EXPERIMENTAL VS NUMERICAL ESTIMATION OF ADHESION ENERGY IN SILICON MEMS

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The phenomena of spontaneous adhesion in silicon MEMS are often localized between parts which should maintain the capability of relative motion. In the literature the term "stiction", contraction of "static friction" describes the results of catastrophic adhesion and of dangerous increments of friction (see e.g. the review [1]). This paper presents a new experimental methodology to measure adhesion energy in real-life MEMS. The experimental outcomes are compared with numerical results, obtained via an innovative technique on the basis of finite-element (FE) mechanical simulations at the micro-scale. Many research works have been devoted to the experimental evaluation of adhesion energy. In [2], the interferometric measurement of the detached length in cantilever beams has been correlated, through a fracture mechanics approach, to the adhesive surface energy. Bachmann et al. [3] approached the problem in a different way, by performing pull-in tests on silicon suspended disc. Recently, the Authors in [4] exploited the pull-out behavior for an indirect measurement of adhesive forces through optical and electrostatic data. This paper is different from the cited ones, since no optical measurement is needed and the adhesion energy can be measured in the actual operating conditions of packaged and unpackaged MEMS. Moreover, the new computational technique (which exploits the experimental results) is used in order to predict the adhesion energy for different geometries and environmental conditions.

The first step of the experimental campaign is represented by the morphological characterization of the poly-silicon surfaces in the devices. This task is accomplished by AFM measurements, which yield precise information on the statistical properties of roughness (Figure 1). After some measurements, we have obtained the following average data: roughness level 6.2nm r.m.s., correlation lengths 1.15μm in both horizontal and vertical direction. AFM experiments can also be used to give a first estimate of adhesive effect. The deflection curve (Figure 2) provides an estimate of the peak adhesive force, that is equal (for the unload branch) to 55nN. The information on the specific adhesion energy can be hardly obtained in view of the difficult estimate of the contact area between the tip and the surface. For this reason, we are currently investigating the possible adoption of tip-less cantilevers for measuring specific adhesion energy via AFM.

Figure 3 shows an optical microscope view of our first experimental device, which has been used for the measurement of adhesion on horizontal surfaces. The central part, which is constituted by an array of clamped-clamped beams, is actuated in the vertical direction and adheres to the substrate. The pull-in and pull-out occurrence can be easily evidenced in the C-V curves (Figure 4). after some data reduction operations, which are essentially based on energetic concepts, the average specific energy of adhesion is evaluated as $13.4 \pm 0.89 \mu J/m^2$. Such value is in excellent agreement with the numerical outcomes, which are shown in Figure 5 for different roughness levels. The same figure shows some previous experimental results reported in [5]. A different device (not shown for the sake of brevity) has been used in order to investigate sidewall adhesion. The basic concepts are the same as the previous case, namely electrostatic actuation is exploited in order to induce pull-in on vertical surfaces. Figure 6 shows the average C-V curve, with error band. In spite of the large region between pull-in and pull-out, the specific adhesion energy is smaller than the previous case: $0.630 \pm 0.024 \mu J/m^2$. This fact can be explained by considering that vertical surfaces are characterized by a regular pattern of scallops, caused by the fabrication process. For this reason, the contact area is by far smaller with respect to the nominal area of the vertical surface.

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References

[1] B. Bhushan, *Microel. Engrg.*, 84 (2007), pp. 387-412.
[2] M.P. de Boer and T.A. Michalske, *J. Appl. Phys.*, 86 (1999), pp. 817–827.
[3] D. Bachmann, S. Kuhne and C. Hierold, *Sensor Actuat. A-Phys.*, 132 (2006), pp. 407-414.
[4] S. Basu, A. Prabhakar and E. Bhattacharya, *J. MEMS*, 16 (2007), 629-634.
[5] F.W. Del Rio, M.P.de Boer et al., *Nature Materials*, 4 (2005), 1254-1262.

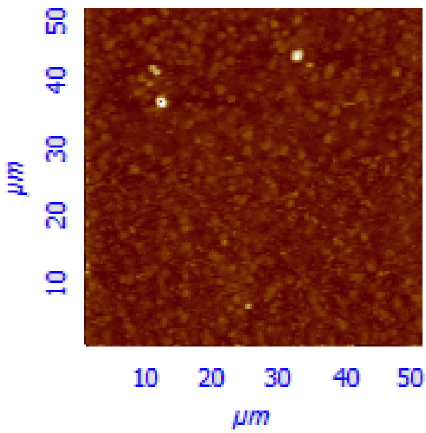

Figure 1. AFM image of a square portion of the MEMS surface.

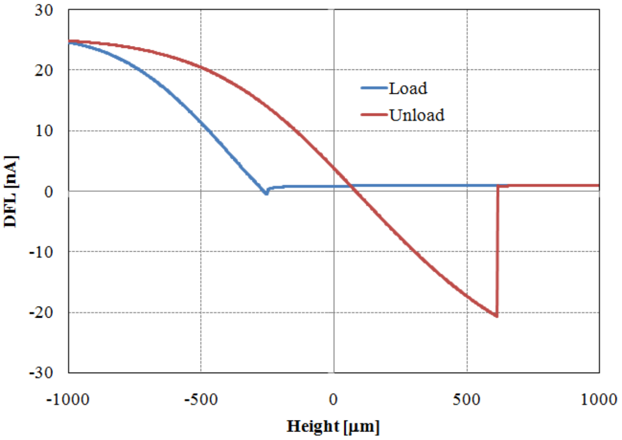

Figure 2. Deflection of the AFM tip versus the relative vertical displacement .

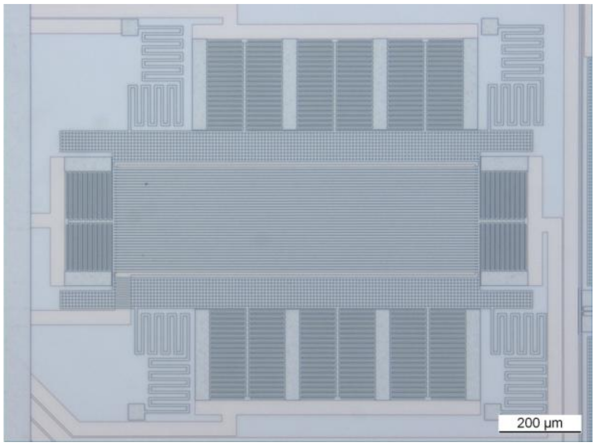

Figure 3. Experimental device for measurement of adhesion on horizontal surfaces.

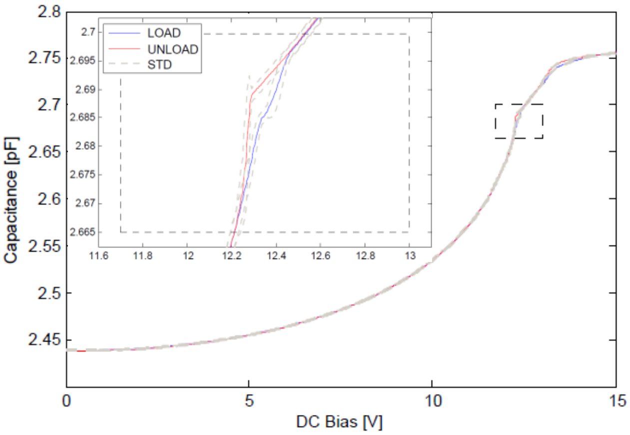

Figure 4. Capacitance vs. voltage for the structure in Figure 3. Error band is shown in light grey.

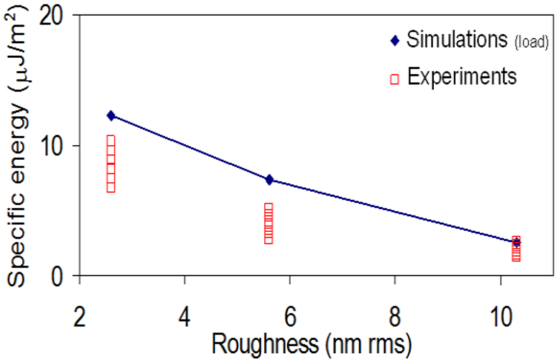

Figure 5. Numerical results: specific adhesion energy for different roughness levels.

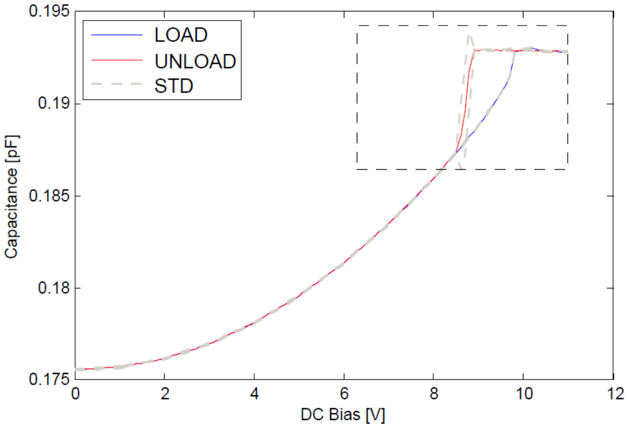

Figure 6. Capacitance vs. voltage for the structure devoted to adhesion measurement on vertical surfaces.