SPM-2002, Proceedings. P. 79

Atomic Force Acoustic Microscopy as a tool for polymer elastisity analysis.

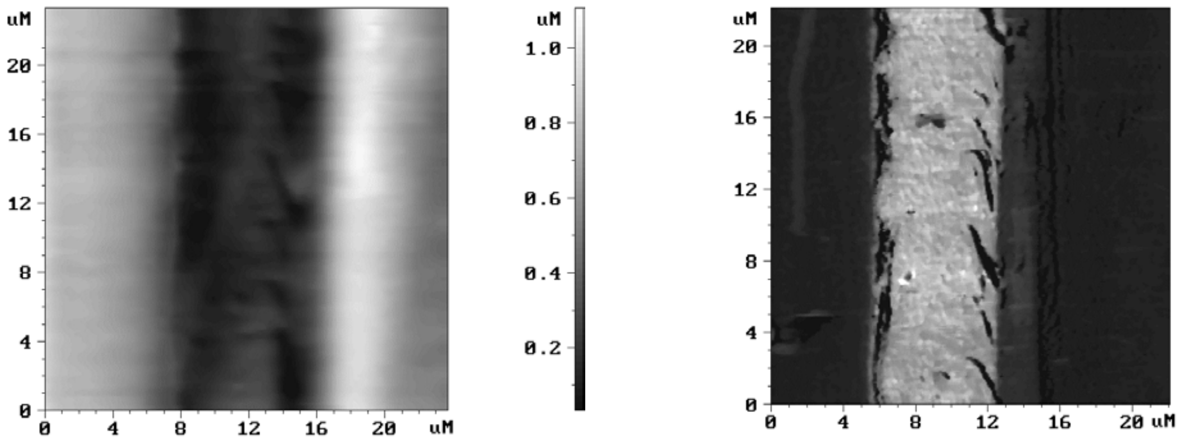
A.E. Efimov, S.A. Saunin,

NT-MDT Co., State Research Institute of Physical Problems, Moscow, Russia, 103460

A variety of SPM techniques developing allow measuring different local physical properties of the surface investigated. One of the key properties of interest is local elasticity and local Young modulus. There are several SPM modes that enable to get qualitative contrast images depending on elastic properties of the sample: phase imaging, force modulation imaging, pulsed force mode and some other dynamic force imaging techniques, but still research tasks are demanding of quantitative measurements [1-4].

The technique considered here is atomic force acoustic microscopy, which was developed by group of Prof. W. Arnold [2]. This method is based on measuring of variations of cantilever dynamic properties such as resonance frequency, amplitude and Q-factor caused by variation of the contact stiffness between tip and sample surface. The cantilever is operating in contact mode with constant deflection while the sample is vibrated by ultrasonic transducer on the frequency of cantilever flexural resonance. If cantilever properties (sizes, force constant and resonance frequency) are known, measurements of contact resonance spectra allow calculation of contact stiffness.

For experiment we used the sample of polyethylene with stripes of different density – cross-section surface of schistose sample.



a b

Fig.1 Contact mode topography (a) and AFAM (b) image of polyethylene sample cross-section with stripes of different density.

All results were obtained on NT-MDT P47H commercial device equipped with conventional ultrasonic transducer for sample vibration. Fig.1 shows contact mode topography and AFAM amplitude image of this test sample. AFAM image allows clear visualization of areas with different elasticity. The bright area on AFAM image is more stiff while the dark is much softer.

Another way to get similar results is to vibrate the cantilever itself by piezotransducer in AFM head. Amplitude images obtained by both ways look practically identical, but consideration of contact resonance spectra shows sufficient difference of these two methods. Resonance spectra obtained by both ways in soft and stiff areas of the sample are shown on Fig.2. One can see that in the case of vibrating by sample resonance frequency shifts and also Q-factor decreases in the soft area. When the cantilever is vibrating, only amplitude of resonance drops down. Also in this case resonance curves have more distorted shape.

Special software option was designed to map the resonance frequency in each point of the scan. Fig.3 shows such maps for two methods of vibration. These results show clearly that vibration of the sample is preferable as it allows obtaining of reasonable resonance frequency maps that in turn may be used for Young modulus calculation [5].

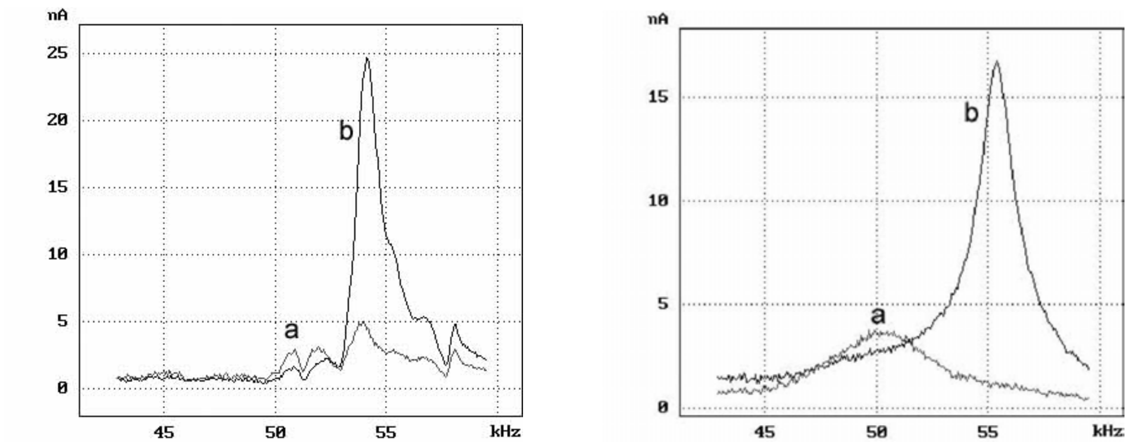


Fig.2 Cantilever contact resonance curves in soft (a) and stiff (b) sample areas: left – vibration by transducer on the cantilever, right – vibration by transducer below the sample.

Knowing the resonant frequency of free cantilever (12.77 kHz) and its force constant (0.05 N/m) we can calculate average contact stiffness in both sample areas. Using equations for clamped-spring-coupled cantilever described in [2], and average contact resonant frequencies in both areas (48.55 kHz and 54,0 kHz respectively) we obtain values of contact stiffness k* = 6.8 N/m for stiffer area and k* = 1.6 N/m for the softer one. This enables us to obtain the ratio of corresponding local Young's moduli. From Hertzian contact theory contact stiffness is equal

$$k^* = \sqrt[3]{6E^{*2}RF_0}\ ,$$

where E* is effective Young's modulus, R – radius of the tip and F_0 – the force applied to the tip. Therefore

$$\frac{E_1^*}{E_2^*} = \left(\frac{k_1^*}{k_2^*}\right)^{3/2} = 8.6\ .$$

If tip radius and applied force would be also known, one can calculate the absolute value of local Young's modulus. However the accuracy of such calculations is limited with uncertainties of cantilever dimensions and tip location. Also in this particular case cantilever force constant is much less than contact stiffness, it also may contribute to resulting error.

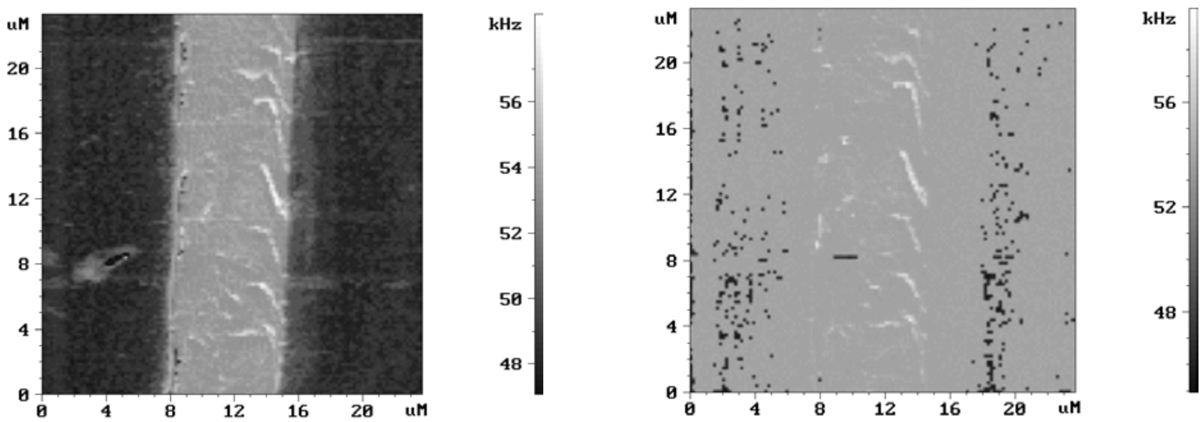


Fig.3 Resonance frequency maps. Left – vibration by transducer below the sample, right – vibration by transducer on the cantilever.

References:

[1] S. Amelio et al, Thin Solid Films 392 (2001), 75.

[2] U. Rabe, K. Janser, and W. Arnold, Rev. Sci. Instr. 67 (9) (1996), 3281.

[3] P. Maivald, H.-J. Butt, S. A. C. Gould et al., Nanotechnology 2 (1991) 103.

[4] H.-U. Krotil et al., Surf. Interface Anal. 27 (1999) 336.

[5] K. Yamanaka et al., Appl. Phys. Let. 78 N.13 (2001) 1939.