

Nanomanipulators with Reduced Hysteresis and Interferometers Build in NanoFabs

Petr LUSKINOVICH, Vladimir ZHABOTINSKIY

LLC 'NANO-ATTO Metriya', Dmitrovsky Proezd, 20/2, Moscow 127206, Russia

Tel.: +7 (495) 611 55 14

E-mail: nano.attometria@gmail.com

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Abstract: The use of nanomanipulators made from monocrystals with many times less hysteresis and creep compared with polycrystal piezoelectric ceramics makes it possible to achieve the following results:

- A two-fold reduction in the measurement time (by using reverse scanning information), as well as reduction in the error compensation time during displacement.
- A ten-fold reduction in the positioning time in NanoFab during vector positioning instead of raster scanning.
- Integration of standards of length (measures of displacement) with actuators (piezoelectric manipulators).

Nanomanipulators based on different directions of the crystallographic axes ensure displacements in the vertical direction up to 120 nm and in the horizontal direction up to 600 nm. Homodyne interferometers installed in NanoFab are characterized by a measurement uncertainty of 0.1-0.3 nm. Copyright © 2013 IFSA.

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1. Nanomanipulators

Hysteresis and creep of piezoelectric ceramic nanomanipulators and their correction with subnanometer imprecision reduces the productivity of NanoFab.

Displacement error can be significantly reduced using monocrystal materials instead polycrystal piezoelectric materials.

These manipulators provide linear displacement throughout the nanometer range -100 nanometers, which is officially equal to the upper boundary of the nanometer range, can be placed on a line of 1000 pixels when displaying on a monitor screen at a scale of up to 0.1 nanometers/pixels.

The amount of manipulator displacement is directly proportional to the amount of control voltage. Nanomanipulators are made from materials like lithium niobate. Designs of manipulators are in

patenting. Depending on the amount of displacement required, manipulators are made by assembling one or several crystals. Joining manipulators ensure their movement in three directions.

The photo of manipulators without a cover based on 3 crystals is given in Fig. 1.

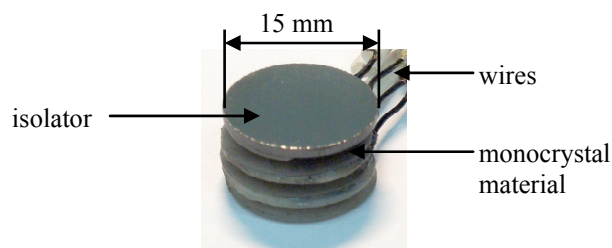


Fig. 1. Unpackaged nanomanipulator on the base of monocrystal material.

Using materials with different directions of crystallographic axes relative to the electric field allows vertical or horizontal displacement.

Measurement results of the dependence of displacement along the normal and parallel to the basis plane under the control voltage are given in Figs. 2 (a, b).

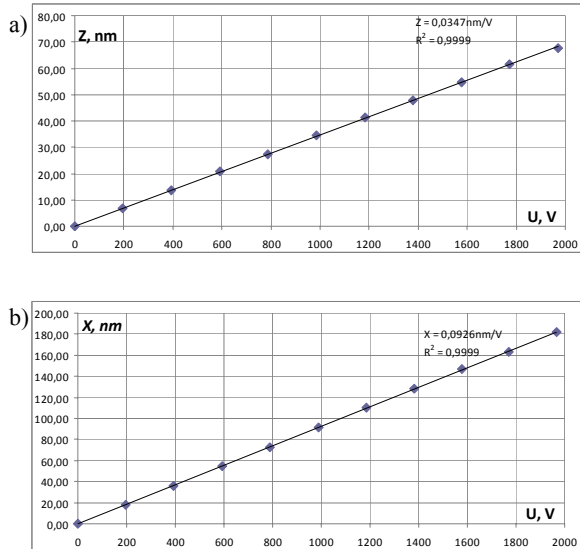


Fig. 2 (a, b). The displacement of nanomanipulators surface under the controlled voltage: a) vertical; b) horizontal.

Measurements were carried out by optical interferometer with a stabilized laser radiation frequency.

The typical form of electrical impulse and vertical movement impulse applied during calibration are given in Fig. 3 (a, b).

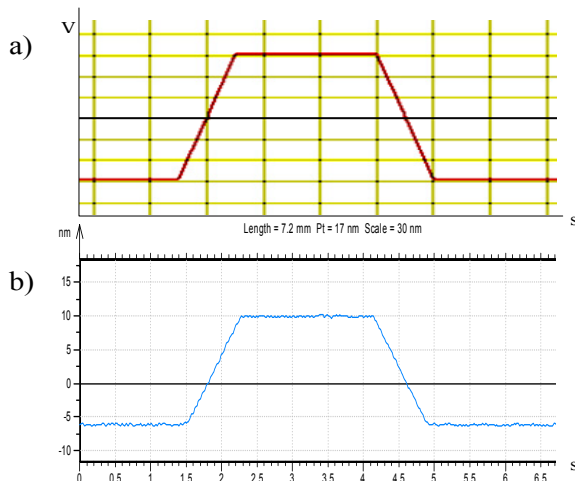


Fig. 3. a) Electrical impulse; b) Vertical movement impulse.

Measurements were carried out during changes under the controlled voltage from ± 1000 volts through ± 100 volts to 0 in and back, through points ± 300 V, ± 700 V, ± 1000 V.

Linear manipulators with a reduction in hysteresis and creep make it possible to use reverse scanning measurement results.

These manipulators also can be used as standards of displacement in nanometer range instead of length standards.

This work presents the calibration results in PTB (Germany) [1] of standards of displacement based on monocrystal manipulators.

It should be noted that due to linear dependence of size of surface, displacement of the standard surface with the control voltage makes it possible to generate displacements, not only in all nanometer, but also in pikometer range.

It is impossible to use static measures not only because they break down outside a vacuum system, but also because of the fixed sizes of atoms.

Thus it is possible to define the amount of measurement imprecision by comparing the noise level of the measuring device and the amplitude of the generated displacements.

Photos of standards of vertical and horizontal displacements are given in Figs. 4 (a, b).

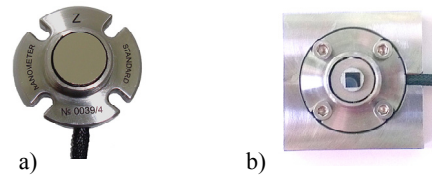


Fig.4. a) Standards of vertical displacements; b) Standards of horizontal displacements.

It is possible to use these standards for calibrating scanning probe and electronic microscopes.

An example of measuring the surface displacement of a standard using a NanoFab Quanta 3D is given in Fig. 5.

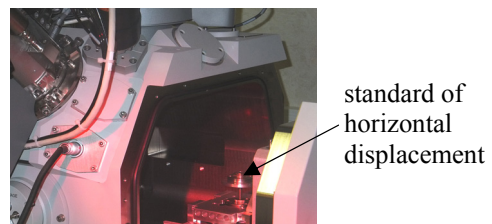


Fig.5. Standard of horizontal displacement build in NanoFab Quanta 3D.

Standards must be stable in time and during operation in usual atmospheric conditions.

As a result of the processes on the surface of different materials (formation of an adsorbed layer, oxidation, diffusion and migration, reconstruction), their form and size change, which interferes with using traditional standards, with a static surface.

Under the influence of operating electric impulses, the surface of displacement measures may

move for fractions of a second, during which the surface shape essentially does not change.

Therefore these standards can be used for many years in different external conditions, including outside vacuum systems and clean rooms.

It should be noted that calibration of manipulators of scanning probe microscopes in the vertical and horizontal directions does not depend on the shape of the probe.

When carrying out vertical calibration on a standard of vertical displacement, different amounts of electric impulses are supplied.

Carrying out horizontal calibration electric impulses of different values are applied to the standard of horizontal displacement.

Vertical displacement is measured using a microscope feed back system that holds a probe at a fixed distance from the surface.

During horizontal calibration, a plate with spatial heterogeneity similar to a diffraction grid is placed on the surface of the measure and the amount of surface displacement is measured.

It is very important to measure the displacement of heterogeneity using the same side of probe since this excludes additional uncertainty of measurement related to its asymmetry.

The use of calibrated linear manipulators integrates displacement instruments with calibration instruments, which increases the accuracy and productivity of NanoFab manifold [2].

If displacement at a distance much higher than the nanometer range is necessary, it is possible to use a combination of wide-range manipulators that ensure positioning with an uncertainty less than 100 nanometers and the given linear manipulators that move within the nanometer range after the wide-range manipulator has stopped.

These calibrated manipulators can also be used for generating fast displacements, which makes it possible to measure the reaction time of the feed back system stabilizing the size of the gap between the probe and the surface being measured.

Examples of displacements of different forms – step and linear are given in Figs. 6 and 7.

The results of measurements of sinusoidal displacements with amplitude close to 10 nanometers are given in Fig. 8.

Displacements with amplitude of 3.2 picometers are given in Fig. 9.

The results of measurements of displacements of the linear nanomanipulator of trapezoidal form are given in Fig. 10.

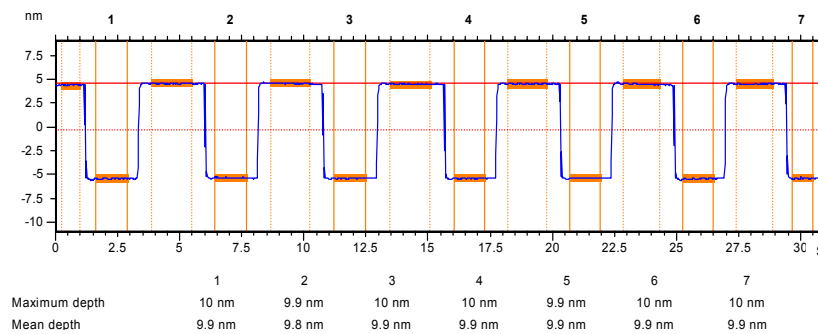


Fig. 6. Displacements of different step form.

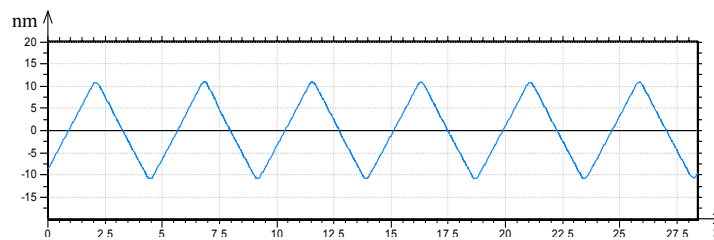


Fig. 7. Displacements of linear form.

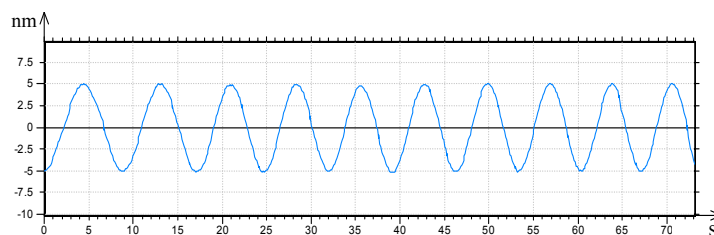


Fig. 8. Sinusoidal displacements.

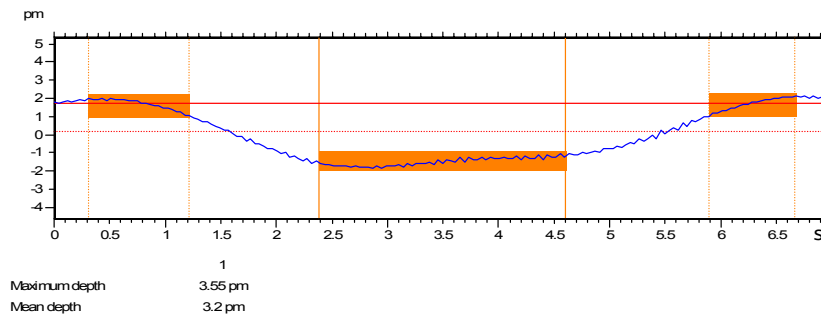


Fig. 9. Step picometer displacement.

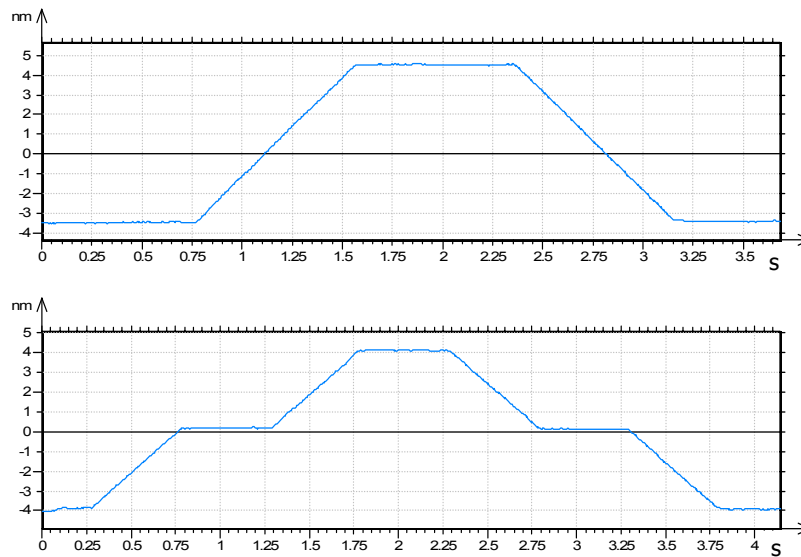


Fig. 10. Different trapezoidal form of displacements.

Control electric signals of up to 2000 volts are generated by an electronic system specialized on the basis of the signal processor programmatically controlled from a computer.

Photo of electronic control system is given in Fig. 11.



Fig. 11. High voltage electronic control system.

Measurement of value of voltage up to 1000 volt was carried out by the Fluke 8846A voltmeter with a relative error less than $2 \cdot 10^{-5}$.

2. Optical Interferometers

Displacements in the nano- and picometer range were measured by a homodyne optical interferometer.

Optical schemes of interferometers were created on the basis of microoptics, as well as fiber optics.

The laser radiation was transmitted through a single-mode optical fiber.

A photo of the optical interferometer based on microoptics is given in Fig. 12.

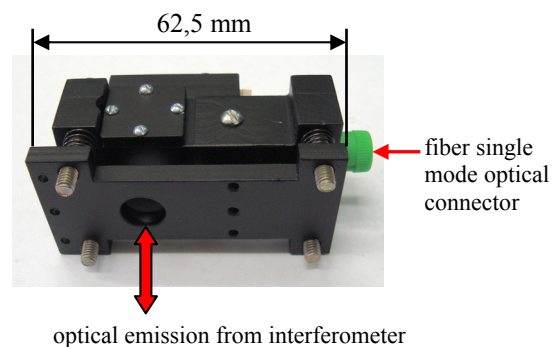


Fig.12. Photo of compact optical interferometer.

Laser radiation frequency was stabilized by the cesium cell. Relative instability of laser radiation frequency was less than 10^{-5} .

Photo of optical isolator and cesium cell is given in Fig. 13.

Optical interferometers may be used for 3D control of displacements of nanomanipulators.

The principal optic scheme and arrangement of cases of interferometers concerning the nanomanipulator in a look of piezotube are given in Fig. 14, 15.

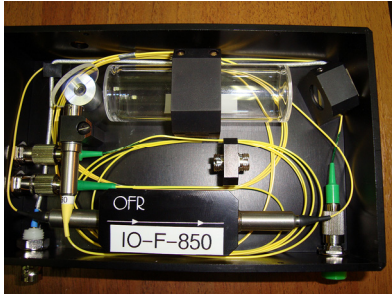


Fig. 13. Optical isolator and cesium cell for stabilization of laser radiation frequency.

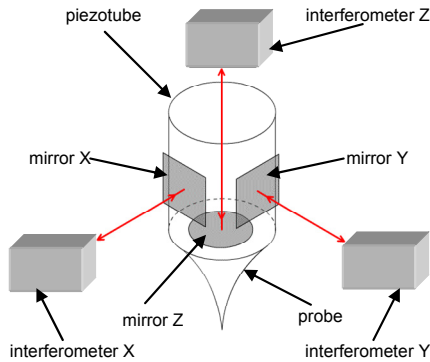


Fig. 14. The principal optic scheme of arrangement of interferometers around nanomanipulator of NanoFab on the base of piezotube.

These interferometers could be built in nanofabs for measuring of displacements of wide range manipulators.

In a range less than 0.1 nanometers to use accumulation and the coordinated filtration methods by one - two orders improve a ratio a signal/noise and provide carrying out measurements with subatomic uncertainty- few picometers.

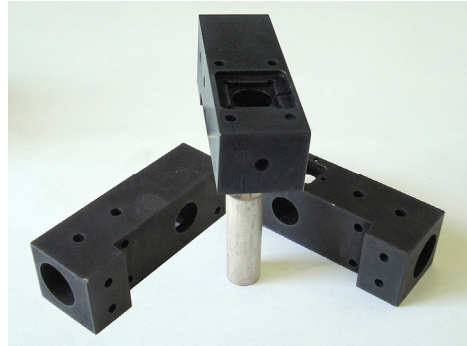


Fig. 15. The arrangement of cases of interferometers around nanomanipulator of NanoFab on the base of piezotube.

References

- [1]. T. Dziomba, P. N. Luskinovich, V. A. Zhabotinsky, P. Krebs, H.-U. Danzebrink, Characterization of novel active dynamic SPM standards, *NanoScale*, 2013, C 22.
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