Thermal Laser Stimulation for MEMS characterization and failure analysis, from principles to case studies

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Purpose

- *Demonstrate how techniques primarily dedicated to Integrated Circuit Failure Analysis can be used for MEMS expertise*
- *Give a focus on Thermal Laser Stimulation techniques that are not only helpful for fault localization but also to study reliability behavior of MEMS devices*
- *Show how it brings unique information that could not be easily found by other means*
- *Validate it through two case studies*

Outline

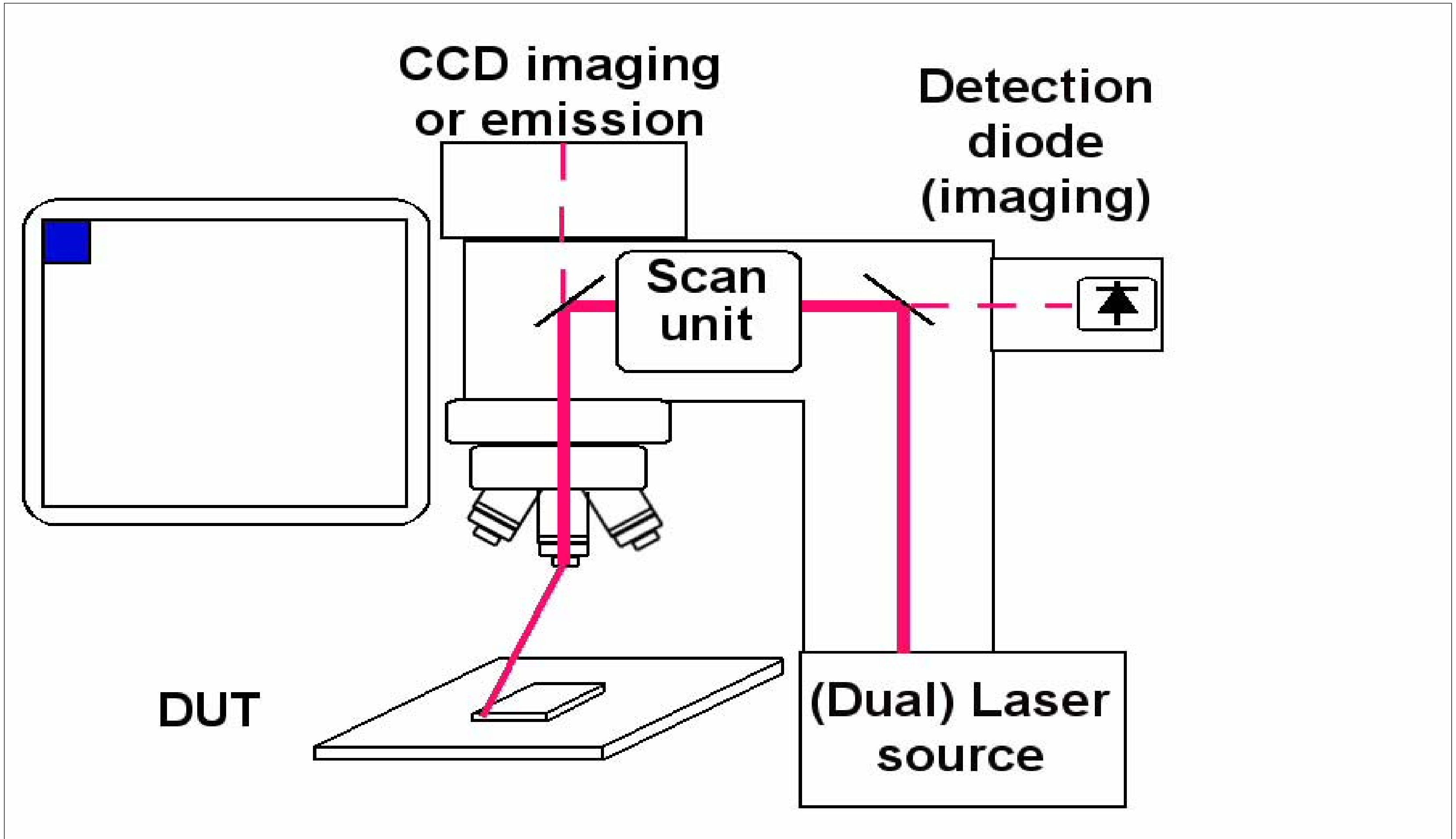
- *Introduction*
- *Thermal Laser Stimulation*
  - Apparatus
  - Resistance change principle and application
  - Seebeck effect imaging principle and application
- *Micro-Heating Elements Suspended on Thin Membranes*
  - Micro-heating sample description
  - Reliability test results
  - TLS studies
- *Micro-relay*
  - Sample description
  - TLS studies
- *Conclusions*

Introduction

- *How can we perform MEMS expertise?*
  - Material / mechanical approach
    - Physical characterization to access material properties
      - Surface and volume
      - Thermal, optical, mechanical
      - Tools: Nanoindenter, profilometer, interferometer
    - Specific failure mechanism
      - Mobile parts …
  - Electronic point of view
    - Electronic function: sensor, signal processing, actuator
    - Electronic FA Tools
  - Two complementary approaches to cover “system” approach

- *Specific approach mixing “mechanical” and “electrical” (i.e. contact)*

TLS Principle : LSM



TLS Principle : OBIRCH, TIVA

- *Resistivity slightly changes with temperature. Under local thermal laser stimulation, local resistivity change occurs*

$$\Delta R = \frac{\rho_0 L}{S}\left(\alpha_{TCR} - 2\delta_T\right)\Delta T$$

α_{TCR} = 4,29x10^{-3}

Aluminum

δ_T = 2,36x10^{-5}

- *Other materials*
  - Metal α_{TCR} >0, δ_T >0
  - Polysilicon or doped Si, α_{TCR}, δ_T >0

$$\Delta I = -\left(\Delta R / R^2\right)V$$

- *Voltage source (OBIRCH: K. Nikawa)*

- *Current source (TIVA: E. Cole)*

$$\Delta V = \Delta R \cdot I$$

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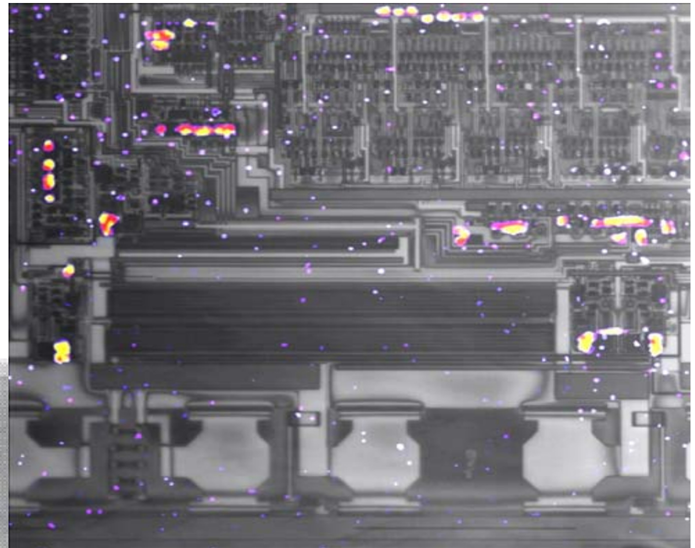
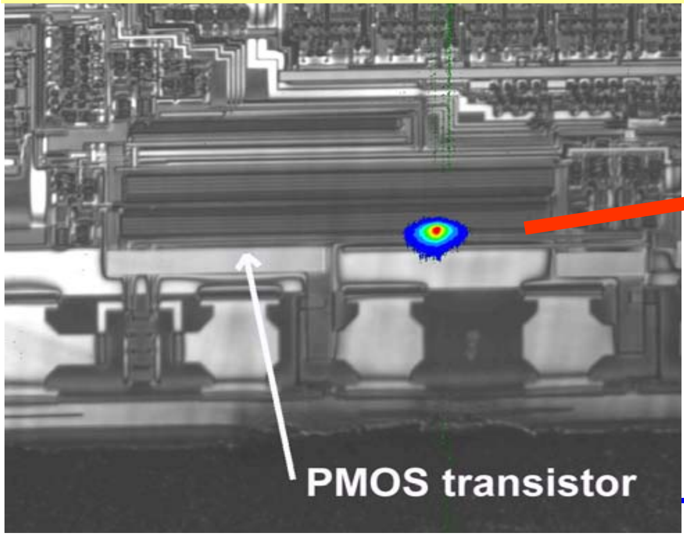
TLS application in IC Failure Analysis

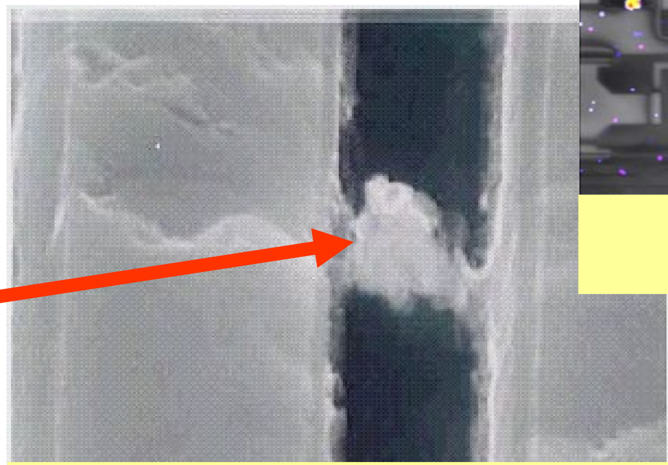
- *Direct defect localization (short circuiit)*
- *Circuit BICMOS (I = 85mA)*
  - Leakage current on some I/O
    - I > 100 µA instead of I < 10 µA
  - 4 interconnection layers



BS EMMI (20x)

BS TLS (20x)

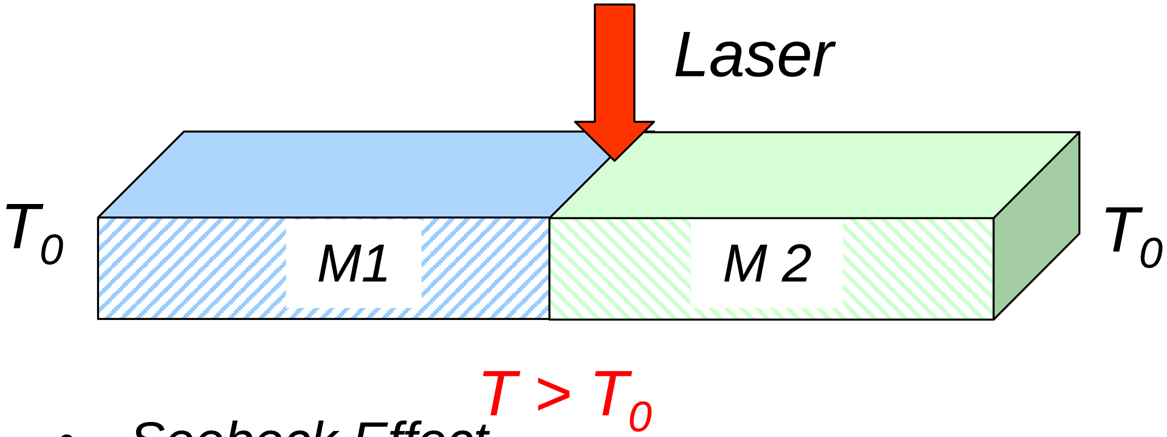




W short (électrodes Drain-Source)

Si ~ 290 µm
Lightly doped

TLS principle: Seebeck Effect Imaging



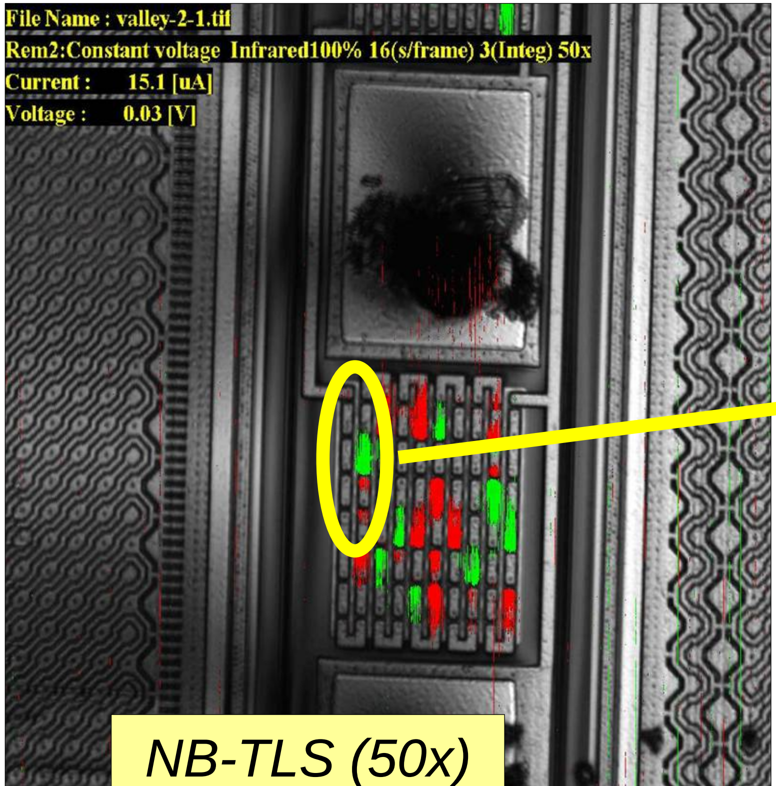
Material	Q_{12} (µV/°C)
Al / W	7,0
Al / n+ Poly	-121
Al / n+ Si ($10^{20}cm^{-3}$)	-105

- *Seebeck Effect*
  - Two materials
  - Temperature difference
  - => induce a voltage between material
- *NB_TLS*
  - No Biased TLS
  - SEI Seebeck effect imaging
- $\Delta V = V_{12}$

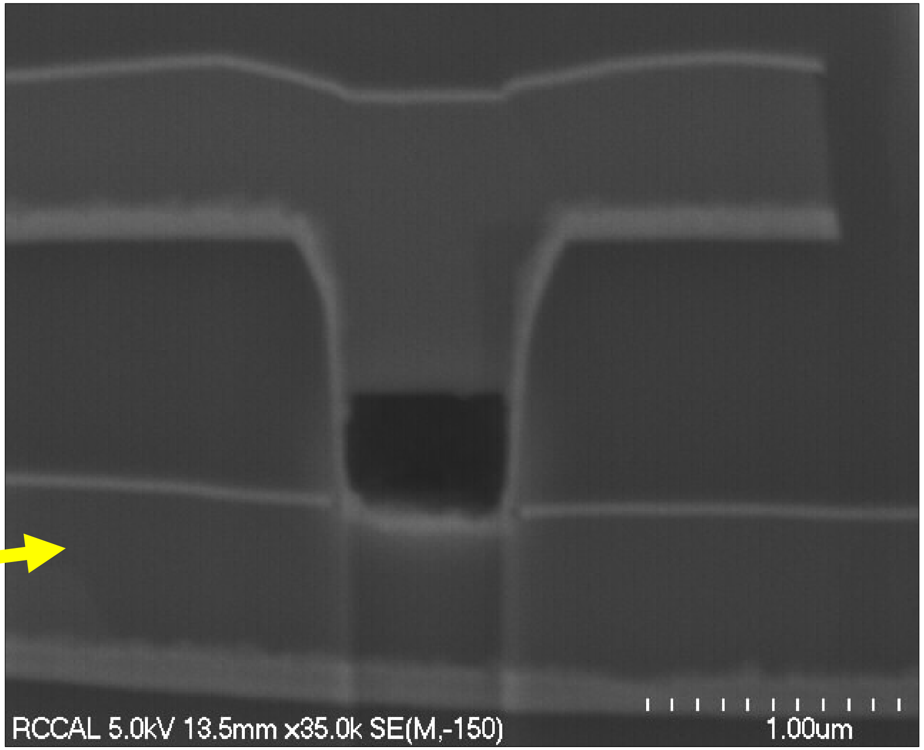
$$V_{12} = (Q_1 - Q_2)(T - T_0) = Q_{12}(T - T_0)$$

NB TLS application in IC Failure Analysis

- *Vias M1-M2*
- *R=7.14 (spec R=0.8 Ohm)*



NB-TLS (50x)



Courtesy of Abdellatif Firiti,
ST Microelectronics

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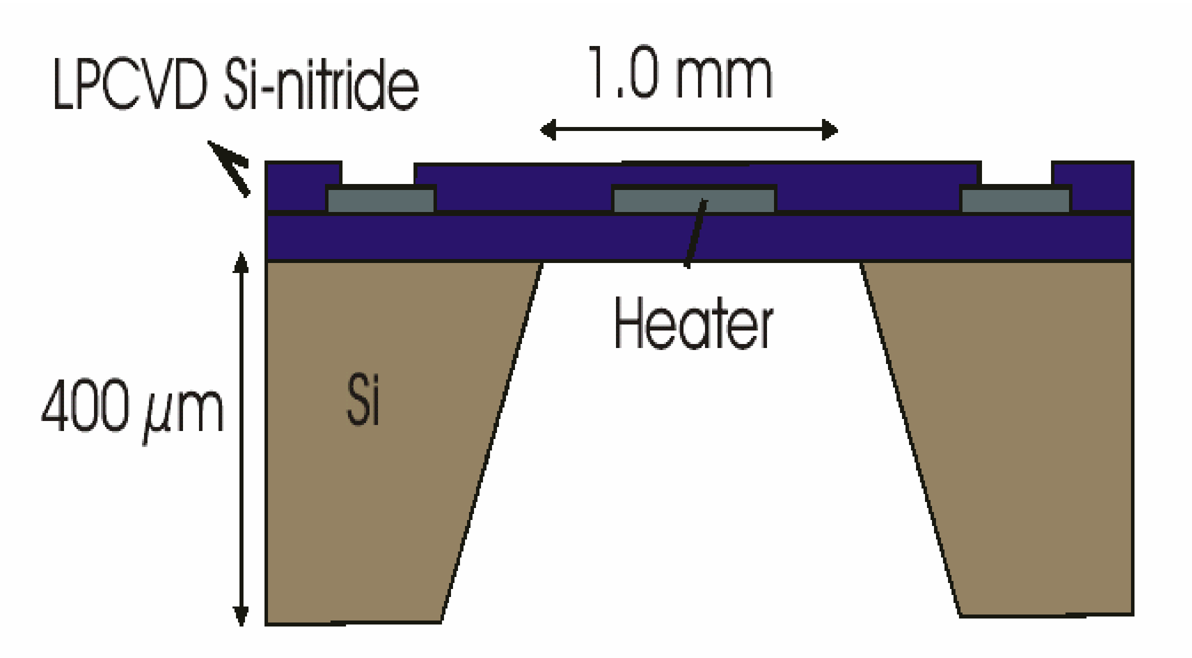
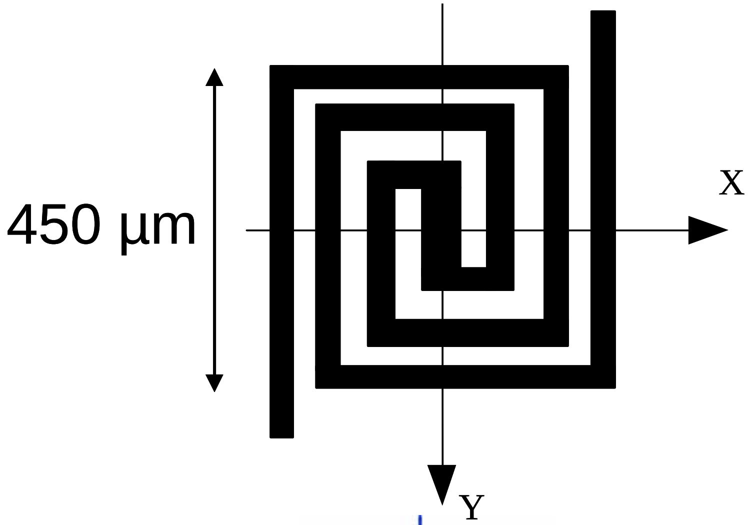
Micro-Heating Elements Suspended on Thin Membranes (MHESTM)

- *Manufacturing process*
  - Si nitride (0.5 µm) deposited on Si substrate
  - Pt (210 nm) and Ta (15 nm) coating
  - Second Si nitride deposit (0.5 µm)
  - Si etching

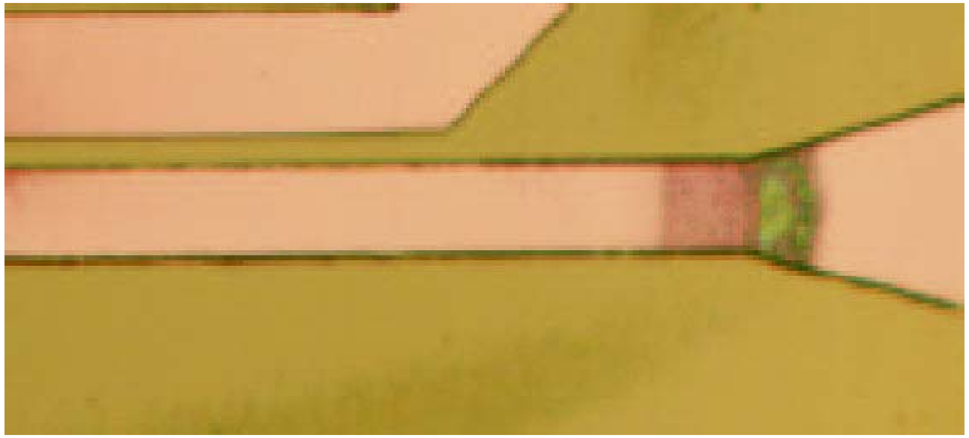
Applications:
- Thermal sensor
- Thermal actuator
- Gaz sensor
- …





MHESTM reliability test

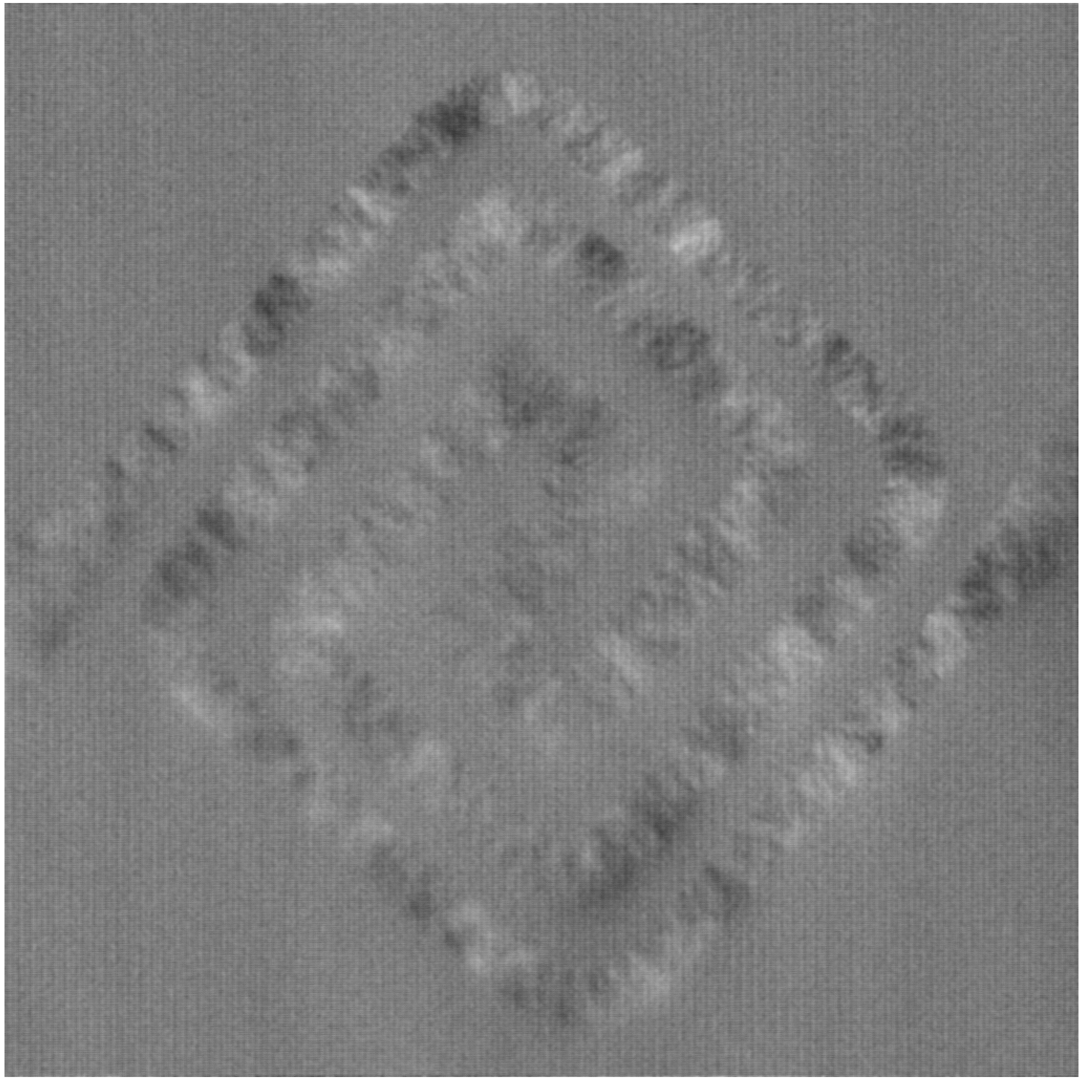
- *Performed by the Neuchâtel Institute of microtechnology*
  - Temperature measured using micro-thermocouples
  - Warping, buckling measured using an optical profilometer
  - Record of resistance value versus temperature
  - Degradation at 575°C after 2000h (resistance increases)
- *« MEMS » Failure Analysis*
  - Electro migration / stress migration site at the spiral start



  - Identification of some critical process steps
  - Why did we get this? => real time monitoring is mandatory
  - Optical microscopy did not give results

→ TLS

NB TLS on MHESTM (1)



- *Initial (before any kind of stress)*
  - SEI Image
  - Thermocouples
  - => Bad homogeneity
    - » Other acquisitions
  - After stress
    - Start
    - 5,8 V (138 mW)
    - Stop
    - Ambient temperature
    - NB TLS Measure
    - Start again

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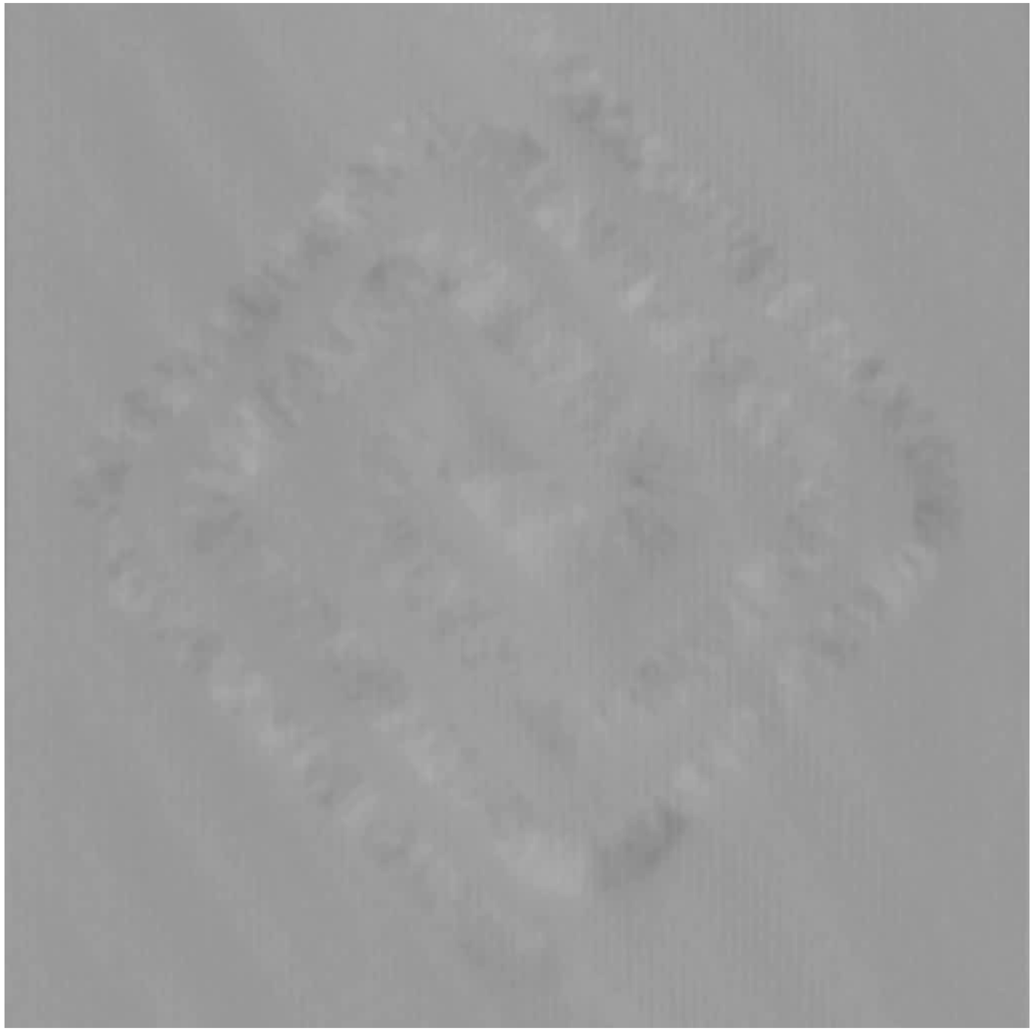
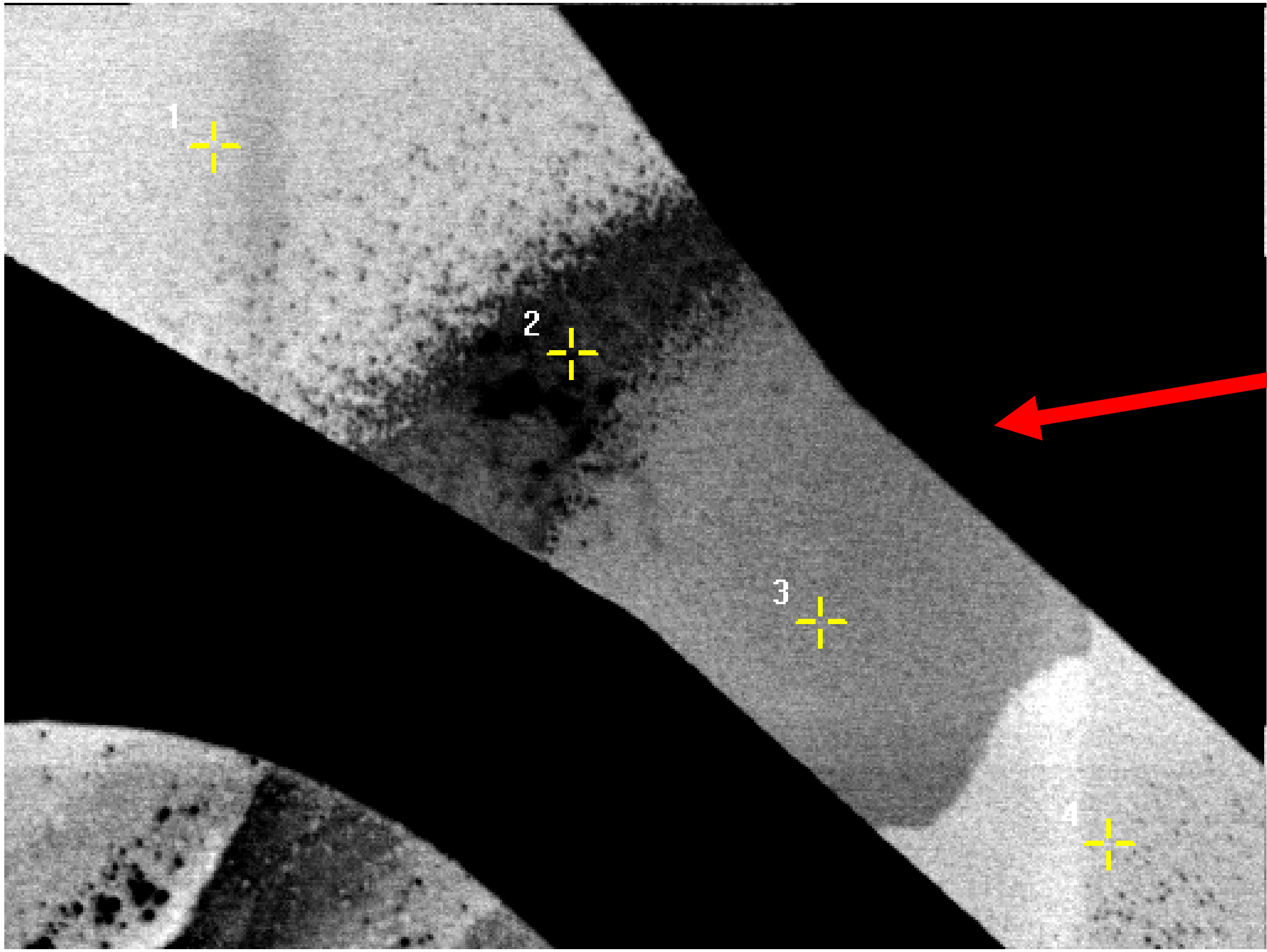
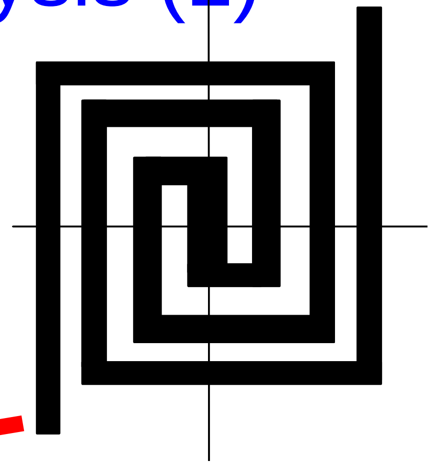
NB TLS on MHESTM (2)



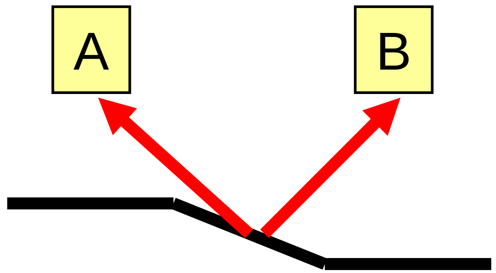
- *Aging monitoring*
  - From 0h to 14h
  - 3 different samples
  - Same signature
- *NB-TLS applications*
  - Characterization of different process flow
    - Homogeneity issues
    - Thermal stress only
    - Mechanical stress only

MHESTM: complementary analysis (1)



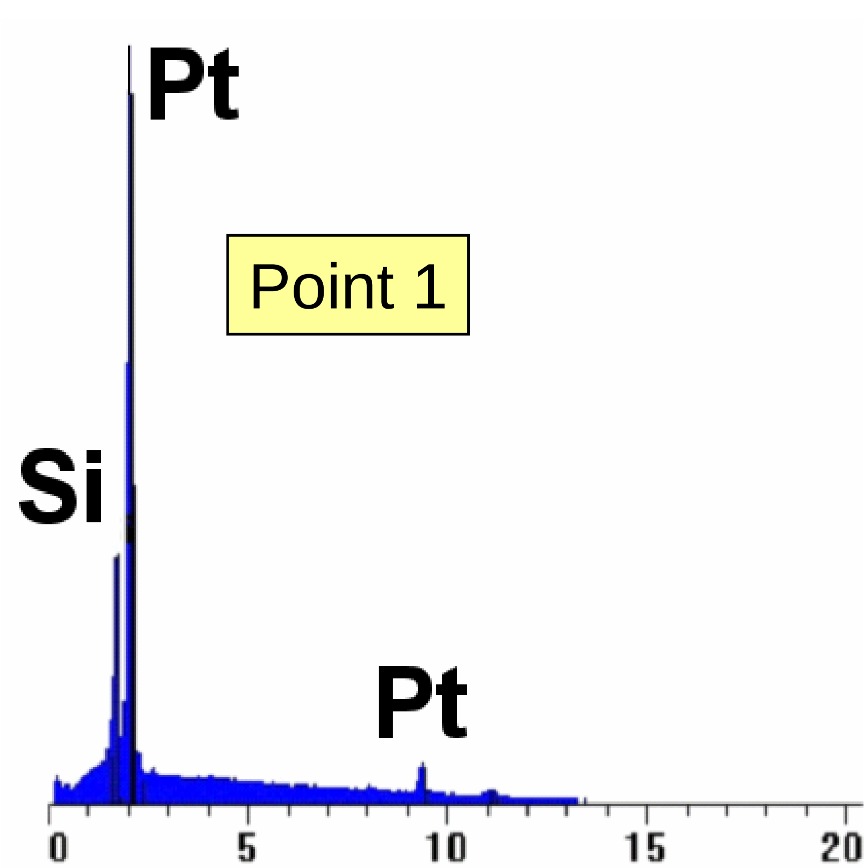


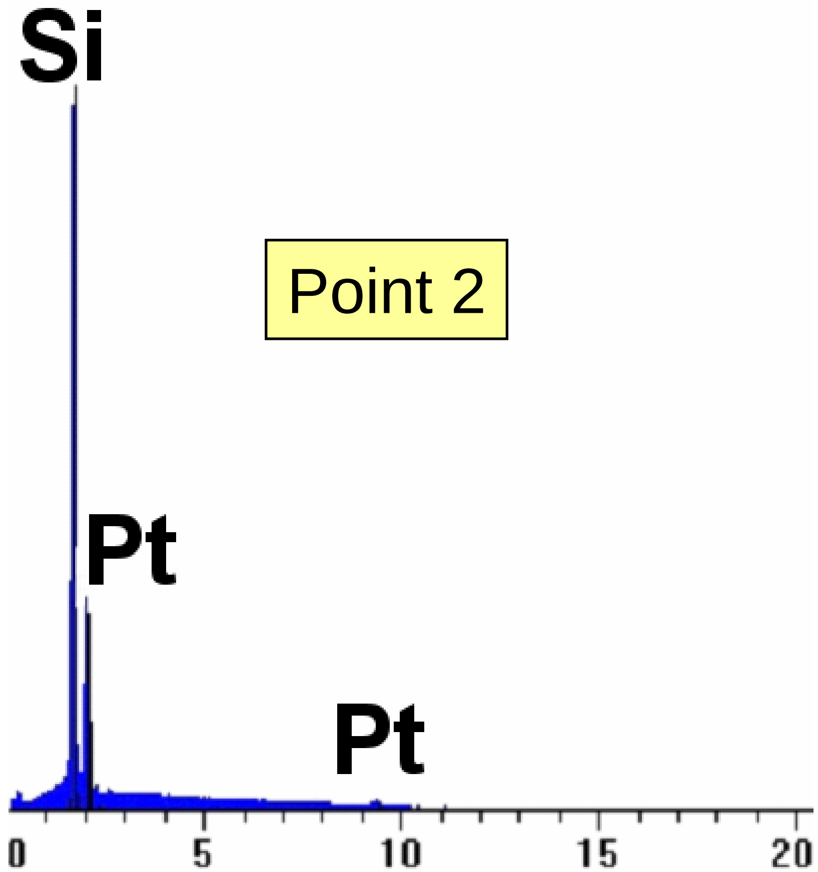
MEB:
Back scattered A+B
(composition mode)



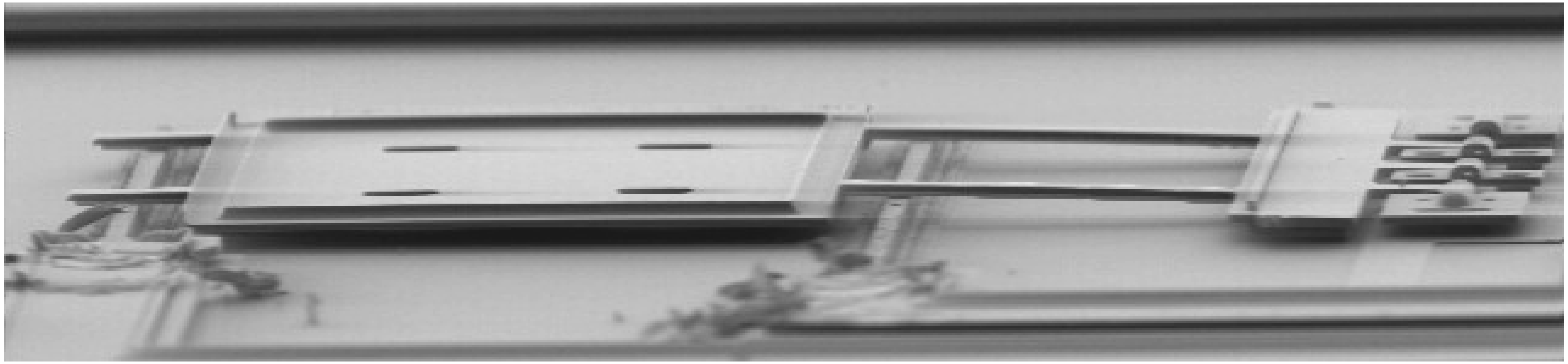
MHESTM: complementary analysis (2)

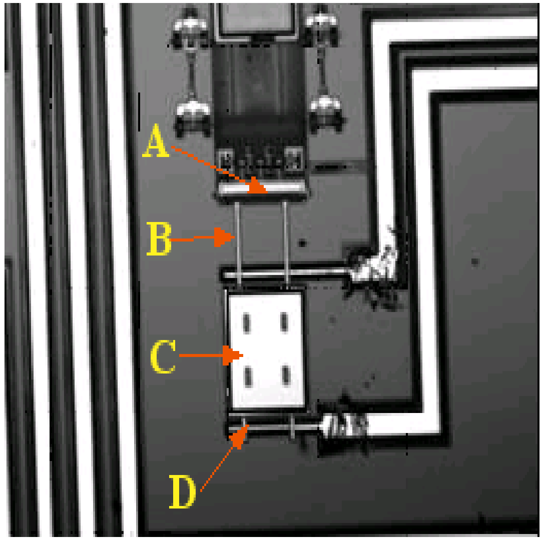
- *X microanalysis*





Micro-relay: sample description

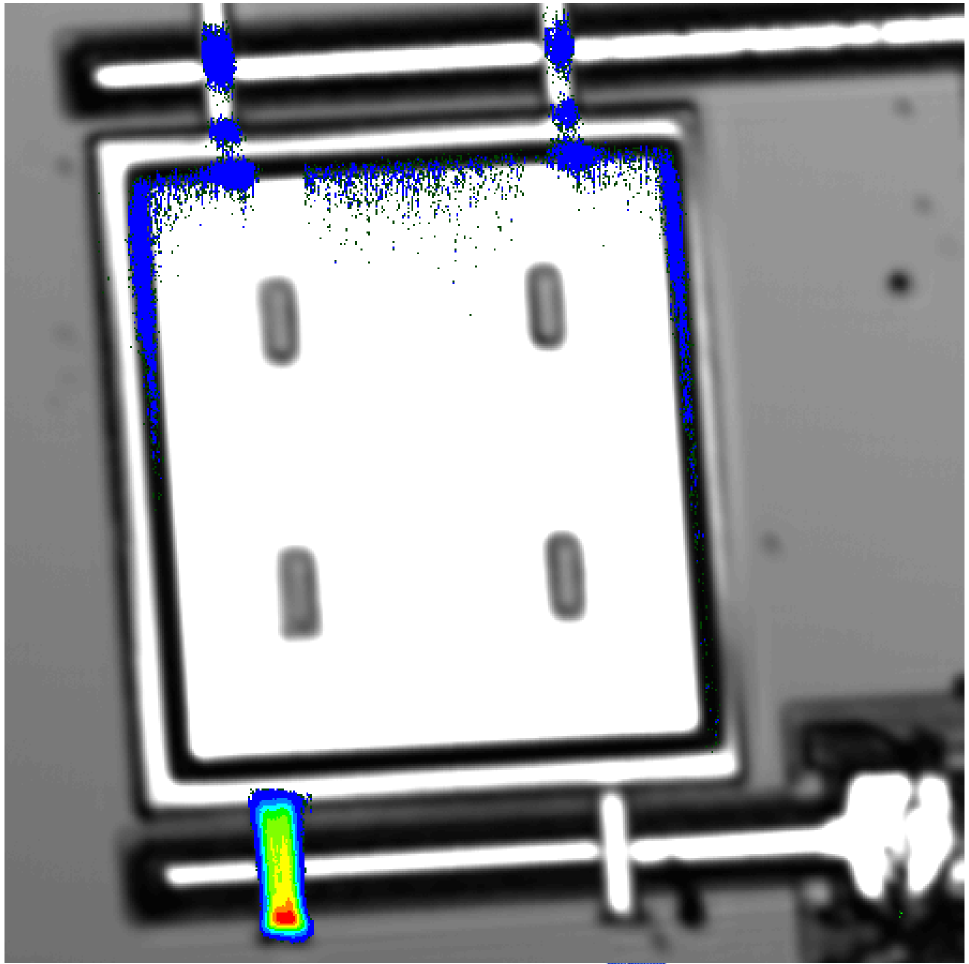




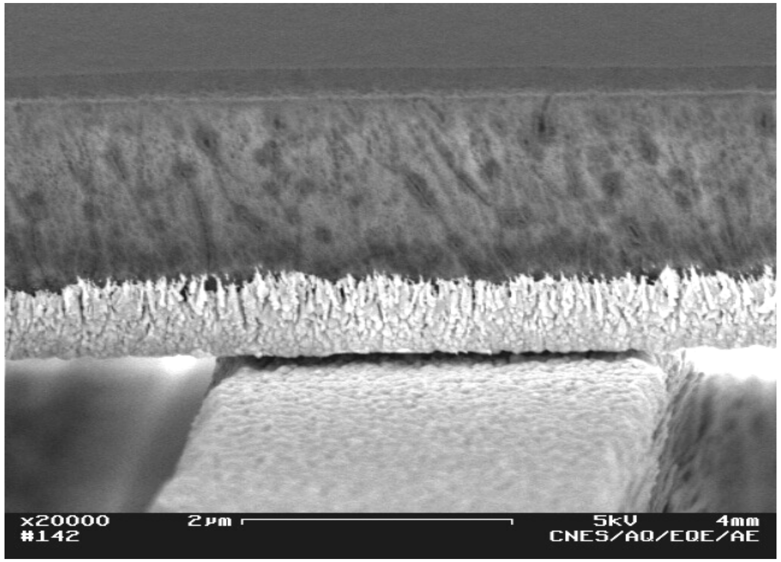
- Mobile part (B, C, D)
- Hinge (A)
- 2 end contact in // (D)
- 2 medium contact in //
- Contact by electrostatic force (C moves down)

NB-TLS on Micro-relay

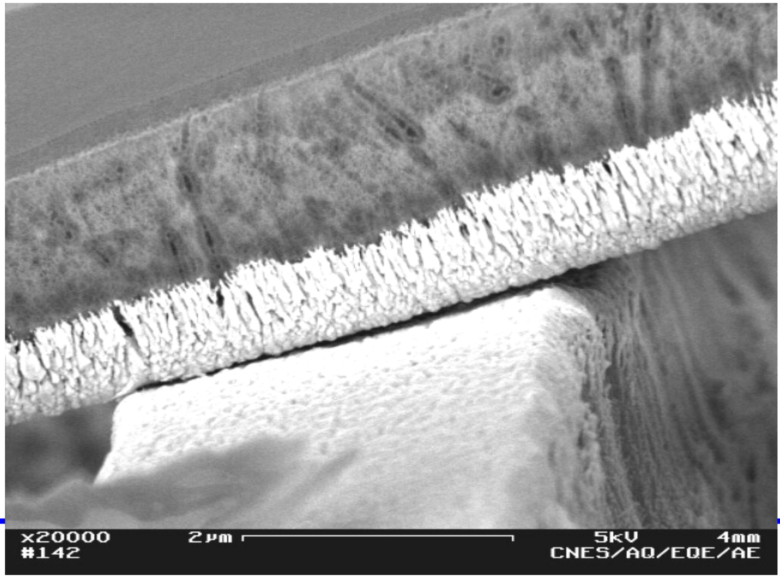
- *20x magnification*
- *Neither applied current nor applied voltage*
- *Good contact (bottom left)*
- *Poor contact (top)*
- *Open contact (bottom right)*

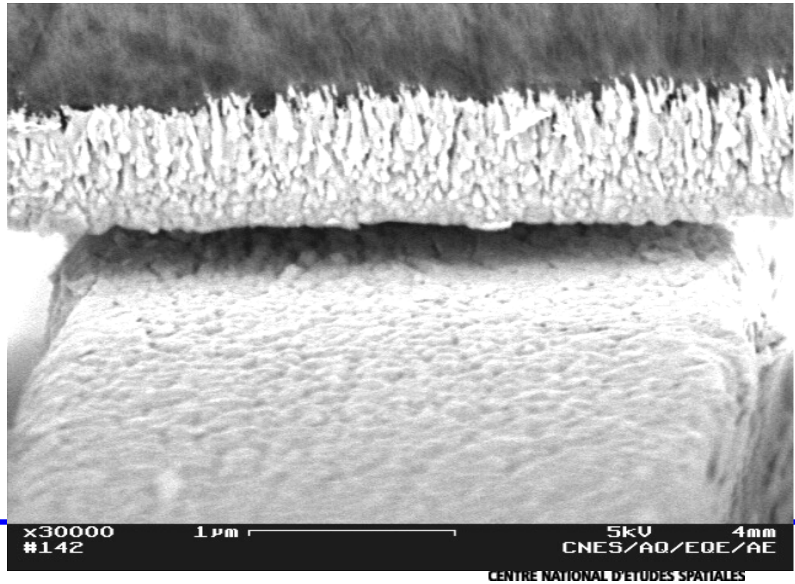


Micro-relay: complementary analysis (1)



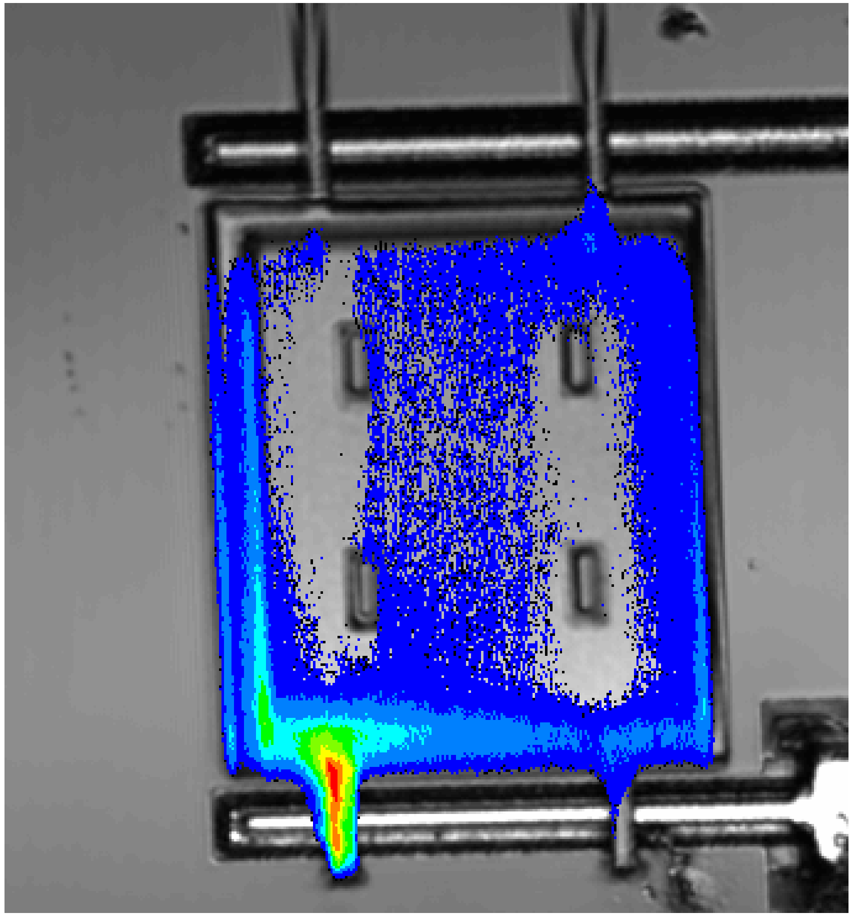
- *SEM pictures of contacts*
  - Bottom left
  - Bottom right
  - Upper left (= upper right)
- *No evidence between poor and good contact*





Micro-relay: complementary analysis (2)

- *TLS analysis*
  - Check where current is flowing
  - Confirm previous NB-TLS results
- *Evidence of reliability risk*
  - Unbalanced current flow
  - Faster wear out of good contact (current flow)
  - Faster wear out of poor contact (resistance => power dissipation
- *NB-TLS validation*
  - Reliable results (good contact)
  - No invasive (neither current nor voltage)



Conclusions

- *Thermal Laser Stimulation has been used for MEMS expertise*
  - Complement mechanical characterization by giving electric signature
    - Not Invasive, Contact less, Submicron spatial resolution
    - Well known on purely electronic behavior (such as ESD)
  - Fast access to cross parameters (mechanical + electrical), no vacuum (SEM)
  - Very helpful for reliability studies
- *Other microelectronics FA tools can be used for MEMS expertise*
  - According to mechanism Particle, fracture, fatigue, wear, stiction, ESD…
  - RX, SAM, FIB, SEM, STEM, TEM, AFM (and electrical modes)
  - Real time analysis can be performed by dynamic tools (dérivate from SDL, PICA …)
- *Cross parameters*
- *Reliability*