NANOMANIPULATOR IN STM METHOD

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1 ABSTRACT

One of the basic methods for determination of nanostructure of tested material is method called STM (Scanning Tunneling Microscopy). This method is well known since last century and it plays very important part of defectoscopy in present nanotechnology. This paper is focused on the basic element of this method, i.e. a nanomanipulator.

2 STM

STM belongs to the group of the methods with raster probe known as SPM (Scanning Probe Microscope) [1]. These microscopes work in this way: the surface of the object is scanned by the help of thin mechanical probe, which is proceeding very close to the surface and the signal acquired from particular point forms subsequently whole picture of the object. The carrier of the information can be electric flow or voltage.

STM uses a tunnel effect, which is coming up when an electric charge breaches the air barrier. The electric charge breaches the barrier even if the distance sample-tip is very low (a few nm). Therefore we need to place the probe very close to the object. When electric current breaches the barrier the magnitude of this current can be read and compile one point of the image.

An example of the studied STM microscopes is the model TS 3130 made by TESCAN Company. It can operate in two modes - constant current mode and constant height mode.

To the proper function of STM, the microscope needs to move with the probe (or the sample) with high accuracy, this movement is provided by piezo-manipulator.

3 NANOMANIPULATOR

It is necessary to control the working tip-sample distance and to move the tip over the sample surface with high accuracy (at a level of Ångström fractions) in order to make the probe microscopes properly working. This problem is solved with the help of special transducers, or scanning elements (scanners) [2]. The probe microscope scanners are made of piezoelectric materials. Piezoelectric materials change their sizes when an external electric field is applied. The inverse piezoeffect equation for crystals is as follows:

$$u_{ij} = d_{ijk} E_k , \tag{1}$$

where u_{ij} is the deformation tensor, E_k are the electric field components, d_{ijk} are the components of piezoelectric tensor. The piezoelectric coefficients are defined by the crystal symmetry.

Transducers made from piezoceramic materials are widely used in various technical applications. The piezoceramics is polarized polycrystalline material obtained by powder sintering from crystal ferroelectrics. Polarization of ceramics is performed as follows. The ceramic is heated up above its Curie temperature T_c (for the majority of piezoceramic T_c < 300°C), and then it is slowly cooled in a strong electric field (about 3kV/cm). After cooling below T_c, the piezoceramic retains an induced polarization and gets the ability to change its sizes (by increasing or reducing which depends on the mutual direction of the polarization vector and the vector of the applied electric field).

The piezoelectric tensor for piezoceramics has only three coefficients, which are not zero: d_{33}, d_{31}, d_{15}, describing respectively the longitudinal, the cross (with respect to the polarization vector) and the shift deformations. First, we consider a flat piezoceramic plate (Fig. 1) in an external field. Let the polarization vector **P** and the vector of the applied electric field **E** be directed both along the X axis. Then, designating *d(parallel)*= d_{33} and *d(perpendicular)*= d_{31}, we get that the piezoceramic deformation in the direction parallel to the field is $u_{xx} = d \perp E_x$.

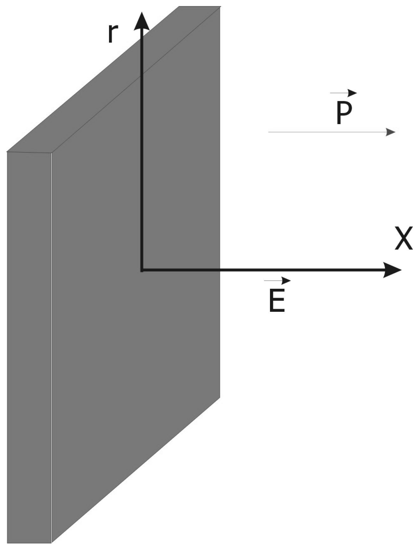

Fig. 1: *Piezoceramic plate in an external electric field*

Tubular piezoelements are widely used in scanning probe microscopy. They allow obtaining large enough movements with rather small control voltages. Tubular piezoelements are hollow thin-walled cylinders with electrodes (thin metal layers), plated on the external and internal tube surfaces, and the end tube faces remain uncovered.

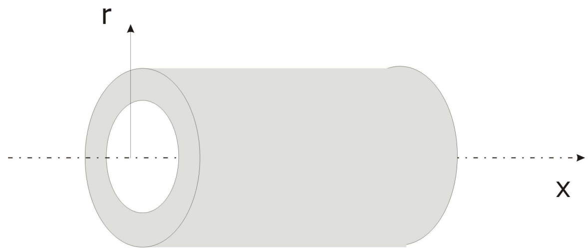

Fig. 2: *Tubular piezoelement*

Under the influence of potential difference between internal and external electrodes the tube changes its length. The relative longitudinal deformation under the influence of radial electric field can be written as:

$$u_{xx} = \frac{\Delta x}{l_0} = d_{\perp} E_r , \tag{2}$$

where l_0 is the length of the unstressed tube. The absolute lengthening of piezo-tube is:

$$\Delta x = d_{\perp} \frac{l_0}{h} V , \tag{3}$$

where h is the thickness of the tube wall, V is the potential difference between internal and external electrodes. Thus, for the sample applied voltage, the tube lengthening will be larger, for longer and thinner tubes.

Assembly of three tubes into one unit allows to produce precise movements in three mutually perpendicular directions. Such scanning element is referred as a tripod.

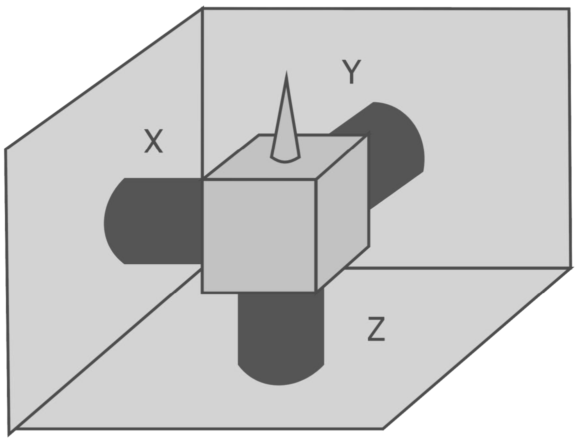

Fig. 3: *Scanning element as a tripod, assembled on tubular piezoelements*

The drawbacks of such scanner are the complexity of manufacturing and the strong asymmetry of its structure. Today the scanners made of one tubular element are most widely used in scanning probe microscopy. The structure of a tubular scanner and the arrangement of electrodes are presented in Fig. 4.

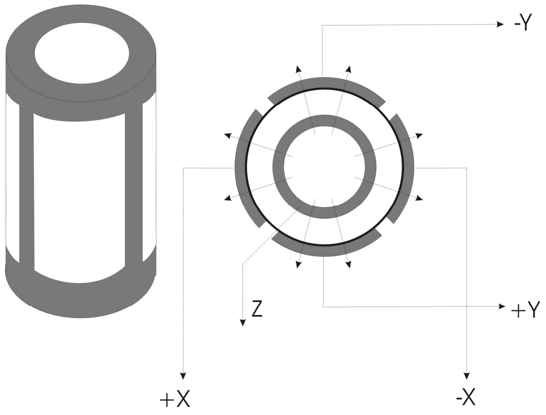

Fig. 4: *Tubular piezo-scanner*

The internal electrode is usually continuous. The external electrode is divided by cylinder generatrixes into four sections. When differential-mode voltage is applied on opposite sections of the external electrode, the part, where the field direction coincides with the polarization direction of the tube, reduces in length. The part where a field and polarization direction are opposite increases in length. This leads to a bend of the tube. Scanning in the X, Y plane is done in this manner. Change of the internal electrode potential with respect to all external sections results in lengthening or reduction of the tube along Z axis. Thus, it is possible to implement the three-coordinate scanner on the basis of one piezo-tube. Real scanning elements frequently have a more complex structure; however the working principle remains the same.

4 RESULTS

In TS 3130 microscope is going to be used the instrument made by Physik Instrumente is used. A manipulator is controlled by the control unit PZT. In the input of PZT, a signal in range from -2V to + 10V of DCV can be fetched. Usually, we test this instrument in three different frequencies, e.g. for STM the frequencies until 50 Hz are used. But, how one can see from the following, the manipulator is much better than this “limit”.

The signal with various frequencies is fetched to the input of the oscilloscope and to the PZT-servo controller E-5509.C3A, too. The movement of the manipulator is controlled by the help of capacitance sensors, and its reaction is displayed as output from PZT.

Fig. 5: *In/Out from PZT-servo controller , E-5509.C3A by 10 Hz*

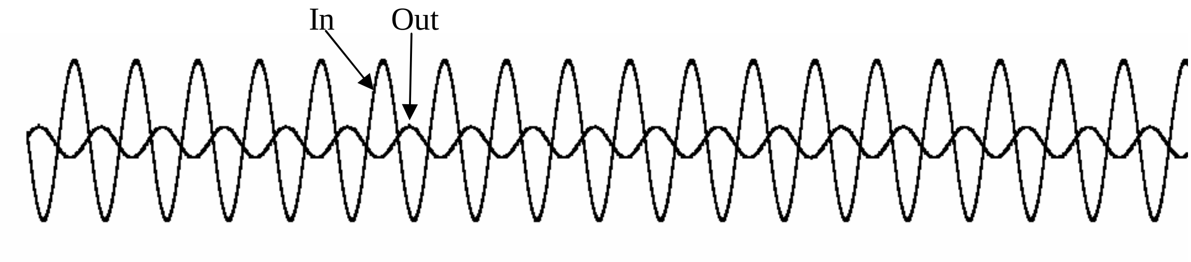

Fig. 6: *In/Out from PZT-servo controller , E-5509.C3A by 100 Hz*

Fig. 7: *In/Out from PZT-servo controller , E-5509.C3A by 200 Hz*

5 CONCLUCION

In the article the nanomanipulator as a main part of Scanning Tunneling Microscopy is described. In the present time, we use the TS 3130 model with the original manipulator from TESCAN. On the score of the development of new SNOM-module (Scanning Near-Field Optical Microscopy) is going to be used manipulator made by Physic Instrumente in the future time. Control of this manipulator is simpler then control of the original one and its IN/OUT characteristics are suitable for this use.

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REFERENCES

[1] Kala, J: Control of Dynamics of SPM Probes for Non-destructive Defectoscopy, Ostrava, Proceedings of XXXth Seminary XXX ASR'05, 2005, p.30-37, ISBN 80-248-0774-2

[2] Mironov, V: Fundamentals of Scanning Probe Microscopy, Nizhnyi Novgorod, The Russian Academy of Sciences, 2004