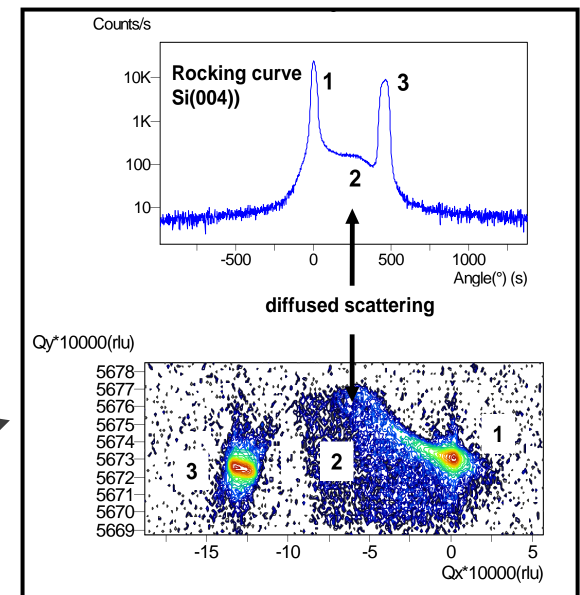
relaxing force

applying force

2. Bended structure (high strain)

RC and RSMs





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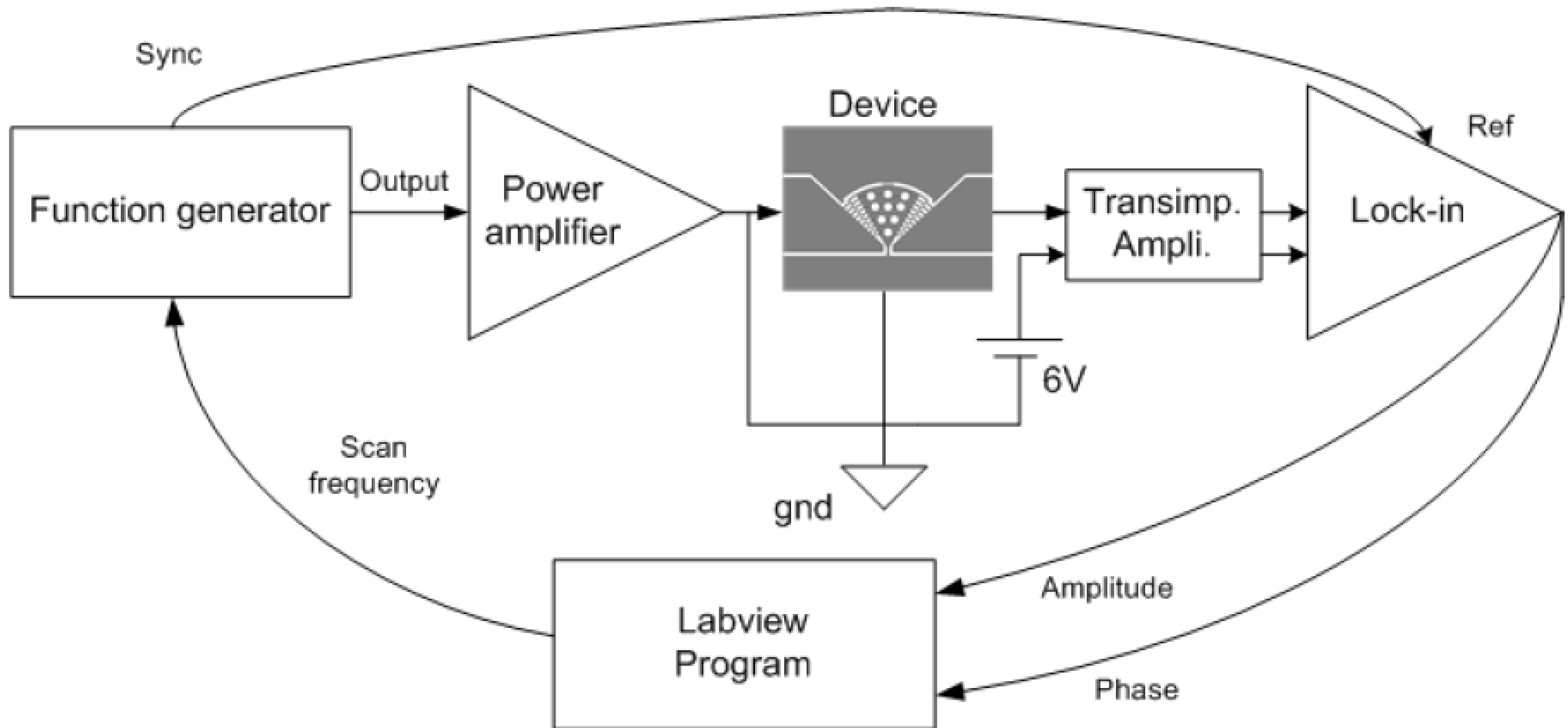
Scheme of the electrical set-up



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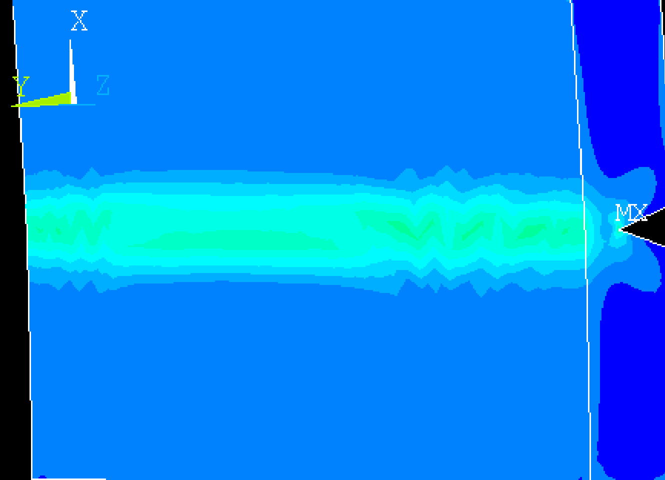
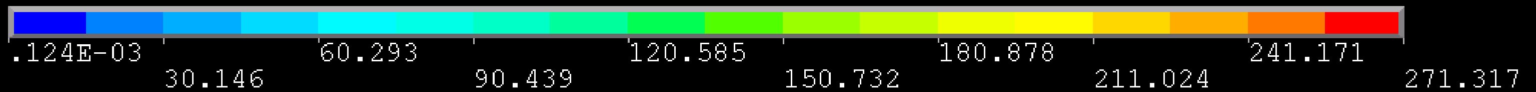
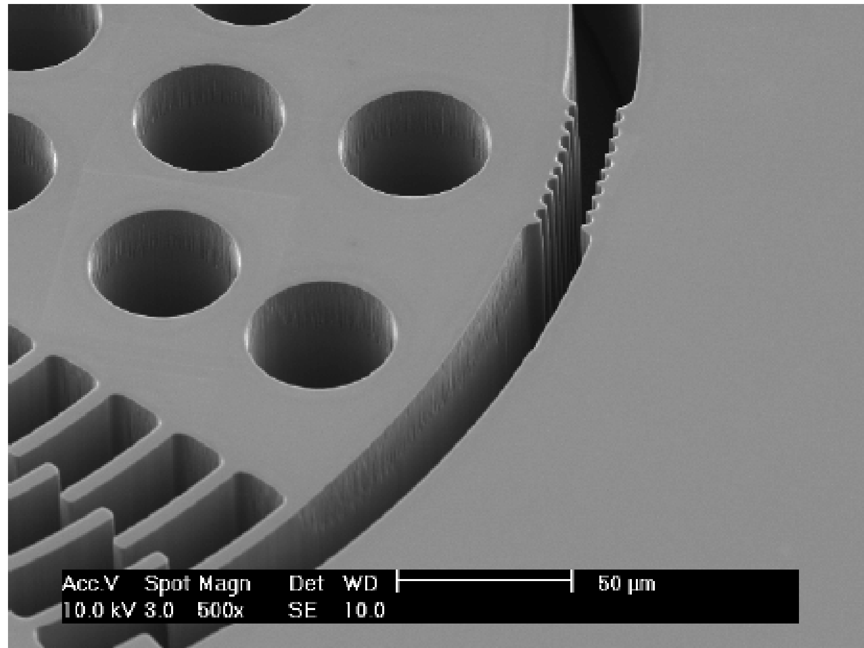


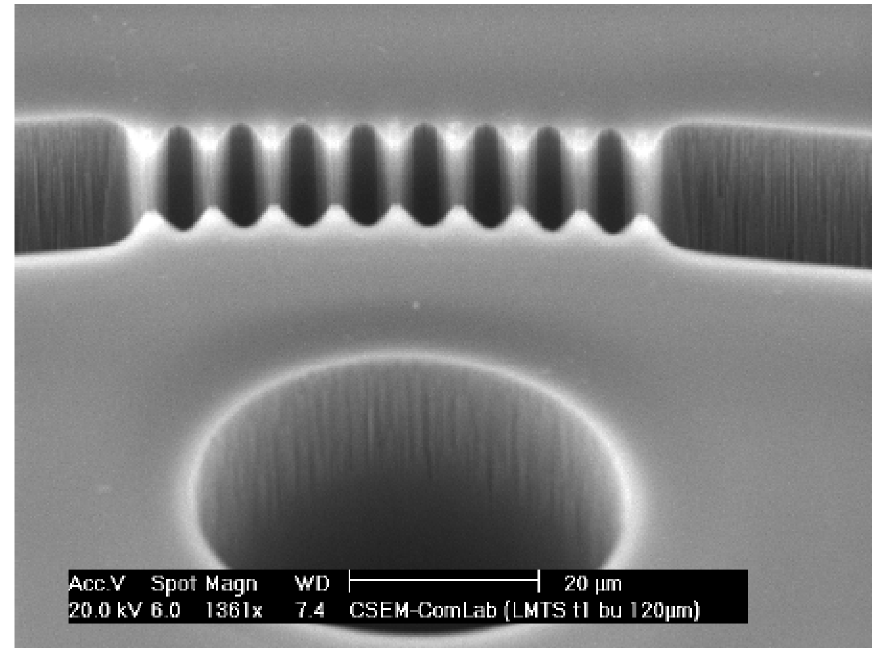
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SINT (AVG)
DMX =1.107
SMN =.124E-03
SMX =271.317
ANSYS
Noncommercial Use Only
JAN 7 2009
16:46:05
X
Y
Z
MX



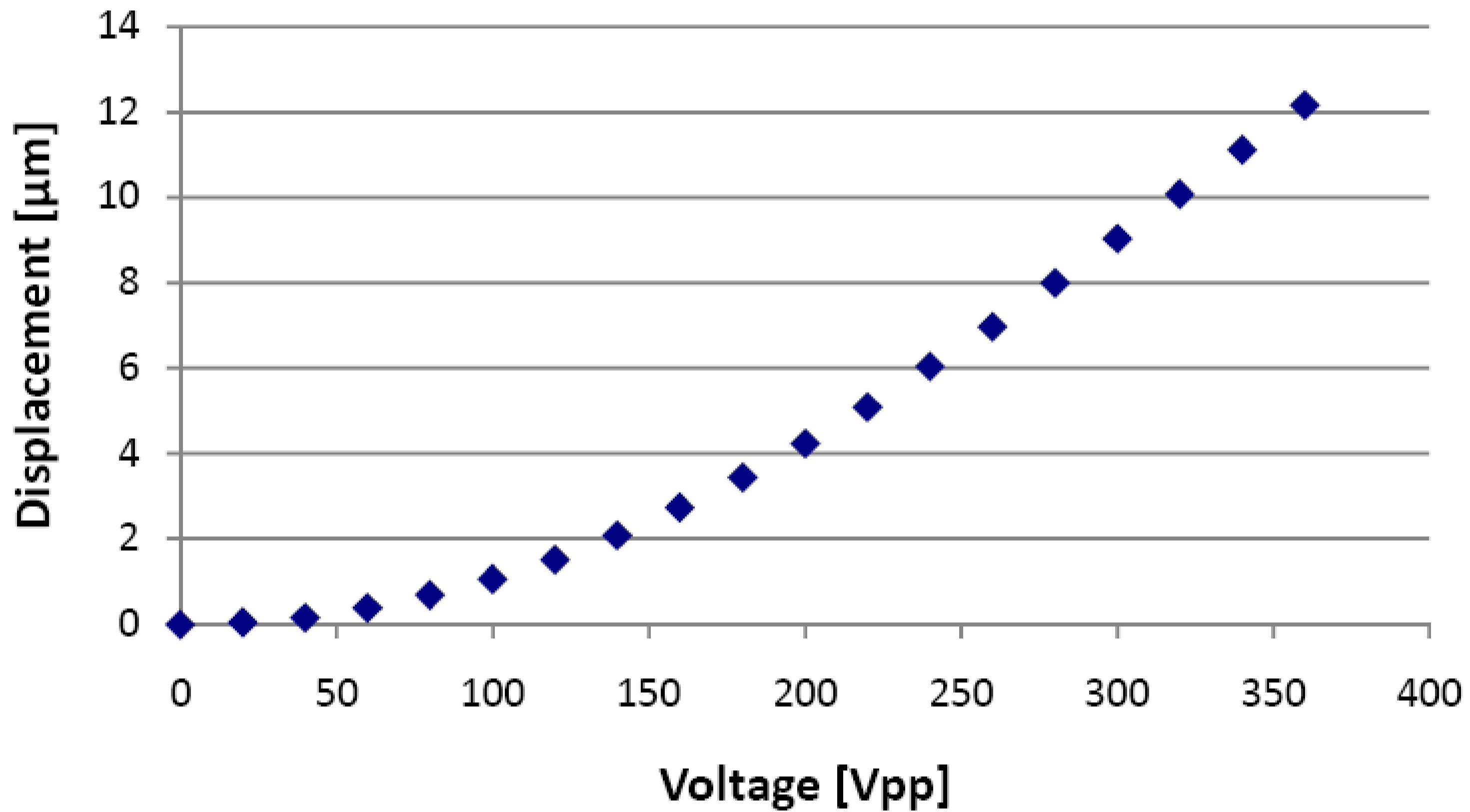
.124E-03
30.146
60.293
90.439
120.585
150.732
180.878
211.024
241.171
271.317

Silicon test device

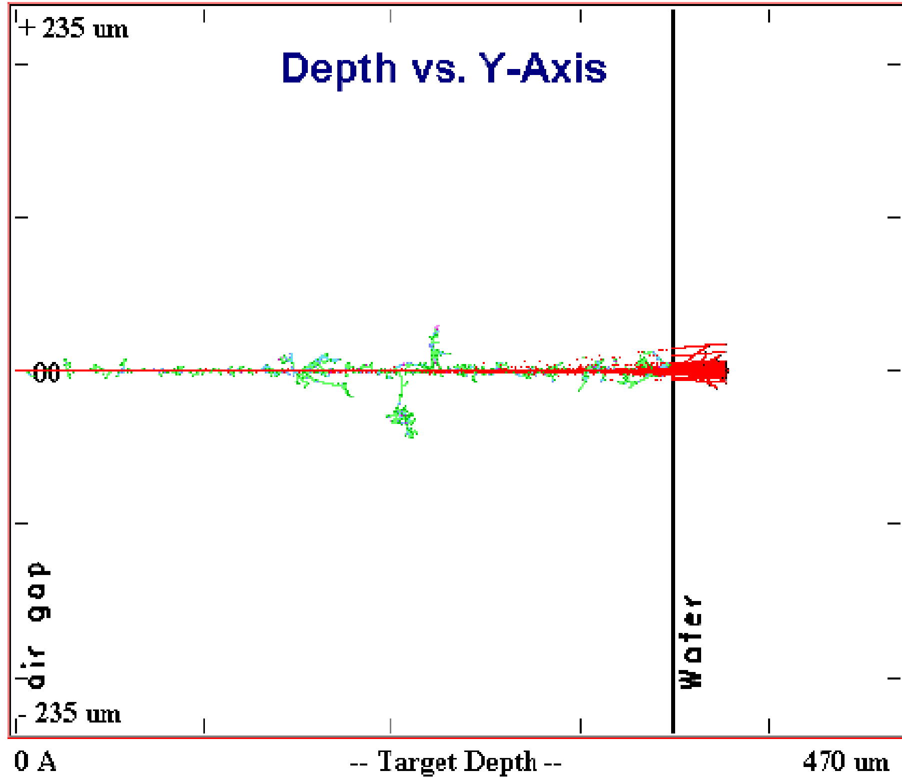


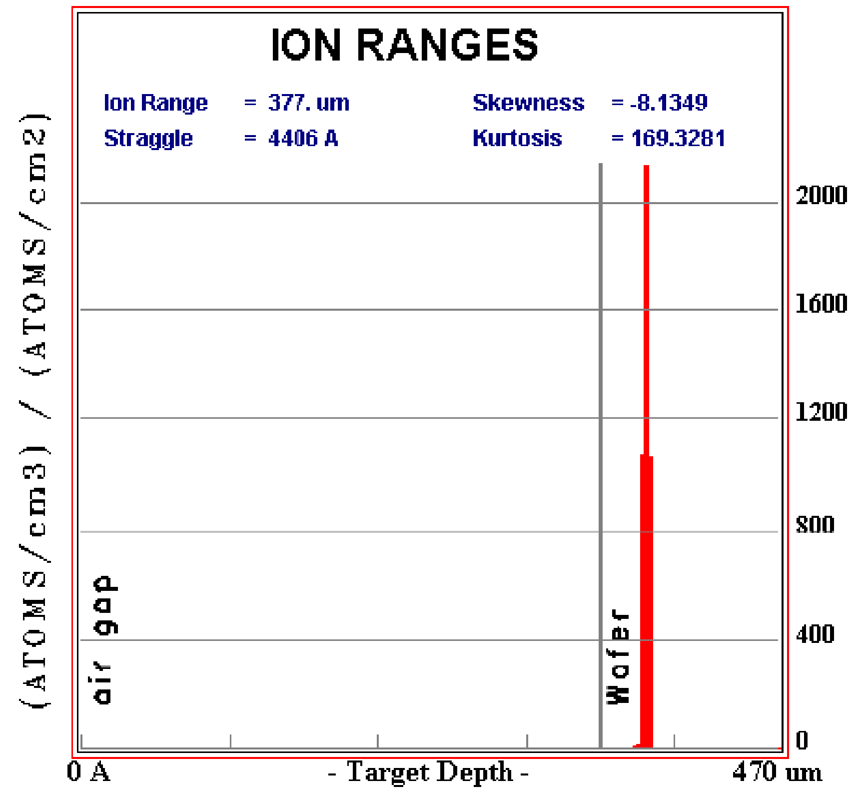


Mechanical Testing

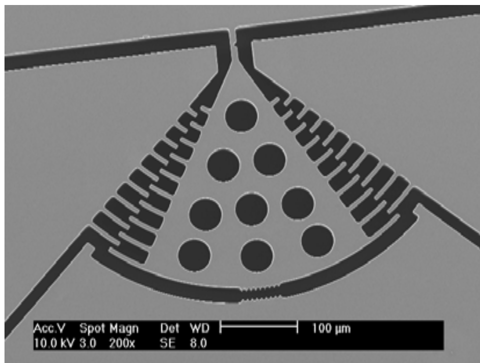


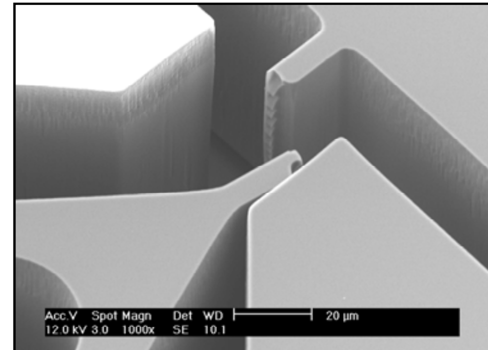
Radiation Damage



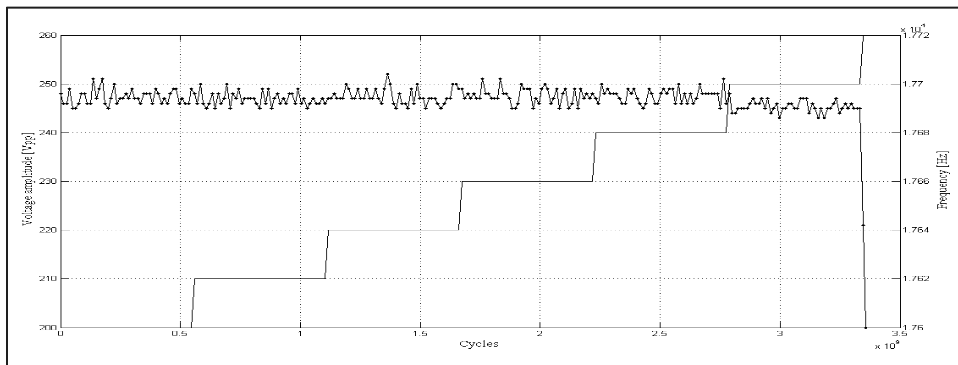


Mechanical Testing: High Cycle Fatigue

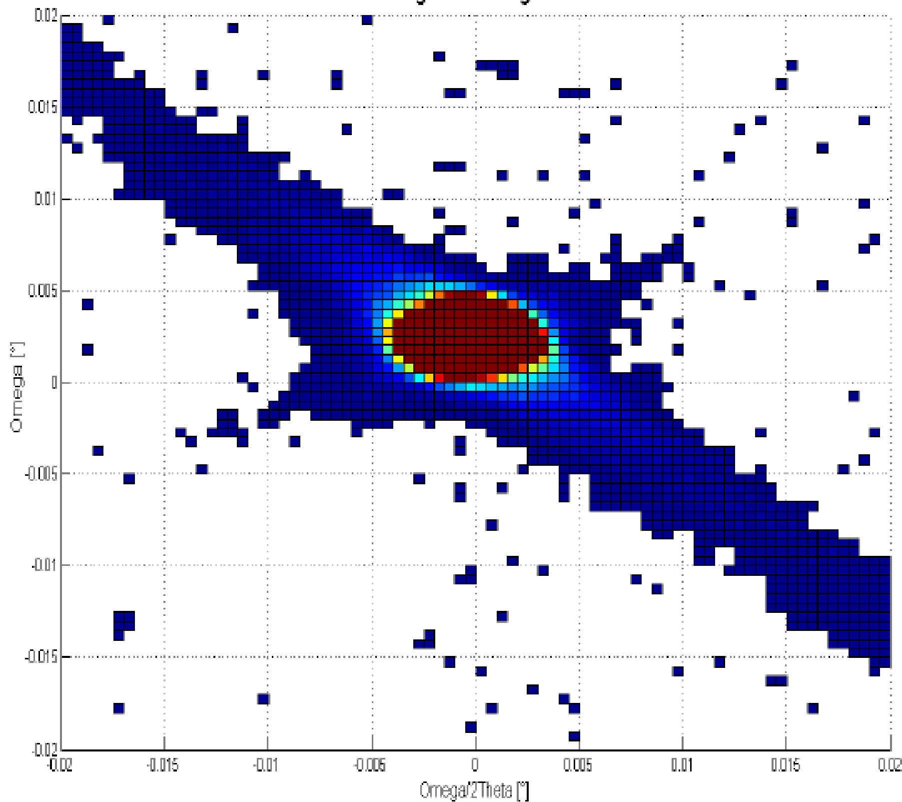


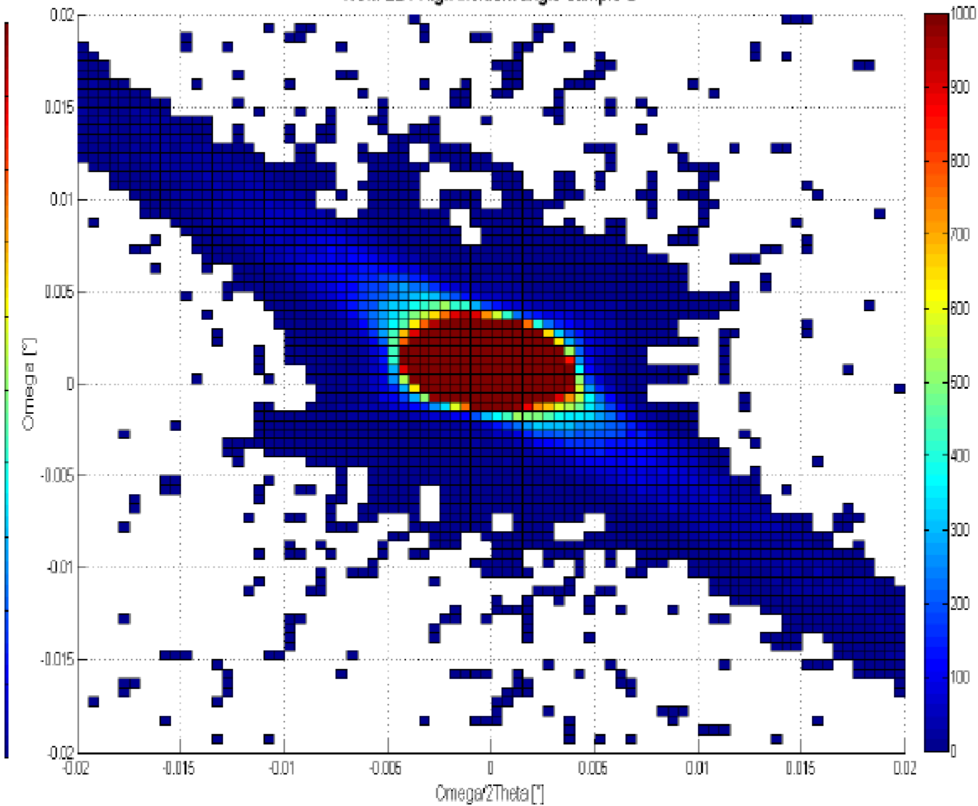


Accelerated aging of MEMS by high cycle fatigue.



Radiation Damage





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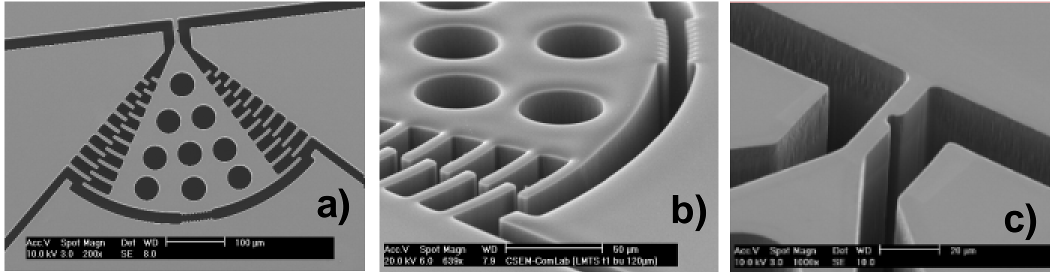
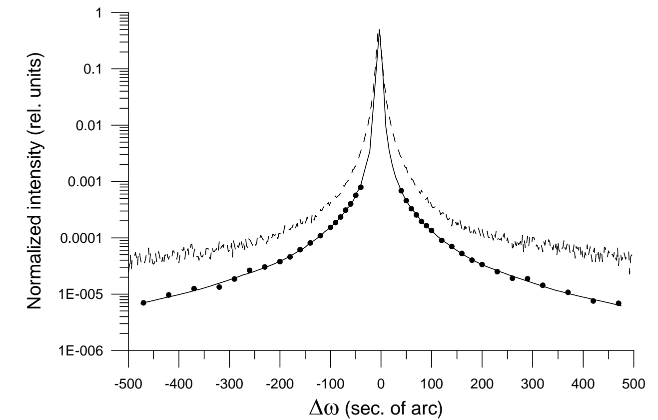
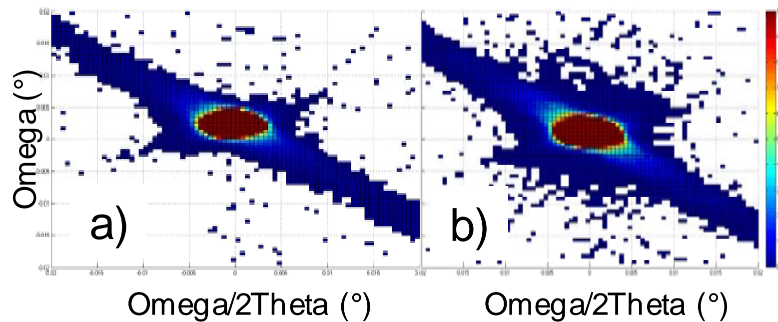
Aging: Radiation Damage

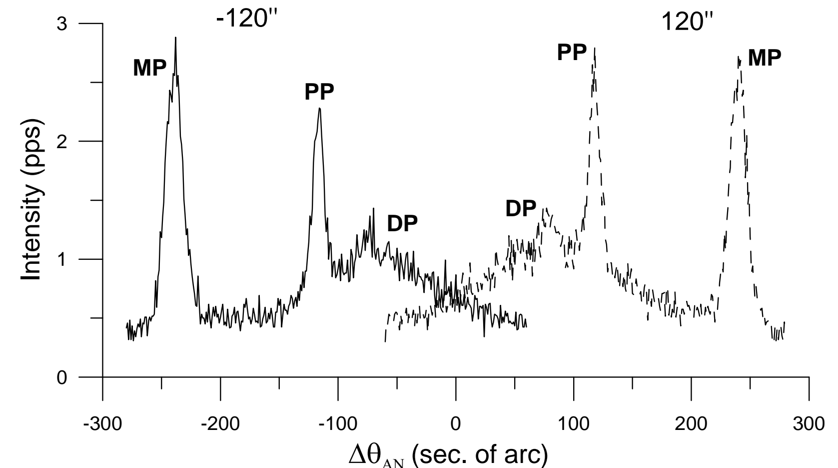




RSMs

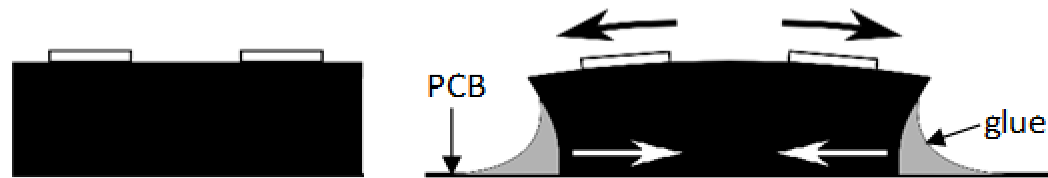


The experimental (dots) and fitted (solid line) TCD intensity curves. Dashed line is the double-crystal rocking curve (for comparison).

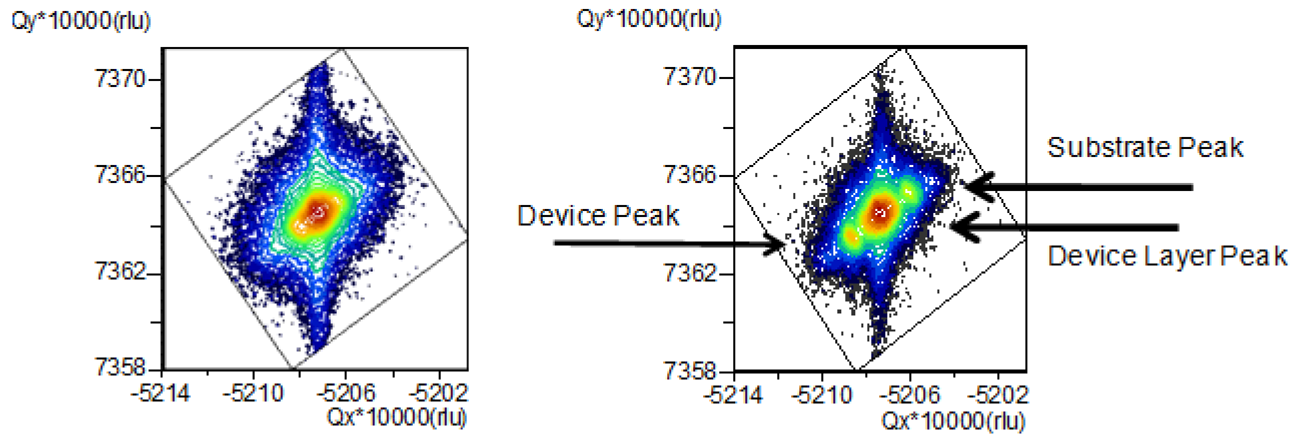


Wide TCD-spectra obtained at positions of the specimen = -120” (solid line) and = 120” (dashed line).

Packaging



Scheme of a chip (a) before bonding and (b) after bonding

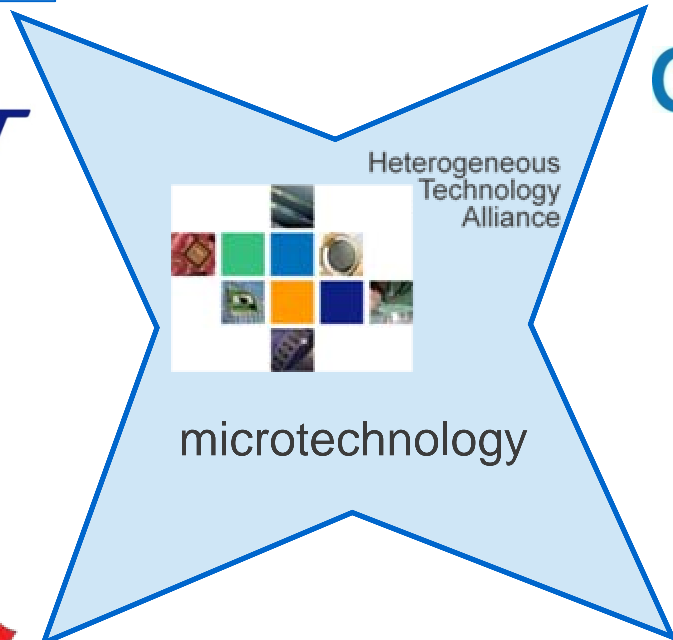


RSM on the Si(224) reflection at high incident angle

The Joint Reliability Team

EUCEMAN –
European Center
for Micro and Nanoreliability

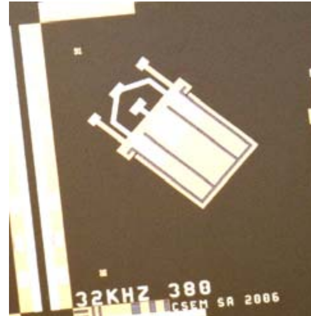
csem



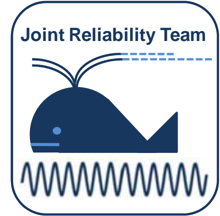
Fraunhofer Verbund Mikroelektronik

WALES « WAfer Level Encapsualtion for micro-Systems »

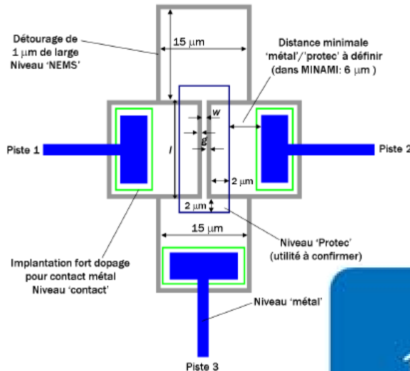
Piezoelectric Resonator
(20kHz – 1MHz)



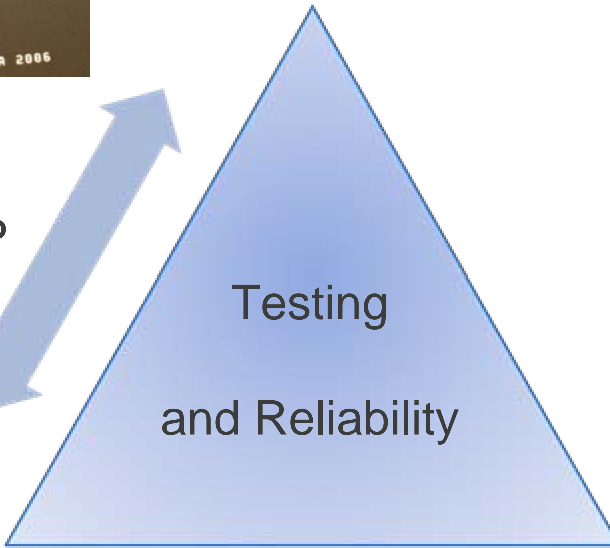
CSEM:
1) Fabrication
2) WLP
3) Testing

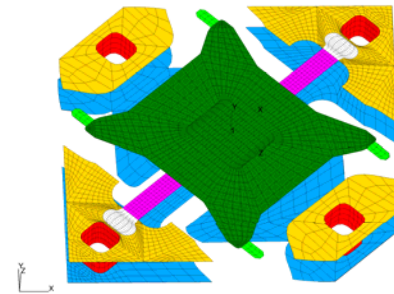


Capacitive Resonator
(100kHz – 10MHz)



WLP





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

Fraunhofer Gesellschaft:
1) Hermeticity
2) Testing

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Thank you for your attention !