Reliability assessment of RF MEMS switches

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7th ESA Round Table on MNT for Space Apps

Outline

- Introduction
- Approaches for Reliability assessment
- Accelerated aging
- Physics of Failure
- Conclusion

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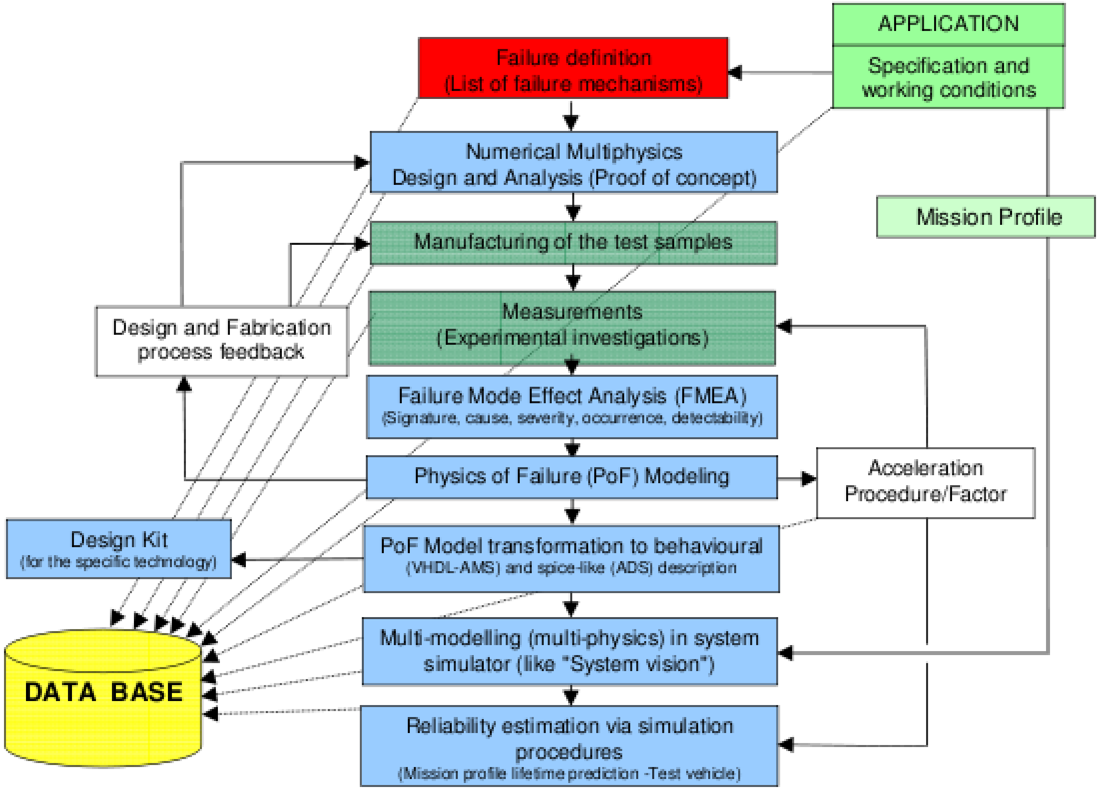
The POLYNOE EDA Project

- Aim: Prove the Physics of Failure concept for reliability assessment of MEMS switches



APPLICATION

Specification and working conditions

Failure definition (List of failure mechanisms)

Numerical Multiphysics Design and Analysis (Proof of concept)

Mission Profile

Manufacturing of the test samples

Measurements (Experimental investigations)

Design and Fabrication process feedback

Failure Mode Effect Analysis (FMEA) (Signature, cause, severity, occurrence, detectability)

Physics of Failure (PoF) Modeling

Acceleration Procedure/Factor

Design Kit (for the specific technology)

PoF Model transformation to behavioural (VHDL-AMS) and spice-like (ADS) description

DATA BASE

Multi-modelling (multi-physics) in system simulator (like "System vision")

Reliability estimation via simulation procedures (Mission profile lifetime prediction -Test vehicle)

Introduction

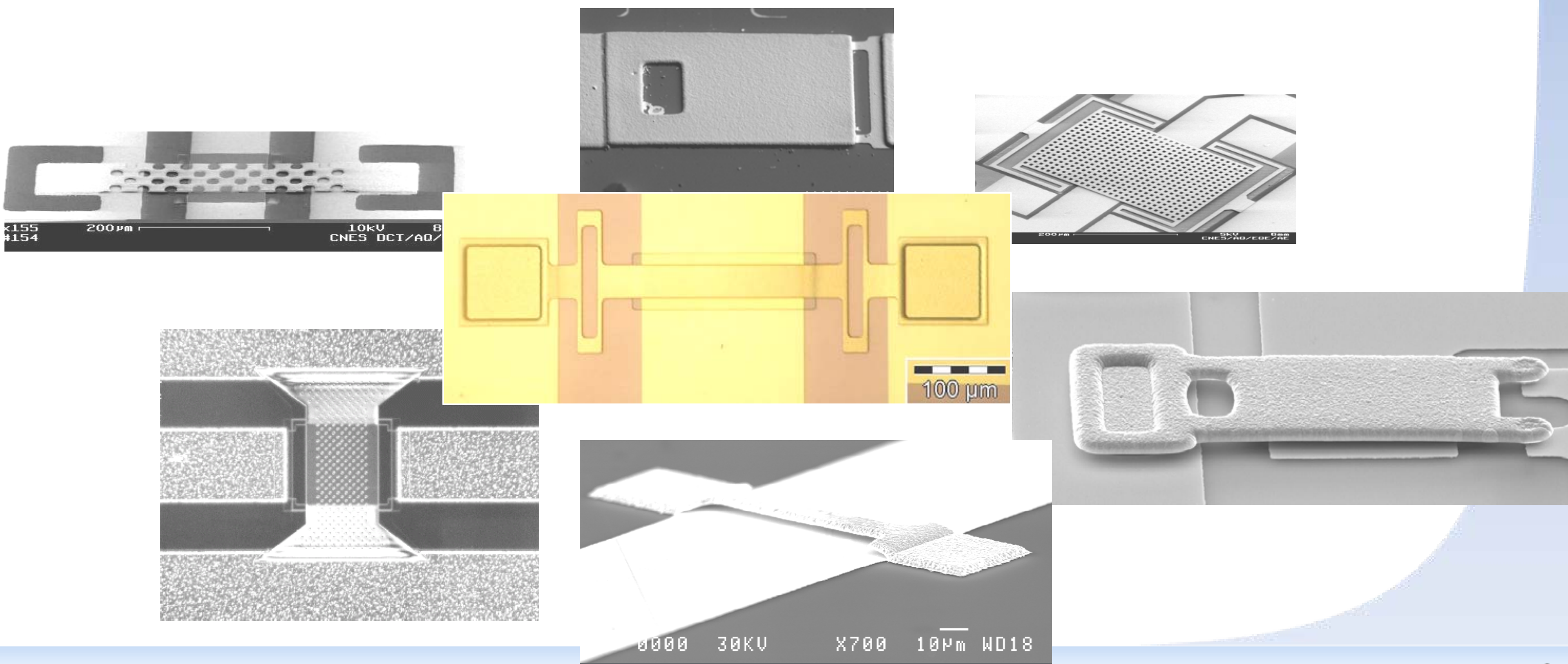
- Several technologies for switching operation

	MESFET	PIN Diode	MEMS
Series Resistance (Ω)	3 to 5	1	< 1
Loss @1GHz (dB)	0.5 to 1.0	0.5 to 1.0	0.1
Isolation @1GHz (dB)	20 to 40	40	> 40
IP3 (dBm)	40 to 60	30 to 45	[illegible]
1 dB compression (dBm)	20 to 35	[illegible]	[illegible]
Size (mm²)	1 to 5	[illegible]	[illegible]
Switching speed	~ ns	~ µs	~ µs
Control Voltage (V)	8	3 to 5	3 to 30
Control Current	< 10 µA	10 mA	< 10 µA

XLIM Lab:
Nanogap switches
(a few tens of nanoseconds !)

Introduction

- Research on contact characterization for MEMS switches driven by the necessity to reach a <u>high-reliability</u> level for micro switch applications



Introduction

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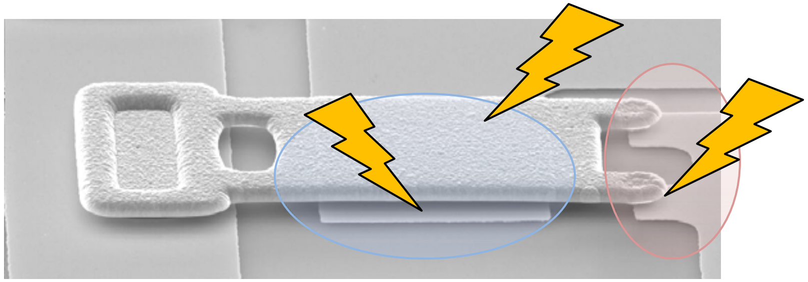


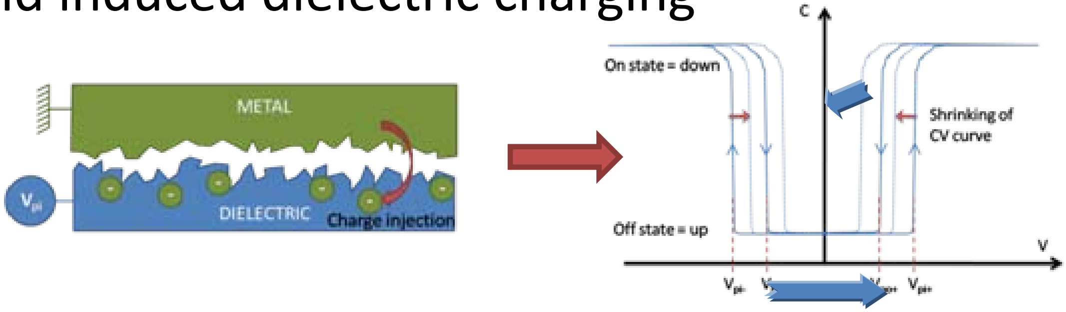
Mechanical system:

➔ Actuation

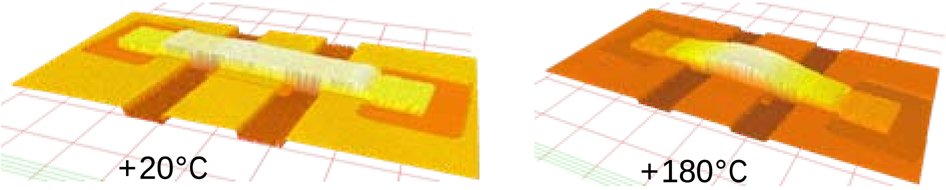
➔ Contact line

Introduction

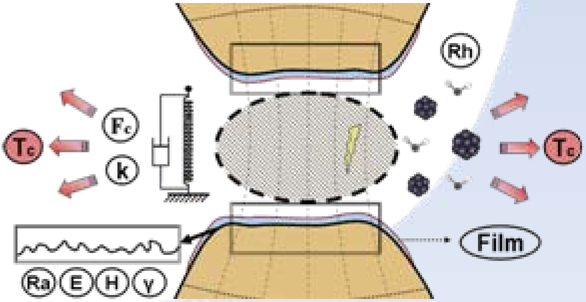
- FMEA: identification of the main failure mechanisms
  - » Field induced dielectric charging



  - » Temperature induced deformation of the structures



  - » Degradation of the electrical micro-contact



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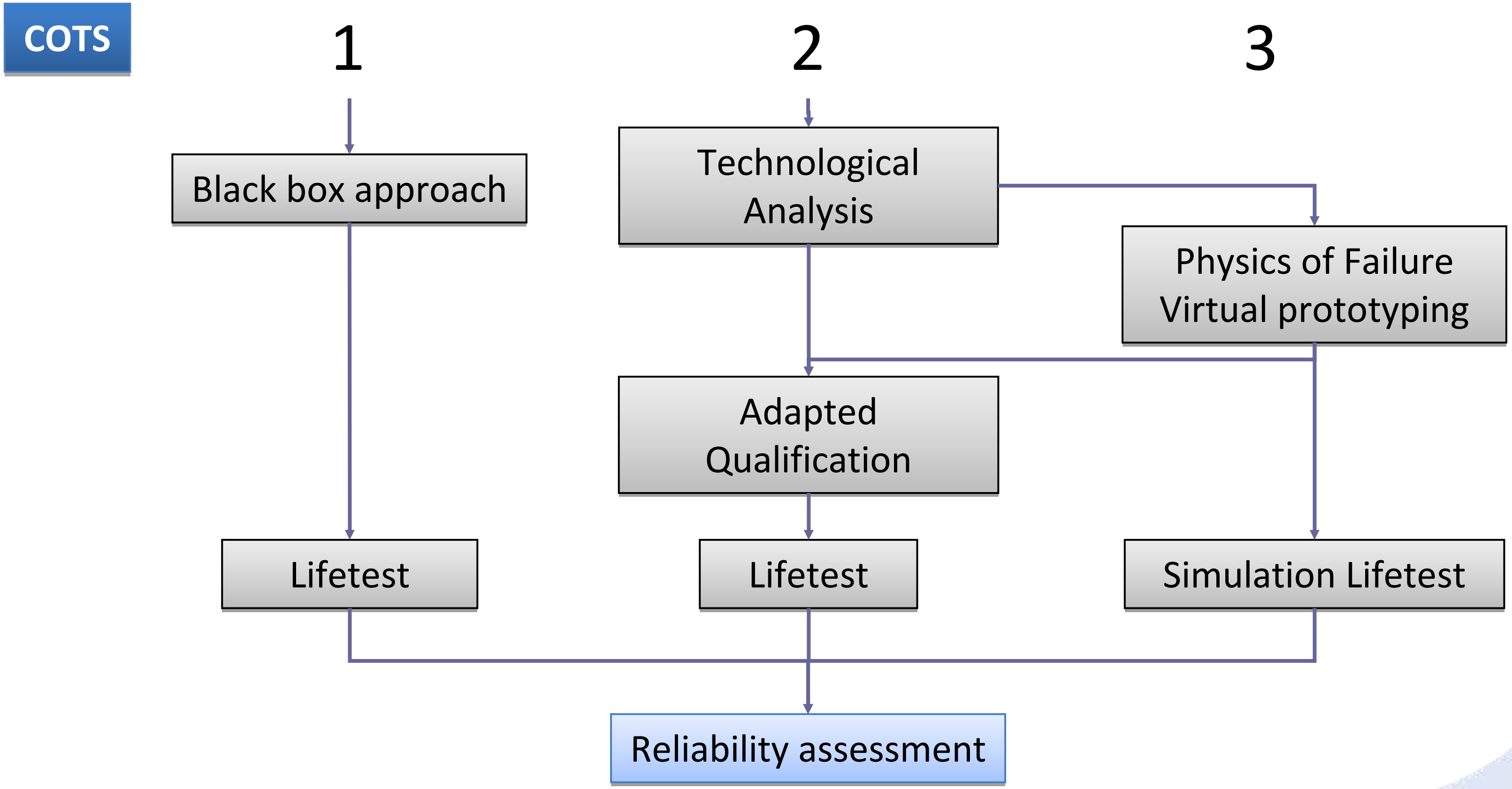
Reliability assessment

- Several approaches



COTS

1

2

3

Black box approach

Technological Analysis

Physics of Failure Virtual prototyping

Adapted Qualification

Lifetest

Lifetest

Simulation Lifetest

Reliability assessment

Reliability assessment

- Blackbox approach: “RF Switches as a black box”.
  - Unknown die / design / materials / technological parameters
  - Observation only at I/O
  - Stress / stimuli is applied according to mission profile (with margins)
  - GO/NOGO Results

☹ ! Switch as a device

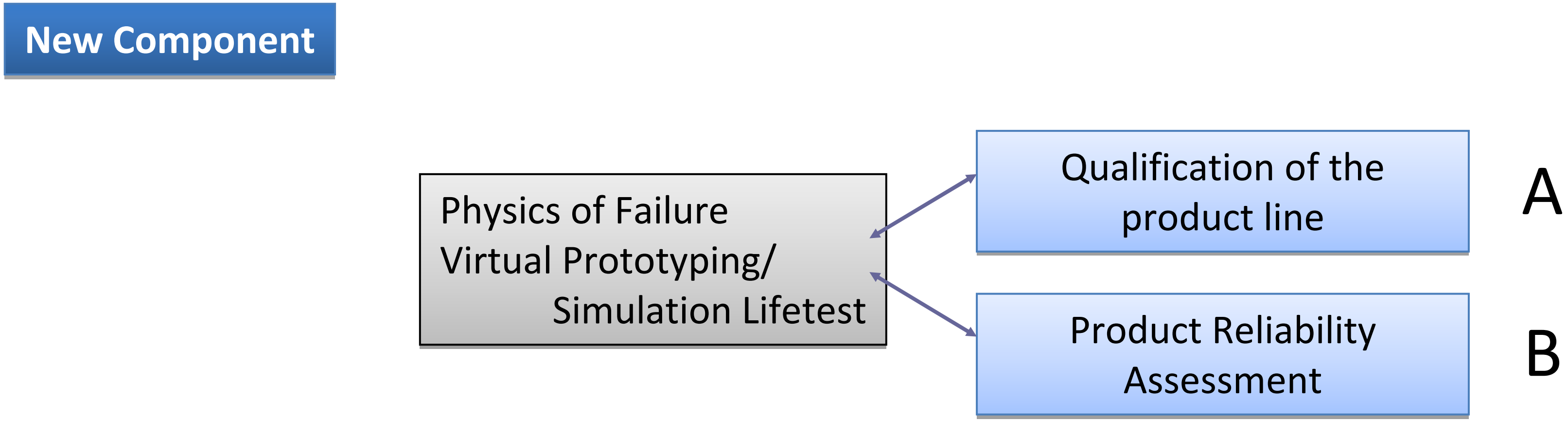
We should considered it as a system → study of the failure mechanisms of subsystems (moving part, electrical contact…)

☹ ! Accelerated aging: inputs ?

☹ ! Statistical approach ➔ irrelevant for dvpt of new technologies.

Reliability assessment

- Several approaches



New Component

Physics of Failure
Virtual Prototyping/
Simulation Lifetest

Qualification of the product line

A

Product Reliability Assessment

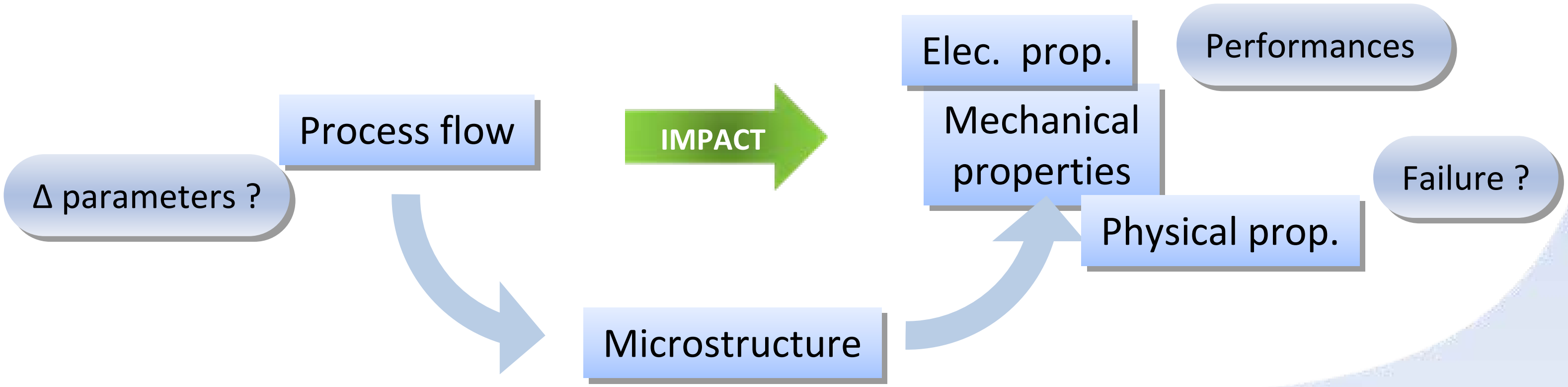
B

Reliability assessment

- New technologies: Production line ?
  Materials & Design

The mechanical properties differ from MacroWorld:

- Strong interaction between microstructural features and the geometry of the thin coatings (eg. Thicknesses)
- Microstructural properties greatly influenced by the process (kind of deposition, temperatures, sacrificial layers…)


Δ parameters ?

Process flow

IMPACT

Microstructure

Elec. prop.

Mechanical properties

Physical prop.

Performances

Failure ?

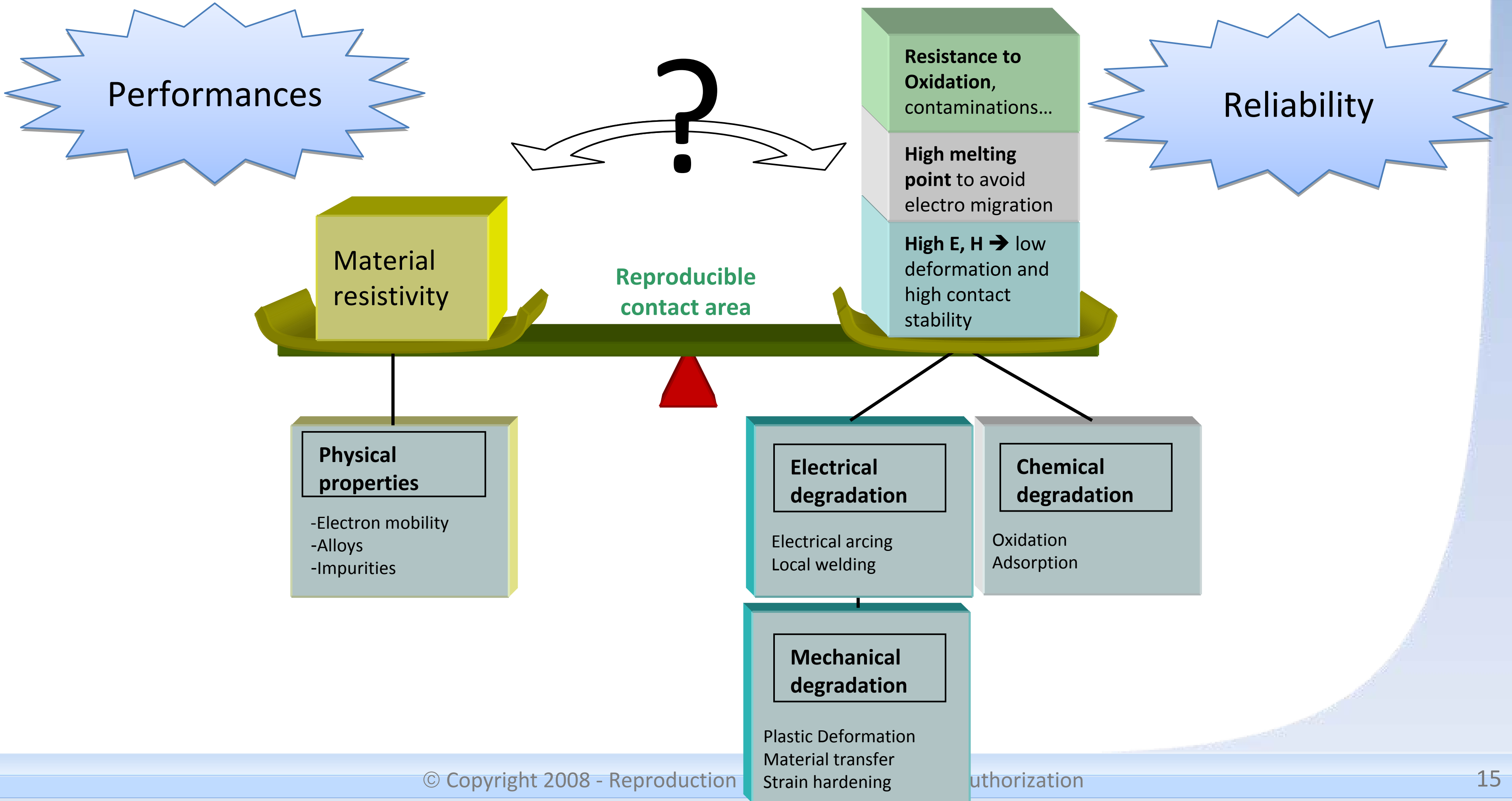
Reliability assessment

- Design for reliability
  - » Working on the very first blocks
  - » Use feedback for the design of new comp.

Reliability assessment

novamems
FOR RELIABLE SYSTEMS

- Design for reliability: necessity of trade-offs



Performances

?

Reliability

Material resistivity

Reproducible contact area

Resistance to Oxidation, contaminations…

High melting point to avoid electro migration

High E, H ➔ low deformation and high contact stability

Physical properties

- -Electron mobility
- -Alloys
- -Impurities

Electrical degradation

Electrical arcing
Local welding

Chemical degradation

Oxidation
Adsorption

Mechanical degradation

Plastic Deformation
Material transfer
Strain hardening

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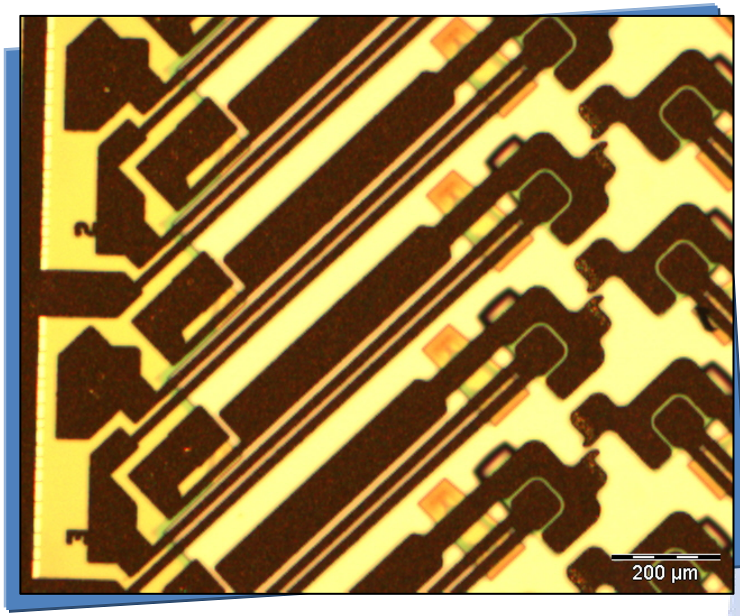
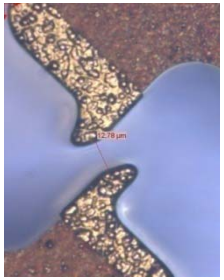
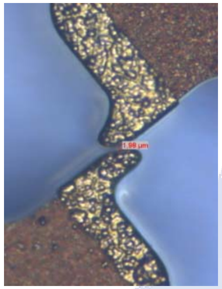
Accelerated aging

- Creep (1/2)
  - » Model: $$\dot{\varepsilon} = A \frac{\sigma^n}{d^p} \exp\left(-\frac{Q}{RT}\right)$$
    - – Power law for secondary creep (*n* is the creep exponent)
    - – Arrhenius acceleration factor (*Q* is the activation energy)
  - » Experiment
    - – Characterization of thermally actuated MEMS switches (MEMSCAP, EDA POLYNOE program)
    - – Loss of isolation with cycles: gap between the electrodes





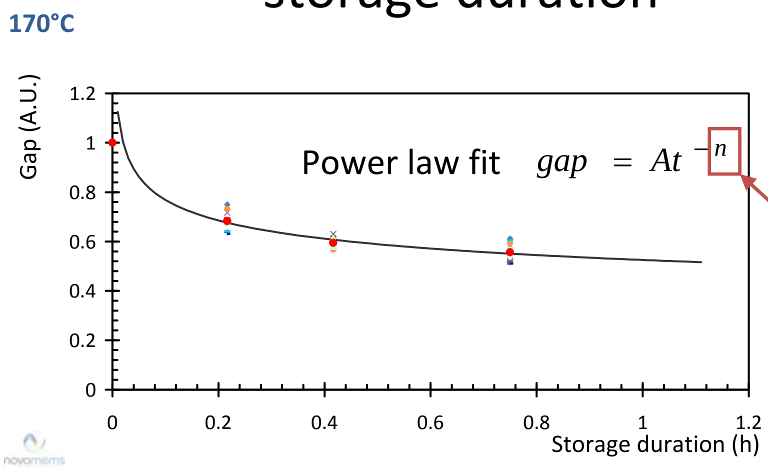
Before



After 3 weeks @150°C (closed position)

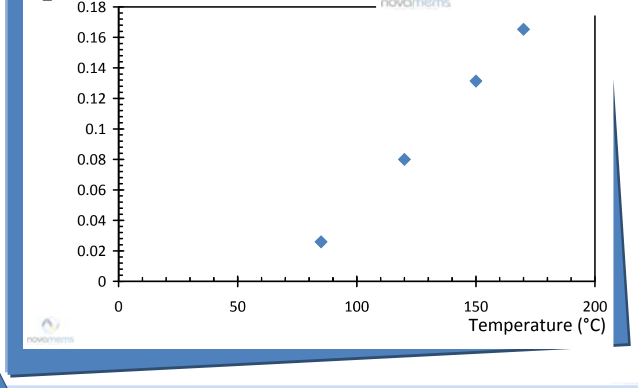
Accelerated aging

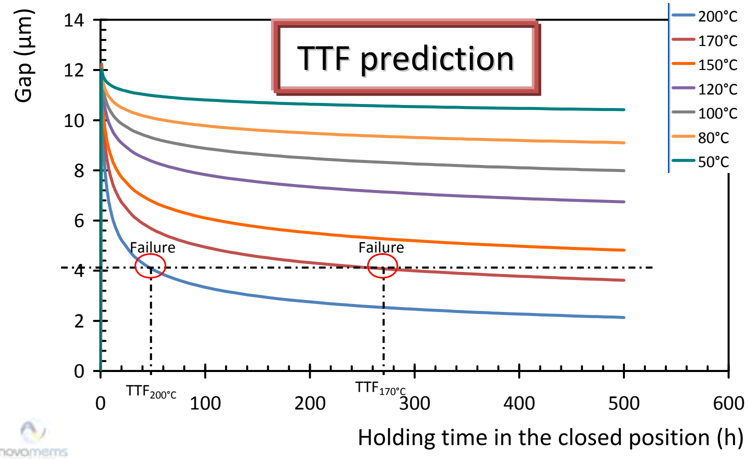
- Creep (2/2)
  - » Modelling the evolution of the gap with temperature and storage duration



Power law fit $gap = At^{-\boxed{n}}$

n versus T°



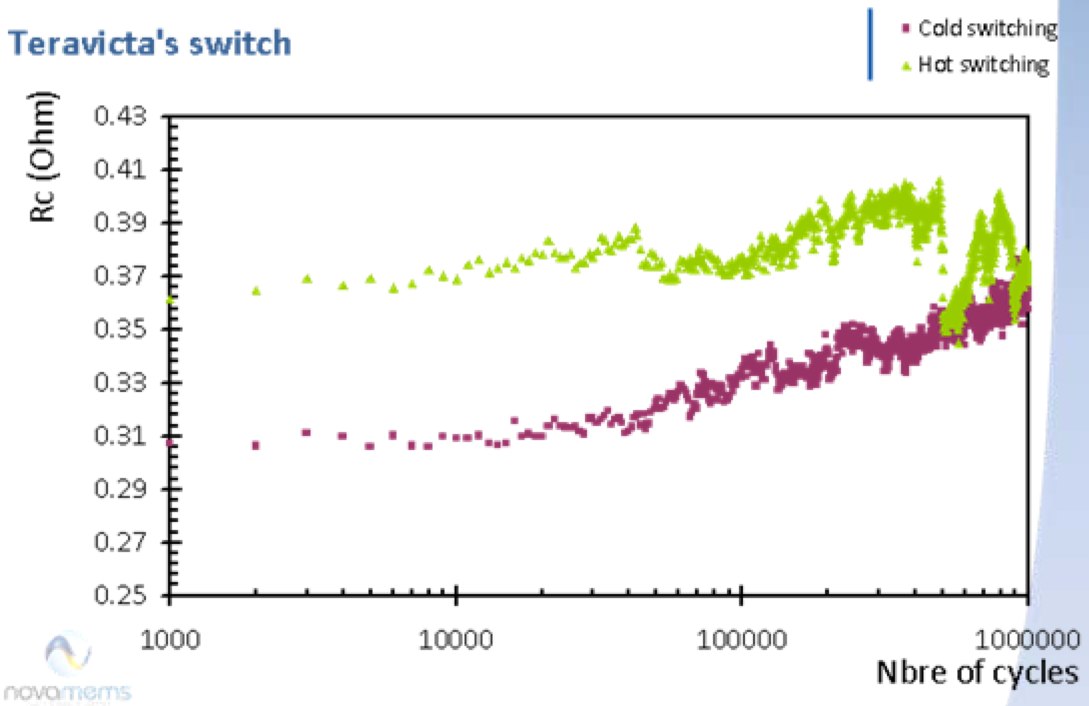


TTF prediction

Holding time in the closed position (h)

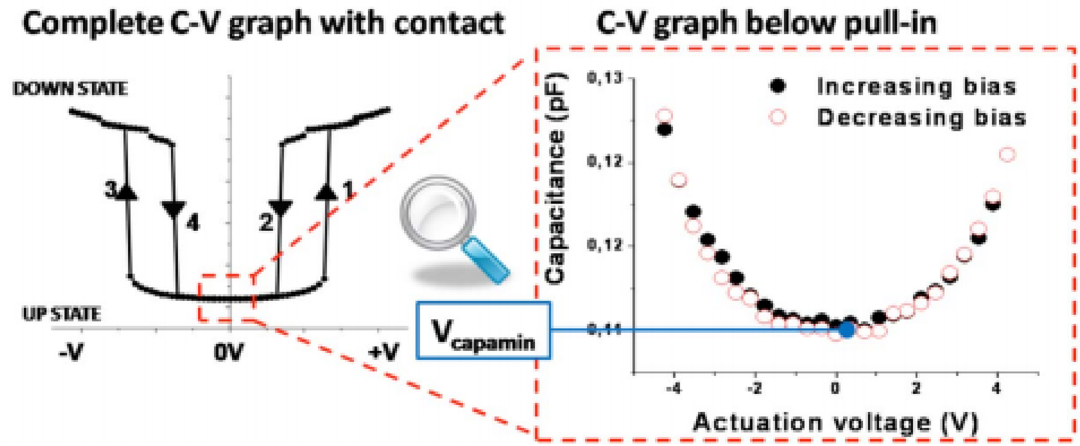
Accelerated aging

- Cycling
  - » Great influence of the testing method on the reliability
    - Progressive increase of the contact resistance for cold switching
    - Erratic behaviour in hot switching

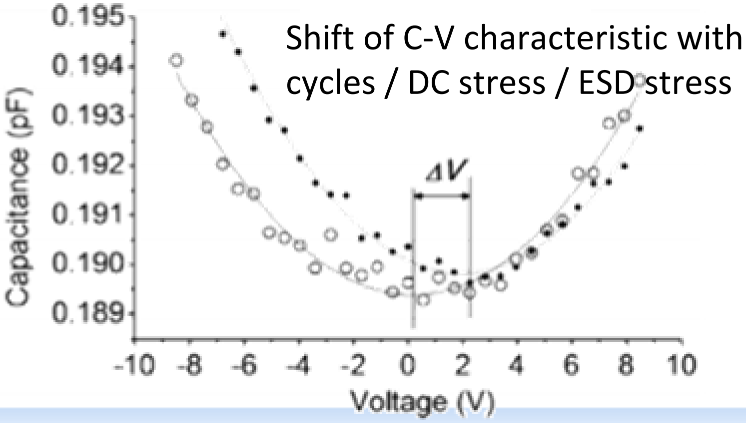


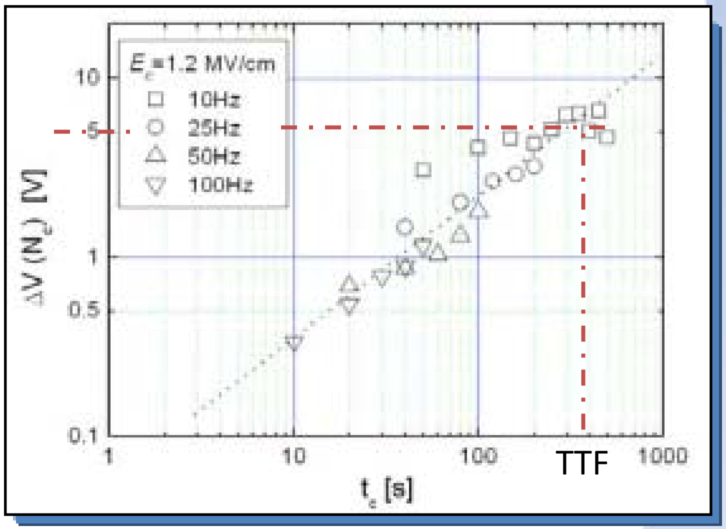
Accelerated aging

- DC Stress / ESD aging for charging effect quantification


Complete C-V graph with contact

C-V graph below pull-in


Shift of C-V characteristic with cycles / DC stress / ESD stress



TTF prediction

J. Ruan et al. (LAAS-CNRS) : FAME (ANR) project

Accelerated aging

- Radiations
  - » Expected effects: Damage of the dielectric layer
    - modification of V_{pi}/V_{po}
    - Increase of leakage current
    - Single event transient: auto-actuation

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- **Physics of Failure**
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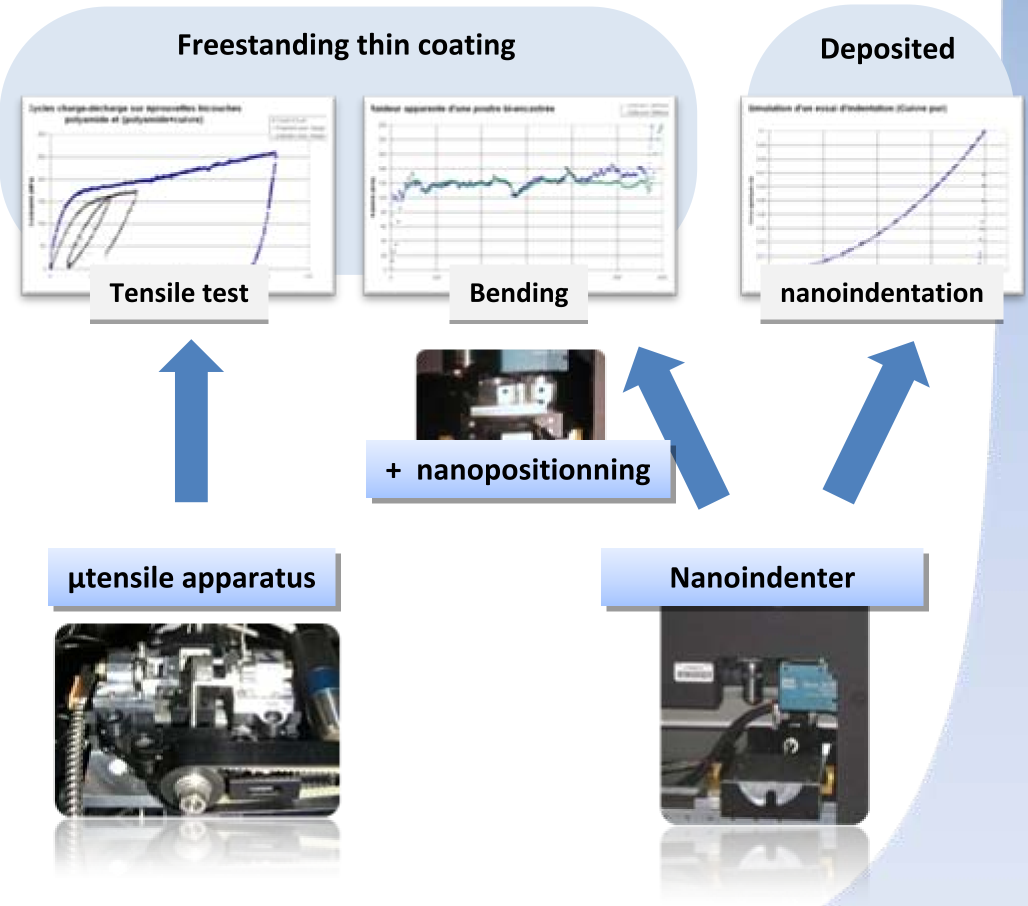
Physics of Failure

- Material level
  - » Evaluate the mechanical properties through mechanical actuation of dedicated specimens
  - » Wide range of materials
    - – Metals (and alloys)
    - – Ceramics
    - – Polymers
  - » Deposited on substrate or freestanding thin coatings



Freestanding thin coating

Deposited

Tensile test

Bending

nanoindentation

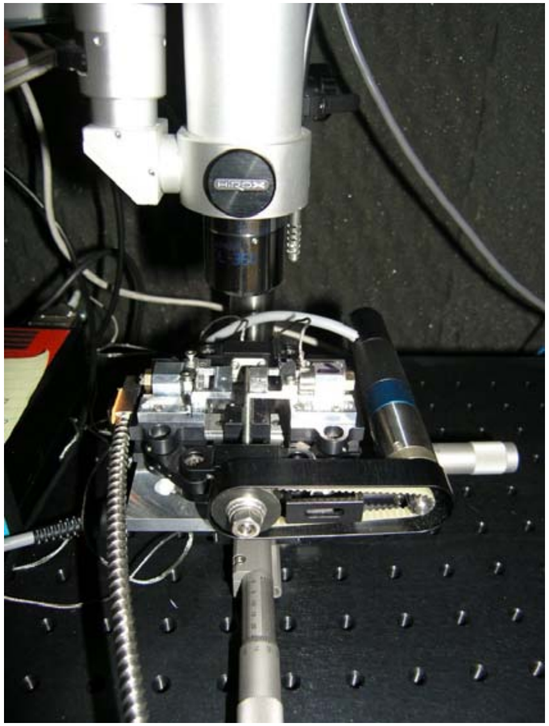
+ nanopositionning

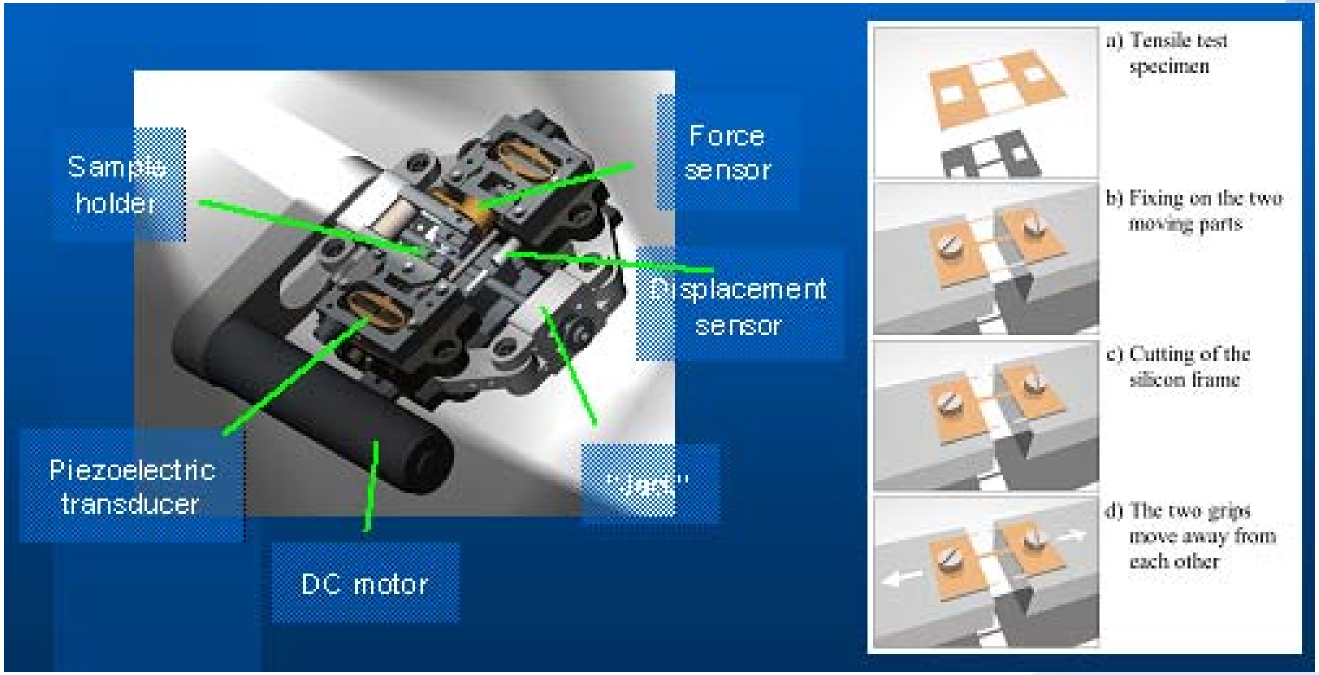
µtensile apparatus

Nanoindenter

Physics of Failure

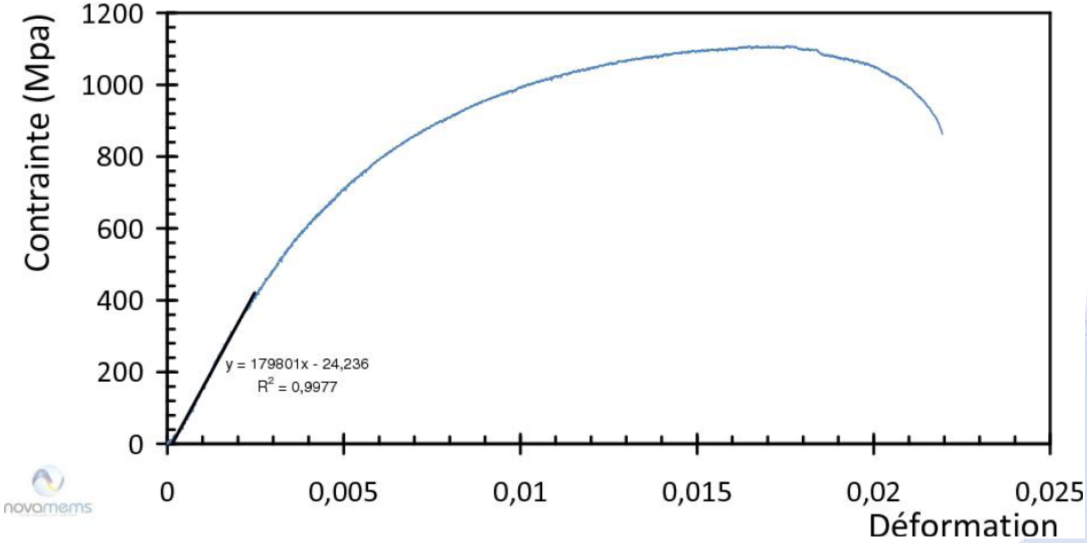
- Micro- tensile experiments
  - » Home-made Developments (NOVA MEMS : C. Seguineau), in collaboration with SIMaP Laboratories (M. Ignat) and INL (C. Malhaire)





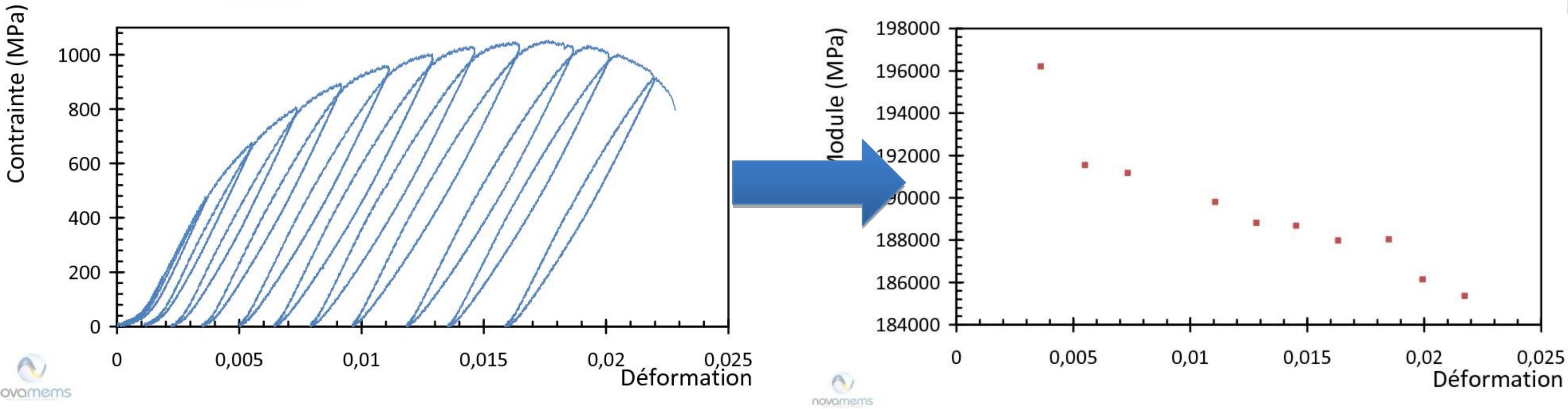
Physics of Failure

- Material level: µtensile test on NiCo specimens (MEMSCAP)
  - » Monotonic experiments
    - Young's modulus
    - Yield stress
    - Strain hardening
    - Ultimate strength



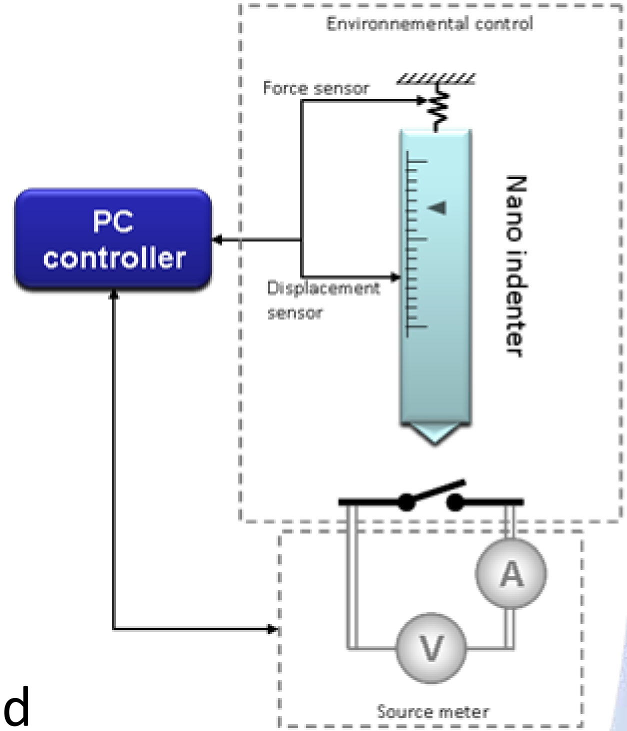
Physics of Failure

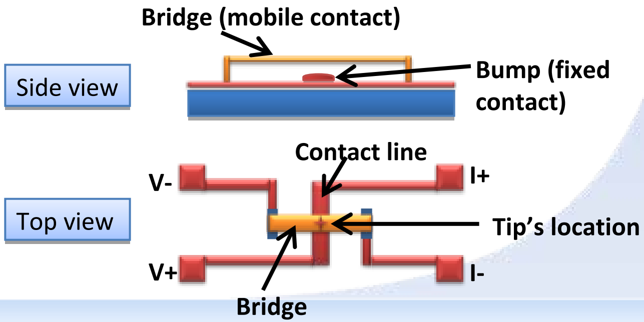
- Material level: µtensile test on NiCo specimens (MEMSCAP)
  - » Multicycle experiments: Damage assessment



Physics of Failure

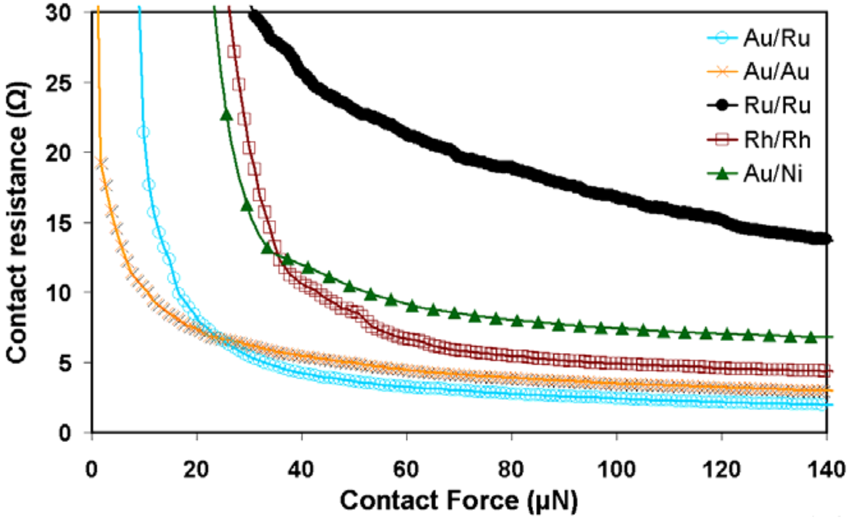
- Electrical contact (subsystem level)
  - » Monitoring R_c evolution versus:
    - – Intensity *I*
    - – Load applied *F*
    - – Compliance level *U*
    - – Switching mode (mechanical, cold, hot)
    - – Number of cycles *n*
    - – Hold duration *t* (creep)
  - » High reproductibility of the actuation load (intensity, location on the beam)

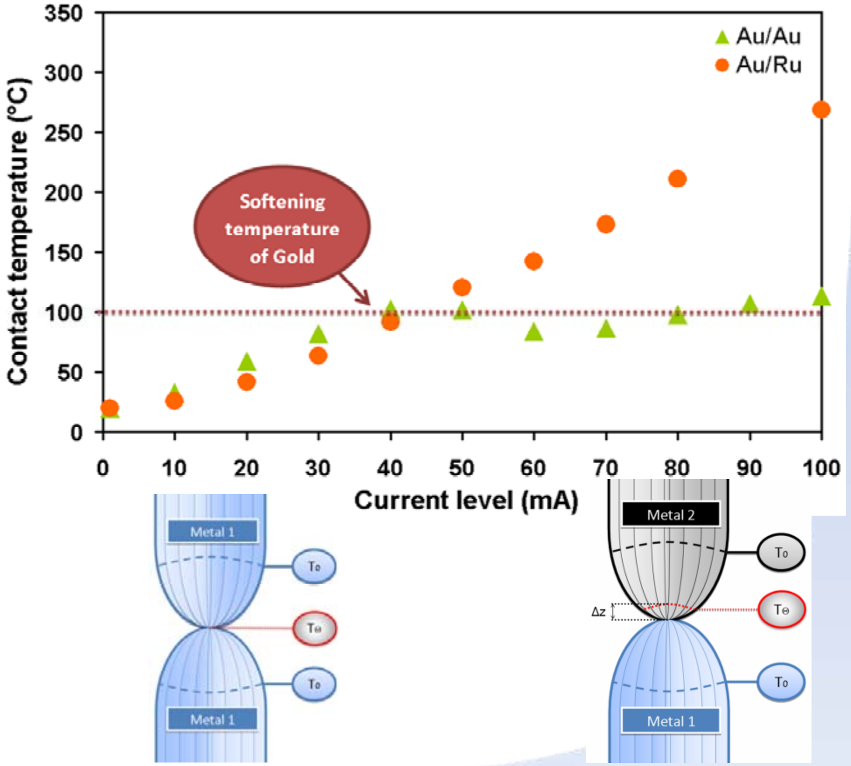




Physics of Failure

- Electrical contact (subsystem level)
  - » Select the best contact material
  - » Investigate power handling capability

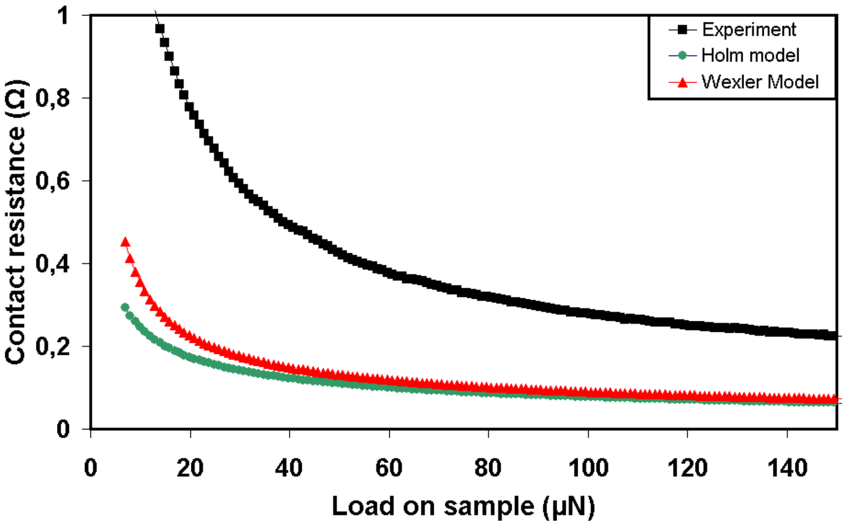


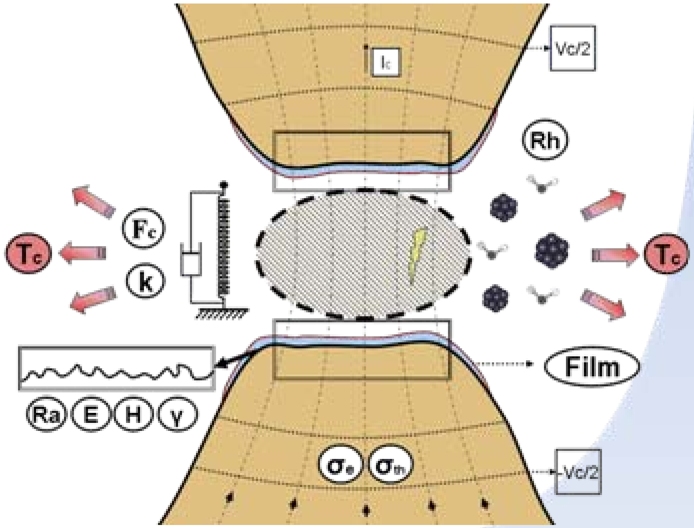


A. Broué et al., *Characterization of Au/Au, Au/Ru and Ru/Ru ohmic contacts in MEMS Switches improved by a novel methodology*. MOEMS/MEMS 2010, SF, CA.

Physics of Failure

- Electrical contact (subsystem level)
  - » Modeling of electrical resistance vs. load applied
    - – Great influence of contaminant films





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Conclusion

- Contact Material:
  - » Performances of the electrical contact strongly linked with the materials used to perform the contact
  - » Trade-off between mechanical and electrical performances to reach the best reliable operations : “**Design for reliability”**
  - » Contact material have to be :
    - – Good electrical conductor for low loss
    - – High melting point to handle power
    - – Appropriate hardness to avoid stiction phenomenon
    - – Chemical inertness to avoid oxidation

- Specific experiments and methods developed, but…

➔ Characterization only. Which standards for a qualification ?