Estimation of the electrical resistance of a micro-contact

Application to Gold Micro-switches

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Outline

- Introduction
- A New bench for characterization
- Application on Gold ohmic micro-switches
- Modeling and performances
- Predictive failure analysis: a useful tool
- Conclusion

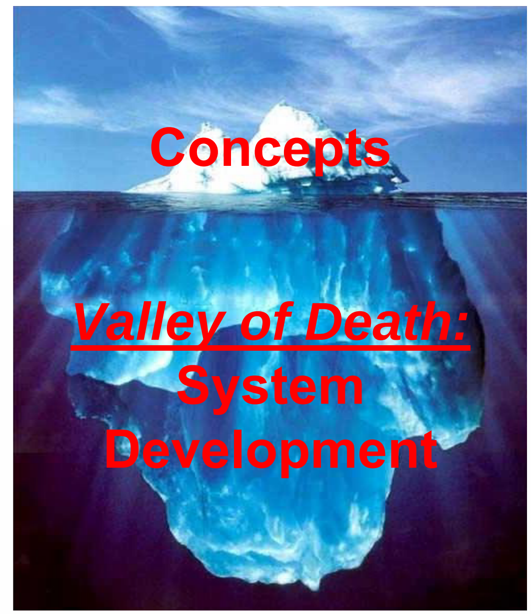
Introduction

- Micro- and nano- technologies are still young.
  - ➔ Lack of feedback in most applications
  - ➔ New failure mechanisms
  - ➔ Tiny scales create specific issues for accurate investigations.

- Bringing MEMS demonstrator to a successful commercial application is compared to "crossing the Valley of Death"

  ➔ TRL Concept: "Technology Readiness Level"

- Harsh environment in space, High reliability is mandatory
  - ➔ Spatial components have to endure the environmental conditions found in the Valley of Death…

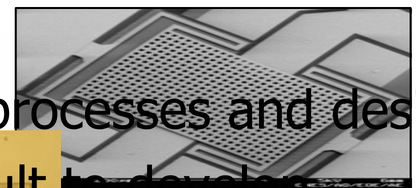


Introduction

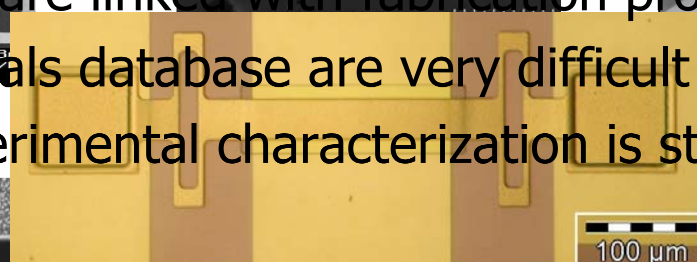
- Micro-switches among the most promising applications:
  Wide panel of needs from DC to high frequency switches (telecommunications and space)
  ➔ Multiplication of the concepts and designs

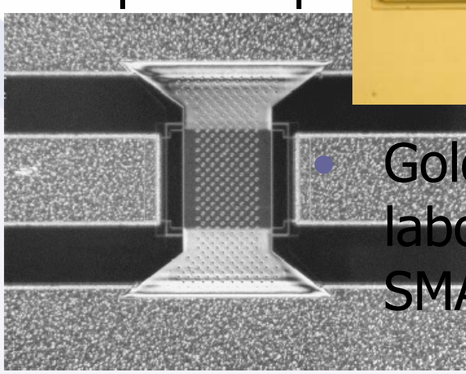
- Performances and reliability hugely depend on the mechanical properties of the implied materials.





- These properties are linked with fabrication processes and designs
  ➔ Useful materials database are very difficult to develop.
  ➔ Adapted experimental characterization is still mandatory



- Gold Ohmic micro-switch on alumina from XLIM laboratory (in the frame of the European Project SMARTIS, Eurimus labelled) : Application case

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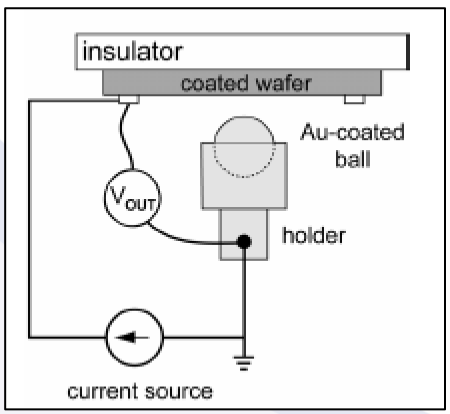
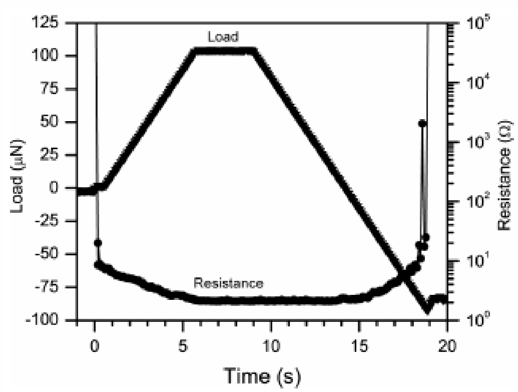
Introduction

- Characterization has to be polyvalent and to induce coupled-field physics.
- Some benches are already available:
  1. Electrostatic actuations for reliability concerns (several thousands of cycles)
  2. Quasi-static experiments for physical studies based on mechanical micro-actuators
- Example of apparatus : *Daniel J. Dickrell III, Sandia National Labs, USA*





- o Nanoindentation apparatus with modified tip used as one of the two electrodes (specific coatings).
- o Tests on coated wafers

- The actual conditions of actuations are not reproduced
- Series of experiments are hard to carry out (new spherical electrode for each material to be tested)

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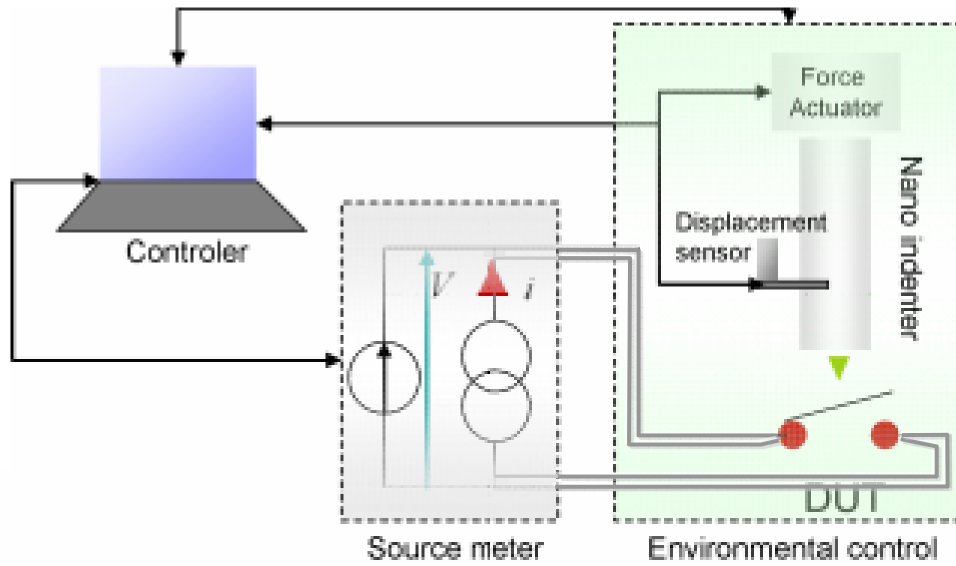
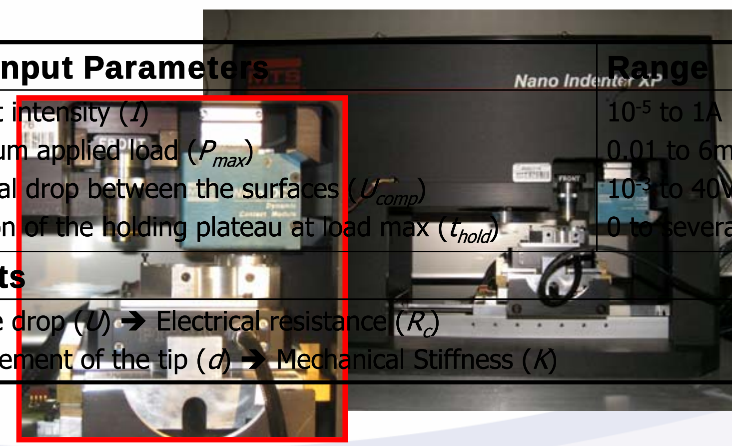
A new bench for characterization

- Mechanical actuation based on nanoindentation apparatus
  - Micro-bending of the free-standing parts
  - Accurate location needed for real switches achieved thanks to a piezo- sample holder
  - Adapted resolutions : 10^{-9}N and 10^{-10}m, respectively for applied load and resulting displacement.
  - Environmental control
- Independent electrical measurements
  - 4-wire measurements
  - Synchronization of the acquisitions





Main Input Parameters	Range
• Current intensity (I)	10^{-5} to 1A
• Maximum applied load (P_{max})	0.01 to 6mN
• Potential drop between the surfaces (U_{comp})	10^{-3} to 40V
• Duration of the holding plateau at load max (t_{hold})	0 to several min
Outputs	
• Voltage drop (U) → Electrical resistance (R_c)	
• Displacement of the tip (d) → Mechanical Stiffness (K)	

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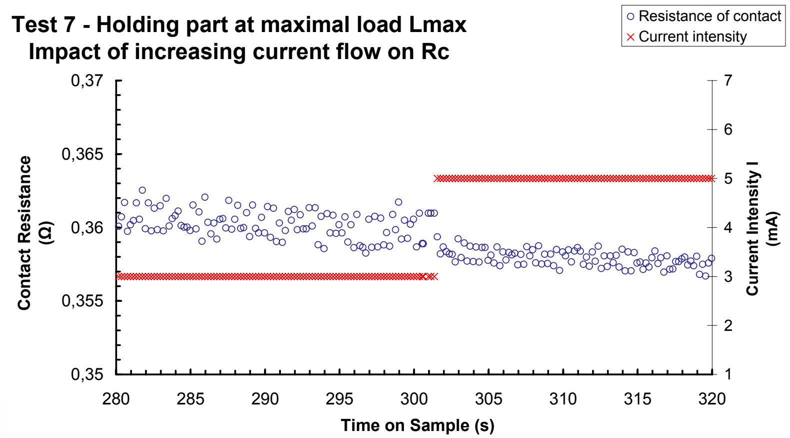
Application on Gold micro-switches

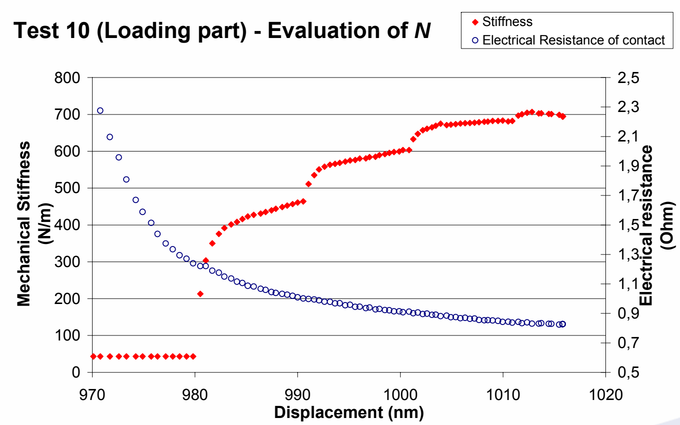
- Main Inputs
  - Loading with a constant rate: 2µN/s
  - Load max L_{max}= 30µN
  - Current intensity I = 1 to 9mA (increments of 2mA every 40s)

➔ Current influence on the level of resistance neglected (thermal considerations)



- Mechanical measurements
  - Determination of the number of asperities N
  - Displacement determination (d = d(L))

➔ The interface between the tip and the free-standing part must be taken into account !



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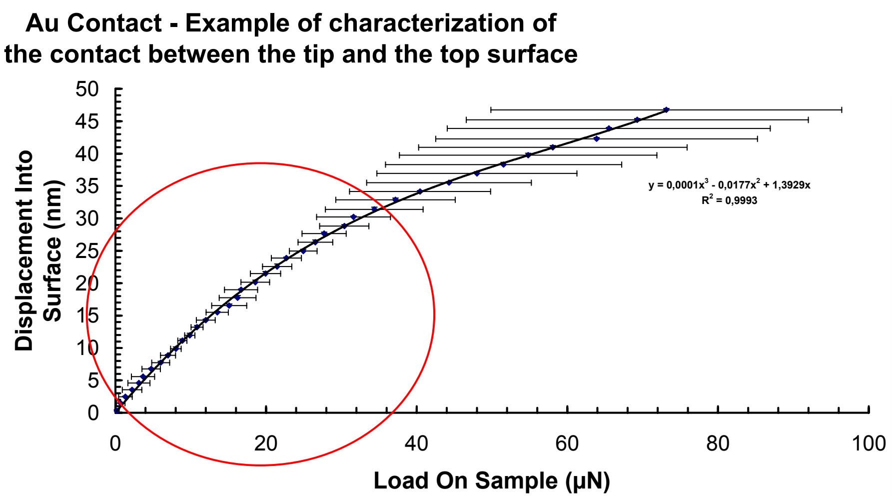
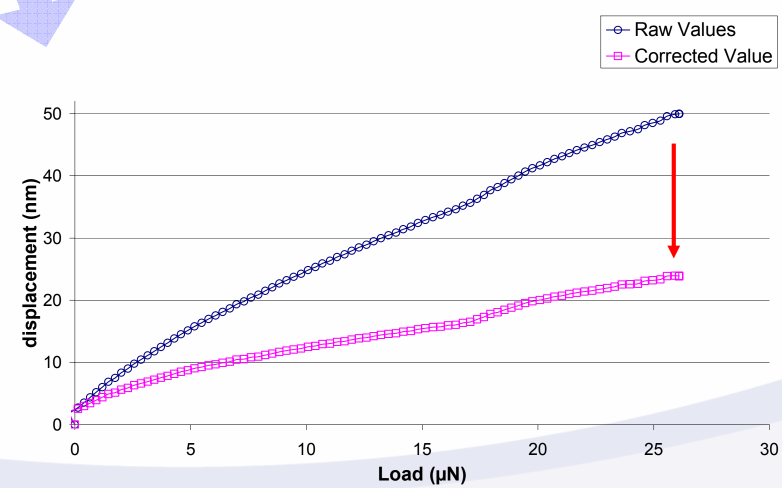
Application on Gold micro-switches

- Stiffness and nanoindentation
  - A "spring" can stands for the contact between the tip and the free-standing part.
    ➔ Characterization of this behavior realized thanks to first nanoindentation tests



$$d_{tip-sur}(L) = \alpha_1 L^3 + \alpha_2 L^2 + \alpha_3 L$$

$$\rightarrow \quad d_{contact} = d - d_{tip-sur}(L)$$



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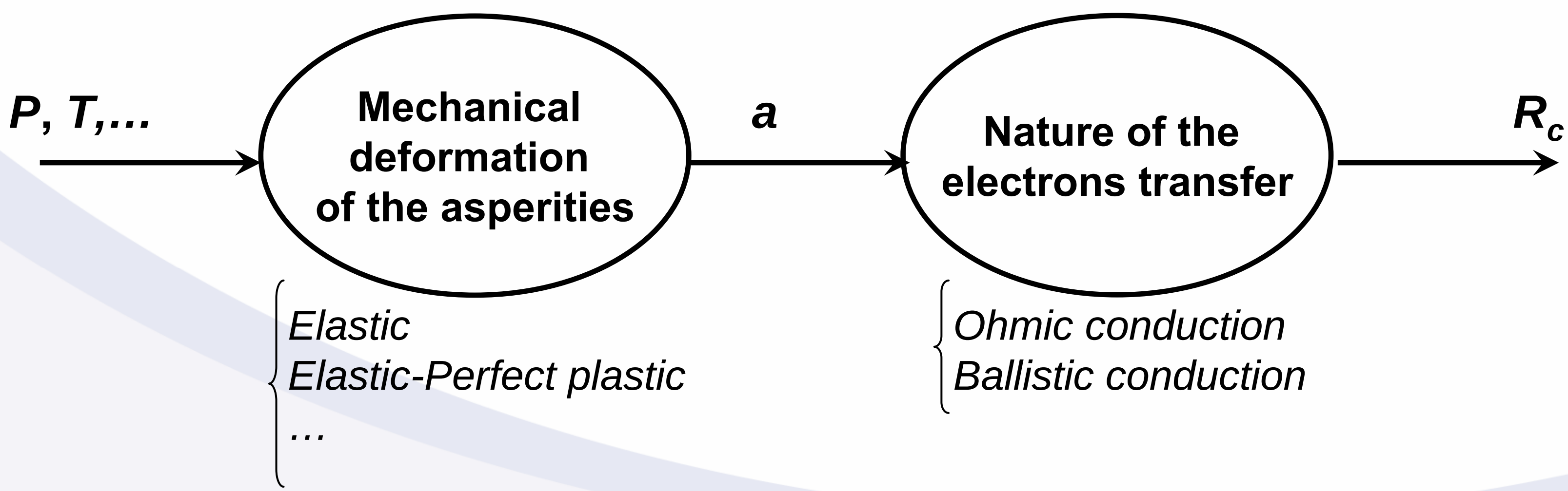
Modeling and performances

- Aim:

  providing a better understanding of the involved physics.

- Mechanical behavior ➔ Effective area of contact *a*

  Electrical behavior ➔ Resistance of contact R_c = performances



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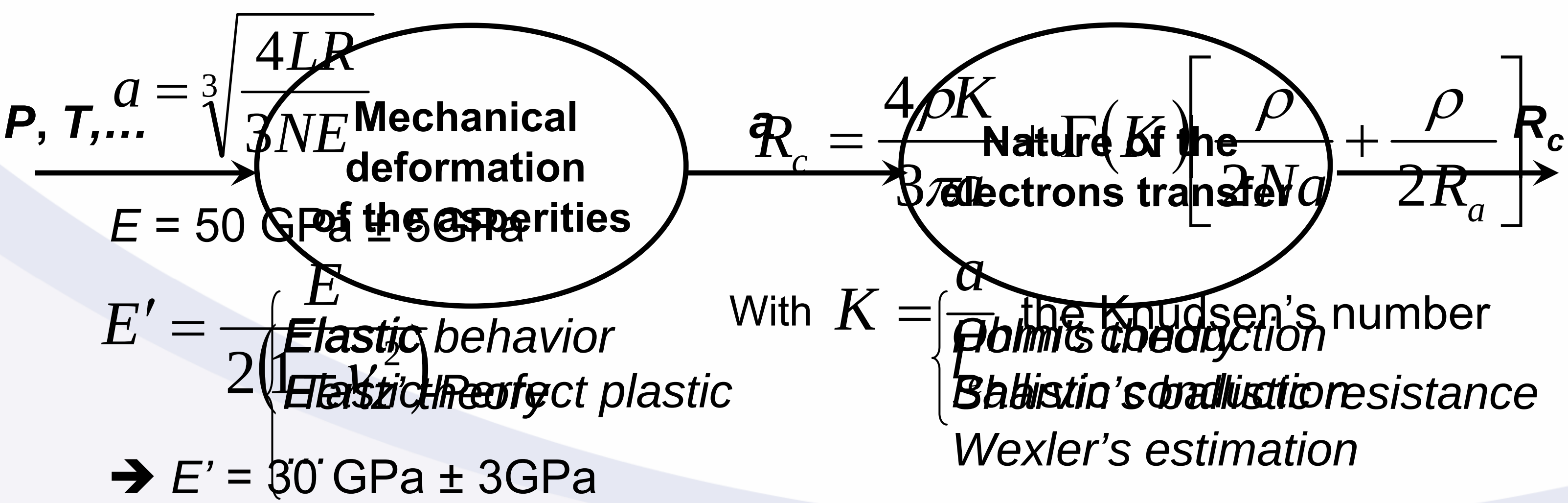
Modeling and performances

- Application on the XLIM switch



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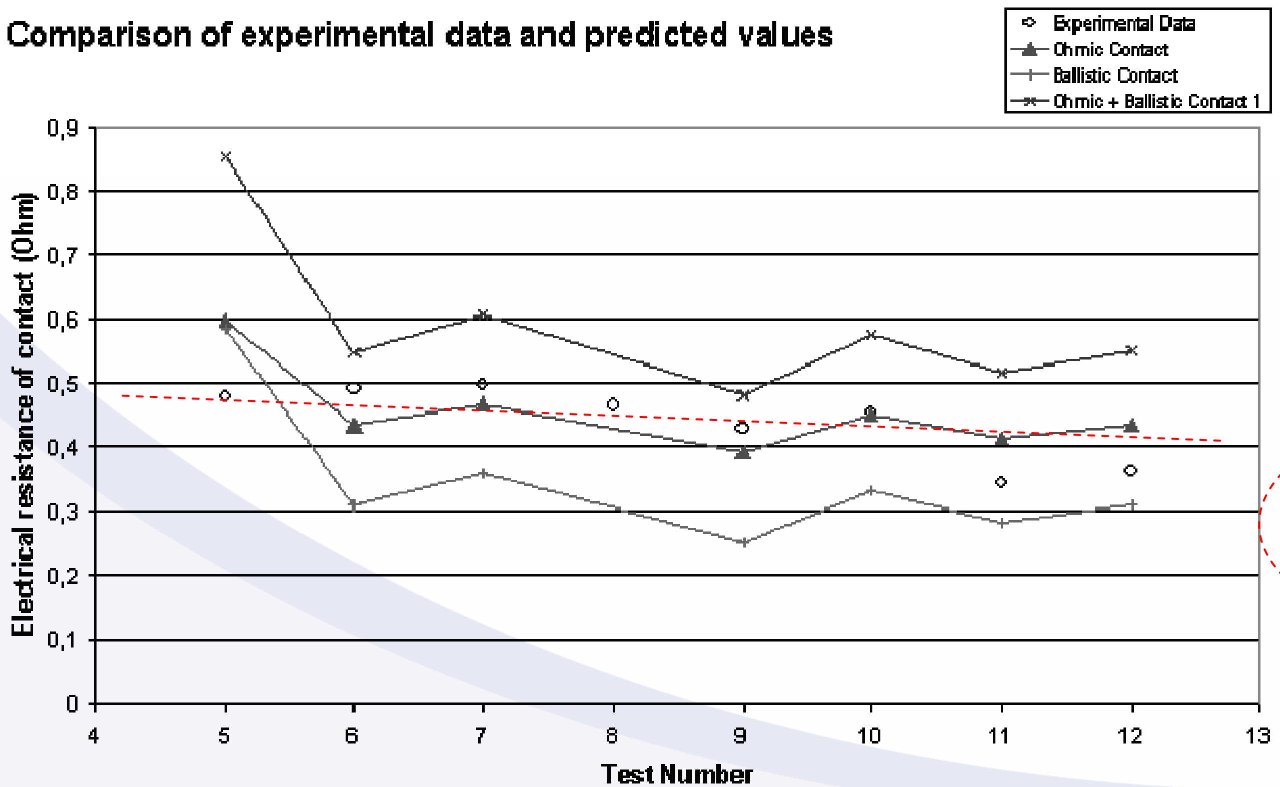
Modeling and performances

- Application on the XLIM switch
  ➔ Comparison of direct measurements of R_c and analytical predictions:



Small decrease of the experimental data
➔ elastic-plastic behavior ?

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Modeling and performances

- Discussion

Overestimation of the analytical model: 35% (0.15Ω)

Acceptable insofar as: $$\frac{\partial R_C}{\partial E'} \approx 0.04 \frac{\Omega}{GPa}$$ then: $\Delta E = 3$ GPa ➔ $\Delta R_c \approx 30\%$

➔ The simplest mechanical model (Elastic behavior, Hertz' theory) provides here acceptable results

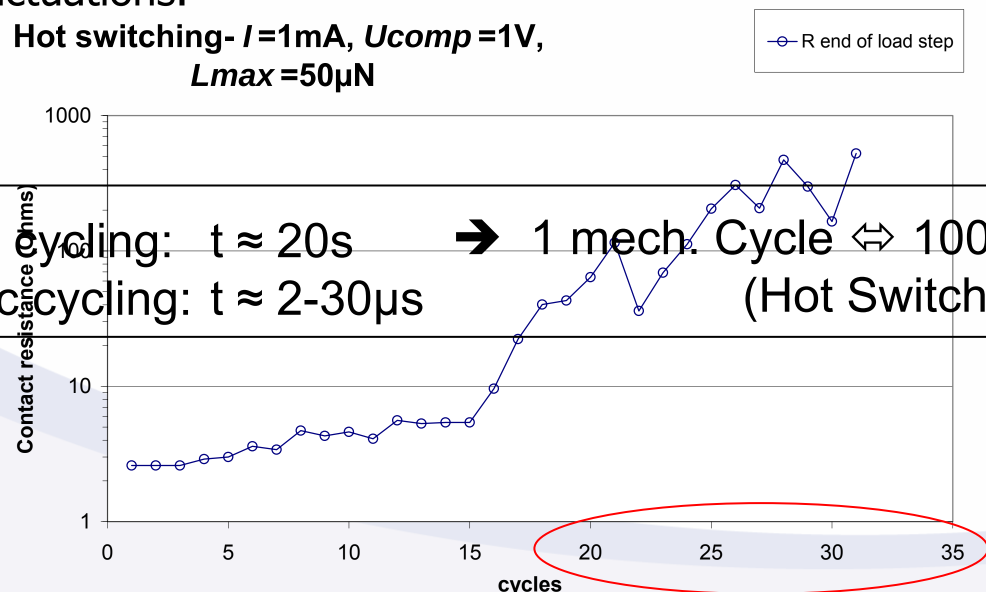
➔ Using a more complex mechanical model (ex: CEB) will not be relevant as long as the mechanical properties can't be more accurately extracted…

Failure Analysis: a useful tool

- Reliability concerns
  - Failure mechanisms occur on specific stage (contact establishment, closed position, breaking of the contact,…)
  - Some damages are linked with the **duration** of these stages (arcing phenomena)

➔ Comparison of mechanical and electrostatic actuations on the base of the cycle duration.

A few number of mechanical actuations can then be equivalent to thousands of electrostatic actuations.



Mechanical cycling: t ≈ 20s
Electrostatic cycling: t ≈ 2-30µs

➔ 1 mech. Cycle ⇔ 100 000 elec. cycles (Hot Switching)

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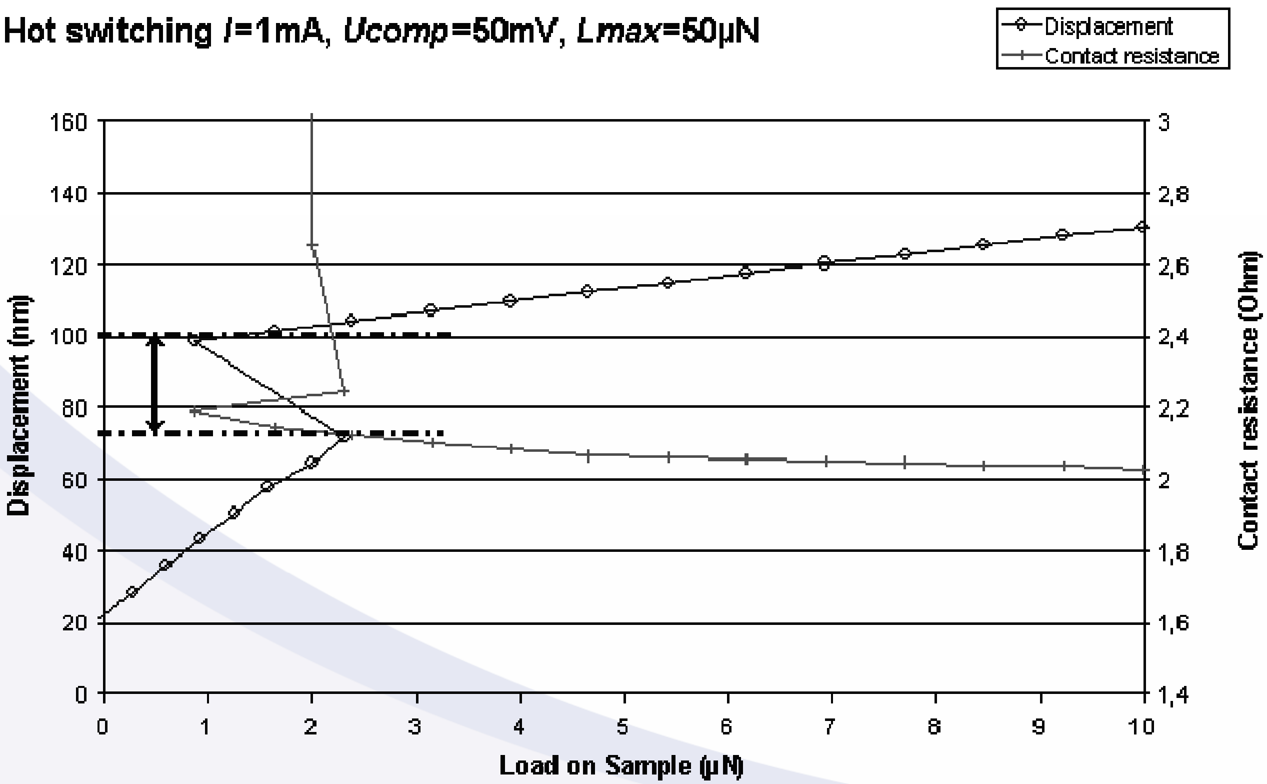
Failure Analysis: a useful tool

- Adhesion forces
  - Controlled load and unload not superimposed ➔ Adhesion forces

Hot switching *I*=1mA, *Ucomp*=50mV, *Lmax*=50µN



- Capillarity
- Van des Waals
- Cold Welding ?
- …

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Conclusion

- Advantages:
  - Reproducible actuations
  - Easier failure mechanisms analysis (input parameters independent from each other)
  - Decoupling of mechanical and electrical effects
  - Good agreement between prediction and experimental data

- Drawbacks:
  - Two mechanical interfaces involved: {Tip/free-standing part} & {electrodes}
    ➔ Correction needed
  - Relatively slow actuations compared with electrostatic ones.
    ➔ Only specific mechanisms directly observable
  - Punctual loading instead of distributed electrostatic pressure
    ➔ A metrix has to be found for direct comparison

Conclusion

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- To be done :
  - To understand the physics of the actuation:
    - Improving the quality of the measurements of the mechanical properties (nanoindentation experiments, **micro-tensile tests**,…)
    - Performing others series of tests on different designs and materials.
    - Using spherical tips in order to reduce the influence of the {tip / free-standing part} interface
  - Failure analysis:
    - Quantitative comparison between electrostatic and mechanical actuations.
    - Comparison of the level of the adhesion force with AFM measures and several models

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… *Thank you for your attention*

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