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Use of Ferroelectric Single-crystal Bimorphs for Precise Positioning in Scanning Probe Microscope

Ilya Kubasov, Aleksandr Kislyuk, Andrei Turutin, Aleksandr Temirov, Sergey Ksenich, Mikhail Malinkovich and Yuriy Parkhomenko

National University of Science and Technology MISiS, Moscow, Moskva, Russia

Scanning probe microscopy and its modes are among the most widely used techniques for surface characterization and modification. Modern scanning probe microscopes (SPMs) are commercially available equipment which combines dozens of methods for different purposes. These devices provide an opportunity to study objects with an atomic resolution and to influence their physical properties *in situ*.

Though a modern multifunctional SPM is a very sophisticated scientific tool including many state-of-the-art devices, one part of it remains almost unchanged for years. Indeed, the probe positioning system that generally includes piezoelectric actuators based on PZT ceramic and controlled by capacitive sensors has been utilized since the first SPM was invented. There are different configurations of the positioning system, but in the most widespread case the table with a specimen is moved by stack piezoelectric transducers in the XY-coordinates, while the probe is moved by a PZT-tube in the Z direction. Despite large displacements provided by ceramic actuators, such disadvantages of PZT as electromechanical creep, non-linearity of the deformation vs. applied voltage and narrow range of operating temperatures limit the possibility to create high-precision actuators based on this material [1]. This is the reason why an extra feedback loop based on capacitive or interferometric sensors of distance needs to be used. The presence of the feedback loop complicates the device, decreases the scanning speed and finally leads to an increased price of an SPM. The reason of the abovementioned disadvantages of PZT is mostly the ceramic nature of the material, thus they cannot be fully eliminated simply changing the composition or processing.

On the other hand, piezoelectric single crystals do not possess these drawbacks, demonstrate a high thermal and electrical stability and almost do not degrade. Despite this fact, the main disadvantage of single-crystal piezoelectrics – small piezoelectric coefficients – is the reason why PZT is still used in most cases.

The problem of the weak conversion of a mechanical deformation into an electrical signal by single-crystal piezoelectric materials can be solved by utilizing complex constructions, such as unimorphs, bimorphs, or multilayer composites, but the presence of adhesive layers or grain boundaries in these composite transducers decreases the sensitivity, as well as the accuracy and thermal stability of the sensors [2]. However, there is a way to manufacture a series bimorph for the piezoelectric sensing element and avoid bonding of separate plates by the formation of two domains with oppositely directed spontaneous polarization vectors in a ferroelectric single-crystal plate. If the crystallographic cut is correctly selected, such a "bidomain" crystal demonstrates a bimorph-like behavior but does not comprise any interface except for an interdomain wall. The application of a voltage across the bidomain plate causes the expansion of one domain and contraction of its counterpart, which leads to the bending of the plate. To the best of our knowledge, among the variety of ferroelectrics only two materials – lithium niobate ($LiNbO_3$) and lithium tantalate ($LiTaO_3$) – can be stable in a bidomain state due to their uniaxial domain structure and high coercive field [3].

Previously the possibility to use bidomain single crystals in linear actuators and deflectors [4, 5], vibrational [2] and magnetic field [6] sensors as well as waste energy harvesters [7, 8] has been shown. In this study, we present the use of ferroelectric single-crystal bimorphs for precise positioning in a scanning probe microscope.

In order to prove the concept, we upgraded a commercially available SPM for educational purposes, NT-MDT Nanoeducator, by replacing the PZT unimorphs in the 3D positioning system by three $LiNbO_3$ bidomain single crystals. The simplicity of the positioning stage of the microscope consists in the use of piezoelectric actuators for moving a sample holder, when a scan is performed while the probe is stationary. The actuators are coupled together by thin flexible metal rods, so that each of the bimorphs is responsible for one of the mutually perpendicular coordinates (Fig. 1). As bimorph actuators are less rigid than PZT stacks or tubes, we fastened the bidomain crystals from both sides, so that the center of each bimorph moved when a voltage was applied. The electronic unit of the SPM can drive piezoelectric actuators by a voltage of ±150 V which is enough for positioning by the bidomain crystals in the range of ca. ±6 μm along each Cartesian direction. A tungsten needle was used as a probe. We used no feedback loops or scan post-processing in our experiments.

In Fig. 2 one can see a comparison of two scans of the same area on a 1.5 μm pitch resolution reference standard. The left scan was made by the Nanoeducator SPM with PZT actuators before the upgrade of the positioning system. The right scan shows the result of the replacement of the PZT unimorphs by the bidomain crystals. It is evident that the scan made after the upgrade is less noisy and gives more relevant information about the walls of the groove. Further calibration of the system, use of a higher-voltage driving electronics and vibration isolation of the microscope may enhance the area of the scan as well as improve the spatial resolution. $LiNbO_3$ is a commercially available material produced in large quantities, thus bidomain crystals are not expensive and can be used in many devices where thermal stability and accuracy of positioning are crucial parameters.

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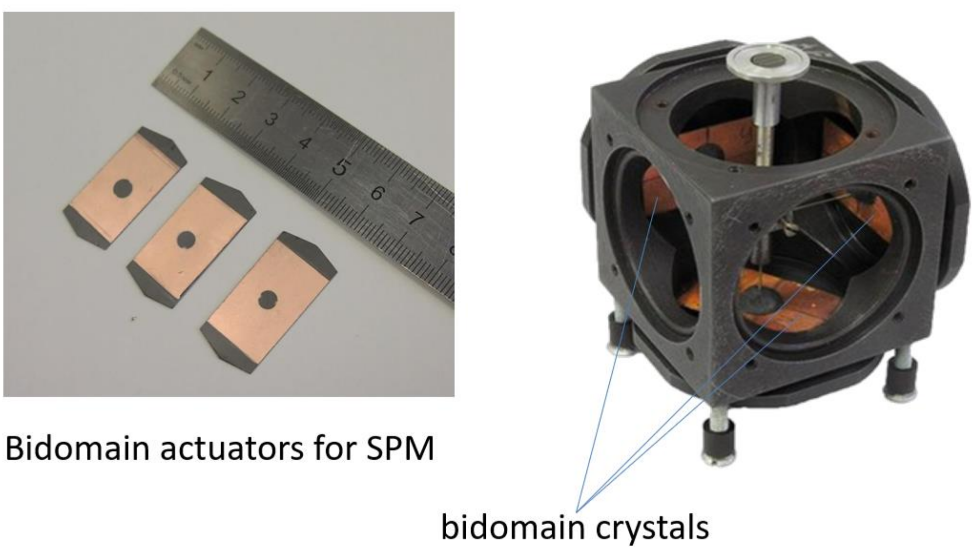

Figure 1. Photography of the bidomain crystals alone (left) and of those mounted on the positioning system of NT-MDT Nanoeducator SPM (right)

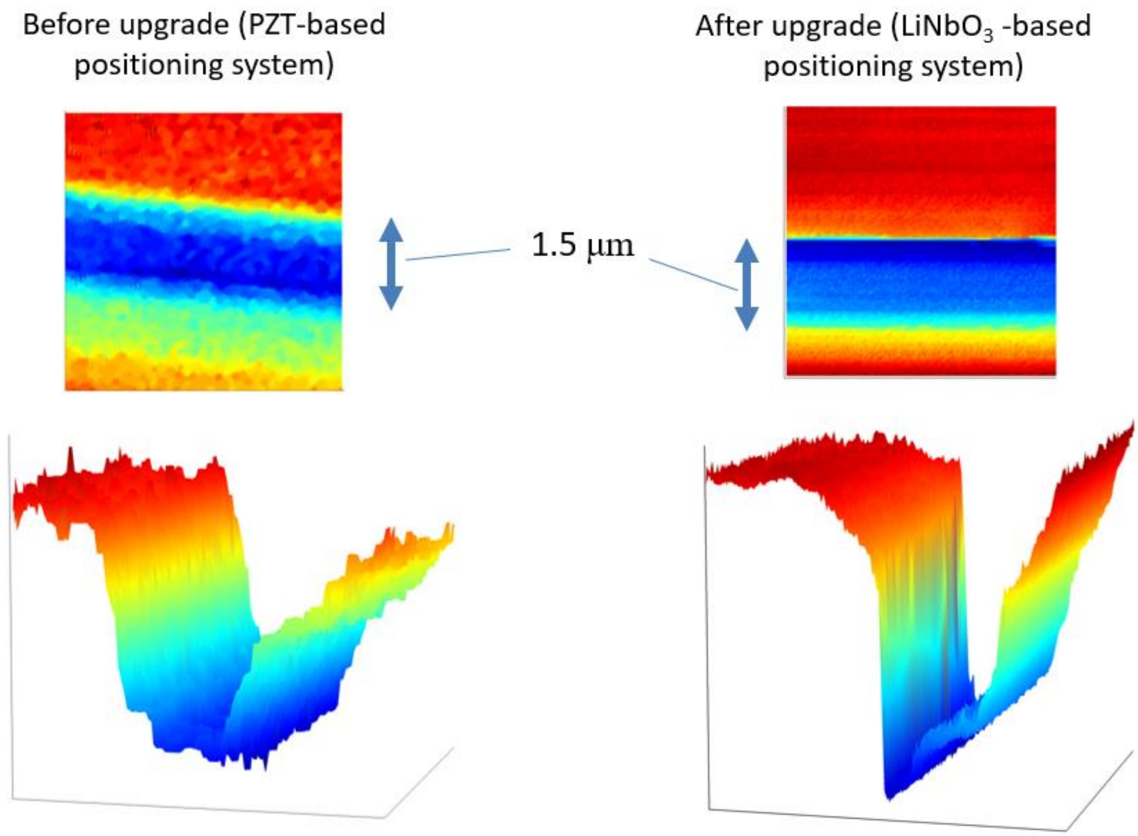

Figure 2. Topography of the groove in a 1.5 μm pitch resolution reference standard scanned with a PZT-based (left) and a LiNbO3 bidomain-based (right) positioning system

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