

## Modelling of spontaneous Adhesion phenomena in Microsystems

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The reliability of microsystems (or micro electro mechanical systems, MEMS), i.e. micro-engines and sensors, is often limited by the phenomena of spontaneous adhesion between the parts that should maintain the capability of relative motion. The problems of catastrophic adhesion, but also of dangerous increase of friction, are often mentioned in the literature with the term *stiction*, a contraction of "static friction". Many research efforts are currently devoted to stiction phenomena, from the experimental point of view, in the ambit of predictive simulations and for the study of possible provisions apt to reduce their effects on MEMS operation (see the review papers [1] and [2]).

The main source of adhesion, in the presence of moisture, is the capillary tension of water droplets condensed around the asperities between rough surfaces. In dry conditions, the uncharged surfaces stick to each other because of different forces, among which the most important ones are represented by the short-range intermolecular Van der Waals interactions.

A computational model is here presented and discussed built with the purpose of simulating the adhesive behaviour in various situations, with reference to silicon Microsystems [3]. The computations are based on three-dimensional finite element analyses of a representative portion of the surface.

The first important issue in the definition of the model is represented by the artificial generation of rough surfaces on the basis of a priori known statistical properties. Two different procedures have been implemented and critically compared: the digital filter method [4] and the linear transformation of random matrices [5]. In particular, the importance of some critical parameters, necessary for the definition of the procedures, has been pointed out. A typical representation of the artificially generated surface is reported in Figure 1. The extension of the representative surface (side  $20\mu\text{m}$  in the figure) is tuned in order to obtain a statistically significant distribution of the asperities. The results have been checked by comparison with the actual topography of manufactured structures, measured by means of atomic force microscopy.

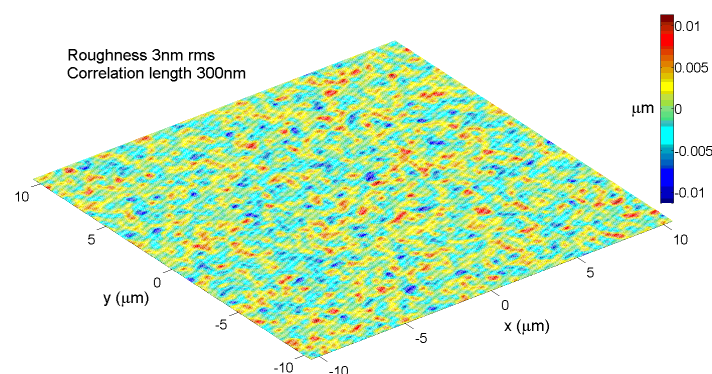


Figure 1: Contour plot of the asperity heights for a typical rough surface generated by the numerical procedures considered in this paper.

The mechanical behaviour of silicon has been modelled by a standard elastic-plastic constitutive law in finite strain. This assumption is rather questionable for a crystalline material and, for this reason, it has been thoroughly checked. The justification has been sought by considering the results of ad-hoc experiments of nano-indentation. The possible application of more sophisticated models (e.g. crystal plasticity [6]) has been considered.

The microscopic forces which are responsible for adhesion are properly introduced in the finite element model. The Van der Waals forces have been computed on the basis of a proximity force approximation, introducing a suitable molecular interaction potential [7]. The effect of capillary tension is evaluated by considering that the amount of capillary condensation is strongly dependent on the degree of relative humidity and on the roughness geometry. The simplified model for capillary attraction has been assessed on the basis of detailed computations for the formation of water meniscus [8].

Parametric studies have been carried out at the microscopic level, changing some significant environmental parameters, namely relative humidity and temperature. An example of the achieved results is sketched in Figure 2. The adhesion energy, computed for a representative rough surface, is plotted versus the environmental humidity. Besides the effect of capillary attraction, it is evident the important role played by plastic deformation. In fact, the *unloading* curve, referred to the phase when asperities have been irreversibly deformed by contact interaction, shows higher values of adhesion energy.

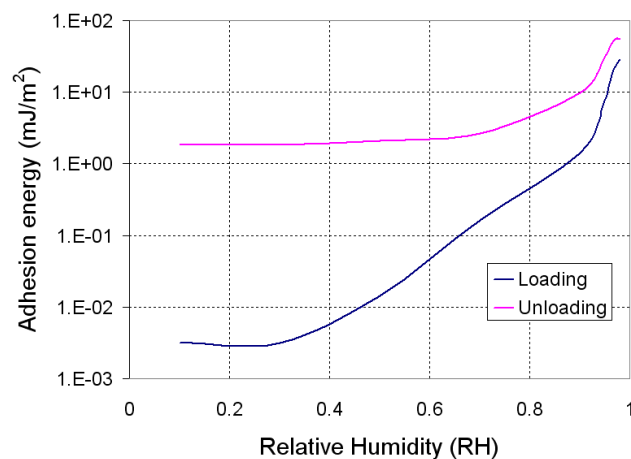


Figure 2: Adhesion energy obtained by the computational method for different humidity conditions. The *loading* curve refers to approaching undeformed surfaces, the *unloading* one includes the effect of plastic deformations due to contact of the asperities.

## References

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