IN-SITU CONTROL OF AFM-SCANNER NONLINEARITY

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Using interference pattern arising between laser beams reflected from cantilever and mirror sample it is possible to control AFM piezoscanner linearity in XY-plane. Obtained with AFM interference pattern allows to calculate transformation eliminating nonlinear distortion from AFM-images.

Nowadays atomic force microscope (AFM) [1] is widely used for investigation of topography and surface forces. One of the AFM mainly part is scanner which allows to scan in *XY*-plane sample in relation to cantilever tip and control the distance tip-sample to maintain constant interaction force (gradient force) between cantilever tip and sample. Usually scanners are fabricated form various piezoceramics, which have big transformation coefficient displacement/applied voltage. However piezoceramics have a significant non-linearity that is especially seen for large-range scanners [2, 3]. Standard methods of AFM non-linearity control are based on or independently monitoring the scanner motion or on scanning of special test pattern with known surface shape and calculation special correcting function which is applying directly during scanning of afterwards to compensate scanner nonlinearity [4]. This article proposes another method to control scanner linearity based on recording of interference pattern appeared at reflection of light beam from sample surface and cantilever.

The measurements were done on standard AFM (Burleigh METRIS 2000) working in contact mode and using optical system of cantilever deflection control and four-quadrant photodiode detector. A mirror inclined to *XY*-scanning plane was used as a sample (Fig. 1). During measurements (scanning in *XY*-plane) cantilever was out of influence field of sample surface forces, backfeed circuit was opened, and signal on detector owing to laser beam reflected from cantilever and to fraction of this beam reflected from sample surface was recorded. It is not difficult to adjust the direction of incident beam with respect to cantilever due to the beam finite size and divergence.

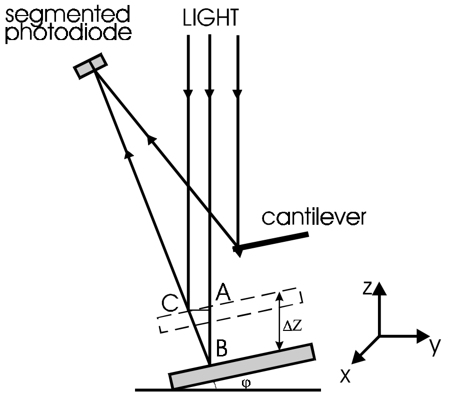

Fig. 1. Experimental setup

In assumption that incident beam is perpendicular to the scanning plane *XY* and sample is inclined at angle φ to the axis *OX* it is easy to obtain that distance change between cantilever and *XY* plane Δ*z* leads to optical path difference of interferencing beams Δ*s*:

$$\Delta s = n\cdot(\mathrm{AB}+\mathrm{BC}) = n\cdot\Delta z\cdot 2\cos^2\varphi, \qquad (1)$$

where n is a refraction index of surrounding media [5].

Analogous dependency will also be obtained in the assumption that sample is inclined at angle ψ to the axis OY. Consequently, during sample scanning the distance change Δz will be defined with relative displacement in XY-plane and inclination angles φ and ψ and will be monotonically changed; and since coherence length of laser diode is significantly larger than distance cantilever-sample so the photo detector will be recorded the interference pattern $I = I(X,Y)$ according to the equation

$$I = I_0 \cos \frac{2\pi n \Delta z \cos^2 \varphi}{\lambda} + C\,, \tag{2}$$

where I_0 and C are the constants, λ is laser wavelength.

In assumption that scanner is linear the interference pattern recorded during scanning must appears as a system of parallel interference strips; the inclination of these strips in XY-plane and period are defined by inclination angles φ and ψ. The cross section of interference pattern with planes perpendicular to the axes OX and OY must appears as sinus-like curves. But the measured interference pattern looks slightly different (Fig. 2a).

It is obvious that visible interference pattern distortion are caused with nonlinearity between applied voltage and sample displacement in XY-plane (during scanning the backfeed is off and Z-voltage is not changing).

To obtain numerical description of seen nonlinearity we introduced two assumptions. First, the square-law approximation of the sample displacement as a function of applied voltage. Second, the mutual influence of voltage applied to $X(Y)$ electrodes X,Y to displacement in $Y(X)$ direction X',Y' is negligible. Thus

$$\begin{cases} X' = a_x X^2 + b_x X + c_x \\ Y' = a_y Y^2 + b_y Y + c_y \end{cases}, \tag{3}$$

where the a_x, a_y, b_x, b_y, c_x, c_y are the constants.

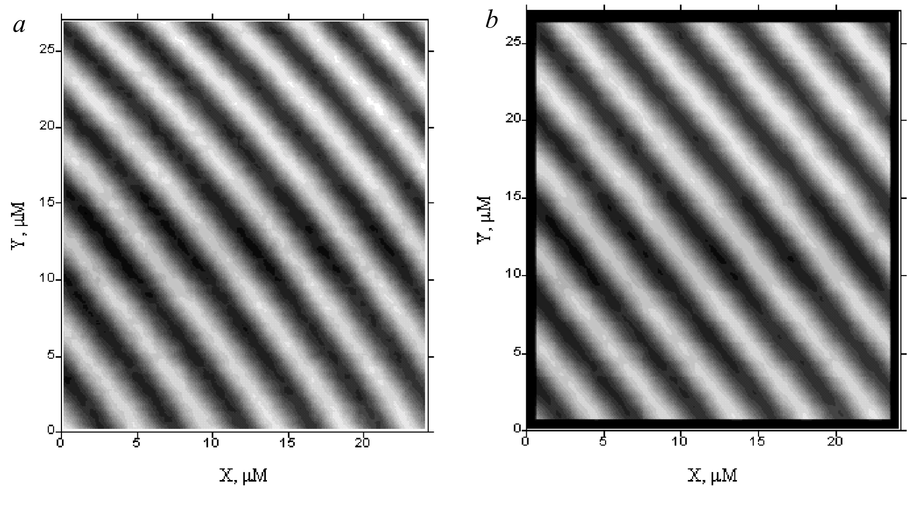

Fig 2. AFM Interference patterns before (a) and after (b) nonleariry removal

To calculate these constants we have done multiple cross sections of original interference pattern (Fig. 2a) with planes perpendicular to the axes OX, OY. Obtained curves were approximated according equation (2) using relationships (3). Besides it we suppose that nonlinearity is small and at low applied voltage (image center) transformation is linear. This assumptions allow us to find coefficients of transformation (3) and apply it to remove distortions (Fig. 2b). Now when we have transformation coefficients removing nonlinearity of interference pattern the same transformation should be used to remove nonlinearity from AFM topographic images.

Thus interference pattern obtained with AFM offer to us simple method of control linearity of AFM scanner. Using it we observe the nonlinearity dependence on initial position (voltages) of scanner, number of scanned frames, and scanning rate. Immediately before measurements it is easy to take interference pattern to be sure about possible nonlinearity of AFM scan.

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