ISSN 1392-2114 ULTRAGARSAS (ULTRASOUND), Vol.65, No.1, 2010.

Piezoceramic scanners on the basis of planar bimorph piezoelements for scanning probe nanomicroscopes

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Abstract

The analysis of some constructions of piezoceramic scanners is carried out. It was found, that the basic shortcomings of known constructions of scanners are strong asymmetry of a construction and an interconnection between actuators on coordinates XYZ. The construction piezoscanner on the basis of planar of bimorph elements in which these drawbacks are eliminated is developed. The scanning range along the coordinates X and Y is increased up to 350 µm, and along the coordinate Z – 40 µm.
Keywords: nanotechnology, scanning probe microscopy, piezoceramic scanner.

Introduction

The scanning probe microscopy allows to analyze at atomic level the structure of different materials - glasses, ceramics, plastic, metals, semiconductors. Measurements can be performed not only in vacuum, but also in air, in environment of any gas and even in a liquid drop. This method is irreplaceable for research of biological objects. Except the research functions, the scanning probe microscopy can be also active - to provide capture of separate atoms, their carrying over to a new position, atomic assemblage of conductors widths of which is single atom, local chemical reactions, a manipulation with separate molecules and other [1-3].

Basic element of the scanning probe microscopy which provides possibility of operation of the device in modes of nuclear permissions and which essentially influences quality of the received image, is a piezoceramic scanner [1].

Problem and approach

In the scanning probe microscopy wide by are used scanners on the basis of tubular piezoelements [1-4]. A drawback of such scanners is that at scanning other sections of the scanner influence each other, what worsens accuracy of measurements, reduces their reliability and reduces the performance of the instrument. Besides, the sections of the tubular scanner which are not participating in movement interfere with a piezoceramic scanner in the necessary direction and that reduces a scanning range.

Application of this scanner in the form of a cylindrical bimorph element divided into sections (actuators) (Fig. 1), allows to increase sensitivity and to reduce link between movements along the coordinates X and Y, however the manufacturing of such scanner becomes more difficult [4, 5].

Also widely are used scanners on the basis of planar bimorph piezoelements. The bimorph piezoelement (BPE), as it is known [6-9], represents two piezoelements or a piezoelement and a metal plate, bonded with the help epoxy glue or fusible solder [8]. When electric voltage is applied the bimorph piezoelement makes bending oscillations that is used for moving of a probe concerning object of researches or object of researches concerning a probe.

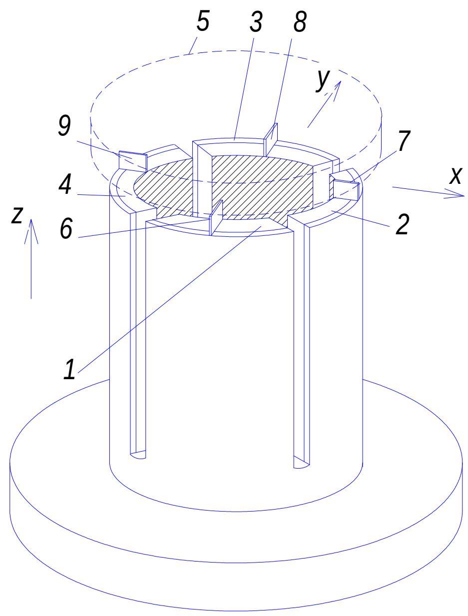


Fig. 1. **Cylindrical bimorph scanner: 1-4 - actuators on coordinates X and Y; 5 - actuator on coordinate Z; 6-9 - planar elastic plates**

In Fig. 2 the three coordinate scanner with three round bimorph piezoelements (tripod) is shown [3].

Shortcoming of this scanner is a strong asymmetry of a construction and also link between movements along the coordinates.

For elimination of the specified drawbacks it is proposed to use two dissymetric bimorph piezoelements of the rectangular shape (1,3 and 2,4), fixed on the one hand

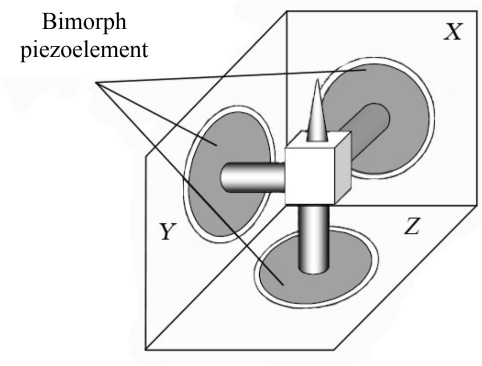


Fig. 2. **The scanner on three bimorph piezoelements**

on the basis 14 (Fig. 3) [10]. These bimorph piezoelements (actuators) are used for movement along coordinates X and Y. The bimorph piezoelements consist of metal plates (6,7 and 8,9) and plates from piezoceramic (10,11 and 12,13), bonded together with epoxy glue.

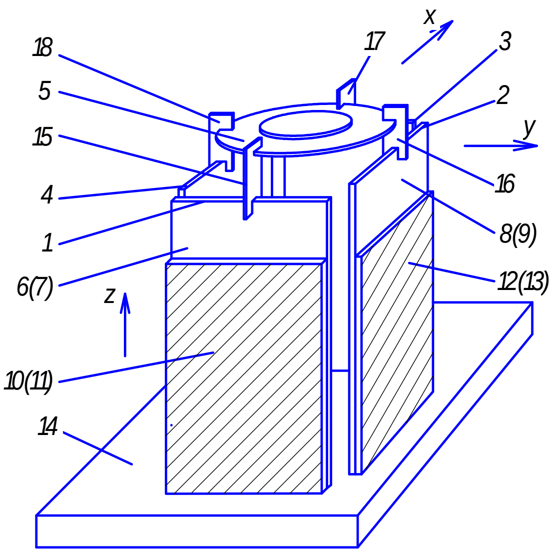


Fig.3. **The piezoceramic scanner on the basis of planar bimorph piezoelements: 1-5 - bimorph elements; 6-9 - metal plates; 10-13 - piezoelements; 14 - the basis; 15-18 - elastic plates**

The bimorph piezoelement 5 providing movement along the coordinate Z, is made of a disk and fastens on bimorph piezoelements (1-4) by means of elastic elements 15-18. Elastic elements are made in the form of plates of the rectangular shape and fixed to the bimorf piezoelements 1-4 in such a manner that at movement of the bimorph piezoelements 1, 3 along the coordinate X the elastic elements 15, 17 have a big rigidity and elastic elements 16, 18 - small. As a result the bimorph piezoelement 5 moves along the coordinate X, practically not influencing the bimorph piezoelements 2, 4.

The bimorph piezoelements 1-4 are fixed consoles, that has allowed to lower their resonant frequency to several hundreds hertz.

The rigidity factor of the bimorph piezoelements 1-4 is given by [11]:

$$k_{1-4} = 3\left[\lambda_B L^3 + (L - l)\Delta\right]^{-1} \quad (1)$$

where

$$\Delta = \lambda_M - \lambda_B,$$

$$\lambda_M = E_M J_M,$$

$$\lambda_B = E_M J_M + E_p J_p^* \frac{12}{b\left(E_M h_M^3 + E_p h_p^3\left(1 + 3\left(1 + \frac{h_M}{h_p}\right)^2\right)\right)},$$

E_M is the module of elasticity of a metal plate; E_p is the module of elasticity of a piezoelement which can be found through a liability polarized piezoceramic; $E_p = \left(S_{11}^E\right)^{-1}$;

$J_M = \frac{bh_M^3}{12}$; $J_p^* = J_p + \frac{(h_M + h_p)^2}{4}\Omega_p$; $J_p = \frac{bh_p^3}{12}$; $\Omega_p = bh_p$; b is the width of the bimorph piezoelement; h_M is the thickness of a metal plate; h_p is the thickness of a piezoelement.

The equivalent electric circuit of the scanner constructed according to a method of electromechanical analogies, is shown in Fig. 4 [12].

Oscillatory circuit R1-C1-L1, R2-C2-L2, R3-C3-L3, R4-C4-L4, R5-C5-L5 correspond to the bimorph piezoelements 1-5 (Fig. 3). The interelectrode capacity of the piezoelements in this case was not taken into account. The bimorph piezoelements 1-5 are connected with each other by elastic links with losses (R6-C6, R7-C7, R8-C8, R9-C9) to corresponding elastic elements 15-18. The weight of these elastic elements is not considered.

For experimental investigation the scanner with the following parameters has been made (Fig. 3).

In bimorph piezoelements – the metal plates were made of brass L63 in the size 40×20×0,3 mm. The piezoelement was made of the piezoceramics PZT-19 with the dimensions 27×20×0,3 mm. The bimorph piezoelement 5 is made of a metal disk of the brass L63, with the diameter 20 mm and thickness 0,3 mm, both piezoelement in diameter 15 mm and thickness of 0,3 mm. The elastic plates have the dimensions – 10×3×0,1 mm.

Movement ranges of the scanner along the coordinates XYZ were defined. The stand, which or this purpose the get-up was developed block diagrams of which is presented in Fig. 5 [12].

Basic elements of the set-up are capacitor differential gauge, microscope MBS-10, which is used only for initial calibration of the capacitor gauge, the system registering results of measurements of the gauge and data transmission system to the computer. To the system registering results of the gauge measurement, the amplifier INA111 with a small current leak (20 pA) and the peak detector collected on the microchip PKD01 are connected. The data transmission to the computer is performed by means of the microcontroller PIC16F688 through the serial interface RS232. The obtained data are processed by means of the program LabView 8.2.

The system registering measurement results of the gauge, is built on the basis of the microchip HCT123N [13].

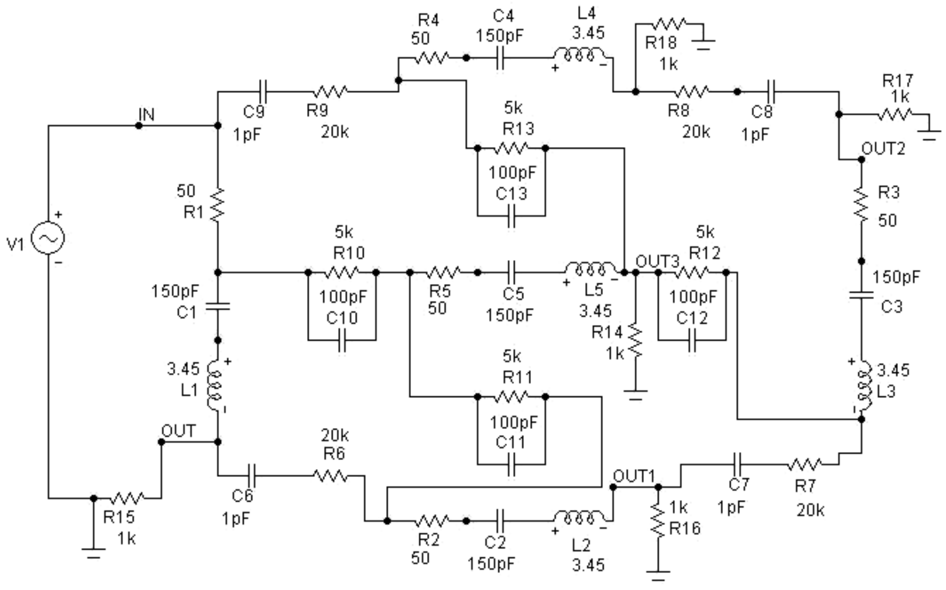


Fig. 4. **The equivalent electric circuit of the scanner**

The set-up operates as follows. On the microscope little table there is the differential gauge between which facings the piezoceramic scanner is placed. The scanner is put so that in the microscope eyepieces it would be visible the facings of the capacitor differential gauge, equidistant from the located between them piezoceramic scanner. Then, to the piezoceramic scanner the alternating voltage is applied. Thanks to it the scanner movement is carried out. In the microscope eyepieces it is possible to observe a strip of the blackout of the oscillating piezoceramic scanner. Hence, the distance between the scanner and facings of the capacitor differential gauge that is registered on a microscope scale will decrease. Thus in this way calibration of the capacitor gauge is carried out.

Dependence of movement of the scanner after application of electric voltage to the bimorph piezoelements 1 and 3 is shown on Fig. 6a. The similar procedure is used for the bimorph piezoelements 2 and 4 as well.

Dependence of the bimorph piezoelement 5 movement on the applied electric voltage is shown on Fig. 6b. The bimorph piezoelement 5 produces movement along the coordinate Z.

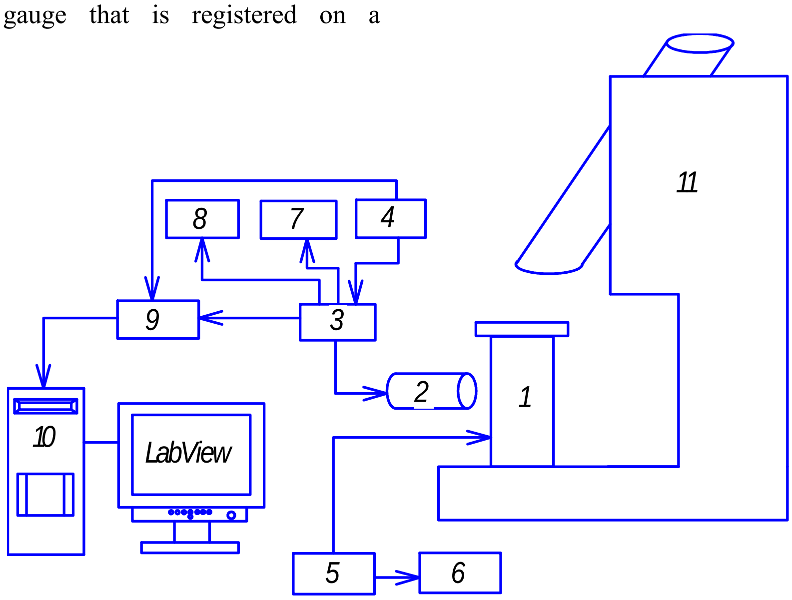
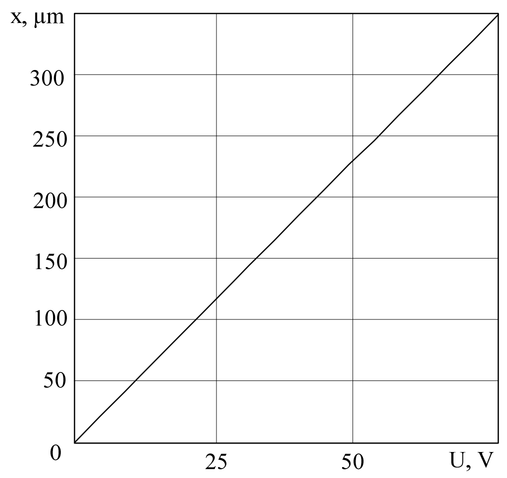
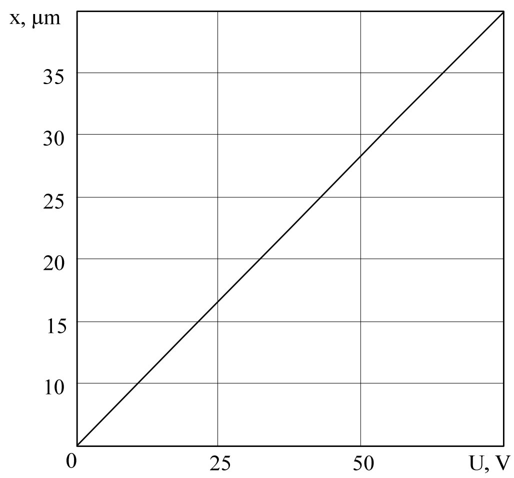


Fig. 5. **The scheme of the set-up for diagnostics of a piezoceramic scanner: 1 - the scanner; 2 - capacitor differential gauge; 3 - the system registering results of measurement of the gauge; 4-power unit; 5 - generator G3-109; 6 – frequency meter CH3-34; 7 – millivoltmetr V3-41; 8 - oscilloscope S1-83; 9 - data transmission system to a computer; 10 - computer; 11 - microscope MBS-10**



a



b

Fig.6. **Dependence of movement of the developed scanner versus voltage: a - at the voltage applied to BPE 1,3; b - at the voltage applied to BPE 5**

From presented results follows that movement of this scanner along the coordinates X is visible, that, Y makes 350 µm, and along the coordinate Z – 40 µm at voltage 75 V.

Influence of oscillations of one of bimorph piezoelements on others bimorph piezoelements has been determined also. To the input of one piezoelement the electric voltage (25 V) at the resonance frequency of the bimorph piezoelement (BPE) (886 Hz for BPE along co-ordinates XY and 1340 Hz for BPE along coordinate Z) were applied and movement measurements were carried out.

As these experiments have shown oscillations of one bimorph piezoelement (actuator) practically does not influence others bimorph piezoelements of the scanner.

Conclusions

The design of the piezoceramic scanner on the basis of planar bimorph piezoelements for probe nanomicroscopes was proposed and investigated.

The equivalent circuit of this scanner modeled by means of the software package MicroCap 7.0 was proposed.

It was found, that a link between bimorph piezoelements which create oscillations along the coordinates X, Y, Z practically is absent.

Application of bimorph piezoelements in actuators has allowed to increase sensitivity of the scanner.

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Pjezokeraminiai skeneriai su plokščiaisiais bimorfiniais pjezoelementais skenuojantiems nanomikroskopams

Reziumė

Nagrinėjamos pjezokeraminių skenerių konstrukcijos. Pagrindinė žinomų skenerių problema yra nemaža konstrukcijos asimetrija ir ryšys tarp koordinačių X, Y, Z. Sukurta pjezoskenerio konstrukcija su plokščiais bimorfiniais pjezoelementais, kuriuose šio trūkumo nebėra. Be to, padidinta skenavimo sritis iki 350 µm pagal X ir Y koordinates ir iki 40 µm pagal Z koordinatę.

Pateikta spaudai 2010 02 08