

Proc. Eurosensors XXV, September 4-7, 2011, Athens, Greece

## Validation of Finite Element Structural Simulation for Ohmic Microcontact

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### Abstract

In the current literature, there is no model able to accurately predict the electrical resistance value of rough micro-contacts. Such model requires a coupled thermo-electro-structural analysis that is very difficult to validate in a straightforward manner. In the present approach, atomic force microscopy (AFM) scanned data of contact surface with roughness are used to build finite element (FE) model. As a first step towards multiphysics analysis, the aim of this study is to validate results of structural simulation of a rough gold micro-contact.

A setup with a nanoindenter and a real microswitch is used to extract force-displacement curves. These results are compared to FE simulations which allow evaluating the effects of the main parameters. It is shown that the accuracy of these structural simulations is acceptable for an accurate evaluation of the electrical contact resistance.

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**Keywords:** microswitch, ohmic contact, finite element, structural simulation

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### 1. Introduction

Reliability of ohmic contacts is a great challenge for microswitches [1]. As fabrication and measurement are highly time and cost consuming, numerical and analytical methods are preferred. FE models for rough surface contact using AFM scanned surface data are currently used by several research groups, but most of them simplify the topography by approximate functions [2], which induce deviations from the real surface. Pennec [3] proposes structural simulations based on real rough surface obtained by

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AFM measurement which looks promising but leads to a poor agreement with electrical measurements. In this paper, the accuracy of the structural simulation is firstly assessed with a simple indentation case and the influence of the grid step and material characteristics on the FE simulation results is discussed. A microswitch setup is then modeled; stiffness and electrical resistance are computed and discussed.

## 2. Validation of Simulation Methodology

### 2.1. Experimental setup and FE model for the indentation example

In order to validate the accuracy of the structural simulation methodology, a  $5.6\text{ }\mu\text{m}$  thick gold electrodeposited film is indented with a very low force, representative of electrostatic-actuated microswitches. The indenter is equipped with a  $5.9\text{ }\mu\text{m}$  radius spherical tip. Experimental force vs displacement results are shown in Fig.1. Loading curves show much higher dispersion than unloading curves. The observed dispersion can be due to the grain orientation, the presence of grain boundary in the indented zone, as well as the presence of foreign particles on the surface of the sample.

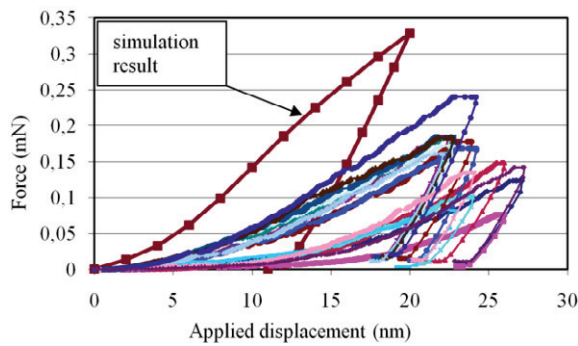


Fig. 1 Results of experiments and simulation for indentation example: force vs displacement

In order to build the FE model, AFM is used to scan the surface, and ANSYS software is used to generate the rough surface and build the contact model. The simulated model is composed of a rough volume and a smooth  $5.9\text{ }\mu\text{m}$  radius spherical volume. The material properties of gold were previously obtained by experiments on samples from the same wafer [4]. A Young's modulus of 80 GPa, a Poisson ratio of 0.42, a yield strength of 300 MPa and an ultimate strength 360 MPa were deduced. Simulation results are shown in Fig.1.

Clearly the model is not accurate for the beginning of the loading. However, average stiffness is quite fairly reproduced in the subsequent phases: in the 15-20 nm loading range, simulation exhibits 42% higher stiffness than average measurements and during unloading, the difference drops to 2%.

### 2.2. Influence of main model parameters

Several parameters influence the simulation results, as discussed below.

The grid step of AFM data is  $7.9 \times 9.45\text{ nm}^2$  and the number of scanned points is 40766. A simulation based on so many data would require too high computational efforts. To reduce the computation time, simulations are done with a coarse factor of 3, 6, 9, 12 and 18. The simulation shows that the deviation on the stiffness is less than 10% between the finest and the coarsest grids. Considering this, a factor of 9 is

adopted in the following simulations to reduce the calculating time while ensuring a stiffness error below 5%.

Material properties have a significant effect on the mechanical behavior. Yield strength and ultimate strength of gold are largely process dependent for microelectromechanical systems (MEMS) [5], therefore their influence is assessed. Fig.2 (a) shows that the stiffness varies by 57% for the load process and 16% for the unload process in the 100-500 MPa range considering a 300 MPa as a reference. The microswitch operates after ‘burn-in’ process, thus the stiffness during unloading is taken into consideration, so the impact of yield strength is weak. In the following simulations, the value of yield strength is chosen as 300 MPa, which corresponds to the value measured for the indented sample.

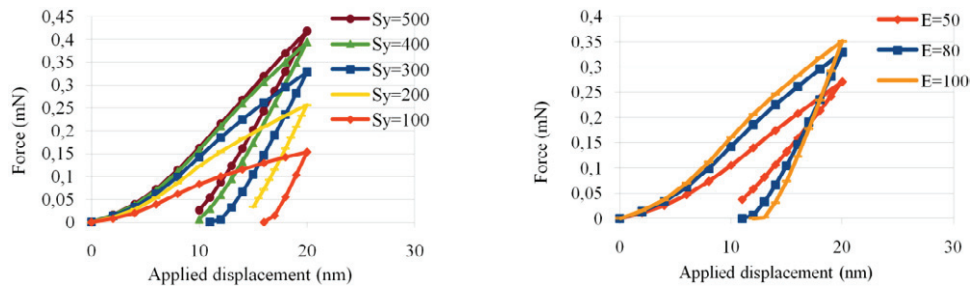


Fig. 2 (a) Influence of yield strength ( $S_y$  in the figure, in MPa); (b) Influence of Young's modulus ( $E$ , in GPa)

Furthermore, some simulations are done with different Young's modulus values (Fig. 2(b)): the average stiffness is proportional to the Young's modulus during unloading, because deformation is quasi-elastic, unlike the case of loading. A Young's modulus of 80 GPa is used for microswitch simulation.

### 3. Study of Microswitch Contact Model

#### 3.1. Microswitch experimental setup and FE model

Broué [6] uses a nanoindenter to investigate the mechanical behavior of ohmic contacts (Fig. 3(a)). The nanoindenter tip pushes the bridge down to the bump. Fig.3 (b) shows the tip displacement vs the bump/bridge contact force, starting at the bump/bridge contact initiation. The average stiffness value is around  $5.5 \times 10^3$  N/m.

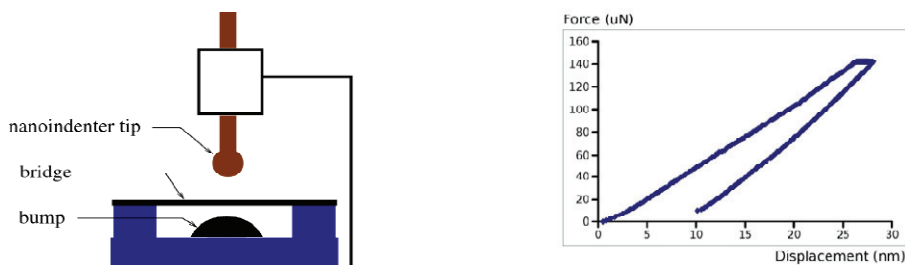


Fig. 3 (a) Microswitch experimental setup; (b) Experimental load vs displacement curve

In our FE simulation, AFM scanned data are used to build the contact model. The roughness on both sides between the bump and the lower surface of the bridge are considered, while many studies ignore the roughness of the lower part of the bridge [7, 8]. The effect of the roughness is discussed below.

Moreover, considering the roughness of the bridge top surface, the stiffness of the upper contact cannot be neglected. Another FE model takes it into account with AFM data of the bridge top surface and a smooth diamond indenter tip.

The experimental protocol includes a “burn-in” process; therefore FE stiffness is read during unloading. Considering the computation time and accuracy, a grid step of 47 nm is adopted.

### 3.2. Results and discussion

The simulation leads to an overall stiffness of  $11.4 \times 10^3$  N/m, compared to  $5.5 \times 10^3$  N/m deduced from experiment. This discrepancy is then evaluated in terms of contact resistance error; using contact spot extraction of FE model and standard multi-spot resistance analytical calculation as Pennec et al. [3].

FE simulations yield that the stiffness deviation corresponds to 35% electrical resistance deviation. Although this value presents high, it is acceptable compared to the huge disagreements between electrical measurement and simulation reported in the literature with a typical factor of 10 to 40 [8].

Simulations with two models for the contact between bump and bridge are done: one with AFM data for the bridge and the other with a smooth surface instead. Resistance ranges from  $0.052 \Omega$  to  $0.043 \Omega$  for the two models. Thus it should be noted that the roughness of the surface under the bridge might add non-negligible errors.

## 4. Conclusion

As a conclusion, a relatively simple structural model gives enough accuracy for investigating ohmic microcontact. The huge discrepancies observed between electrical measurements and simulations are most likely due to the electrical modeling of electrical contacts.

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