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Quantitative Contact Spectroscopy by Atomic Force Acoustic and Piezo-Mode Microscopy

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Abstract

In Atomic Force Microscopy (AFM), the forces acting between the AFAM sensor tip close to of a sample surface determine the contrast observed in imaging or in the various spectroscopies possible with such techniques. These forces are sometimes summarized under the term contact mechanics. In fact, as the term AFM stands for, this technique is used to measure these forces in a direct or indirect way. Atomic Force Acoustic Microscopy (AFAM) is a near-field technique which combines the ability of ultrasonics to image elastic properties with the high lateral resolution of scanning probe microscopes. In AFAM flexural vibrations are excited in an AFM cantilever. The eigenfrequencies of these modes depend on the forces acting between the tip and the sample surface. In the so-called repulsive AFM mode, a situation can be achieved where the Hertzian contact stiffness is prevailing. The evaluation of the cantilever vibration spectra at ultrasonic frequencies is discussed in order to discern local elastic data quantitatively, here the indentation modulus for isotropic and anisotropic materials. The spatial resolution obtained is approximately 10 nm. Such experiments are performed at sufficiently low ultrasonic amplitudes so that the cantilever tip displacements are typically a few Angströms. Nanocrystalline magnetic and piezoelectric materials, multidomain piezoelectric ceramics, diamond-like carbon layers, polymeric materials, clay in rocks, and crystalline silicon have been examined.

In the ultrasonic piezo-mode a sinusoidal voltage is applied between the sensor tip in contact with a piezoelectric sample. The ac-field at the tip generates a local vibration by the inverse piezoelectric effect. Selecting a frequency close to a resonance leads to an enhanced vibration of the cantilever and allows one to image the ferroelectric domain structure and to obtain information on the local piezoelectric constant.

At higher ultrasonic amplitudes distinct non-linearities can be observed in the contact resonance curves which are caused by the non-linearities in the contact mechanics between the tip and the sample surface. Whereas in silicon and other materials a softening behavior is common, i.e. a decrease of the resonance frequency, the situation is more complex in piezoelectric ceramics. There exist theoretical approaches to analyze such data relating them to the non-linearities of the material properties and to the adhesion between the tip and the sample surface. Furthermore the nonlinear transmission of ultrasound in such a "single" point contacts is related to the nonlinear transmission of a large ensemble of contacts in bond interfaces and cracks important for applications in NDE.

Finally a new approach is presented for studying friction and the stick-slip phenomenon using torsional resonances of AFM cantilevers. Extending the Friction Force Microscope to ultrasonic frequencies, one can obtain friction maps revealing additional material contrast. Non-linearities can also be observed when transverse surface displacements are induced in the sample leading to non-linear torsional resonances. These effects are related to frictional properties between the tip and the sample surface.