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Surface chemical analysis — Scanning-probe microscopy — Measurement of drift rate

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee CII/60, Surface chemical analysis.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 11039 was prepared by Technical Committee ISO/TC 201, *Surface chemical analysis*, Subcommittee SC 9, *Scanning probe microscopy*.

Introduction

Scanning-probe microscopy (SPM) is a well-known microscopic technique for nanoscience and nanotechnology. Working at, or close to, atomic-scale resolution, it is recognized that the time stability of such instruments is very sensitive to their design, operating environment and usage. Among the many technical specifications of SPM, the drift rate is an essential parameter. A knowledge of, and minimization of, drift in the X-, Y- and Z-directions is required for designing many experiments. It is not only important for obtaining undistorted images and series of images throughout an experiment, but is also critical when, for example, measuring physical properties, monitoring dynamic behaviour, making micro/nanoassemblies, and manipulating materials at the nanoscale. Furthermore, a knowledge of the instrumental drift rate is also important when selecting an instrument for use. It is therefore desirable that manufacturers provide suitable information about the instrumental drift characteristics in a common way. Many manufacturers provide closed-loop scanners in their instruments. Unfortunately, drift is still present, although the magnitude of the drift rate is significantly reduced. Therefore, practical methods to measure and characterize drift rates of SPM instruments in the X-, Y- and Z-directions are required and are contained in this International Standard.

Two measures, the maximum and the average drift rates, are described for both the X-Y plane and the Z-axis. The maximum drift rate is given as the maximum observed, for reasons of economy, after a small number of fairly simple measurements. The maximum drift rate allows the user to design experiments that fall within the working zone available given the duration of the intended experiments; however, the maximum observed X-Y and Z-drift rates are based on a small number of observations and are less precise than the average drift rates determined. To deduce a working zone, a rule of thumb is to assume that the maximum is twice the value of the average. Clearly, in any population, the true maximum for a very large number of measurements would be very large, but here it is expected that the user only expects some 90 % of experiments not to require repetition as a result of the drift properties of the instrument. Depending on the importance of the measurements, users may, of course, set themselves any chosen margin of safety based on the data derived using this International Standard.

INTERNATIONAL STANDARD ISO 11039:2012(E)

Surface chemical analysis — Scanning-probe microscopy — Measurement of drift rate

1 Scope

This International Standard defines terms and specifies measurement methods for characterizing the drift rates of scanning-probe microscopy (SPM) instruments in the X- and Y-directions and, for SPM instruments measuring topography, the drift rate in the Z-direction. Though the behaviour of the long-term drift rate might be nonlinear, both that and the behaviour of the short-term drift rate after a user-defined settling time can be characterized by either typical average or typical maximum drift rates.

This International Standard is suitable for evaluating the drift rate based on SPM images. It is intended to help manufacturers quote drift figures in specifications in a meaningful and consistent manner and to aid users to characterize the drift behaviour so that effective experiments can be designed. These measurements are not designed for image correction.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 18115-2, *Surface chemical analysis — Vocabulary — Part 2: Terms used in scanning-probe microscopy*

3 Terms and definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 18115-2 and the following apply.

3.1.1
drift
change in position of the probe tip, for a given positional setting by the instrument controller, relative to the test specimen

NOTE Drift occurs in all parameters (e.g. X-, Y-, Z-displacements, laser positioning on the cantilever, intensity in SNOM sources) but in this International Standard the term drift is restricted to the unintended change in position of the probe tip for given scanner X-, Y- and Z-coordinates, relative to the test specimen.

3.1.2
drift rate
quotient of the linear displacement of the probe tip, for a given positional setting, relative to the test specimen over a given time interval by that time interval

NOTE 1 The time interval is usually chosen to be the time between successive images.

NOTE 2 The drift rate may be given for each of the X-, Y- and Z-axes separately or as the magnitude of the resulting vector.

3.1.3
average drift rate
average of appropriate **drift rates** measured during a specified period of time

NOTE 1 The average drift rate may be given for each of the X-, Y- and Z-axes separately or as the magnitude of the resulting vector.

NOTE 2 The average drift over a long period might be low if, by chance, the test specimen returns to its original position whilst the average drift rate, being measured non-vectorially between successive images, remains high.

NOTE 3 The average drift rate obtained here is intended for designing experiments so that the effects of the drift can be minimized or eliminated so that e.g. the important region of the test specimen remains in the field of view. Thus, the user may multiply the average drift rate by a factor of 2 and add some safety factor to ensure that a certain fraction of the field of view is maintained during the experiment.

3.1.4
maximum drift rate
maximum of the **drift rates** measured during a specified period of time

NOTE 1 The maximum drift rate may be given for each of the X-, Y- and Z-axes separately or as the magnitude of the resulting vector.

NOTE 2 As in any set of measurements, the true maximum drift rate measured might increase slowly with the number of measurements. The maximum value obtained here is intended for designing experiments so that the effects of the drift can be minimized or eliminated so that e.g. the important region of the test specimen remains in the field of view. Thus, the user may add some safety factor and a very accurate value of the maximum is not required.

3.1.5
settling time
time after selecting the area of the test specimen or point on the test specimen for measurement and the commencement of the measurements for which the drift data are relevant

NOTE Settling times are often chosen to be from 5 min to 60 min, for convenience.

3.2 Abbreviated terms

AFM atomic-force microscope

NPG non-periodic grating

SPM scanning-probe microscopy

4 Measurement method

To characterize the drift behaviour of an SPM instrument, it is important to recognize that drift occurs as a result of many processes, as shown in Annex E, and each of these processes causes an onset of drift that might slowly reduce with time. Thus, after switching on the final part of the instrument, a drift behaviour may be observed that, after a suitable waiting period, will generally be lower than that initially obtained. After inserting a new test specimen into the measurement position, a similar behaviour occurs. After moving the specimen to a new point using the specimen stage controls, a further drift will be initiated. Finally, after moving the SPM probe to a new region of the specimen using the piezoelectric scanner, a fourth drift behaviour is seen. Each of these behaviours might occur in a different direction and be of different magnitude. Indeed, each time this process is repeated, all these might change in magnitude and direction. Nevertheless, after deciding on a certain protocol for operating the instrument, typical average and maximum drift rate behaviours can be established. Important in this protocol is the settling time, i.e. the period during which the instrument is allowed to stabilize after selecting the area of the specimen or point on the specimen for measurement and the commencement of the measurements for which the drift data are relevant. The average and maximum drift rates permit the user to decide what influences the drift behaviour and hence what actions need to be taken to ensure that the drift performance is suitable for the user's requirements. This is described in Clause 6 and Annex E. Subclause 6.1 describes an initial check to see if there is a significant drift behaviour that might need further investigation. If the instrument is adequate, the investigation may cease. If further investigation is required, a

basic characterization is described in 6.2 to evaluate an appropriate settling time. For those interested in a fuller characterization, the effects of changing operating conditions are evaluated in 6.3.

For the drift rate measurement, the following three methods are specified in this International Standard:

— image correlation method (see Annex A);

— characteristic-marker method (see Annex B);

— non-periodic grating method (see Annex C).

To facilitate the selection of the drift rate measurement method, guidance is given in Annex D.

5 Requirements

5.1 Instrument requirements

5.1.1 The SPM instrument shall have the capability of measuring and recording digital images of the specimen surface, as a function of time, throughout the work.

5.1.2 The instrument shall maintain its dimensional calibration throughout the work.

5.2 Environment requirements

5.2.1 The instrument should, if possible, be operated under the required, or better, environment conditions specified in the manufacturer's documented instructions.

5.2.2 It is recommended that the measurement be performed in controlled conditions with the temperature stable within ±1 °C and the relative humidity preferably less than 50 %. The laboratory environment should be clean, with levels of electromagnetic interference, ambient vibration and ambient noise which are sufficiently low that they do not influence the characterization of the instrument. The measured data will relate to the instrument used in whatever operating conditions are selected and might or might not be relevant to any other operating conditions. Suggested ways to improve the operating conditions, likely to lead to improved drift characteristics, are provided in Annex E.

6 Measurement procedures

6.1 Initial check

6.1.1 Select the probe in accordance with the manufacturer's documented instructions.

6.1.2 Operate the instrument in the manner and operating mode for which drift data are required. For low-drift performance, keep as much of the instrument operational continuously and switch on remaining items more than 1 h before conducting measurements.

NOTE Different operating modes might lead to different amounts of drift if different amounts of power are supplied to different parts of the instrument.

6.1.3 Prepare the test specimen together with any reference material required for the measurement method. When using the image correlation method of Annex A, it is preferable to have obvious features within the field of view. For the characteristic-marker method of Annex B, there will need to be at least two sharp features at a distance of approximately a quarter of the image size in from two opposite corners of the field of view. For the non-periodic grating method of Annex C, obtain a suitable grating. Ensure, as far as possible, that these items are clean in order to avoid probe tip contamination. Particulate matter might move during analysis, causing

erroneous drift determination. Particulates can be removed by washing in, for example, high-purity iso-propyl alcohol with ultrasonic agitation. Ensure that any solvents used do not adversely affect the specimen.

6.1.4 Mount the specimen in accordance with the instrument operator's manual or in-house documented procedures.

NOTE Poor specimen-mounting methods might increase the drift behaviour.

6.1.5 Optimize the image acquisition parameters in accordance with the instrument operator's manual or in-house documented procedures.

NOTE High tip loads will cause tip wear and this might lead to imprecision in the drift measurements.

6.1.6 Set the scan field of view to a suitable value to define the drift behaviour. If uncertain about the behaviour, 5 µm is a suitable value for initial studies. Select a region of the specimen with at least two sharp features at a distance roughly a quarter of the image size in from two opposite corners if using the characteristic-marker method of Annex B or obvious features across the field of view if using the image correlation method of Annex A. Scan the specimen with the frame time used for the studies for which this characterization is required (e.g. 5 min to 10 min).

6.1.7 Record two successive images. Determine the X-, Y- and Z-drift rates in accordance with the selected method listed in Annex A to Annex C, using images that all have the same X- and Y-scan directions.

NOTE Some instruments scan with the slow scan firstly in one direction and secondly in the reverse direction. There might be a shift between these images. By restricting the analysis to one direction, issues associated with this shift are removed.

6.1.8 If the measured drift rates are significantly smaller than the minimum drift rates required to conduct the required experiments, the instrumental operating conditions are satisfactory and no further drift characterization will be required. The initial check may be considered complete and the evaluation terminated. If the measured drift rates are not significantly smaller than the minimum drift rates required to conduct experiments, or if further characterization is required, proceed to 6.2. If the measured drifts exceed 20 % of the scan size in the X-, Y- or Z-directions, increase the relevant scan size to satisfy that condition and repeat 6.1.7.

6.2 Basic characterization and the settling time

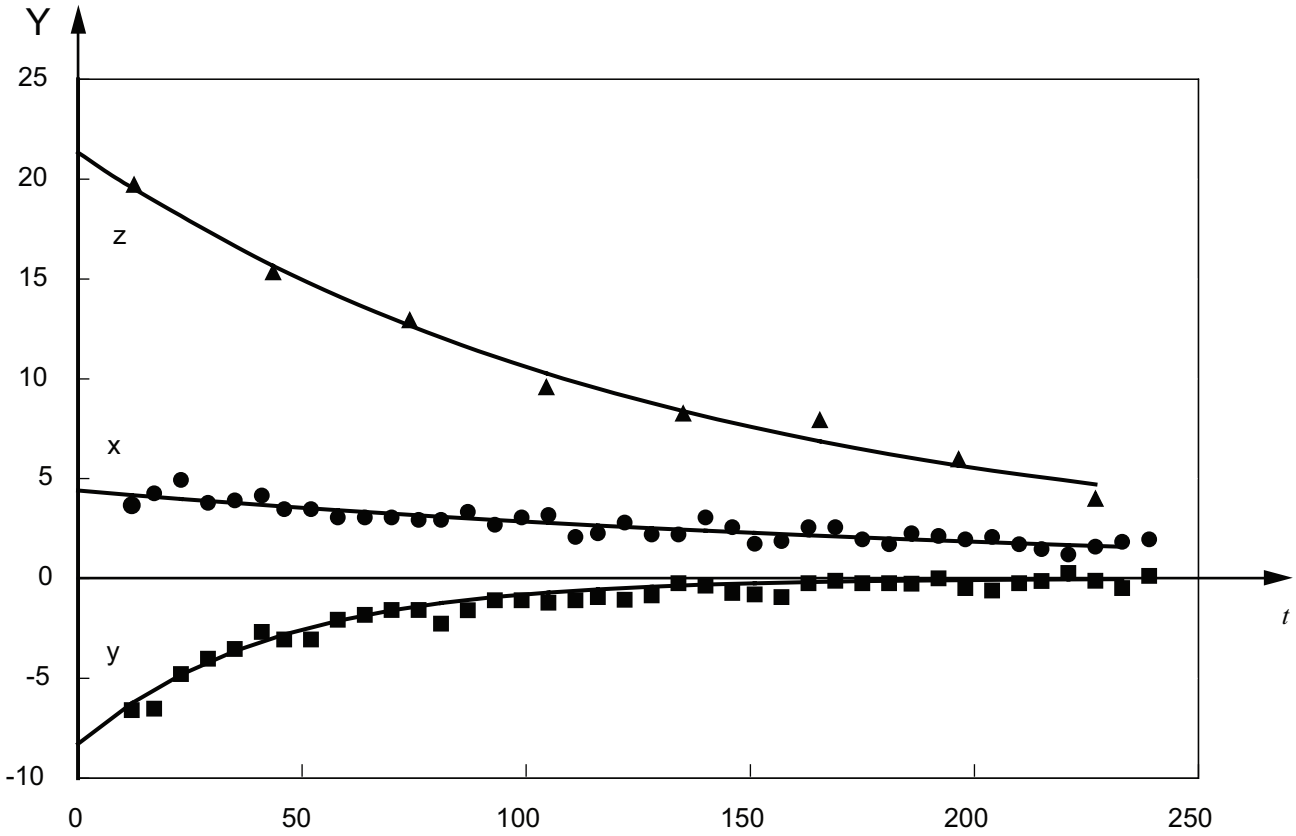
6.2.1 Continue from 6.1.8 and record a series of successive images for 2 h. For measuring the drift rate performance, the time at which the specimen position has been set and the image area has been selected is taken as the origin of time. For each change in specimen position or imaged area, a new time origin is established.

6.2.2 Determine the X-, Y- and Z-drift rates as in 6.1.7.

6.2.3 Observe the variation of the drift rate with time and decide a practical time after setting the specimen in position and addressing the selected point on the specimen for which the drift rate is adequate for the work intended. This is the settling time. If the drift rate after 2 h is too high for the intended use of the instrument, continue for a longer period or consider operational improvements to the instrument or use the equipment as suggested in Annex E, and repeat 6.1.1 to 6.2.2.

NOTE 1 An example of such measurements is shown in Figure 1. In that example, if 9 nm/min is an acceptable drift rate in the X-Y plane, further data could be recorded with no delay after identifying a new point on the specimen for study. If 4 nm/min is acceptable, a settling time of 1 h is required after starting with a new specimen.

NOTE 2 Occasionally, it might be found that the drift rate increases with time as the several independent contributions can partially cancel near the start of the measurements. Extending the settling time is then unhelpful and operational improvements will have to be checked.



Key

t time, in minutes

Y drift rate, in nm/min

Figure 1 — Measured drift rates in the X-, Y- and Z-directions as a function of time at a new point in an instrument in which everything except the laser is on continuously and the laser has been switched on for 16 h[1]

6.3 Further characterization and fresh image areas

6.3.1 Next, establish a grid of four points near the extremities of the X-Y scan range of the piezoelectric scanner to which the probe tip will be addressed, as well as the central point, as shown in Figure 2. These five points define the centres of five image areas with fields of view sufficiently large to cover any drift likely to occur.

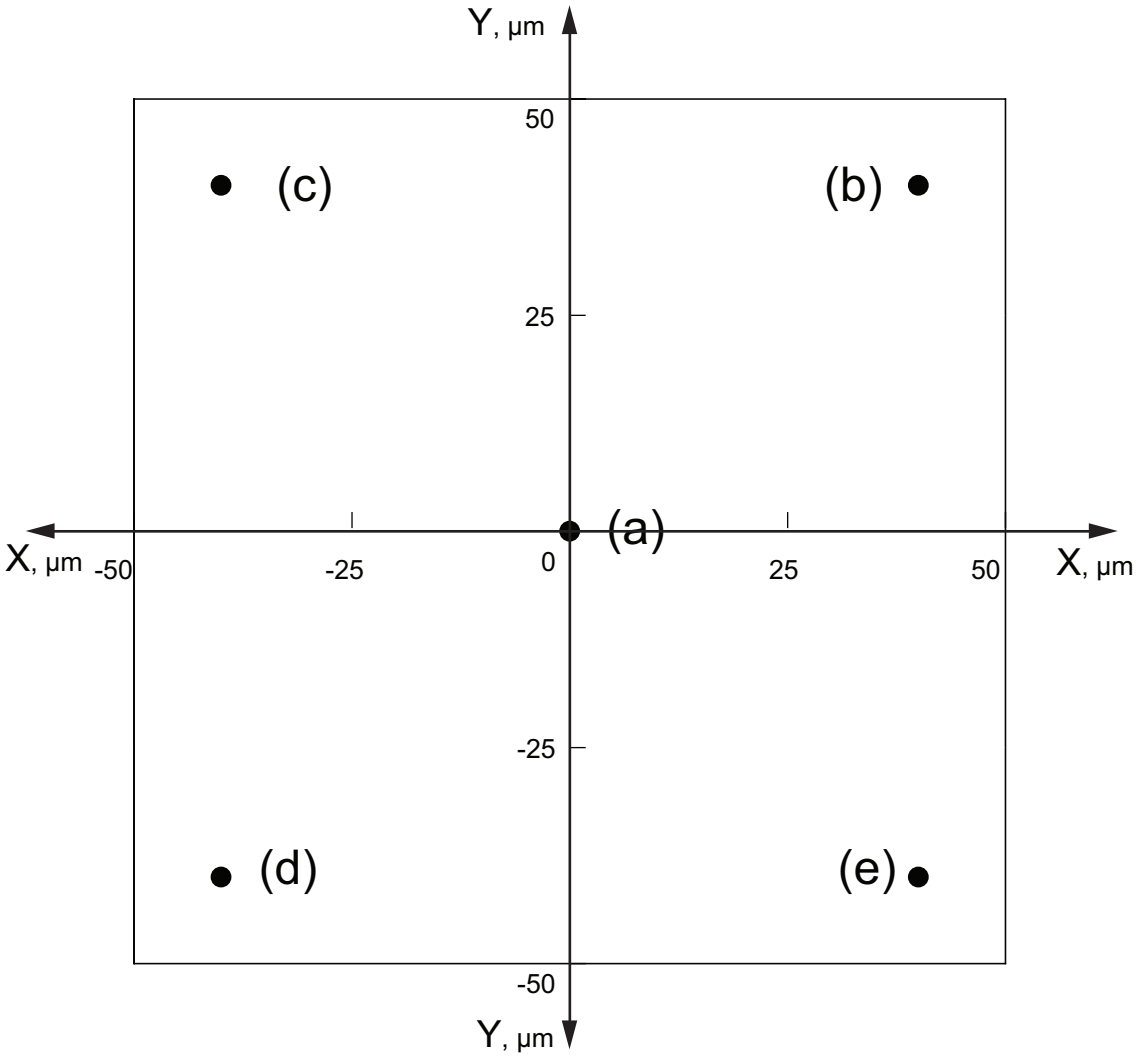


Figure 2 — The grid of four points described in 6.3.1

6.3.2 Measure the drift rate after the settling time defined at 6.2.3 at each point (a) to (e) and then (a) again, in succession. Note that, for the settling time, the origin of time is taken as the time at which imaging starts at each of the five points.

6.3.3 Determine the X-, Y- and Z-drift rates in accordance with the selected method listed in Annex A to Annex C. The maximum drift rate in the X-Y plane is the maximum of the drift rates determined from the square root of the quadrature sum of the individual X- and Y-direction drift rates for each of the six measurement points. The value of the maximum drift rate in the Z-direction is determined without regard to the up and down directions, although the direction shall be noted.

NOTE A worked example is given in Annex F, illustrating computation of both the average and the maximum drift rates.

6.3.4 If these drift rates are too high for the intended use of the instrument, consider operational improvements to the instrument or use the equipment as suggested in Annex E, and repeat 6.3.1 to 6.3.3.

6.3.5 The drift rates might depend on actions taken before the settling time in a way that cannot be predicted. It is therefore useful to repeat 6.3.1 to 6.3.3 on another day following the first satisfactory use of the procedure described here. If desired, repeat 6.3.1 to 6.3.3, noting the difference in any actions prior to the settling time.

6.3.6 If the results of 6.3.5 are significantly different from those of 6.3.3, and if it is important to characterize the drift more closely, repeat 6.3.1 to 6.3.3 a third time.

6.4 Other specimens

If a range of significantly different types of specimen or specimen mount are to be studied, consider repeating 6.1 and, if necessary, 6.2 and 6.3 with these specimens since the specimen and its mounting can provide a significant contribution to drift.

7 Measurement report

The measurement report should include the following information:

a) a reference to this International Standard (ISO 11039);

b) available details of the probe and the SPM instrument;

c) the method used to determine the drift rates;

d) the measurement parameters, including the following:

   1) the operating mode,

   2) any reference signal and its magnitude,

   3) the scan rates, noting the fast-scan direction,

   4) the image size,

   5) the number of pixels scanned;

e) the settling time;

f) details of the specimen and the method of mounting it;

g) the test environment (temperature, humidity) to the extent that it is known;

h) the average and/or maximum drift rates obtained.

NOTE The average and maximum drift rates are illustrated in the worked example in Annex F.

Annex A
(normative)

Image correlation method

A.1 General

The drift rates in the X-, Y- and Z-directions are determined by cross-correlation analysis of sequentially scanned SPM images. The basic assumption is that, during the serial scan of images, the size of the scanned area and the scanning resolution remain the same.

NOTE This method is described in Reference [2].

A.2 Principle

If the reference image is denoted by $f(x,y)$ and the image for comparison is indicated as $g(x,y)$, the cross-correlation function for the two images is then calculated as

$$C(u,v) = \frac{\sum_x \sum_y [f(x,y) - f_{\mathrm{m}}][g(x+u, y+v) - g_{\mathrm{m}}]}{\sqrt{\sum_x \sum_y [f(x,y) - f_{\mathrm{m}}]^2} \sqrt{\sum_x \sum_y [g(x+u, y+v) - g_{\mathrm{m}}]^2}} \quad \text{(A.1)}$$

Here, f_{m} and g_{m} are the mean image values (e.g. surface heights in atomic-force microscopy) of the digital images f and g, respectively. The maximum of the two-dimensional correlation matrix represents the best alignment of the two images. The deviation of this maximum from the centre of the matrix is the X- and Y-direction drift distances (in pixels) between the two images.

The drift rate in the Z-direction is determined by analysing the average value of the height deviations of the aligned images. The alignment can be obtained using Equation (A.1), assuming the X- and Y-direction drifts are linear translations of the image.

A.3 Procedure

The measurement procedure is as follows:

a) Raw-data acquisition

   1) Conduct the measurement in accordance with Clause 6.

   2) Record the required images and their time after the start of the settling time as defined at 6.2.1 (see Figure A.1).

b) Calculation of the X- and Y-drift rates

   1) Calculate the drift distance, in pixels, between successive images in both the X- and Y-directions using Equation (A.1).

   2) Convert the drift distances from pixels to nanometres.

   3) Determine the drift distances between successive images as a function of time. Note that each whole image is allocated a time and that time is taken as the average of the time at the start and finish of the image from the origin of time defined in 6.2.1.

4) Calculate and plot the drift rates in the X- and Y-directions (see Figure 1).

c) Calculation of the Z-drift rate

1) Align the series of images in the X- and Y-directions (see Figure A.2).

2) Calculate the height change for each sampling point between successive images after alignment (the common area in the images shown in Figure A.2).

3) Obtain the average height change for each image.

4) Determine the height change between successive images as a function of time.

5) Calculate and plot the drift rate in the Z-direction (see Figure 1).

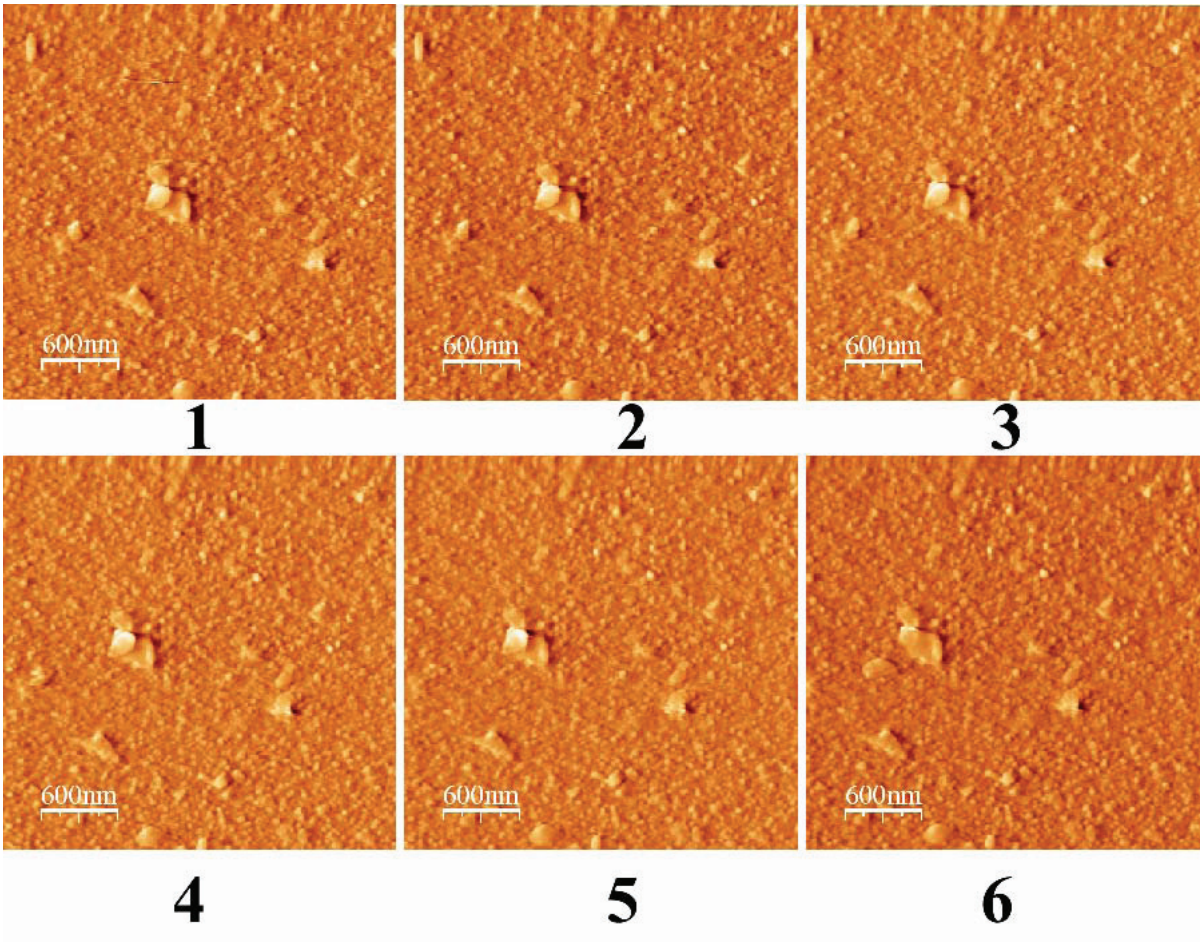
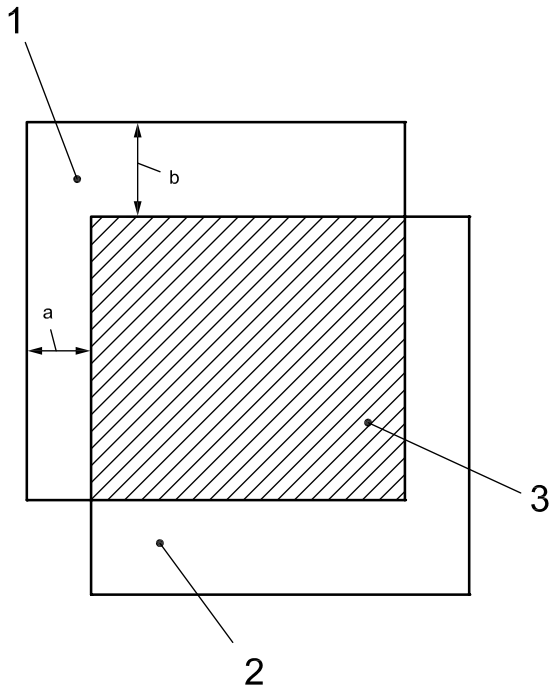


Figure A.1 — Series of topography images successively scanned
(3 mm × 3 mm, 512 pixels × 512 pixels)



Key

1 first image
2 drifted image
3 common area

a X-drift.
b Y-drift.

Figure A.2 — Schematic illustration of the Z-drift rate calculation
(The mean height deviations of the image points in the common area are used to calculate the Z-drift rate)

A.4 Example

Example of drift measurement using the image correlation method:

SPM instrument: Nanotec AFM.

Specimen: thin Pt film on Si.

Operating mode: contact mode.

Environment: clean room, temperature: 22 °C, humidity: 45 %.

Scan rate: 1,220 Hz.

Fast-scan direction: X.

Scan size: 3 µm × 3 µm, 512 pixels × 512 pixels.

Measured drift rates: X-direction: −0,02 nm/s, Y-direction: −0,11 nm/s and Z-direction: −0,09 nm/s.

Annex B
(normative)

Characteristic-marker method

B.1 General

In this method, the drift rates in the X-, Y- and Z-directions are determined from the change in position of at least two characteristic markers in sequentially scanned SPM images. The basic assumption is that, during the serial scan of images, the size of the scanned area and the scanning resolution remain the same.

NOTE This method is described in Reference [1].

B.2 Procedure

The measurement procedure is as follows:

a) Raw-data acquisition

   1) Conduct the measurement in accordance with Clause 6.

   2) Identify the characteristic features (at least two) on the specimen images. Select a region of the specimen with at least two sharp features at a distance roughly a quarter of the image size inwards from two opposite corners, as described in 6.1.6.

   3) Record the required images and their time after the start of the settling time as defined in 6.2.1 (see Figure B.1).

b) Calculation of the X- and Y-drift rates

   1) Calculate the average drift distance between successive images in both the X- and Y-directions, using all the chosen characteristic markers, in nanometres, or in pixels which are then converted to nanometres.

   2) Determine the average drift distances between successive images as a function of time. Note that each feature has an associated unique time from the origin of time, as defined in 6.1.6, depending on its position in the raster frame.

   3) Calculate and plot the drift rates in the X- and Y-directions (see Figure 1).

c) Calculation of the Z-drift rate

   1) Calculate the average height change of all the characteristic markers between successive images.

   2) Determine the height change of each marker as a function of time. Note that each feature has its own unique time depending on its position in the raster frame and so the most accurate value of time is the average time for all the markers used. For determining the drift rates in this International Standard, this time may be taken as the average time for the image as a whole.

   3) Calculate and plot the drift rate in the Z-direction (see Figure 1).

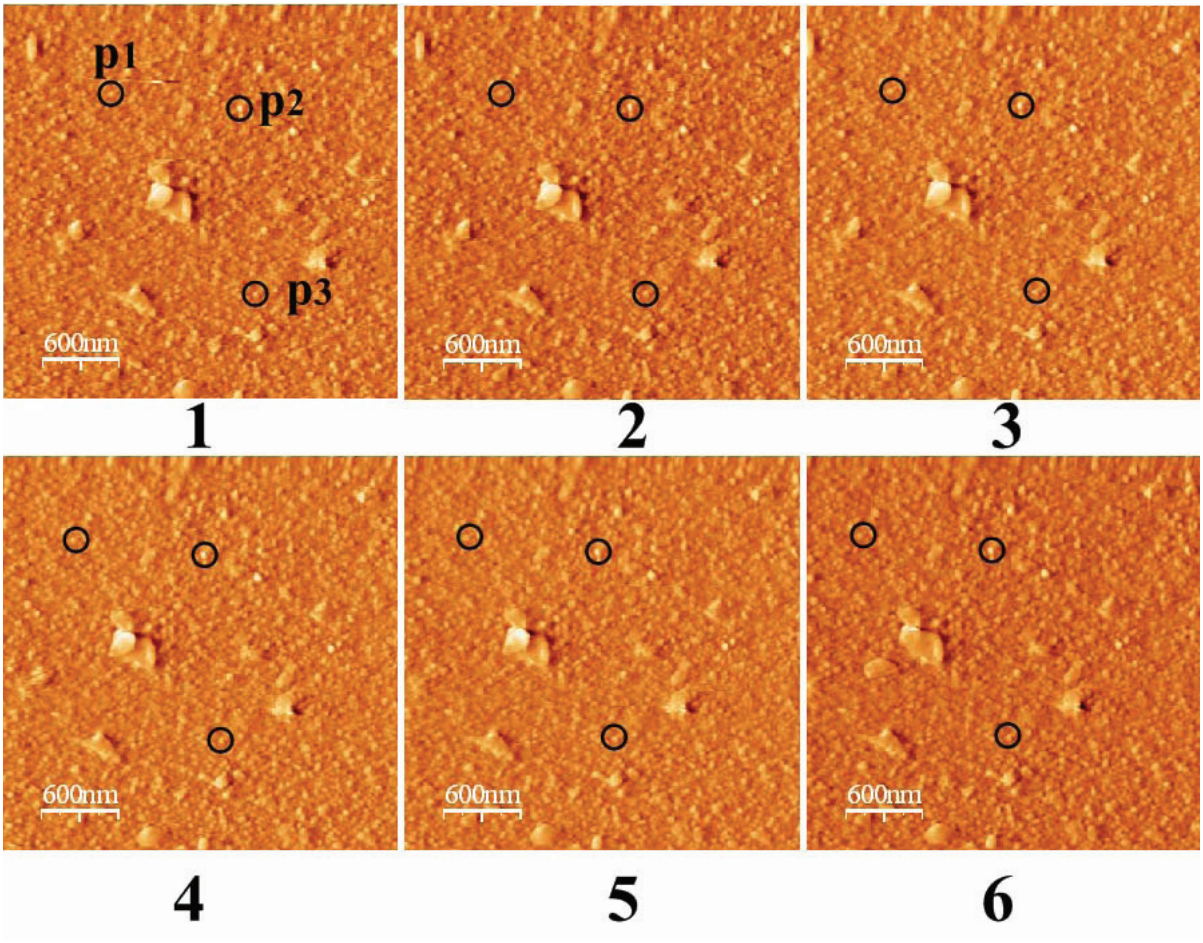


Figure B.1 — Series of topography images successively scanned
(3 mm × 3 mm, 512 pixels × 512 pixels)
(Three characteristic markers have been selected as shown by the circles)

B.3 Example

Example of drift measurement using the characteristic-marker method:

SPM instrument: Nanotec AFM.

Specimen: thin Pt film on Si.

Operating mode: contact mode.

Environment: clean room, temperature: 22 °C, humidity: 45 %.

Scan rate: 1,220 Hz.

Fast-scan direction: X.

Scan size: 3 µm × 3 µm, 512 pixels × 512 pixels.

Measured drift rates: X-direction: −0,02 nm/s, Y-direction: −0,11 nm/s and Z-direction: −0,09 nm/s.

Annex C
(normative)

Non-periodic grating method

C.1 General

This method takes a two-dimensional (2D) non-periodic grating (NPG) as the reference material. It provides large measuring range and high-contrast imaging, and is less affected by tip-induced artefacts. The basic assumption is that, during the serial scan of images, the size of the scanned area and the scanning resolution remain the same.

NOTE The principle of the application of the NPG to drift measurement is described in Reference [3].

C.2 Principle

The structure of the 2D NPG can be represented by a binary matrix of the form

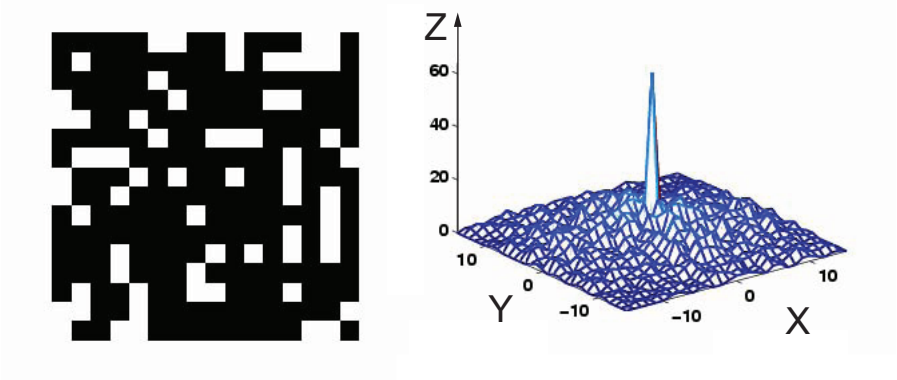
$$\left[x_{ij}\right] = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nn} \end{bmatrix}_{n\times n} \tag{C.1}$$

Here, n^2 is the total number of grating elements. When the two NPGs have a relative displacement of k units in the X-direction and l units in the Y-direction, the output of the correlation function (without normalization) of the two NPGs is expressed by $S_{kl} = \sum_i \sum_j x_{ij} x_{i+k,j+l}$. If the step element is denoted as “1”, the low element is “0” and the total number of grating elements with “1” is τ, the maximum value of the autocorrelation function can be expressed by

$$S_{\max} = \sum_{i=1}^{n} \sum_{j=1}^{n} x_{ij} = \tau \tag{C.2}$$

The contrast of the maximum peak of the autocorrelation matrix can be defined by the ratio of the maximum value to the second maximum. Letting D denote the contrast ratio, then $D = S_{\max} / S$. Here, S is the second maximum value of the correlation function, and it is described by $\max_{k^2+l^2\neq 0} [S_{kl}]$. The code of NPG is optimized to have the maximum D value. Figure C.1 shows schematically the NPG structure and the corresponding autocorrelation function.

The unique, high-contrast peak in the correlation function when taking NPG as reference material enables the stable and accurate determination of drift distance and drift direction via image correlation analysis.



Key

X in units representing the width of one square element in the illustration at left

Y in units representing the width of one square element in the illustration at left

Z correlation intensity, in arbitrary units

Figure C.1 — Schematic illustration of the structure of a 16 × 16 coded NPG and the corresponding autocorrelation function (the white elements denote the NPG elements with a defined step height)

C.3 Procedure

The measurement procedure is as follows:

a) Raw-data acquisition

1) Conduct the measurement in accordance with Clause 6, using the NPG as the specimen.

2) Record the required images and their time after the start of the settling time as defined at 6.2.1. Examples of images are shown in Figure C.2.

b) Calculation of the X- and Y-drift rates

1) Calculate the drift distance, in nanometres, or in pixels which are then converted to nanometres, in both the X- and the Y-directions using Equation (A.1).

2) Determine the drift distances as a function of time. Note that each feature has an associated unique time from the origin of time, as defined in 6.1.6, depending on its position in the raster frame.

3) Calculate and plot the drift rates in the X- and Y-directions (see Figure 1).

c) Calculation of the Z-drift rate

1) Align the series of images in the X- and Y-directions to determine the common areas (see Figure A.2).

2) Calculate the height change of each sampling point in the successive images after alignment.

3) Obtain the average height of each image.

4) Determine the height change of each image as a function of time.

5) Calculate and plot the drift rate in the Z-direction (see Figure 1).

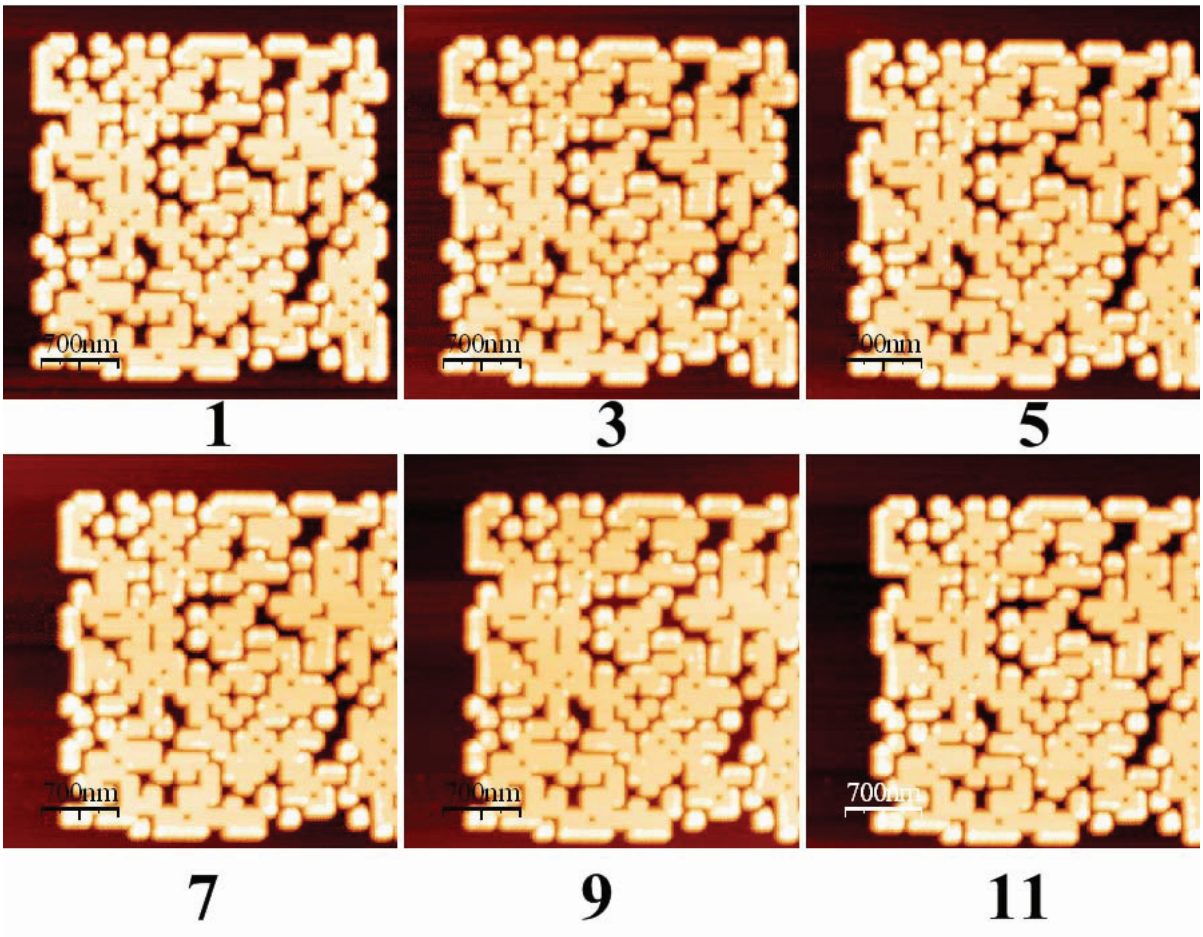


Figure C.2 — Series of non-periodic grating images successively scanned
(3,5 mm × 3,5 mm, 512 pixels × 512 pixels)

C.4 Example

Example of drift measurement using the non-periodic grating method:

SPM instrument: DI Multimode AFM.

Specimen: non-periodic grating.

Operating mode: tapping mode.

Environment: clean room, temperature: 22 °C, humidity: 45 %.

Scan rate: 1,970 Hz.

Fast-scan direction: X.

Scan size: 3,5 μm × 3,5 μm, 512 pixels × 512 pixels.

Measured drift rates: X-direction: 0,03 nm/s, Y-direction: 0,09 nm/s and Z-direction: 0,002 nm/s.

Annex D
(informative)

Guidance to users

To facilitate the selection of the drift rate measurement method, Table D.1 lists general advantages and disadvantages although, for particular instruments and requirements, other factors might also be important.

Table D.1 — Advantages and disadvantages of the drift rate measurement methods

Method	Annex	Advantages	Disadvantages
Image correlation method — as part of instrument	A	— Fully automatic. — Fast. — Requires no extra software or data translation. — Requires no validation of algorithms (if manufacturer has done this). — Works on most specimens.	— Might need a separate, manual Z-drift evaluation.
Image correlation method — separate software[a]	A	— Fully automatic. — Fast. — Works on most specimens.	— Might require validation of algorithms. — Might be difficult to output data in a useful format for insertion into the separate software.
Characteristic-marker method	B	— Requires no software or data translation. — Requires no validation of algorithms. — Works on most specimens. — Allows drift of the image magnification and any rotation of the image to be determined. — Can be used to partially validate the computer-based methods.	— Slow and labour-intensive.
Non-periodic grating method[b]	C	— Can evaluate drifts beyond the frame of the image in both the X- and Y-directions. — High stability.	— Requires separate specimen and requires measurement on that specimen and not on the working specimen. — Might involve additional settling time.

[a] Third-party software accepting many SPM output files is available from Image Metrology A/S, Lyngsø Alle 3A, DK-2970 Hørsholm, Denmark (http://www.imagemet.com) or from Nanotec Electronica S.L., Centro Empresarial Euronova 3, Ronda de Poniente 12, ES-28760 Tres Cantos, Madrid, Spain (http://www.nanotec.es). This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of these products.

[b] A non-periodic grating is available from GermanTech Co. Ltd., Room 706, Building 7, Hua Qing Jia Yuan, Wu Dao Kou, Haidian District, 100083 Beijing, China (http://www.germantech.com.cn). This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of this product.

Annex E
(informative)

Instrumental parameters to consider to reduce drift rates

E.1 General

Many factors influence the drift rate of instruments. These may involve the environment, the instrument operating conditions and the specimen. To reduce drift rates, what one should consider depends on the number of experiments expected to require low drift rates, the extent to which the experiment itself may be modified and many other factors that might be easier in some laboratories than in others.

E.2 Environment

Temperature effects are generally the most important factor. Use a temperature-controlled laboratory if possible, with an airflow that does not cause low-frequency airborne vibrations. Many users place their equipment in thermally and acoustically baffled enclosures that are, in turn, mounted on anti-vibration tables. If these enclosures are thermostatically controlled, the need for a temperature-controlled laboratory may be relaxed. In this case, it is important to wait for the temperature of the enclosure to stabilize after starting it up or opening it. Avoid exposing the equipment to direct sunlight.

E.3 Operating conditions

Load specimens as early as possible and address the area of the specimen to be measured as early as possible. Ensure an adequate settling time for equipment parts and the specimen to come to temperature equilibrium.

E.4 Specimens and specimen mounts

Ensure that specimens are firmly mounted on the correct instrument specimen mounts. If adhesives are used, ensure that they have time to cure fully and are properly at room temperature. Avoid handling the specimens, as this leads to local warming. Ensure, as far as possible, that the specimen environment is dust-free, since trapped dust particles can lead to specimen creep. If double-sided adhesive tape is used to attach specimens, and if the drift is unacceptable, try a different mounting method. As a general rule, mounting involving stiff materials with a low coefficient of thermal expansion is best.

Annex F
(informative)

Example of drift results and analysis

Data analysed in accordance with this International Standard for an AtomScale III AFM with the large working-space stage, operated in the intermittent contact mode with closed-loop control, a scanned field of view of 1,5 µm × 1,5 µm, using 512 pixels × 512 pixels, with the fast scan in the X-direction at a scan rate of 0,853 Hz and a frame time of 5 min. The Z-scanner range was 15 µm. The data are for a Si wafer analysed using the characteristic-marker method. The instrument was maintained in a ThermoFog thermal and acoustic enclosure at (21 ± 1) °C on a DynaSand IVb active isolation table.

Table F.1 — Example of drift rate data obtained using a 30 min waiting time at each point

Position	X-drift rate	Y-drift rate	Z-drift rate	Calculated drift rate in X-Y plane
	nm/min	nm/min	nm/min	nm/min
(a)	0,49	−18,80	30,13	18,81
(b)	0,30	−12,88	20,14	12,89
(c)	−0,86	−9,85	13,89	9,89
(d)	−0,54	−7,41	8,16	7,43
(e)	0,06	−5,99	9,78	5,99
(a)	−0,25	−4,27	5,41	4,27
Average drift rate	−0,13	−9,87	14,58	9,88
Maximum drift rate (ignoring sign)	0,86	18,80	30,13	18,81

The data in the fifth column are calculated from the square root of the sums of the squares of the data in columns two and three for positions (a) to (e) and (a) again. From Table F.1, the following can be stated:

average drift rate in the X-Y plane, using a 30 min waiting time, = 10 nm/min;

maximum drift rate in the X-Y plane, using a 30 min waiting time, = 19 nm/min;

average drift rate in the Z-direction, using a 30 min waiting time, = 15 nm/min;

maximum drift rate in the Z-direction, using a 30 min waiting time, = 30 nm/min.

Bibliography

[1] CLIFFORD, C.A., SEAH, M.P., Simplified drift characterization in scanning probe microscopes using a simple two-point method, *Meas.Sci.Technol.*, 2009, Vol. 20, Article No. 095103

[2] HUANG, W.-H., WANG, W.-W., XIA, A.-D., JIN, N., HU, Z.-Q., Time-stability measurement and compensation of a scanning probe microscope instrument, *J. Vac. Sci. Technol. B*, July/Aug 2000, Vol. 18, No. 4, pp. 2027-2029

[3] CHEN, Y.-H., HUANG, W.-H., Application of a novel nonperiodic grating in scanning probe microscopy drift measurement, *Rev. Sci. Instrum.*, 2007, Vol. 78, Article No. 073701

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