Accuracy of probe-sample contact stiffness measurements in an atomic force microscope

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In atomic force microscopy (AFM), the local mechanical properties of a sample are studied using load-unloading dependences of the indentation force on the sample deformation (force curves). The force curves play a special role in the novel AFM techniques: Hybrid mode (NT-MDT SI), PeakForce QNM (Bruker), Fast force mapping mode (Asylum Research), – they are also used to determine the height of the relief and serve as the basis for electrical, piezoelectric, magnetic, and thermal measurements.

Friction at the AFM probe-sample contact can significantly change the shape of the measured force curve. If the cantilever probe slides the surface, the force applied to its tip acts normal to the sample and the console bends so that the bending angle monotonously increases along the console [1]. If the probe is clamped by the sample, a substantial lateral component of the friction force is added, due to which the console buckles (the deflection angle changes non-monotonously) [1, 2]. Most of the AFM use an optical beam deflection (OBD) technique. Therefore the profile of the angle of deflection of the console is not controlled, and instead just the value of the angle is detected at a single point – at the focus of the OBD laser on the console. Because of this, the AFM control system is not able to distinguish the buckling from bending [3, 4], which leads to errors of the measured amplitude and direction of the indentation force. In principle, the OBD may detect two parameters (bending and twisting angles of the console at the selected point), but the contact point displacement vector and the concentrated force have three spatial components. Only recently a commercially available scheme for monitoring cantilever deflections has appeared [5], combining the OBD with an interferometer that allows measuring the missing third parameter – the vertical displacement of the selected point on the console.

In AFM, the normal local stiffness of the probe-sample contact k_S is calculated from the force curves slopes, S at the point of interest on the sample and S_0 on the conditionally infinitely rigid and flat sample, and the console bending stiffness k_C [6]:

$$k_S = k_C S/(S_0 - S). \tag{1}$$

Expression (1) corresponds to the representation of the cantilever and the sample as a model of two series-connected springs. This view does not take into account: the probe is clamped or slides over the sample, the deformation of the probe itself, the local inclination of the sample and the possible anisotropy of its mechanical properties, design features and location of the cantilever above the sample. As a result, expression (1) determines not the k_S, but rather the apparent stiffness k_A.

The above has a negative effect on the accuracy and reliability of nanomechanical measurements in AFM and the subsequent theoretical analysis of AFM experiments. As a consequence, there is a need in accurate analytical calculations of the AFM cantilever deformations, taking into account: the contact friction effects, features of the console and probe design, sample anisotropic mechanical properties. In this lecture, such calculations are presented and discussed, and the results of these calculations are compared with AFM measurements.

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