

Feature-Oriented Scanning Probe Microscopy

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1. INTRODUCTION

Feature-oriented scanning probe microscopy (FOSPM) is a set of probe methods intended for surface investigation with high spatial resolution. FOSPM allows direct operations with surface features (objects), which linear dimensions range from tens of nanometers to several angstroms. Operations with features include measurements of topography and surface properties as well as active surface modification. Capabilities of the method related to an active influence on surface features allow us to consider FOSPM as a basis for implementation of “bottom-up” nanofabrication. In that case, the scanning probe microscope (SPM) will serve as a prototype of a nanoassembler. Operating in the completely autonomous mode, FOSPM can provide high precision of measurements, stimulations, and manipulations at room temperature. Specialized probes that form a set of various measuring and technological tools may be used consistently in FOSPM. FOSPM is based on the following methods: feature-oriented scanning (FOS) [1, 2], counter-scanning (CS) [3-5], distributed calibration [1, 6-10], and feature-oriented positioning (FOP) [1, 2, 11].

2. FEATURE-ORIENTED SCANNING

2.1. Method Definition

FOS is a method intended for the high-precision measurement of nanotopography as well as other surface properties and characteristics by an SPM using features (objects) of the surface as reference points for the microscope probe. With FOS method, during consecutive passings from one surface feature to another located nearby, the relative distance between the features and the feature topographies called surface segments are measured. This approach allows us to scan an intended area of a surface by parts and then reconstruct the whole image from the obtained fragments.

2.2. Method Description

The segment is a raster scan of a surface feature. The sizes of the segments are adjusted such that the segments of the neighboring features partially overlap each other so that the topography of a measured surface can be reconstructed without any gaps. Scanning in the segment is carried out in a counter manner (see Section 3), thus permitting correction of raster distortions produced by drift of the microscope probe relative to the measured surface.

Real-time program recognition of a feature in the segment allows us to determine the drift-induced displacement of this feature relative to the segment center. The displacement found is compensated by the corresponding change in the probe position. Repeating periodically the segment scan, the segment recognition and correction of the probe position, it is possible to implement a tracking of the feature with the probe also known as the attachment of the microscope probe to the surface feature.

Any topography element that looks like a hill or a pit in wide sense may be taken as a surface feature. Examples of surface features (objects) include atoms, interstices, molecules,

clusters, grains, nanoparticles, crystallites, quantum dots, nanoislets, pillars, pores, short nanowires, short nanorods, short nanotubes, elements of chains, bacteria, viruses, cells, organelles, and the like.

The only restriction imposed on the used feature is a requirement of commensurability of its lateral sizes. In other words, extensions of the features should be comparable in different directions in the lateral plane. Otherwise, the feature cannot be localized in a small-sized segment. “Unsuitable” surface, for instance, would be a defectless surface of a one-dimensional diffraction grating or a surface of an integrated circuit with a great number of long conducting wires.

On the whole, FOS of a surface is carried out by the following steps:

1. Detecting and catching the nearest (current) surface feature.
2. Scanning the current feature neighborhood called an aperture. Aperture is a raster scan that contains several neighboring features.
3. Selecting among the neighboring features the next one in accordance with a certain rule of connection.
4. Implementing the “skipping” between the current and the next features.
5. Moving the microscope probe to the position of the next feature which becomes current after that.

The pointed out sequence of operations is repeated until the set surface area is scanned out (theoretically, there are no restrictions on the sizes of the area).

Skipping is a basic measurement operation in FOS intended for accurate determination of relative coordinates of the neighboring features and acquisition of topography segments. The operation of feature skipping consists in moving the probe from the current feature position to the next feature position, scanning-recognizing the segment of the next feature, calculating the “forward” difference between the current and the next feature coordinates, moving the probe back to the position of the current feature, scanning-recognizing its segment, and calculating the “backward” difference between the current and the next feature coordinates.

The relative coordinates of the next feature are calculated as a half-sum of the obtained forward and backward differences that allows us to exclude the influence of drift on measurement of the distance between the features. Thus, by specifying a large number of skipping cycles, the measurement precision can be considerably improved by means of measurement averagings. The microscope resolution can also be improved this way provided that a sharp probe is available. The number of averagings may reach up to hundreds of thousands or even some millions. Theoretically, the number of averagings is unlimited. In practice, however, the number of averagings is mainly restricted by a long-term stability of the investigated surface, the experimental environment, and the characteristics of the probe microscope itself.

Generally, FOS is based on the following principles: localization of the measurements, operating with separate surface features, movement by short distances from one feature to another located in the vicinity, measurement

of relative distances, multiple measurement iterations, consecutive probe attachments to surface features, continuous monitoring of drift velocity, and the use of hierarchically organized counter movements.

It should be noted that, unlike the conventional scanning, the trajectory of probe movement in the FOS method is not predefined; it is composed dynamically during the measurement. Only the law of feature connection responsible for the selection of the next surface feature is preset in a general form.

The advantage of FOS method as compared to the regular scanning is direct operating with surface features which are mostly the subject of research or technology. It should be emphasized that the FOS topography measurement method proves to be ineffective when scanning surfaces with small number of features or no features at all. The fact is that FOS on such surfaces will attempt to reveal the rare features by gradually increasing the number of points in the aperture, and on failure it will try to change the scale of the measurements by gradually decreasing or increasing the scan step. The increase in the aperture size is equal to the degeneration of FOS method into the conventional scanning. Adjustment of aperture size and search for suitable scale require additional time.

Strictly speaking, there are no absolutely smooth surfaces, as even atomically flat surface has finite corrugation. The problem is usually formulated as follows: whether the features on a particular surface correspond to the measurement scale within which a researcher or technologist is currently engaged and whether the features are contrast and stable enough to serve as reliable places of microscope probe attachment.

SPM is the major area of FOS method application. Since the FOS method implies recognition of the image scanned, the topography features should be understood in a broad sense. They refer not only to pure topography but also to physical inhomogeneities such as magnetization domains, places of localized electric charge, and so forth. Therefore, the method may be used with any instrument of the SPM family: a scanning tunneling microscope (STM), an atomic-force microscope (AFM), a magnetic-force microscope, a near-field scanning optical microscope, and so on. FOS can also be applied to a scanning electron microscope. Generally speaking, the FOS method may be used with any device that has a probe (mechanical tip, focused light beam, focused electron beam, focused ion beam, etc.), a scanning system (a scanner), and a unit that registers probe interaction with the measured surface (a detector).

Beside the SPM, FOS may be applied to the bottom-up nanofabrication. The bottom-up nanofabrication implies element-wise assembling of nanodevices. Nanoclusters, nanoparticles, molecules, or even single atoms may be used as construction blocks. The apparatus able to implement assemblage of nanodevices is called nanoassembler. In the future, the nanoassembler will have an array of specialized probes—one part of them is intended for technological operations and the other for analytical measurements and checking. FOS is able to take control over the nanoassembler making the nanofabrication completely automatical. An operator should only formulate the task in general

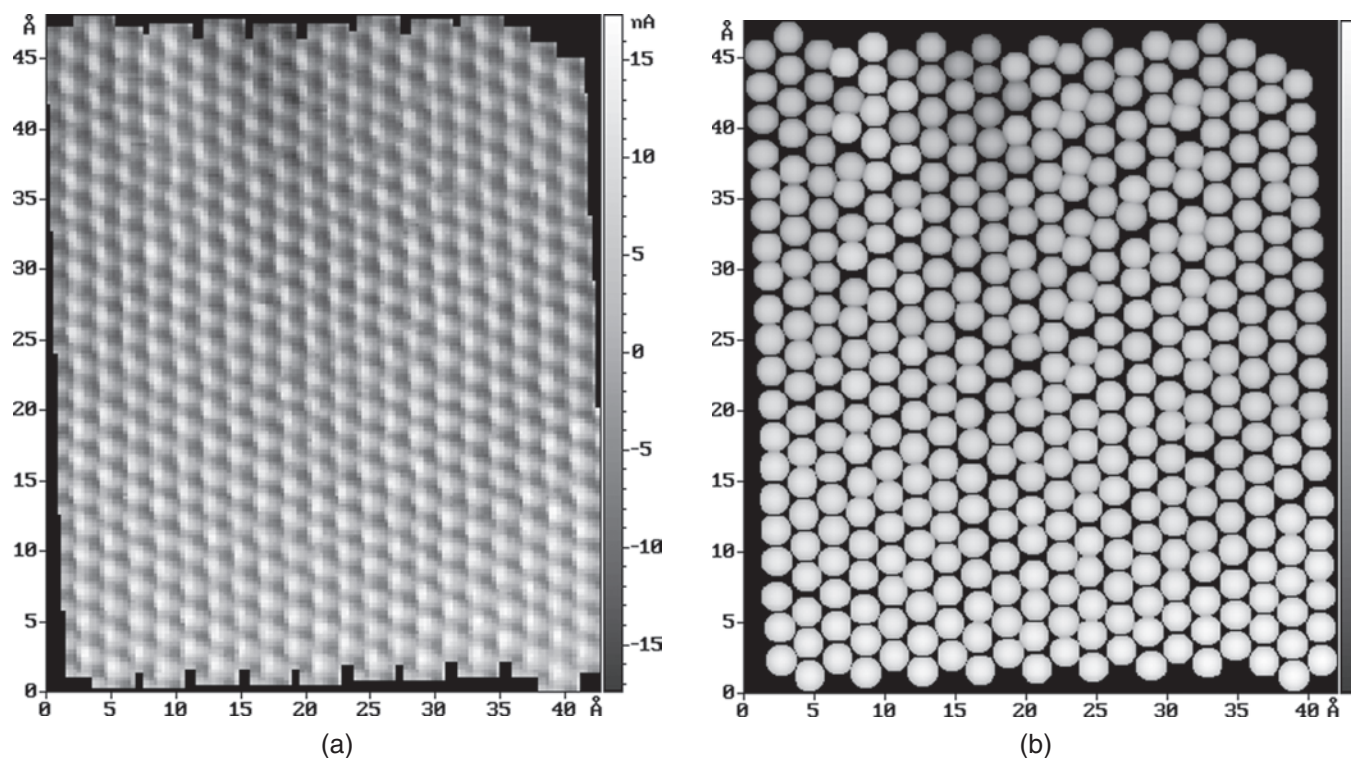


Figure 1. Atomic surface of pyrolytic graphite (STM, constant Z mode). Carbon atoms are used as surface features. (a) Surface reconstructed from segments. The number of skipping cycles is 3. The number of segment averagings is 6. (b) Sphere model of the surface. Reprinted with permission from [1], R. V. Lapshin, *Nanotechnology* 15, 1135 (2004). © 2004, IOP Publishing Ltd.

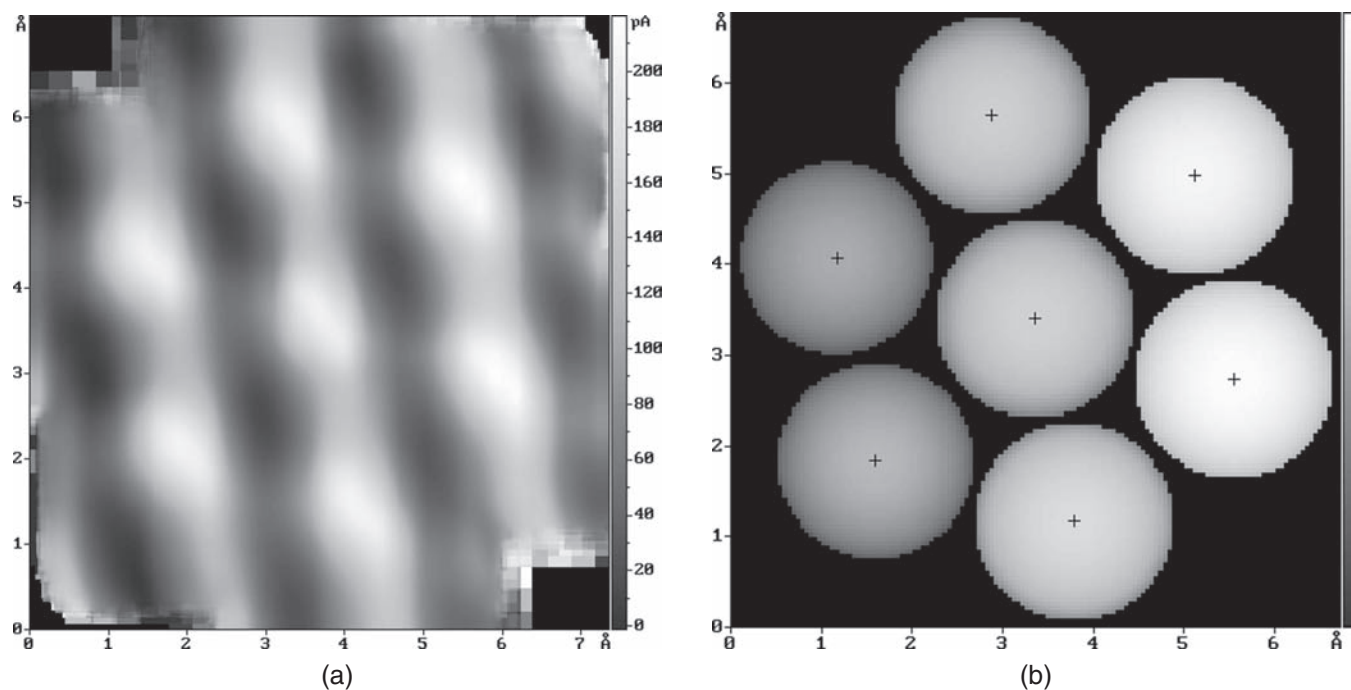


Figure 2. Atomic surface of pyrolytic graphite measured with high resolution (STM, constant Z mode). Carbon atoms are used as surface features. (a) Surface reconstructed from segments. The elements corresponding to the minimum step of the scanner are well seen in the top left and the bottom right corners of the image. 1000 segments and coordinate differences were measured for each of the seven carbon atoms. (b) Sphere model of the surface. Reprinted with permission from [1], R. V. Lapshin, *Nanotechnology* 15, 1135 (2004). © 2004, IOP Publishing Ltd.

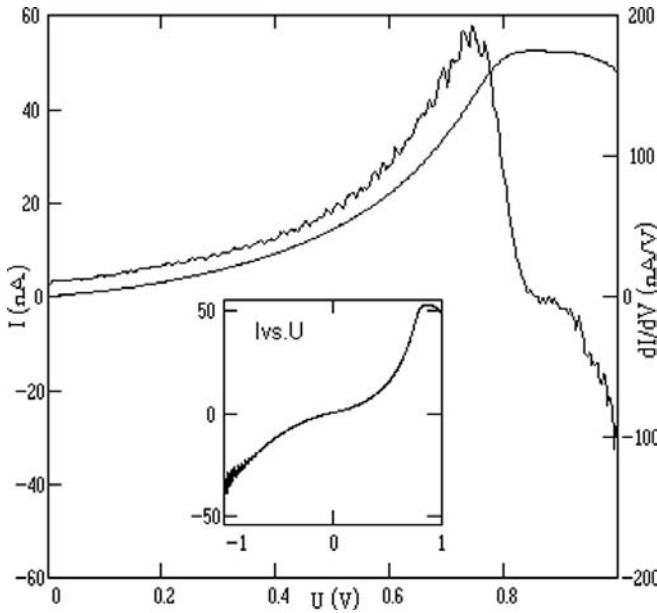


Figure 3. Averaged I - V characteristic and its derivative. I - V characteristic is measured for the tunnel junction localized immediately on the apex of the carbon atom of the pyrolytic graphite monocrystal. The number of averagings is 10^4 . Reprinted with permission from [1], R. V. Lapshin, *Nanotechnology* 15, 1135 (2004). © 2004, IOP Publishing Ltd.

terms, then he should act according to the principle “run and forget.” At present, SPM is used as the nanoassembler, which allows testing various measurement techniques, particular technological modes, and operations.

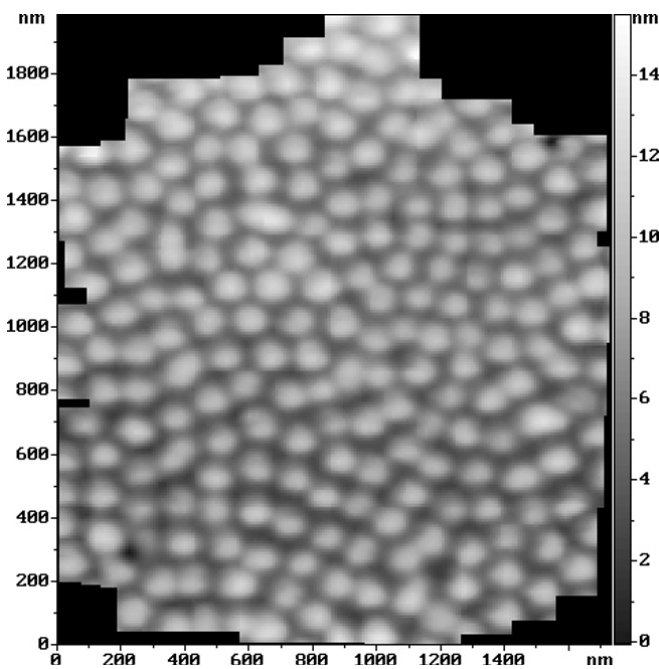


Figure 4. Reconstructed surface of electrochemically polished aluminium (AFM, tapping mode). Aluminium nanobumps are used as surface features. The number of skipping cycles is 2. The number of segment averagings is 4. Reprinted with permission from [1], R. V. Lapshin, *Nanotechnology* 15, 1135 (2004). © 2004, IOP Publishing Ltd.

2.3. Practical Results

Today, a number of unique measurements on surface of solids have been conducted using FOS approach [1]. In particular, the image of an atomically resolved crystal surface of highly oriented pyrolytic graphite (HOPG) free of thermal drifts was obtained with STM (Solver™ P4, NT-MDT Co.) at room temperature (Fig. 1), the possibility was experimentally confirmed of improving the utmost microscope resolution in dozens of times (Fig. 2), the distance between the neighboring atoms on a single crystal surface was measured with the highest precision ever reached with a probe instrument (the measurement error made ± 0.0005 Å after executing 250,000 skipping cycles), and a tunneling spectroscopy with high signal-to-noise ratio was performed precisely above the top of a single atom (Fig. 3).

Steady FOS on a quasi-ordered and disordered surfaces with lateral feature size of tens to hundreds nanometers was demonstrated with AFM (Solver™ P4) [1]. In Figure 4, a reconstructed image of quasi-ordered surface of electrochemically polished aluminium is presented. In Figure 5, a reconstructed image of disordered surface of plasma-deposited carbon film is shown. The obtained images are practically free of distortions produced by thermal drift of the microscope as well as creep and hysteresis [12] of the scanner piezoceramics.

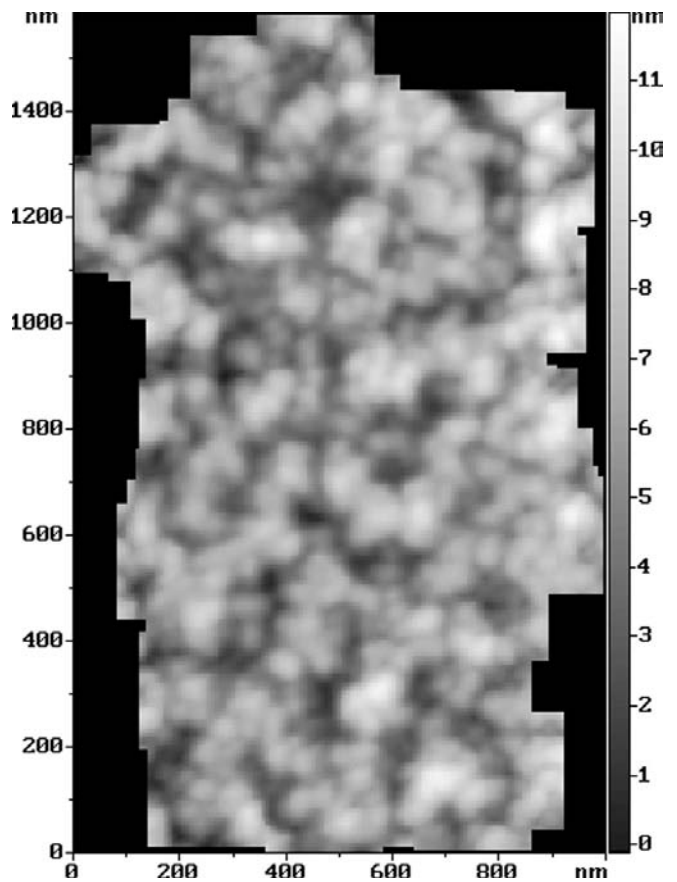


Figure 5. Reconstructed surface of plasma-deposited carbon film (AFM, tapping mode). Carbon clusters and intercluster spaces are used as surface features. The number of skipping cycles is 2. The number of segment averagings is 4. Reprinted with permission from [1], R. V. Lapshin, *Nanotechnology* 15, 1135 (2004). © 2004, IOP Publishing Ltd.

During the measurements, undistorted statistics of the features was automatically collected, enabling detailed characterization of the surfaces under investigation.

3. COUNTER-SCANNING

3.1. Method Definition

CS is a method for measuring surface topography with an SPM that enables correction of raster distortions resulted

from drift of the microscope probe relative to the surface being measured. Two surface scans, viz., direct scan and counter scan, are obtained during CS one after another. The counter scan starts in the point where the direct scan ends. This point is called the coincidence point (CP). With the counter scan, the probe movement along the raster line and the probe movement from one raster line to the other raster line are carried out along the directions that are opposite to the movements in the direct scan. The obtained pair of images is called the counter-scanned images (CSIs).

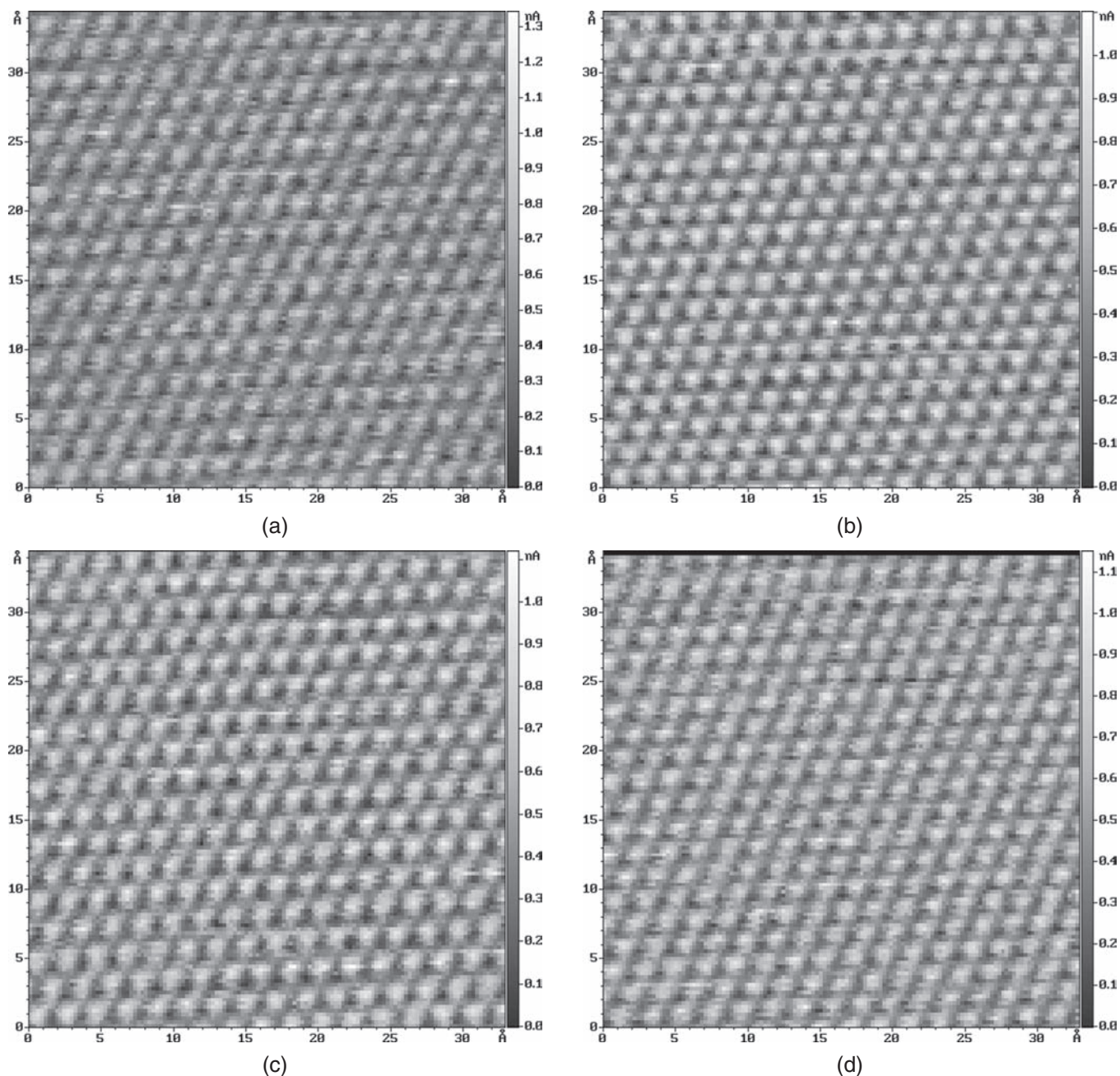


Figure 6. Drift-distorted CSIs of the atomic surface of pyrolytic graphite. (a, b) The first CSI pair. (c, d) The second CSI pair. Measurement mode: STM, constant Z. Drift-induced maximal relative measurement error in the lateral plane: (a, b) 7.8% and (c, d) 8.0%. Reprinted with permission from [3], R. V. Lapshin, *Meas. Sci. Technol.* 18, 907 (2007). © 2007, IOP Publishing Ltd.

3.2. Method Description

To implement correction, it is required to find the same feature on both CSIs and to determine its lateral coordinates. Because of drift, the same topography points on the direct and the counter scans do not coincide with each other except for a single point—the CP. Building a simple system of linear equations, linear transformation coefficients (LTCs) may be calculated for each CSI. Using the LTCs found, drift correction is carried out along x , y , and z , then the corrected images are matched in CP, and then the topography is averaged out in the overlap area of these images. It is supposed while composing the system of equations that the drift velocity is constant during the scanning time. Therefore, the slower is the change in drift velocity, the higher is the correction precision.

By reading the signal during the retrace sweep while scanning the direct and the counter images, another CSI pair may be obtained. Working with two CSI pairs allows us to increase the accuracy of the drift correction as well as to decrease the noise level in the output image. If the drift velocity is changing significantly during CS, then the nonlinear correction methods suggested in Ref. 3 should be applied.

The less the scan sizes are, the less probable is a change in the drift velocity during CS. Therefore, CS method would reach a maximal effect when used with the FOS method, which operates with small-sized scans—segments and apertures. Moreover, as drift is correctable within the apertures, it allows increasing FOS productivity by refusing the skipping operation and building the surface of apertures instead of segments. This is, however, at the cost of some decrease in FOS measurement precision.

Application of CS allows:

1. Easy detecting feature pairs on CSIs owing to the existence of a CP whose neighborhood actually contains the same topography.

2. Increasing the drift correction precision owing to a greater difference in position coordinates of the features that compose a pair.
3. Ensuring a preset measurement error within the bounds of a certain image area in accordance with the actual change in drift velocity that occurred during the CS.
4. Decreasing the creep produced by the piezoscanner during FOS by means of inducing a counter creep while scanning topography segments or apertures.

3.3. Practical Results

Performance of the CS method is demonstrated by the example of surface scans of a single crystal of pyrolytic graphite (ordered surface, feature scale—atomic, small drift—hundredth parts of \AA s^{-1} , insignificant creep component of the drift, STM) and porous alumina surface (quasi-ordered surface, feature scale—tens of nanometers, large drift—exceeded 10\AA s^{-1} , significant creep component of the drift, AFM) [3].

Two CSI pairs of atomic surface of pyrolytic graphite, where thermodrift-induced raster distortions are well noticeable, are shown in Figure 6. In Figure 7, corrected graphite surface is shown. Carbon atoms and interstices were used as surface features. Two CSI pairs of quasi-ordered porous alumina surface are given in Figure 8. These scans are very much distorted by creep. In Figure 9, corrected porous alumina surface is presented. Hillocks and pores were used as surface features.

Application of CS method resulted in decrease of the maximal measurement error from 8% to 0.6% for graphite and from 25% to 0.9% for alumina. The mean error within the area of the corrected image makes 0.1% for graphite and 0.2% for alumina. CS was carried out on microscope Solver™ P4.

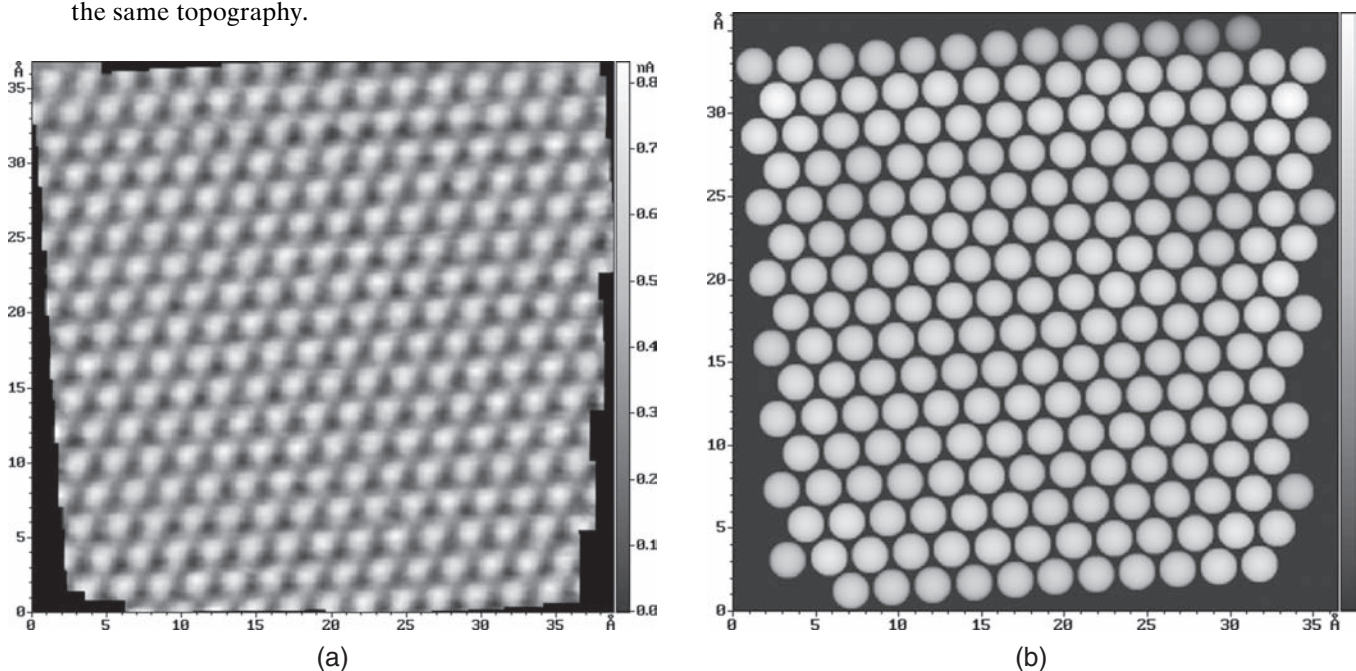


Figure 7. Corrected surface topography of pyrolytic graphite: (a) real image and (b) sphere model. Reprinted with permission from [3], R. V. Lapshin, *Meas. Sci. Technol.* 18, 907 (2007). © 2007, IOP Publishing Ltd.

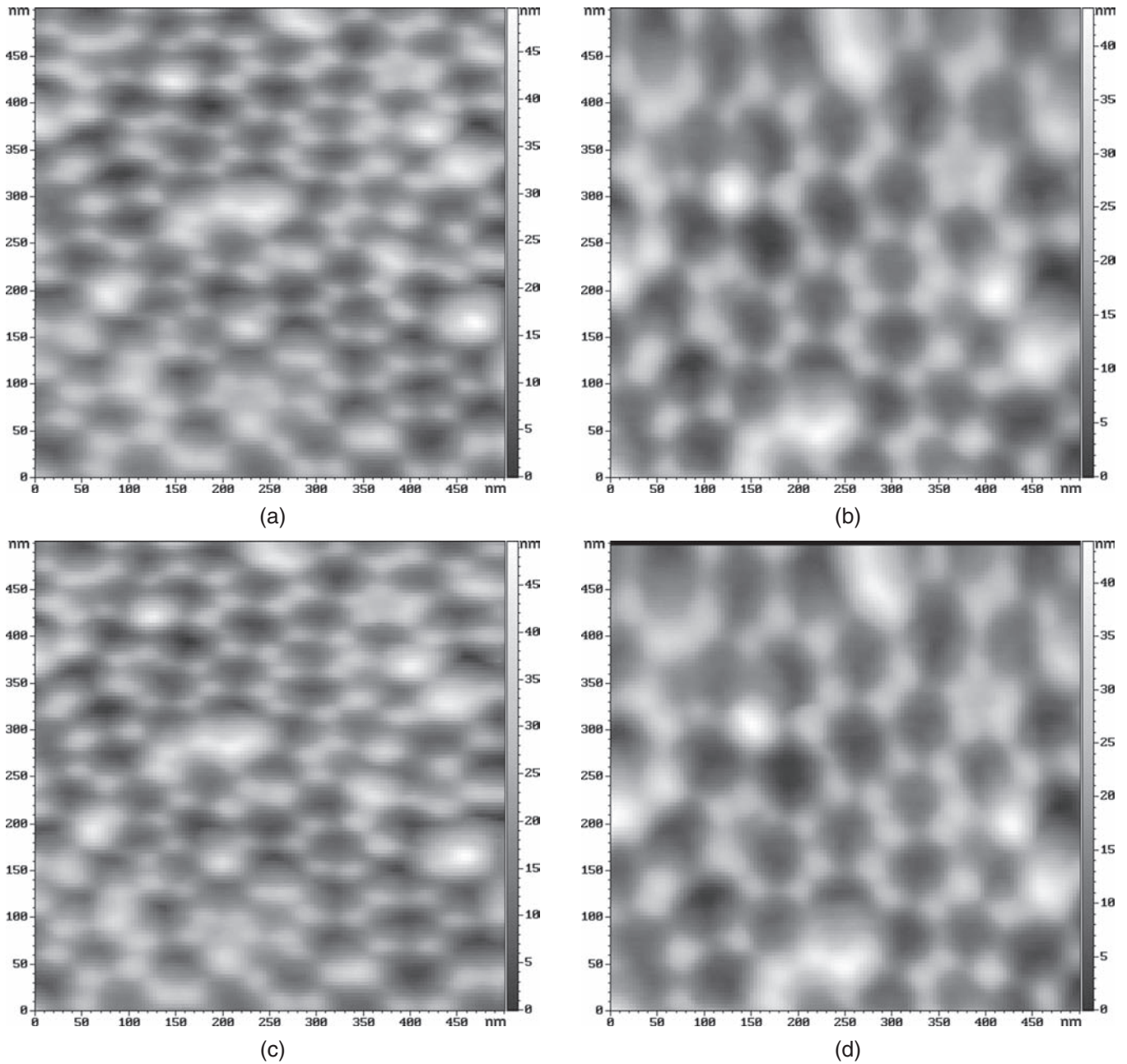


Figure 8. Drift-distorted CSIs of porous alumina surface. (a, b) The first CSI pair. (c, d) The second CSI pair. Measurement mode: AFM, tapping. Drift-induced maximal relative measurement error in the lateral plane: (a, b) 24.6% and (c, d) 24.4%. Reprinted with permission from [3], R. V. Lapshin, *Meas. Sci. Technol.* 18, 907 (2007). © 2007, IOP Publishing Ltd.

4. DISTRIBUTED CALIBRATION

A sort of FOS called distributed calibration [1, 6, 7] being implemented on a standard surface makes it possible to determine the local calibration coefficients (LCCs) K_x , K_y , and K_z for each point of the scanner movement space [1, 6–10]. Application of FOS excludes in situ the negative influence of thermal drift, creep, and hysteresis on the obtained results. The sensitivity of LCCs to errors in the determination of position coordinates of surface features forming the local calibration structure (LCS) is

eliminated by performing multiple repeated measurements followed by building a regression surfaces. There are no principle restrictions on the number of repeated LCS measurements.

By using the collected calibration database, all spatial distortions caused by nonlinearity, nonorthogonality, and parasitic crosstalk couplings of the X , Y , and Z manipulators of the scanner may be corrected in one operation. To provide high precision of spatial measurements in nanometer range, the calibration is carried out using natural standards—stable reconstructions of atomic surfaces of crystals.

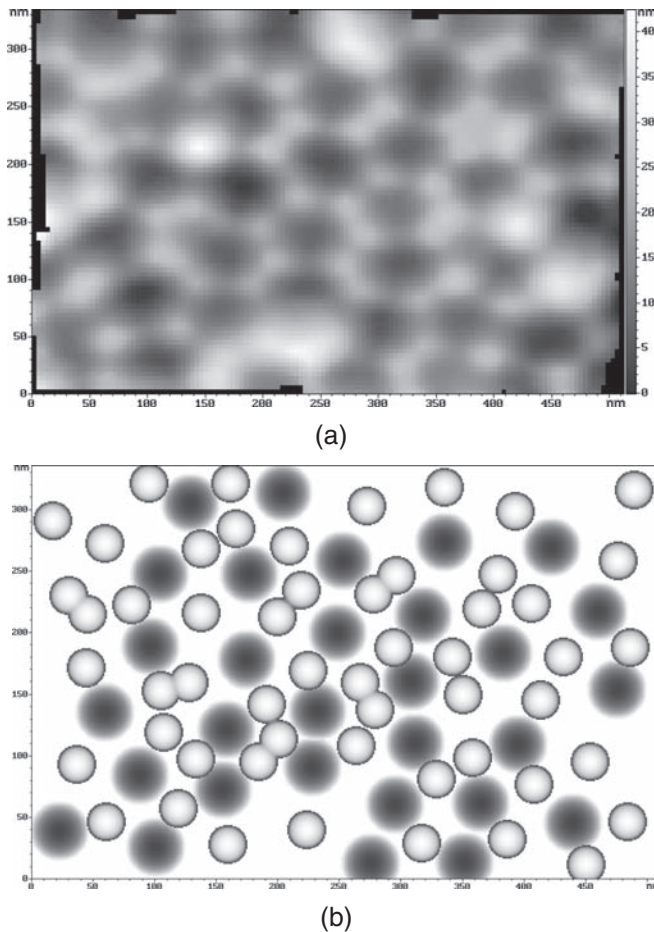


Figure 9. Corrected surface topography of porous alumina: (a) real image and (b) stylized image. Reprinted with permission from [3], R. V. Lapshin, *Meas. Sci. Technol.* 18, 907 (2007). © 2007, IOP Publishing Ltd.

5. FEATURE-ORIENTED POSITIONING

5.1. Method Definition

FOP is a method of precise movement of the scanning microscope probe across the surface under investigation. With this method, surface features are used as reference points (points of probe attachment). Actually, FOP is a simplified variant of FOS. With FOP, no topographical image of a surface area is acquired. Instead, a probe movement by surface features is only carried out from the start point A (neighborhood of the start feature) to the destination point B (neighborhood of the destination feature) along some route that goes through intermediate features of the surface.

5.2. Method Description

To be distinguished are a “blind” FOP and an FOP by known feature “map.” The blind FOP is when the coordinates of features used for probe movement are unknown in advance. FOP by known feature map is when the relative coordinates of all features are known, for example, in

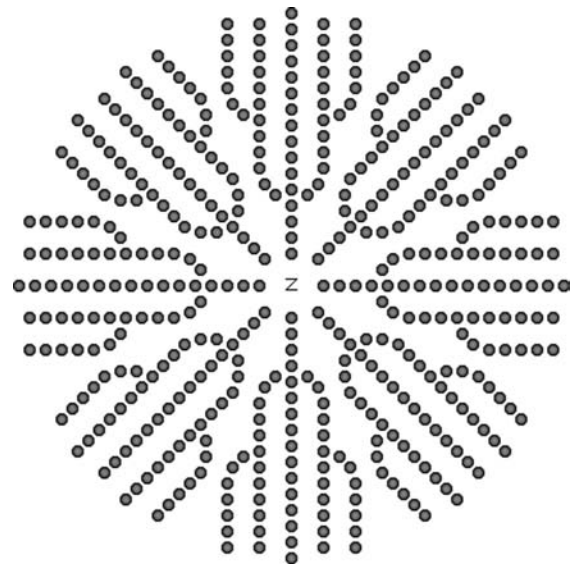


Figure 10. Navigation structure in the form of a system of feature chains converging into an operational zone (designated as z). This structure is intended for automatic probe return into the operational zone after sample dismounting-mounting. Reprinted with permission from [1], R. V. Lapshin, *Nanotechnology* 15, 1135 (2004). © 2004, IOP Publishing Ltd.

case they were obtained during preliminary FOS. Probe movement by a navigation structure is a combination of the above-pointed methods. With this method (see Fig. 10), a general topology of the structure is known a priori and also approximately (because of technological uncertainty and surface instability) known are: the sizes of the elements, their shape, the distance between the neighboring elements, and the movement direction. At the same time, the current probe position within the structure is not required to be known precisely, it is also admissible for the probe to get into a defective area on the structure, and so on.

Besides providing high-precision movement of the microscope probe within the field of the fine positioner, application of FOP allows for high-precision placement of the fine positioner field in an arbitrarily large field of a coarse positioner. When the fine positioner reaches the edge of its movement range (see Fig. 11, pos. 2), it is carrying out repeated probe attachments to the current feature (shown as arc). At the same time, the coarse positioner starts to move the probe relative to the sample surface slowly by small steps (pos. 3). The fine positioner “feels” this movement in the attachment cycles by a displacement of the current feature. The movement direction of the coarse positioner is chosen so as to make the fine positioner follow the current feature toward the opposite edge of its range. The coarse positioner continues to move until the fine positioner reaches the opposite edge of its range. After that, the fine positioner may proceed moving along the previous direction.

The described method of allocating the fine positioner field within the coarse positioner field permits both scanning and technological operations at large surface areas with the accuracy of the fine positioner. In both the cases, the movement length is only restricted by the range of the coarse positioner. The advantage of the suggested approach

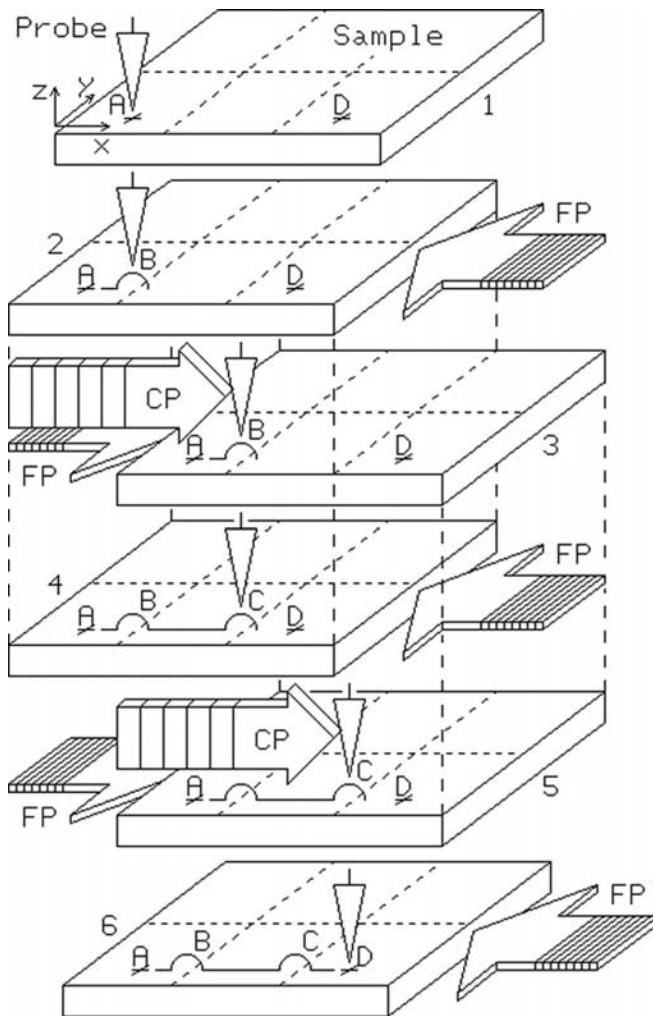


Figure 11. Accurate travel of the microscope probe from point A to point D at a distance longer than one range of the fine positioner. Designations: FP is the fine positioner and CP is the coarse positioner. Dotted lines on the sample show the coarse positioner field partitioning into adjacent ranges of the fine positioner. The arcs in the probe positions B and C symbolize some surface features. Reprinted with permission from [1], R. V. Lapshin, *Nanotechnology* 15, 1135 (2004). © 2004, IOP Publishing Ltd.

is that no strict demands are actually made of the accuracy of the coarse positioner.

Beside SPM, tunneling spectroscopy, and force spectroscopy, FOP method may be used in bottom-up nanofabrication to implement high-precision movement of the nanolithograph or nanoassembler probe along the sample surface during nanotechnological operations. Moreover, once made along some route, FOP may be then exactly repeated the required number of times.

With multiprobe instruments, FOP approach allows us to apply any number of specialized technological and/or analytical probes successively to any surface feature (object) or to any point of its neighborhood [1]. That enables complex nanofabrication consisting of a large number of technological, measuring, and checking operations.

The starting point of FOP should be considered the work published by Pohl and Möller [13], where a hardware-based

implementation of automatic tracking of a surface feature was suggested. Carrying out a circular dithering of probe position in the lateral plane, the local derivatives of surface topography along x and y are determined. Lateral servosystems form control signals for the scanner so that the scanner moves in the direction of decreasing the derivative and thus makes the microscope probe climb to the top of a hill or descent to the bottom of a pit.

Later this method was successfully implemented by Swartzentruber [14] for direct measurement of surface diffusion of Si atoms. Aketagawa et al. [15] applied Pohl-Möller method for probe movement by carbon atoms along a crystallographic direction on a HOPG surface. The drawback of Pohl-Möller method in comparison with a software-based servosystem is an additional noise produced by the lateral servosystems to the probe position while operating at the top microscope resolution.

5.3. Practical Results

The experiments with moving the probe of STM (Solver™ P4) by separate atoms of a single crystal surface along a preset direction illustrate the utmost performance capabilities of FOP. In particular, a stable movement of the microscope probe from atom to atom along a crystallographic direction was demonstrated on HOPG surface in ambient conditions at room temperature (Fig. 12). The distance traversed was about $1\ \mu\text{m}$ (4060 carbon atoms), the movement speed made $1\ \text{atom}\cdot\text{s}^{-1}$ [1]. The movement distance in the experiment

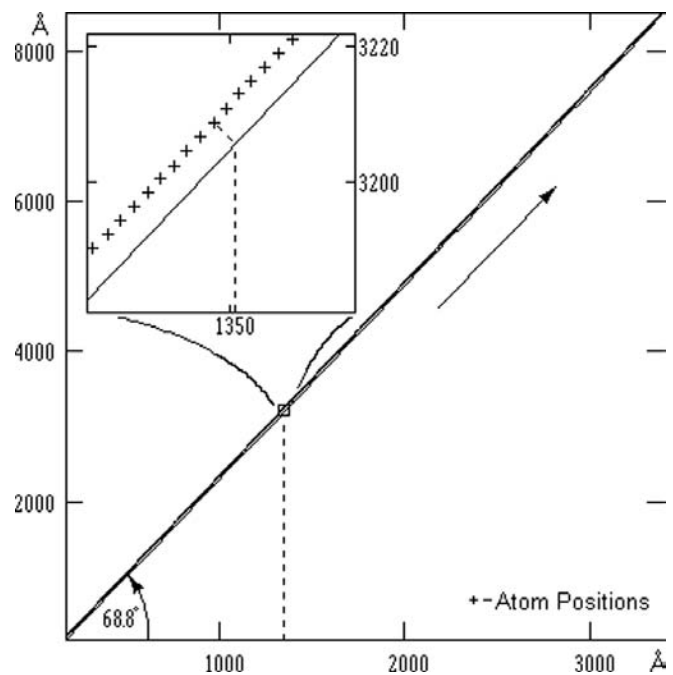


Figure 12. Movement of the STM probe by carbon atoms in the set direction on the HOPG surface. The traversed path length is $\sim 1\ \mu\text{m}$. The number of atoms in the chain is 4060. The number of skipping cycles is 3. The movement velocity is $1\ \text{atom}\cdot\text{s}^{-1}$. The arrow points the direction of the probe movement. Reprinted with permission from [1], R. V. Lapshin, *Nanotechnology* 15, 1135 (2004). © 2004, IOP Publishing Ltd.

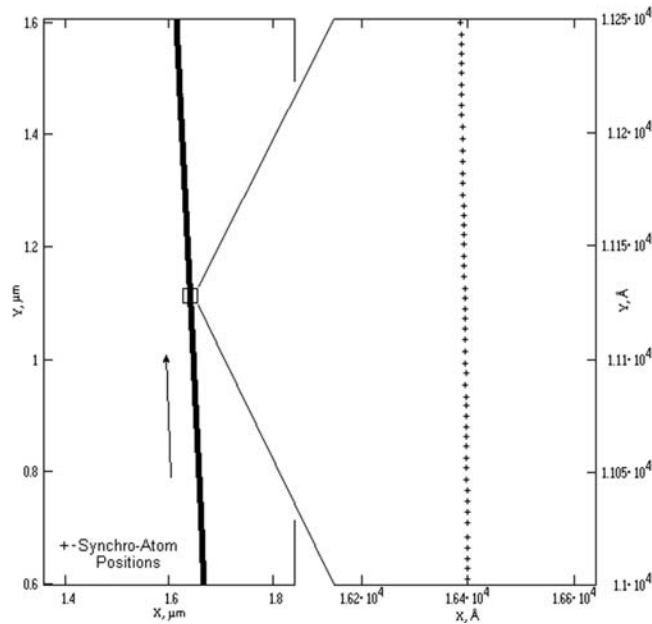


Figure 13. Keeping the STM probe on the bit track consisting of pyrolytic graphite single crystal carbon atoms. Odd carbon atoms serve as track synchroelements and even carbon atoms are informational elements. The length of the track traversed is 2048 synchroatoms ($\sim 1 \mu\text{m}$). The readback rate is $33 \text{ infoatoms s}^{-1}$. The number of probe attachment failures is 0. The arrow points the direction of the probe movement. Reprinted with permission from [11], R. V. Lapshin, *Rev. Sci. Instrum.* 71, 4607 (2000). © 2000, American Institute of Physics.

was only restricted by the size of the atomically smooth areas on graphite surface formed during cleaving.

Beside precise probe movement at long distances and the ability of measuring long distances by simply counting periods of the atom lattice, the method allows us to reveal and estimate the curvature of the crystallographic direction that may indicate the presence of macrodefects and/or elastic stresses in the crystal body.

By using a specialized type of FOP, a principle ability was demonstrated to stabilize the probe of a high-capacity storage device on atomic-sized data track in ambient conditions at room temperature [11]. An STM (Solver™ P4) was used as a prototype of the probe storage device. The carbon atoms on HOPG surface located along a crystallographic direction served as information bits composing a data track. The “information” atoms alternated with the “synchronizing” ones used for probe attachment. Figure 13 shows the movement along the data track at a distance a little more than $1 \mu\text{m}$. Readback rate made $33 \text{ infoatoms s}^{-1}$. A peculiarity of the method is that the data can be read by means of just a single sensor and a single vertical plane servosystem.

6. CONCLUSION

The distinguished features and functional capabilities of FOSPM are:

1. Weak dependence of the performed operations (such as topography scanning, probe movement, surface

modification-stimulation, and object manipulation) upon thermal drifts, creeps, and hysteresises.

2. High precision of surface scanning and higher spatial resolution.
3. Automatic distributed calibration of the scanner in nanometer scale, which excludes all nonlinear static distortions. Application of nature measures as a length standard.
4. Unlimited time of keeping the object under measurement or modification within the device’s “field of view” despite the influence of external disturbing factors.
5. Accurate localization of position and high signal-to-noise ratio during tunneling or force spectroscopy of the surface.
6. Adaptation to the ever-changing physical environment, in particular, to temperature variations.
7. Automatic adjustment-optimization of the scan parameters and/or the local modification parameters during operation.
8. Precise movement of the probe by the surface features within the fine positioner field.
9. Accurate placement of the field of the fine positioner in the field of the coarse positioner.
10. Automatic detection of the object under measurement or modification.
11. Making local modification-stimulation of a surface feature or its neighborhood in automatic mode.
12. Manipulations with objects on the surface in automatic mode.
13. Practically unrestricted sizes of surface scans and areas available for technological operations in case a “walking” coarse positioner is present in the system.
14. Automatic determination of the exact relative positions of the analytical and technological probes in multiprobe instruments.
15. Precise consecutive application of any number of technological and analytical probes to the same surface feature (object) or to its vicinity in automatic mode.
16. Automatic probe return into the operational zone after sample dismounting-mounting; probe movement between the different operational zones in automatic mode. In both cases a navigation structure is required. Nanoelements fabricated on a surface during a technological process may be used for navigational purposes.
17. Possibility to “heal” surface defects automatically.
18. Automatic surface characterization. Automatic search for specific features, surface defects, acquisition of defect statistics, and building map of defects. Automatic detection of subsurface macrodefects and mechanical strains in crystal substrates.
19. Simple data exchange between the SPM and the computer-aided molecular modeling-design systems.

ACKNOWLEDGMENTS

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GLOSSARY

AFM Atomic-force microscope, atomic-force microscopy
CP Coincidence point
CS Counter-scanning
CSI Counter-scanned images
FOP Feature-oriented positioning
FOS Feature-oriented scanning
FOSPM Feature-oriented scanning probe microscopy
LCC Local calibration coefficient
LCS Local calibration structure
LTC Linear transformation coefficient
SPM Scanning probe microscope, scanning probe microscopy
STM Scanning tunneling microscope, scanning tunneling microscopy

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