Abstracts of selected papers

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An improved parametric model for hysteresis loop approximation

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A number of improvements have been added to the existing analytical model of hysteresis loops defined in parametric form. In particular, three phase shifts are included in the model, which permits us to tilt the hysteresis loop smoothly by the required angle at the split point as well as to smoothly change the curvature of the loop. As a result, the error of approximation of a hysteresis loop by the improved model does not exceed 1%, which is several times less than the error of the existing model. The improved model is capable of approximating most of the known types of rate-independent symmetrical hysteresis loops encountered in the practice of physical measurements. The model allows building smooth, piecewise-linear, hybrid, minor, mirror-reflected, inverse, reverse, double, and triple loops. One of the possible applications of the model developed is linearization of a probe microscope piezoscanner. The improved model can be found useful for the tasks of simulation of scientific instruments that contain hysteresis elements.

APPLIED SURFACE SCIENCE, VOLUME 470, PAGES 1122-1129, MARCH 2019

Drift-insensitive distributed calibration of probe microscope scanner in nanometer range: Real mode

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A method is described intended for distributed calibration of a probe microscope scanner consisting in a search for a net of local calibration coefficients (LCCs) in the process of automatic measurement of a standard surface, whereby each point of the movement space of the scanner can be defined by a unique set of scale factors. Feature-oriented scanning (FOS) methodology is used to implement the distributed calibration, which permits to exclude in situ the negative influence of thermal drift, creep and hysteresis on the obtained results. The sensitivity of LCCs to errors in determination of position coordinates of surface features forming the local calibration structure (LCS) is eliminated by performing multiple repeated measurements followed by building regression surfaces. There are no principle restrictions on the number of repeated LCS measurements. Possessing the calibration database enables correcting in one procedure all the spatial distortions caused by nonlinearity, nonorthogonality and spurious crosstalk couplings of the microscope scanner piezomanipulators. To provide high precision of spatial measurements in nanometer range, the calibration is carried out using natural standards – constants of crystal lattice. The method allows for automatic characterization of crystal surfaces at room temperature. The method may be used with any kind of scanning probe microscope (SPM).

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Drift-insensitive distributed calibration of probe microscope scanner in nanometer range: Virtual mode

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A method of distributed calibration of a probe microscope scanner is suggested. The main idea consists in a search for a net of local calibration coefficients (LCCs) in the process of automatic measurement of a standard surface, whereby each point of the movement space of the scanner can be characterized by a unique set of scale factors. Feature-oriented scanning (FOS) methodology is used as a basis for implementation of the distributed calibration permitting to exclude in situ the negative influence of thermal drift, creep and hysteresis on the obtained results. Possessing the calibration database enables correcting in one procedure all the spatial systematic distortions caused by nonlinearity, nonorthogonality and spurious crosstalk couplings of the microscope scanner piezomanipulators. To provide high precision of spatial measurements in nanometer range, the calibration is carried out using natural standards – constants of crystal lattice. One of the useful modes of the developed

calibration method is a virtual mode. In the virtual mode, instead of measurement of a real surface of the standard, the calibration program makes a surface image "measurement" of the standard, which was obtained earlier using conventional raster scanning. The application of the virtual mode permits simulation of the calibration process and detail analysis of raster distortions occurring in both conventional and counter surface scanning. Moreover, the mode allows to estimate the thermal drift and the creep velocities acting while surface scanning. Virtual calibration makes possible automatic characterization of a surface by the method of scanning probe microscopy (SPM).

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STM observation of a box-shaped graphene nanostructure appeared after mechanical cleavage of pyrolytic graphite

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A description is given of a three-dimensional box-shaped graphene (BSG) nanostructure formed/uncovered by mechanical cleavage of highly oriented pyrolytic graphite (HOPG). The discovered nanostructure is a multilayer system of parallel hollow channels located along the surface and having quadrangular cross-section. The thickness of the channel walls/facets is approximately equal to 1 nm. The typical width of channel facets makes about 25 nm, the channel length is 390 nm and more. The investigation of the found nanostructure by means of a scanning tunneling microscope (STM) allows us to draw a conclusion that it is possible to make spatial constructions of graphene similar to the discovered one by mechanical compression, bending, splitting, and shifting graphite surface layers. The distinctive features of such constructions are the following: simplicity of the preparation method, small contact area between graphene planes and a substrate, large surface area, nanometer cross-sectional sizes of the channels, large aspect ratio. Potential fields of application include: ultra-sensitive detectors, high-performance catalytic cells, nanochannels for DNA manipulation, nanomechanical resonators, electron multiplication channels, high-capacity sorbents for hydrogen storage.

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Drift-insensitive distributed calibration of probe microscope scanner in nanometer range: Approach description

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The method of distributed calibration of a probe microscope scanner consists in a search for a net of local calibration coefficients (LCCs) in the process of automatic measurement of a standard surface, whereby each point of the movement space of the scanner can be defined by a unique set of scale factors. Feature-oriented scanning (FOS) methodology is used to implement the distributed calibration, which permits to exclude *in situ* the negative influence of thermal drift, creep and hysteresis on the obtained results. The sensitivity of LCCs to errors in determination of position coordinates of surface features forming the local calibration structure (LCS) is eliminated by performing multiple repeated measurements followed by building regression surfaces. There are no principle restrictions on the number of repeated LCS measurements. Possessing the calibration database enables correcting in one procedure all the spatial distortions caused by nonlinearity, nonorthogonality and spurious crosstalk couplings of the microscope scanner piezomanipulators. To provide high precision of spatial measurements in nanometer range, the calibration is carried out using natural standards – constants of crystal lattice. The method may be used with any scanning probe instrument.

SURFACE INVESTIGATION. X-RAY, SYNCHROTRON AND NEUTRON TECHNIQUES, VOLUME 4, NUMBER 1, PAGES 1-11, JANUARY-FEBRUARY 2010

Vacuum ultraviolet smoothing of nanometer-scale asperities of poly(methyl methacrylate) surface

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Smoothing of the nanometer-scale asperities of a poly(methyl methacrylate) (PMMA) film using vacuum ultraviolet (VUV) with the wavelength λ=123.6 nm was studied. The exposure time and the residual air pressure in a working

chamber were varied during the process of VUV treatment. A nanostructured surface of PMMA film is used as a sample to be exposed. The nanostructured surface of the PMMA film was obtained by treating the initially smooth spin-coated film in oxygen radio-frequency plasma. The degree of VUV exposure is estimated using changes in the morphology and roughness of the nanostructured surface, which were determined by atomic-force microscopy (AFM). Recognition of morphological surface features on the AFM-images and determination of main geometrical characteristics of these features are performed by using virtual feature-oriented scanning method. It is discovered by morphology and Fourier spectra that the nanostructured surface of the PMMA film is partially ordered. The developed VUV smoothing procedure can be used to treat the electron-beam, UV, and X-ray sensitive PMMA resists, PMMA elements of microelectromechanical systems, biomedical PMMA implants, as well as to certify nanotechnological equipment incorporating UV radiation sources.

MEASUREMENT SCIENCE AND TECHNOLOGY, VOLUME 18, ISSUE 3, PAGES 907-927, MARCH 2007

Automatic drift elimination in probe microscope images based on techniques of counter-scanning and topography feature recognition

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An experimentally proved method for the automatic correction of drift-distorted surface topography obtained with a scanning probe microscope (SPM) is suggested. Drift-produced distortions are described by linear transformations valid for the case of rather slow changing of the microscope drift velocity. One or two pairs of counter-scanned images (CSIs) of surface topography are used as initial data. To correct distortions, it is required to recognize the same surface feature within each CSI and to determine the feature lateral coordinates. Solving a system of linear equations, the linear transformation coefficients suitable for CSI correction in the lateral and the vertical planes are found. After matching the corrected CSIs, topography averaging is carried out in the overlap area. Recommendations are given that help both estimate the drift correction error and obtain the corrected images where the error does not exceed some preliminarily specified value. Two nonlinear correction approaches based on the linear one are suggested that provide a greater precision of drift elimination. Depending on the scale and the measurement conditions as well as the correction approach applied, the maximal error may be decreased from 8–25% to 0.6–3%, typical mean error within the area of corrected image is 0.07–1.5%. The method developed permits us to recover drift-distorted topography segments/apertures obtained by using feature-oriented scanning. The suggested method may be applied to any instrument of the SPM family.

NANOTECHNOLOGY, VOLUME 15, ISSUE 9, PAGES 1135-1151, SEPTEMBER 2004

Feature-oriented scanning methodology for probe microscopy and nanotechnology

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A real-time scanning algorithm is suggested which uses features of the surface as reference points at relative movements. Generally defined hill- or pit-like topography elements are taken as the features. The operation of the algorithm is based upon local recognition of the features and their connection to each other. The permissible class of surfaces includes ordered, partially ordered, or disordered surfaces if their features have comparable extents in the scan plane. The method allows one to exclude the negative influence of thermodrift, creep, and hysteresis over the performance of a scanning probe microscope. Owing to the possibility of carrying out an unlimited number of averages, the precision of measurements can be considerably increased. The distinctive feature of the method is its ability of topography reconstruction when the ultimate details are smaller than those detectable by a conventional microscope scan. The suggested approach eliminates the restrictions on scan size. Nonlinearity, nonorthogonality, cross coupling of manipulators as well as the Abbé offset error are corrected with the use of scan-space-distributed calibration coefficients which are determined automatically in the course of measuring a standard surface by the given method. The ways of precise probe positioning by local surface features within the fine manipulator field and the coarse manipulator field, automatic probe return into the operational zone after sample dismounting, automatic determination of exact relative position of the probes in multiprobe instruments, as well as automatic successive application of the whole set of probes to the same object on the surface are proposed. The possibility of performing accurately localized low-noise spectroscopy is demonstrated. The developed methodology is applicable for any scanning probe devices.

REVIEW OF SCIENTIFIC INSTRUMENTS, VOLUME 71, NUMBER 12, PAGES 4607-4610, DECEMBER 2000

Digital data readback for a probe storage device

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An experimentally proved method is described for data readback from an information track using separate atoms on a crystal surface as memory elements. The key idea consists of local scanning and recognition of memory elements on the carrier surface followed by attaching the device probe to them so as to keep the probe position over the track.

REVIEW OF SCIENTIFIC INSTRUMENTS, VOLUME 69, NUMBER 9, PAGES 3268-3276, SEPTEMBER 1998

Automatic lateral calibration of tunneling microscope scanners

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A practical method is described to find automatically the calibration coefficients and residual nonorthogonality of a tunneling microscope scanner. As initial data, the coordinates of three atoms were used forming a triangle in a highly oriented pyrolytic graphite surface appearing in the form of a spatially geometrical measure. A recognition procedure is described which can be applied to determine the lateral coordinates of the atoms. Length and orientation distortions were calculated, estimates of calibration errors were given and the requirement on the nonorthogonality limit was formulated for manipulator a given that ensures measurements of the predetermined accuracy. The sensitivity of the method to a noise in atom coordinates was determined. Experimental data showing the practical suitability of the method developed are presented.

REVIEW OF SCIENTIFIC INSTRUMENTS, VOLUME 66, NUMBER 9, PAGES 4718-4730, SEPTEMBER 1995

Analytical model for the approximation of hysteresis loop and its application to the scanning tunneling microscope

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A new model description and type classification carried out on its base of a wide variety of practical hysteresis loops are suggested. An analysis of the loop approximating function was carried out; the parameters and characteristics of the model were defined - coersitivity, remanent polarization, value of hysteresis, spontaneous polarization, induced piezocoefficients, value of saturation, hysteresis losses of energy per cycle. It was shown that with piezomanipulators of certain hysteresis loop types, there is no difference in heat production. The harmonic linearization coefficients were calculated, and the harmonically linearized transfer function of a nonlinear hysteresis element was deduced. The hysteresis loop type was defined that possesses minimum phase shift. The average relative approximation error of the model has been evaluated as 1.5%-6% for real hysteresis loops. A procedure for definition of the model parameters by experimental data is introduced. Examples of using the results in a scan unit of a scanning tunneling microscope for compensation of raster distortion are given.

REVIEW OF SCIENTIFIC INSTRUMENTS, VOLUME 64, NUMBER 10, PAGES 2883-2887, OCTOBER 1993

Fast-acting piezoactuator and digital feedback loop for scanning tunneling microscopes

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The design of a sectional piezoactuator is described, and the principle of operation of a tunnel junction digital stabilization system is given. The total settling time of the system while the least significant section is in operation is 1 μs at 0.01-nm resolution (in the Z direction). The application of the sectional piezoactuator permitted an increase in operating frequency and also eliminated errors caused by the piezoceramics hysteresis. Introduction of a fast-acting ALU as a digital accumulator of regulation errors made it possible to achieve high stability of the loop operation at high operating frequencies. The system suggested can adapt the speed of the loop operation depending on the relief steepness values. The blunting of the tip and sample destruction is avoided because there is a mechanism of smooth approach of the tip to the nominal scanning height.