ON THE MODELING OF ADHESIVE CONTACT AND STICTION FAILURE IN MICRO-SWITCHES

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ABSTRACT

Undesirable stiction, which results from contact between surfaces, is a major failure mode in micro-switches. Indeed the adhesive forces can become so important that the two surfaces remain permanently glued, limiting the life-time of the MEMS. This is especially true when contact happens between surfaces where elasto-plastic asperities deform permanently until the surfaces reach plastic accommodation, increasing the surface forces. To predict this behavior, a micro adhesive-contact model is developed, which accounts for the surfaces topography evolutions during elasto-plastic contacts. This model can be used at a higher scale to study the MEMS behavior, and thus its life-time. For illustration purpose, an electrostatic-structural analysis is performed on a micro-switch.

1. INTRODUCTION

Stiction is one of the most common failure mechanisms in micro-electromechanical systems (MEMS) and remains a major issue for micro-switches [1]. Stiction happens when two components entering into contact permanently adhere to each-other because the restoring forces are smaller than the surface forces (capillary, van der Waals (VDW) or electrostatic). This can happen either during the fabrication process at etching (release stiction) or during normal use (in-use stiction). The risk of in-use stiction increases when plasticity is involved during the contact phase, as the contact surface of asperities increases.

2. MICRO-MODEL FOR ELASTO-PLASTIC ADHESIVE-CONTACT

2.1. Single Asperity Elasto-Plastic Contact

Let an asperity of tip radius R, Young modulus E, and yield stress S_Y, interacts with a rigid plane at an interference distance δ, positive in case of contact and negative otherwise, as illustrated in Figure 1.a and 1.b, defined as the distance between the original profile of the asperity tip and the plane. When the plane starts interacting with the asperity during loading, the critical yield interference δ_{CP} is defined as the interference at which the asperity starts yielding.

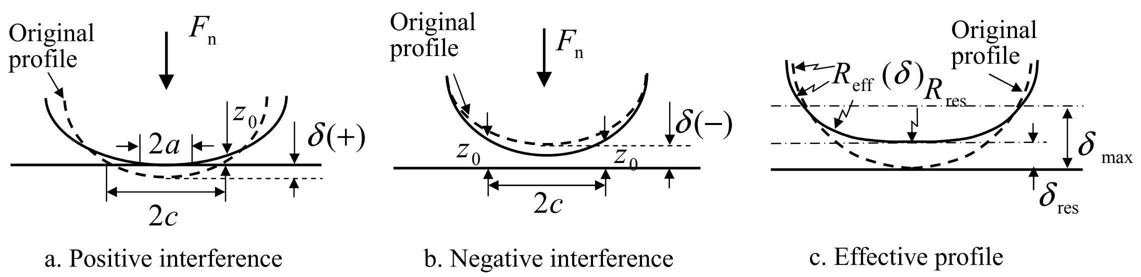

Figure 1. Definition of single asperity interference [2]

The adhesive contact theory taking into account the elasto-plastic behavior happening during contact (Figure 1.c) has been developed in details in reference [2]. This theory results in different adhesive-contact forces during loading $F_n^L(\delta)$ and unloading $F_n^U(\delta)$. The elastic-plastic adhesive contact of a micro sphere is considered here for Ruthenium (Ru) [3] for which material properties and initial asperity tip radius are reported in Figure 2. This figure compares the predicted adhesive-contact forces to the FE results for the loading and unloading adhesive-contact forces at three maximum interferences δ_{max} successively equal to 17, 34 and 51 nm. It is seen that an excellent agreement is obtained for the three loading conditions.

2.2. Rough Surfaces Interaction

Greenwood and Williamson 'asperity-based model' [4] is applied to simulate the rough surface/plane interaction. A rough surface is described by a collection of spherical asperities with identical end radii R, whose height h have a statistical distribution

$$\varphi(h) = \frac{1}{\sigma_s \sqrt{2\pi}} \exp(\frac{-h^2}{2\sigma_s^2}) \quad (1)$$

where σ_s is the standard deviations in asperity heights. Note that the contact of two rough surfaces can be represented by the contact between an equivalent rough surface and a smooth plane [5]. The interaction between two rough surfaces is also characterized by the distance d between the two rough surface mean planes of asperity heights, and by N the surface density of asperities. All these values can be identified from the study of the surfaces topography, and, in particular, depend on the surface RMS roughness R_q.

Properties of Ru films		
Initial asperity tip radius	R [µm]	4
Young modulus	E [GPa]	410
Poisson coefficient	ν [-]	0.3
Yield stress	S_Y [GPa]	3.42
Standard deviation in asperity height	σ_s [nm]	7.78
Surface RMS roughness	R_q [nm]	7.81
Surface density of asperities	N [µm^{-2}]	10

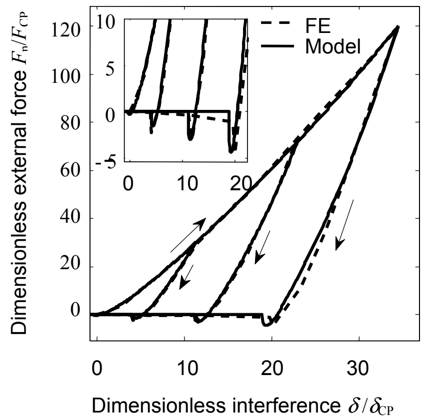

Figure 2. Comparison of the single asperity model with finite element results for Ru

The surface loading and unloading forces, respectively F_{nT}^L and F_{nT}^U can now be evaluated by integrating on the surface the effect of each asperity, for which the interference reads $\delta = h - d$ as described previously. It bears emphasize that as asperities enter into plasticity for different surface distances, the effective profile is different for each asperity. Details on the procedure of integration are provided in [2].

3. CYCLIC LOADING OF A MICRO-SWITCH

D_0 [µm]	2
t_d [µm]	0.15
ε_0 [pF/m]	8.854
$\varepsilon_d/\varepsilon_0$ [-]	7.6
t_s [nm]	180

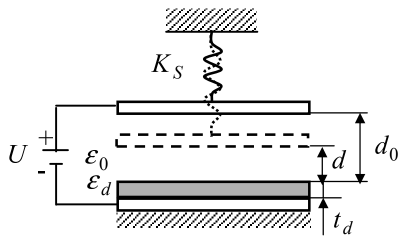

Figure 3. Geometry and properties of the micro-switch

A one-dimensional model of micro-switch is considered (Figure 3). In this model, a voltage difference U is applied between a movable electrode and a substrate electrode covered by a dielectric layer (SiN) of thickness t_d and permittivity ε_d. The movable electrode is attached to a spring of stiffness K_S per unit area, and is initially at a distance d_0 from the substrate. The switch is supposed to work in vacuum (permittivity ε_0) so that any damping effect due to a squeeze film is neglected. Contact is assumed to occur between two Ru surfaces, for which typical topography values are reported in Figure 2. Ru films of thickness t_s are deposited on the movable electrode, and also on a part of the substrate. From these data, the pull-in voltage and the impact energy can be computed in terms of the stiffness K_S. This computation has been performed in [2], and in this application we consider an impact energy of E_I=0.5 J/m^2.

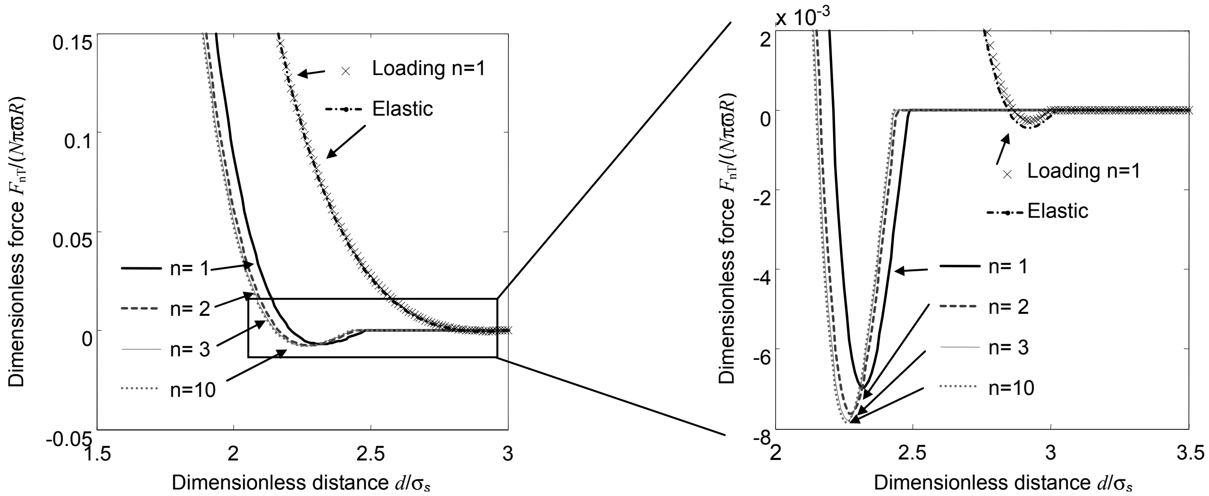

Figure 4. Cyclic loading of the 1D micro-switch

The loading/unloading cycles (accounting for asperities profiles modifications at each cycle) were calculated in [2]. The loading and unloading curves after 1, 2, 3 and 10 cycles are reported in Figure 4 as well as the pure elastic solution. It is observed that the unloading curves change after repeated interactions until accommodation is reached. It appears that the elastic solution underestimates the pull-out force which can be better predicted by the proposed approach, thus opening the way to stiction-free design.

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