Modeling of RF MEMS contact for Investigation of the Degradation Mechanism

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PURPOSE

- Development of an innovative numerical method in oder to get a deeper insight on the physic of contact of DC contact MEMS cells and investigate the degradation mechanism in the case of reliability studies.
- This method is used to determine the contact resistance as a function of the applied force

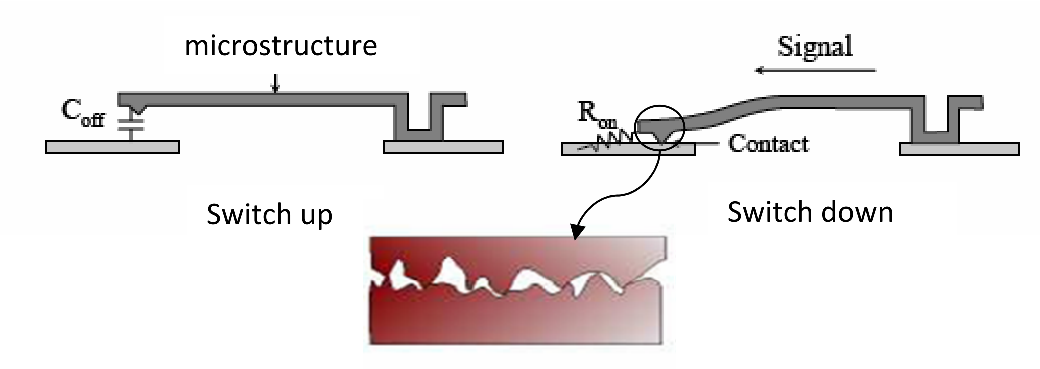
OUTLINE

- Introduction
- Principle
- Reverse engineering methodology
- Contact algorithms implemented in ANSYS
- Electrical contact models
- Exemple:
  - definition
  - results
  - Contact resistance calculation
- Investigation of degradation mechanism
  - Samples and experimental set up description
  - Reverse engineering method
  - Results & observations
- Conclusions & Perspectives

INTRODUCTION

- Limitations of DC contact RF MEM switches:
  - Quality and repeatability of the contact that drive the RF performance
  - Reliability

  → Intense research effort to understand the failure mechanism at contact interface



- New methodology allowing the simulation of the DC contact of RF MEMS devices through element multy-physic analysis and surface characterization

PRINCIPLE

1. Reverse Engineering Method

   Real shape and contact surfaces are extracted from characterization and then implemented in a finite element software

2. Mechanical Contact Simulation

   Finite element analysis is performed using contact algorithms and a non-linear solver

3. Results (post-processing)

   Contact is defined by contact area and pressure distribution

4. Calculation of Contact resistance

   R_c is deduced from pressure distribution and size of the contact spots using analytical expressions

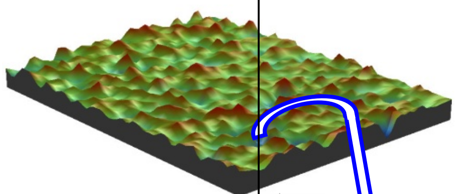
REVERSE ENGINEERING METHODOLOGY

3D Mapping
VEEKO - AFM

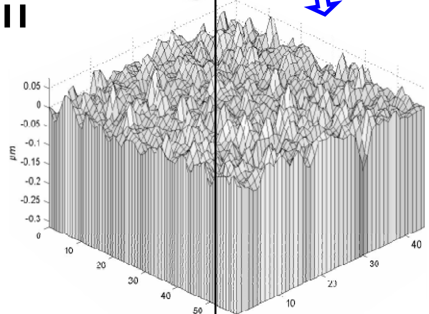
ASCII file
X Y Z Coordonates

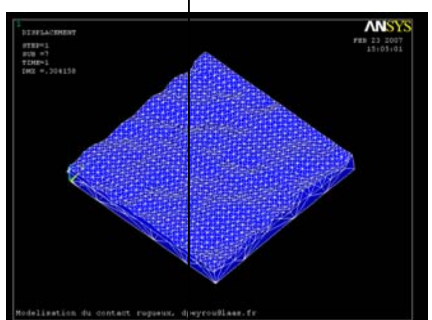
Numerical treatment

Generating rough surface in ANSYS:
- ANSYS Parametric Design Language (APDL)
- Creating array of Keypoints
- Bottom up solid modeling to create the block volume



ASCII

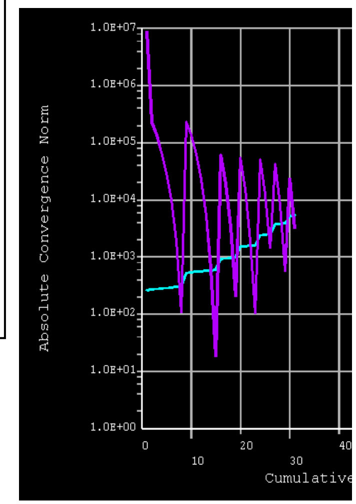




Contact Algorithms
- Penalty
- ***Augmented Lagrangian***
- Lagrangian: zero penetration enforced
- Penalty/Lagrangian: zero penetration normal /penalty spring tangential

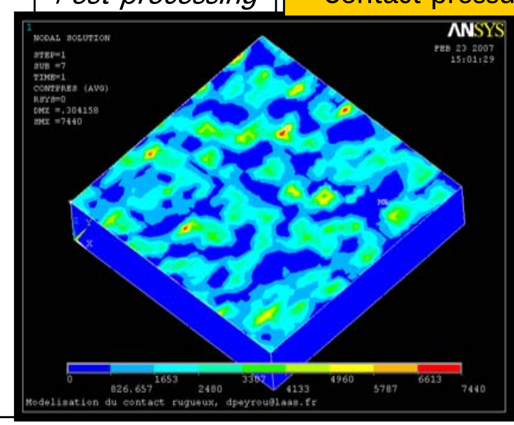
Non-linear solver

Convergence stack



Results
Post-processing

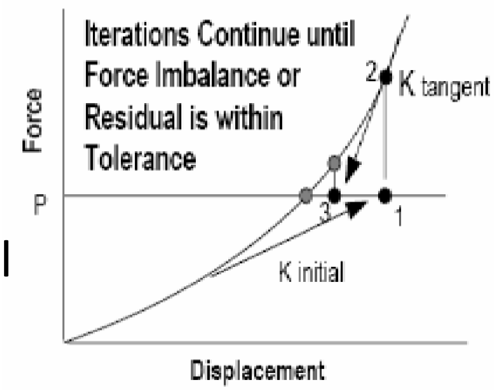
Contact pressure distribution



Solving Non-linear contact problems in ANSYS

We choose the combined method based on penalty and lagrangian methods called the ***augmented Lagrange method***.

It means a penalty method with penetration control :
1. The Newton-Raphson iterations start off similar to the pure
penalty method.
2. Similar to the pure Lagrange multiplier method, the real constant
TOLN determines the maximum allowable penetration.



3. If the penetration at a given equilibrium iteration exceeds this maximum allowable penetration, the contact stiffness per contact element is augmented with Lagrange multipliers for contact force (pressure). For the contact element stiffness, the force (pressure) is

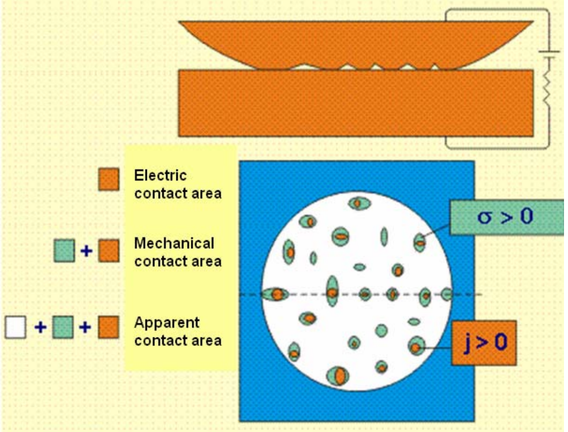
$$\lambda_{i+1}=\lambda_i+ k_{cont}\, x_{pene}$$

if the penetration is greater than the maximum allowable value

Electrical contact models

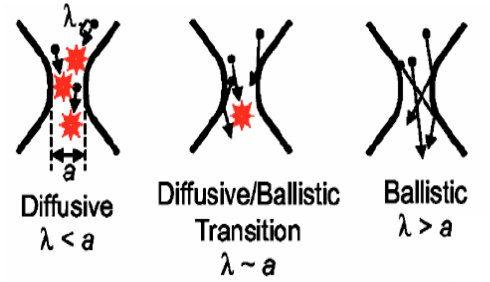
First model: classical point contact : Maxwell resistance (Ohmic constriction)

1. For a small orifice with radius a >> λ (λ = electronic mean free path) : $\mathbf{R_c = \rho/2a}$ **(1)**
2. For n identical contact spots of radius a located inside an apparent contact surface of radius R: $\mathbf{R_c = \rho/2na + \rho/2R}$ **(2)**



Second model: semiclassical description of a ballistic point contact (λ<<a): Sharvin resistance

$\mathbf{R_c = 4\rho\lambda/3\pi a^2}$ **(3)**

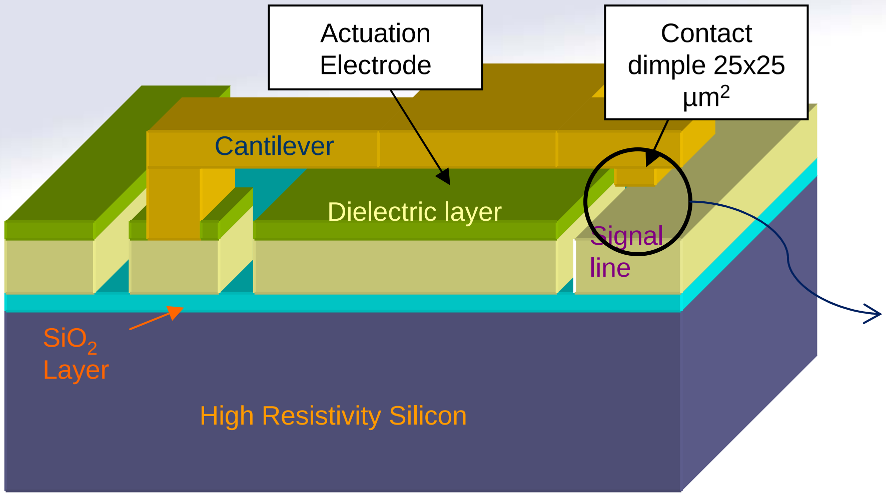


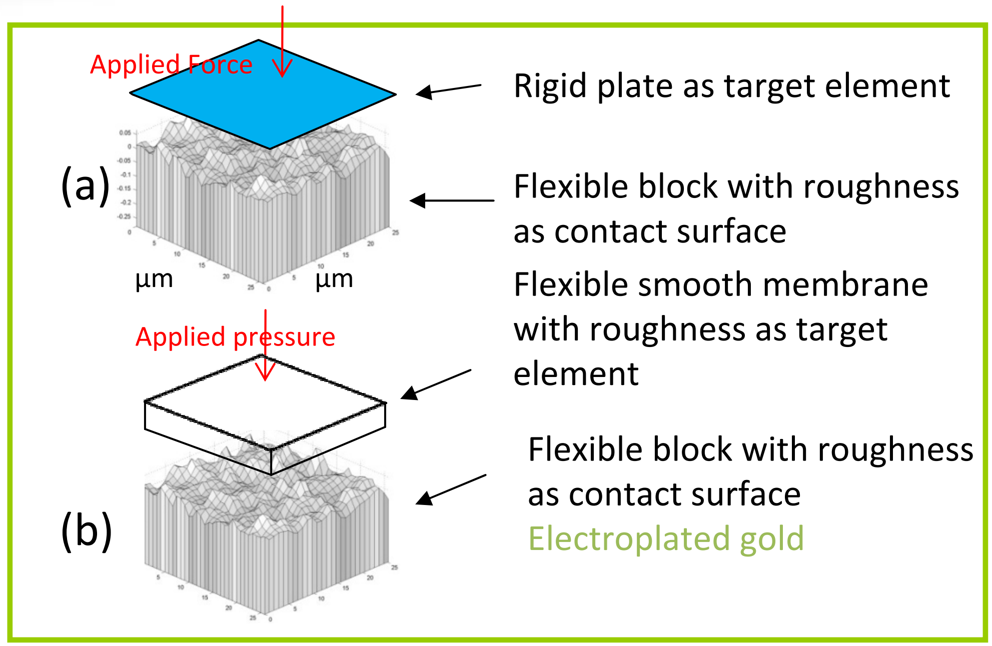
Third model: Diffusive / Ballistic transition λ ~ a

$$R_c = \gamma(\frac{\lambda}{a})R_M + R_S = \frac{1+0.83(\frac{\lambda}{a})}{1+1.33(\frac{\lambda}{a})}\frac{\rho}{2a} + \frac{4\rho\lambda}{3\Pi a^2} \quad \textbf{(4)}$$

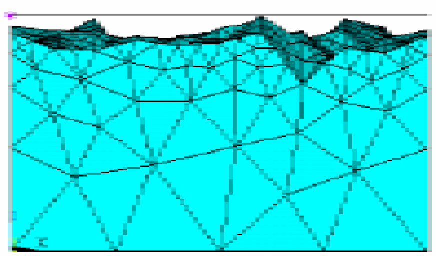
B. Nicolic and P.B. Allen, *Electron transport through a circular constriction*, 1999.

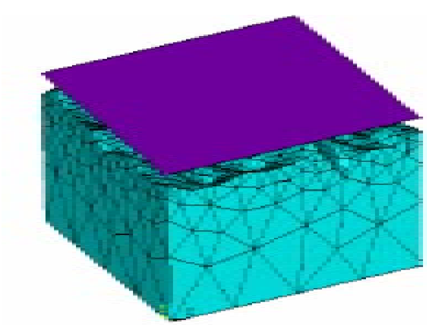
First model : DEFINITION

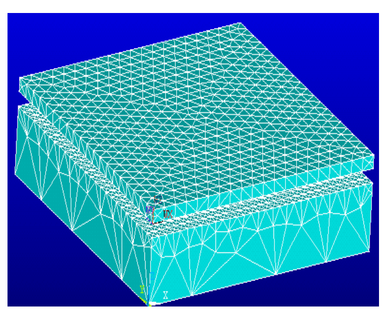




ANSYS contact model

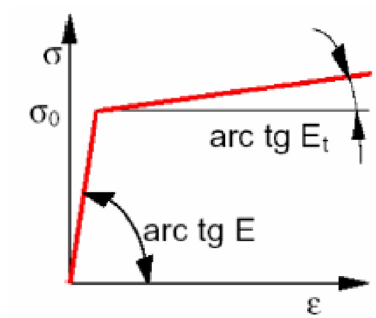




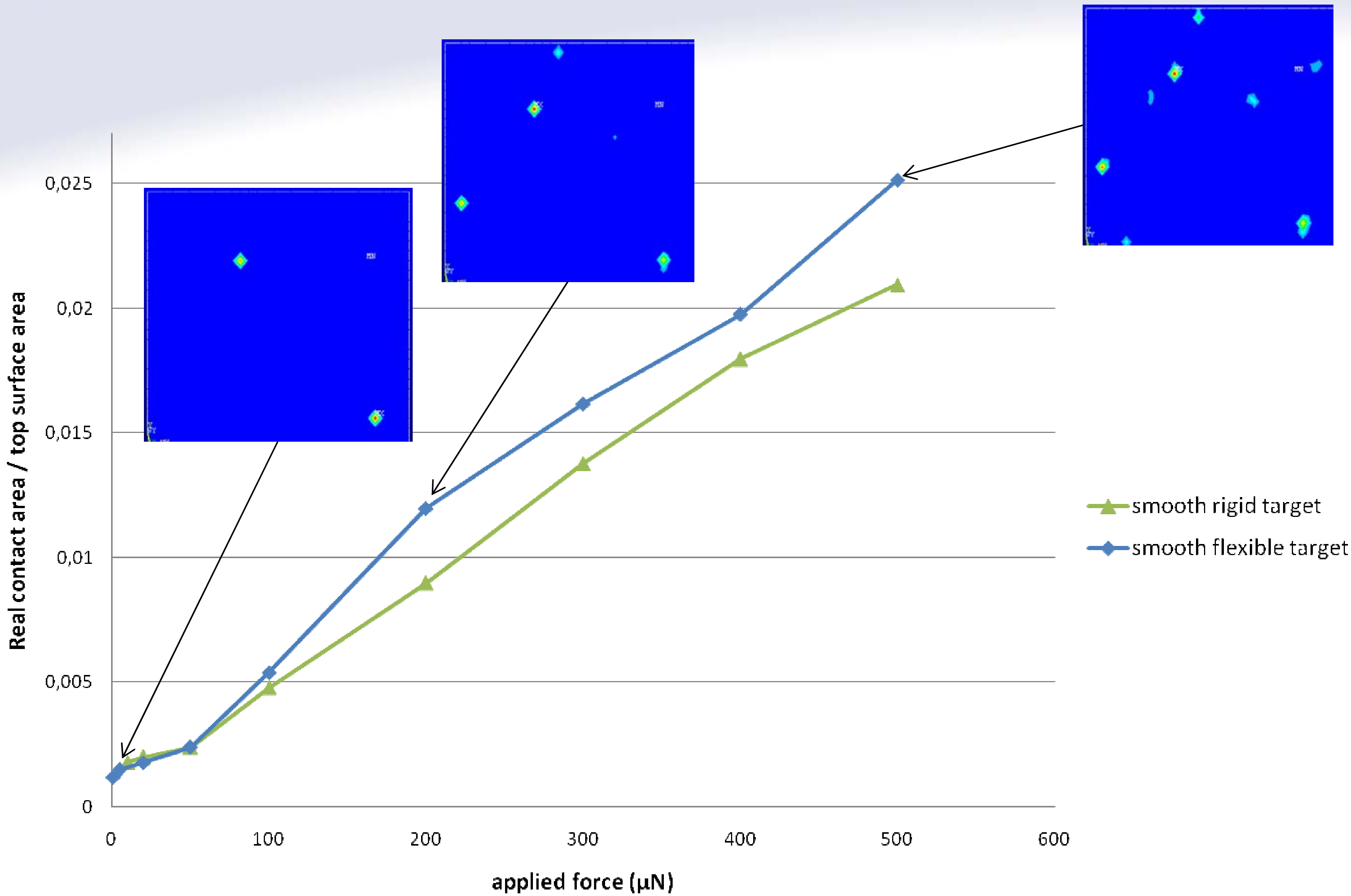


Material properties

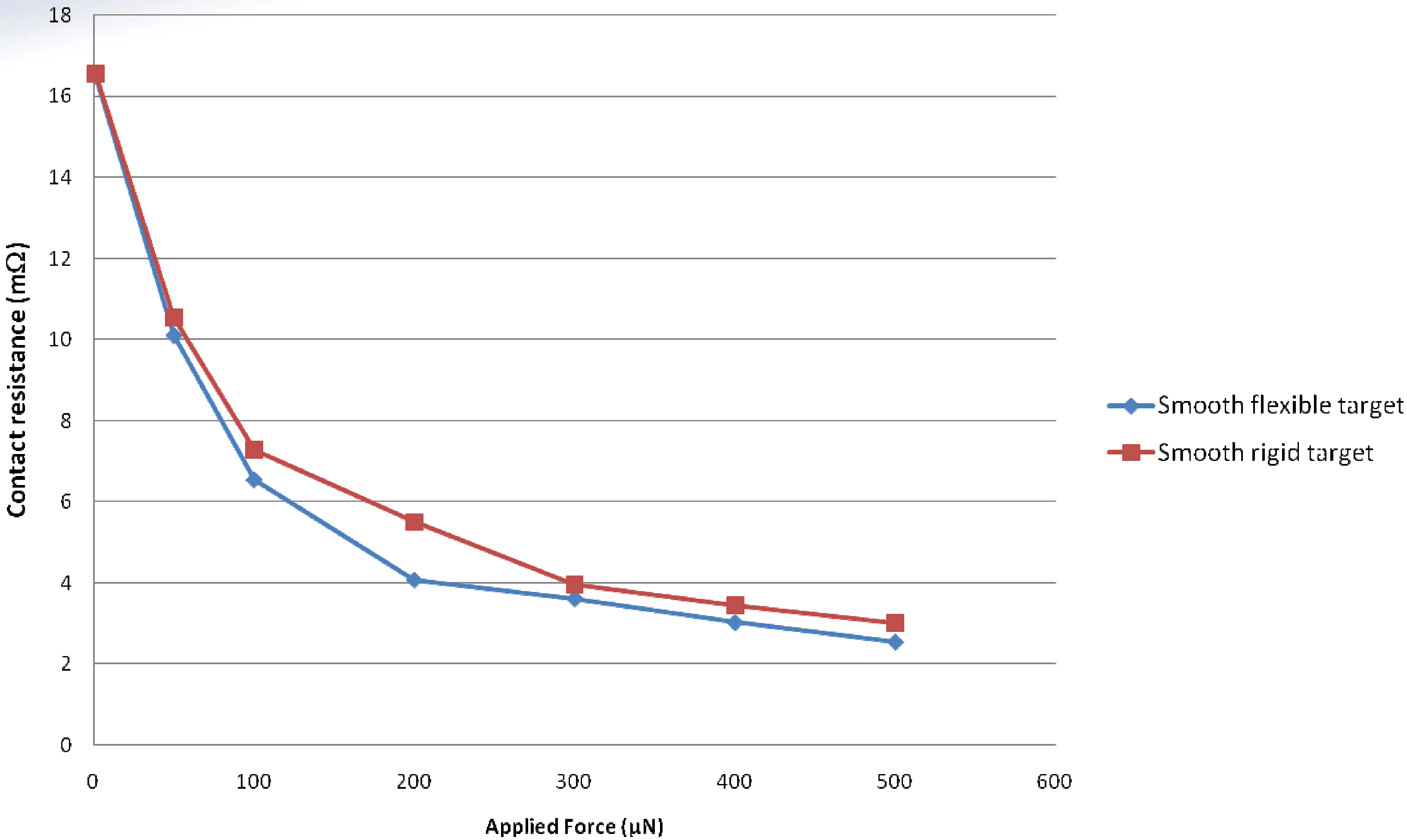
	Young modulus E	Poisson ration ν	Yield stress σ_0	Tangent modulus E_t
Au	80 GPa	0.42	300 MPa	10 GPa



First model : RESULTS

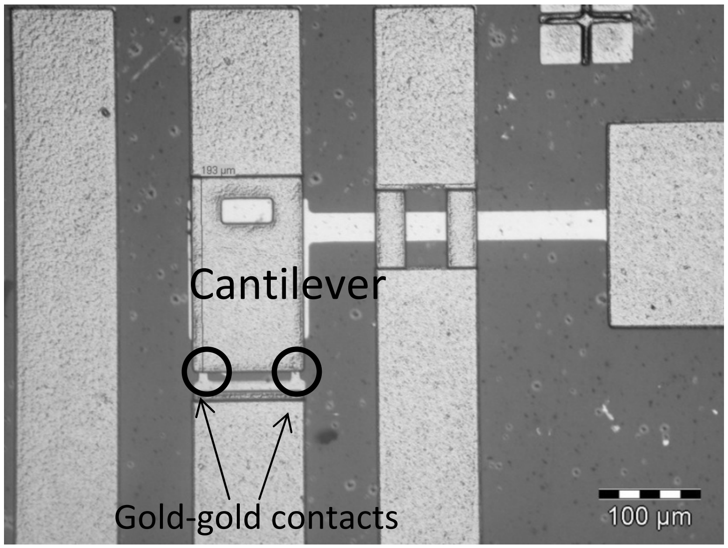


First model : contact resistances calculation

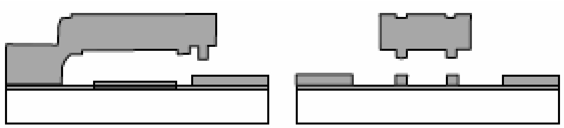


Investigation of degradation mechanism

__Samples:__ suspended microstructures prepared by surface micromachining with ohmic contacts



Optical view of an ohmic XLIM switch

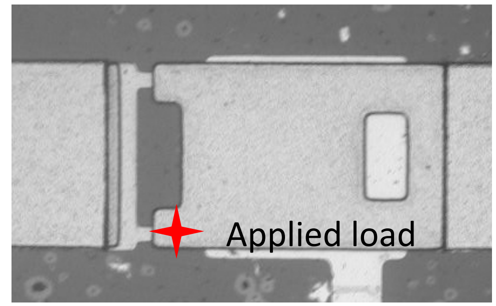


Design of an ohmic XLIM switch

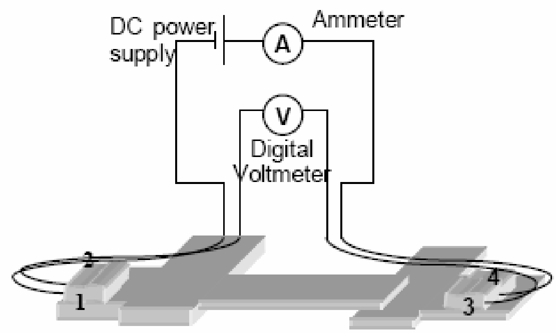
XLIM Laboratory, Minacom department
pothier@xlim.fr

__Experimental set up:__

MTS nanoindenter from CNES/NOVAMEMS lab



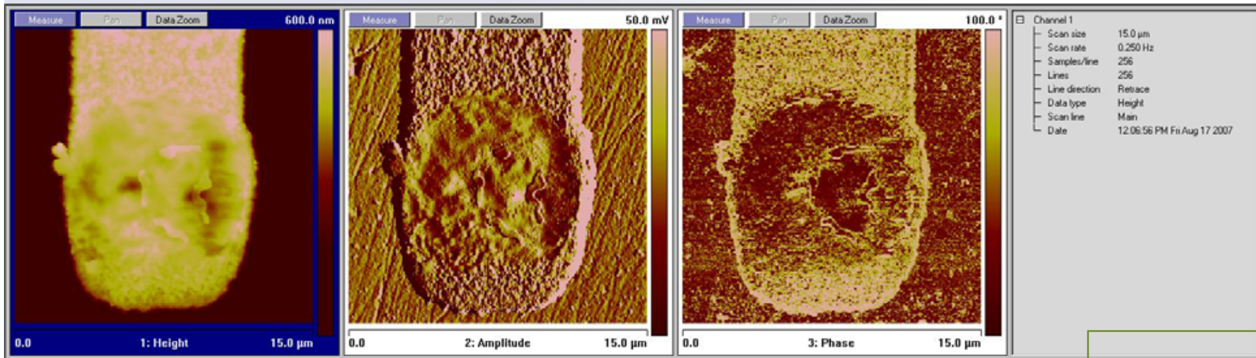
Mechanical actuation: location of the applied load



Four wires measurements set up

➡ Contact resistance measurement through the number of cycles

Reverse engineering method



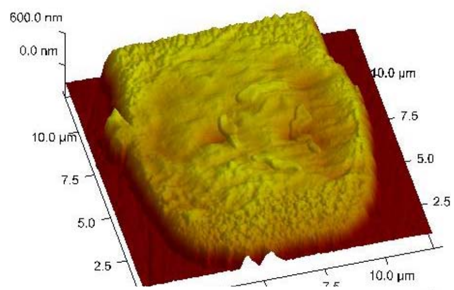
AFM images of left bottom contact for a XLIM microstructure after cycling

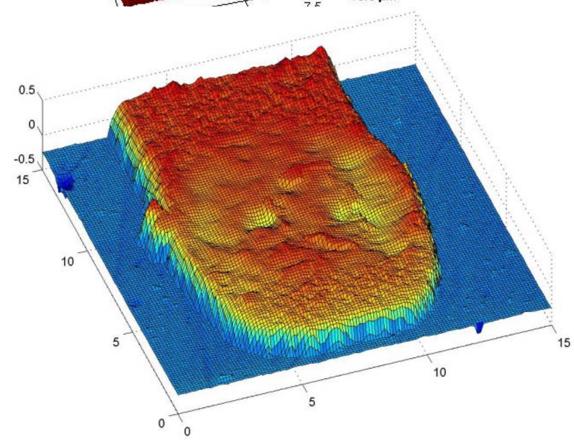
3D mapping *AFM*

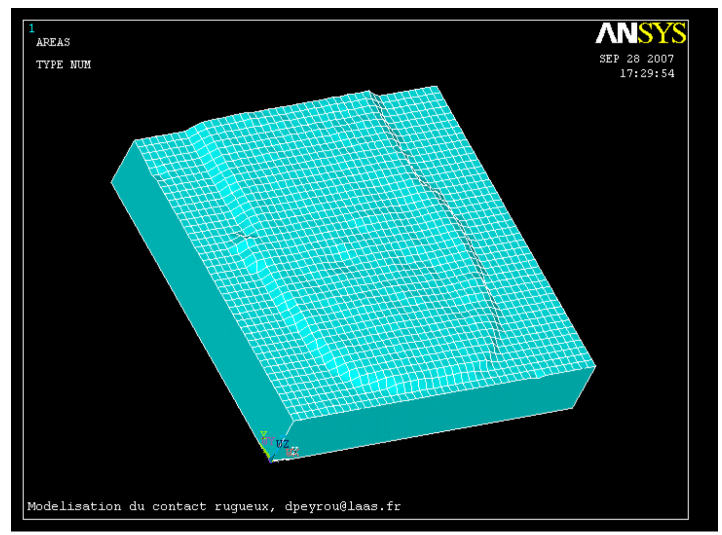
ASCII file x y z coordinates

Numerical treatment in MATLAB

Generating rough surface in ANSYS

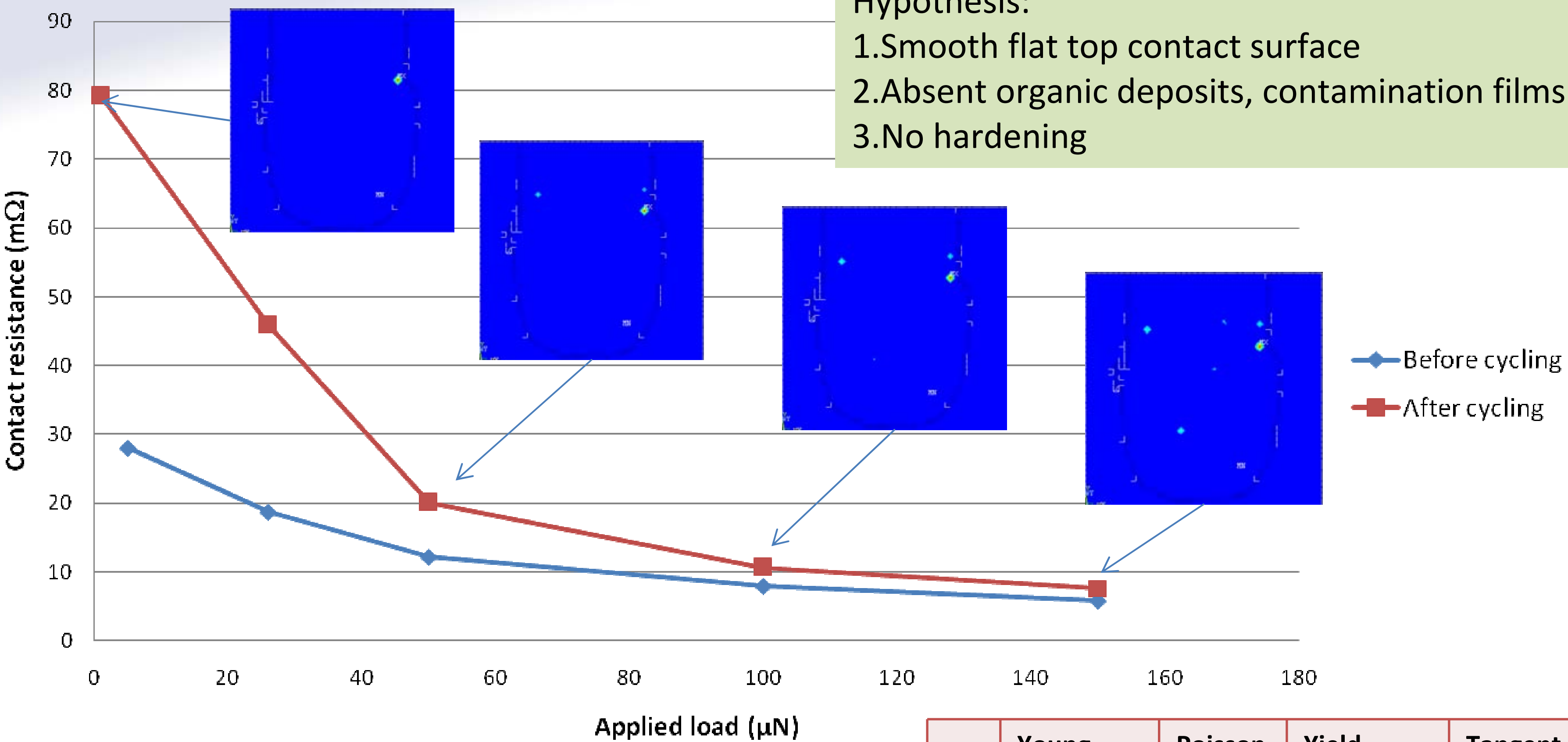






RESULTS & OBSERVATION

Hypothesis:
1.Smooth flat top contact surface
2.Absent organic deposits, contamination films
3.No hardening



	Young modulus E	Poisson ration ν	Yield stress σ_0	Tangent modulus E_t
Au	50 GPa	0.42	200 MPa	10 GPa

✓Limitation due to the mesh size.
Minimum extracted contact area = 0.061µm²→R=0.14µm

✓Needing other structures to experiment the mechanical and electrical behaviour with cycling and compare with contact simulations.

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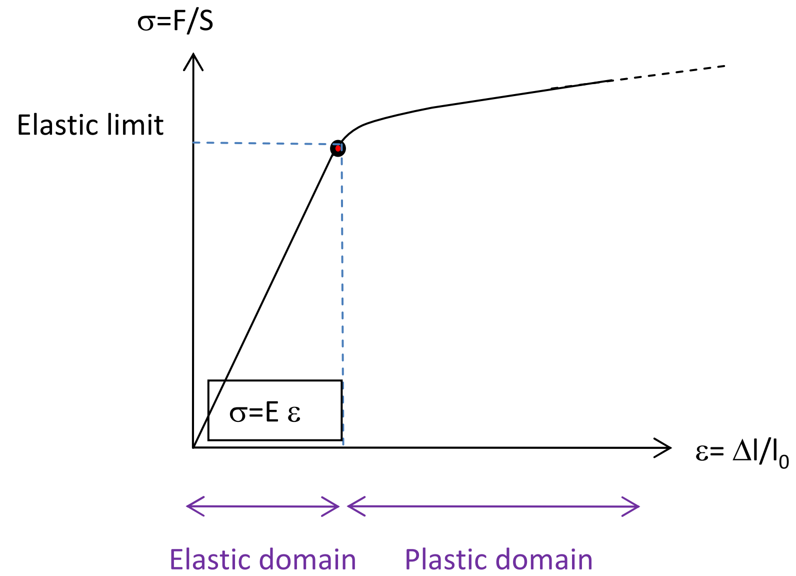
CONCLUSIONS

- Development of an innovative method to analyse surface topography effect such as roughness
- This should be intensively study in corelation with mechanical and electrical characterization in order to have a deeper insight of the phenomena that imply the contact degradation
- This could be study to investigate the impact of materials, roughness, technological process, topology

PERSPECTIVES

- Run a multiphysics and parametric simulation (elements contact and target 174 support structural-thermal-electric coupled applications: keyopt(1)=3) to extract the contact resistance
- Run a contact simulation with cycling to analyse the contact surface behaviour with the number of contact opening and closing



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