MODELING MULTISCALE CONTACT IN MEMS

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ABSTRACT
A model is presented to investigate contact and friction between sliding microelectromechanical systems (MEMS) surfaces. Roughness of MEMS surfaces exhibits multiscale structure. This was observed with analysis of asperities on atomic force microscope (AFM) images of real MEMS surfaces. The contact model is developed using multiple scales of surface roughness, with a single asperity contact model for the behavior of an asperity at a particular length scale, including effects such as surface forces (adhesion). The roughness information for the model is obtained from the AFM image of the MEMS surface under consideration. Results for true contact area and a prediction of the macroscopic coefficient of friction are discussed.

INTRODUCTION
The roughness of silicon MEMS surfaces has multiscale geometry that continues for several orders of magnitude of length scale. Many models reported in the literature have attempted to connect the behavior of such surfaces across different length scales [1–4]. Fractal surfaces, which show self affinity across multiple length scales, are used in some of these studies. However, there exist surfaces that are not fractal, but that nonetheless have rich multiscale characteristics [5, 6], as described below.

Bora et al. [6] has developed a new “summit search” technique for analyzing the roughness of surfaces. When this technique is applied to AFM images of silicon MEMS surfaces, multiscale characteristics are apparent. In this technique, the height of each data point of an AFM image (pixel) is compared to the heights of all neighboring data points within a square search region of dimension \( d \) by \( d \). If the height of a data point exceeds those of all neighbors within the search region, then it is called a summit. Thus, the number of summits present on a surface changes with the value of \( d \). Figure 1 shows an example, where the average radius of curvature calculated at the summits is plotted versus the size of the search region \( d \). Similar scale-dependent behavior is also seen for the heights of the summits and also number density of summits present on a given surface. The details of this behavior can be found elsewhere [6].

CONTACT MODEL
A contact model is developed using a single surface with multiple length scales for roughness that is pressed into a smooth counter surface. Each successively smaller roughness scale is modeled as asperities that are superposed on the asperities of the next larger scale, as shown in figure 2. The construction of a surface begins with a “template” shape that is defined at the largest length scale, using the summit data found with our “summit search” routine. A scaling constant \( s \) is selected to define the smaller scales of roughness [6].

At a particular length scale, each contacting asperity is assumed to follow the Hertz contact law [7], and the total contact area that is predicted is seen to approach a limit with
increasing number of roughness scales. When the correct scale dependence of the heights and radii is used, as obtained from the analysis of AFM images, the contact area calculated does not depend on the scaling constant $s$. This is important as it shows that a simpler surface representation with large scale constants and fewer scales is valid. Figure 3 shows this behavior. The number of small-scale contacts within a large contact area is constrained using two different methods: the experimentally-determined asperity density constraint and the close-packed distribution assumption. Of these, the latter gives a higher area estimate. Together these two schemes can be thought of as providing upper and lower bound estimates for the true contact area.

The next embellishment in this modeling approach is the inclusion of adhesion, i.e. JKR [8] and DMT [9] single asperity contact models. Preliminary work with these models shows that a technique must be used that preserves the adhesion associated with the large asperities when considering the smaller scales of roughness. The JKR and DMT adhesion models account for adhesion only over the contact area [8] or in a very small region around it [9]. Thus, when evaluating the adhesive forces for smaller length scales, the effects of the larger length scale cannot be neglected. One method to include adhesion of the bulk material is to model it as adhesion between two nominally flat surfaces [10]. Adhesion problem will be the subject of further studies.

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REFERENCES