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Surface chemical analysis — Vocabulary —

Part 2:
Terms used in scanning-probe microscopy

Analyse chimique des surfaces — Vocabulaire —

Partie 2: Termes utilisés en microscopie à sonde à balayage

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 201, *Surface chemical analysis*, Subcommittee SC 1, *Terminology*.

This second edition cancels and replaces the first edition (ISO 18115-2:2010), which has been technically revised.

ISO 18115 consists of the following parts, under the general title *Surface chemical analysis — Vocabulary*:

- *Part 1: General terms and terms used in spectroscopy*
- *Part 2: Terms used in scanning-probe microscopy*

Introduction

Surface chemical analysis is an important area which involves interactions between people with different backgrounds and from different fields. Those conducting surface chemical analysis might be materials scientists, chemists, or physicists and might have a background that is primarily experimental or primarily theoretical. Those making use of the surface chemical data extend beyond this group into other disciplines.

With the present techniques of surface chemical analysis, compositional information is obtained for regions close to a surface (generally within 20 nm) and composition-versus-depth information is obtained with surface analytical techniques as surface layers are removed. The terms covered in this part of ISO 18115 relate to scanning-probe microscopy. The surface analytical terms covered in ISO 18115-1 extend from the techniques of electron spectroscopy and mass spectrometry to optical spectrometry and X-ray analysis. Concepts for these techniques derive from disciplines as widely ranging as nuclear physics and radiation science to physical chemistry and optics.

The wide range of disciplines and the individualities of national usages have led to different meanings being attributed to particular terms and, again, different terms being used to describe the same concept. To avoid the consequent misunderstandings and to facilitate the exchange of information, it is essential to clarify the concepts, to establish the correct terms for use, and to establish their definitions.

The terms and definitions in this International Standard have been prepared in conformance with the principles and style defined in ISO 1087-1:2000 and ISO 10241:1992. Essential aspects of these standards appear in 2.1 to 2.3. This part of ISO 18115 comprises the 98 abbreviations and 277 definitions of the combined ISO 18115-2:2010 and Amendment 1 to ISO 18115-2:2010. Corrections have been made to terms 3.23, 3.25, 3.36, 5.52, 5.53, 5.54, 5.55, 5.73, 5.83, and 5.151 that appeared in ISO 18115-2:2010. The terms are given in alphabetical order, classified under Clauses 3, 4, and 5 from the former International Standard with corrections and Clauses 6 and 7 from Amendment 1:

Clause 3: Definitions of the scanning-probe microscopy methods;

Clause 4: Acronyms and terms for contact mechanics models;

Clause 5: Definitions of terms for scanning-probe methods;

Clause 6: Definitions of supplementary scanning-probe microscopy methods;

Clause 7: Definitions of supplementary terms for scanning-probe methods.

Many terms concerned with profilometry, or more correctly, surface texture measuring instruments, may be found in ISO 3274 and ISO 4287. ISO 3274 specifies the properties of the instrument that influence profile evaluation and provides basic considerations of the specification of contact (stylus) instruments (profile meter and profile recorder) whereas ISO 4287 concerns some issues involving surface texture.

Those interested in a more detailed understanding of profilometry or surface texture measuring instruments should consult ISO 3274, ISO 4287, ISO 25178, and other referenced documents.

INTERNATIONAL STANDARD ISO 18115-2:2013(E)

Surface chemical analysis — Vocabulary —

Part 2:
Terms used in scanning-probe microscopy

0 Scope

This International Standard defines terms for surface chemical analysis. ISO 18115-1 covers general terms and those used in spectroscopy while this part of ISO 18115 covers terms used in scanning-probe microscopy.

1 Abbreviated terms

In the list below, note that the final “M”, given as “microscopy”, may be taken equally as “microscope”, depending on the context. References to the entries where the abbreviations, or keywords in the abbreviations, are defined are given in brackets.

3D-PFM	vector PFM (see 6.21)
AFM	atomic-force microscopy (see 3.2)
AM-AFM	amplitude modulation atomic-force microscopy (see 6.1)
AM-KPFM	amplitude modulation Kelvin-force microscopy (see 6.2)
ANSOM	apertureless near-field scanning optical microscopy (deprecated) (see 3.36)
ASNOM	apertureless scanning near-field optical microscopy (deprecated) (see 3.36)
BEEM	ballistic-electron emission microscopy (see. 5.8)
BEES	ballistic-electron emission spectroscopy (see 5.8)
CFM	chemical-force microscopy (see 3.3)
CITS	current-imaging tunnelling spectroscopy (see 3.5)
CPAFM	conductive-probe atomic-force microscopy (see 3.4)
CRAFM	contact resonance atomic-force microscopy (see 6.4)
CRFM	contact resonance force microscopy (see 6.4)
DFM	dynamic-force microscopy (see 3.6)
DMM	displacement modulation microscopy
DTM	differential-tunnelling microscopy
EC-AFM	electrochemical atomic-force microscopy (see 3.8)
ECFM	electrochemical-force microscopy
EC-SPM	electrochemical scanning-probe microscopy
EC-STM	electrochemical scanning tunnelling microscopy (see 3.9)

EFM	electrostatic-force microscopy (see 3.7)
FFM	frictional-force microscopy (see 3.11)
FM-AFM	frequency modulation atomic-force microscopy (see 3.10)
FM-KPFM	frequency modulation Kelvin-force microscopy (see 6.6)
FMM	force modulation microscopy (see 5.60)
FRET	fluorescent resonance energy transfer (see 5.54)
FS	force spectroscopy (see 5.58)
HFM	heterodyne force microscopy
HPICM	hopping probe ion conductance microscopy (see 6.7)
IC	intermittent contact (see 5.73)
IETS	inelastic electron tunnelling spectroscopy
IFM	interfacial-force microscopy
KFM	Kelvin-force microscopy (deprecated) (see 3.12)
KPM	Kelvin-probe microscopy (see 5.76)
KPFM	Kelvin-probe force microscopy (see 3.12)
LFM	lateral-force microscopy (see 3.13)
LFMM	lateral-force modulation microscopy (see 5.77)
MDFM	magnetic dynamic-force microscopy (see 3.14)
MDM	microwave dielectric microscopy
MFM	magnetic-force microscopy (see 3.15)
MOKE	magneto-optic Kerr effect
MRFM	magnetic-resonance force microscopy (see 3.16)
MTA	microthermal analysis
NC-AFM	non-contact atomic-force microscopy (see 3.18)
NIS	nanoimpedance spectroscopy
NSOM	near-field scanning optical microscopy (see 3.17)
PF-AFM	pulsed-force atomic-force microscopy (see 5.125)
PFM	piezoresponse force microscopy (see 5.100)
PSTM	photon scanning tunnelling microscopy
PTMS	photothermal micro-spectroscopy (see 3.19)
RNSOM	reflection near-field scanning optical microscopy (see 5.133)
RSNOM	reflection scanning near-field optical microscopy (see 5.133)

SCFM	scanning capacitance force microscopy (see 6.13)
SCM	scanning capacitance microscopy (see 3.20)
SCPM	scanning chemical-potential microscopy (see 3.21)
SECM	scanning electrochemical microscopy (see 3.22)
SECM-SICM	scanning electrochemical microscopy - scanning ion conductance microscopy (see 6.14)
SERRS	surface-enhanced resonant Raman spectroscopy (see 5.154)
SERS	surface-enhanced Raman scattering (see 5.151)
SFM	scanning force microscopy (deprecated) (see 3.2)
SGM	scanning gate microscopy
ShFM	shear-force microscopy (see 3.37)
SHG	second harmonic generation
SHPFM	second harmonic piezo force microscopy
SHPM	scanning Hall probe microscopy (see 3.23)
SICM	scanning ion conductance microscopy (see 3.24)
SIM	scanning impedance microscopy
SKPM	scanning Kelvin-probe microscopy (see 5.76)
SMCM	scanning micropipette contact method (see 6.17)
SMRM	scanning magneto-resistance microscopy (see 3.25)
SMSM	scanning Maxwell stress microscopy (see 3.26) SMSM is sometimes given as SMM, but the latter acronym is also used for scanning microwave microscopy and scanning magnetic microscopy and so should not be used for scanning Maxwell stress microscopy.
SNDM	scanning non-linear dielectric microscopy (see 3.29)
SNFUH	scanning near-field ultrasound holography (see 3.28)
SNOM	scanning near-field optical microscopy (see 3.17)
s-NSOM	scattering near-field scanning optical microscopy (see 3.36)
SNTM	scanning near-field thermal microscopy (see 3.27)
SPM	scanning-probe microscopy (see 3.30)
SP-STM	spin-polarized scanning tunnelling microscopy (see 3.38)
SP-STS	spin-polarized scanning tunnelling spectroscopy (see 3.39)
SRTM	spin-resolved tunnelling microscopy (deprecated) (see 3.38)
SSCM	scanning surface confocal microscopy (see 6.18)
SSM	scanning superconducting interference device (SQUID) microscopy

s-SNOM	scattering scanning near-field optical microscopy (see 3.36)
SS-PFM	switching spectroscopy piezoresponse force microscopy (see 6.20)
SSPM	scanning surface potential microscopy (see 3.32)
SSRM	scanning spreading-resistance microscopy (see 3.31)
STM	scanning tunnelling microscopy (see 3.34)
SThM	scanning thermal microscopy (see 3.33)
STHM	scanning tunnelling hydrogen microscopy (see 6.19)
STS	scanning tunnelling spectroscopy (see 3.35)
SVM	scanning voltage microscopy
TECARS	tip-enhanced coherent anti-Stokes Raman scattering
TEFS	tip-enhanced fluorescence spectroscopy (see 3.41)
TERS	tip-enhanced Raman spectroscopy (see 3.42)
TNSOM	transmission near-field scanning optical microscopy
TSM	thermal-scanning microscopy (deprecated, see 3.33, Note 2)
TSNOM	transmission scanning near-field optical microscopy
UFM	ultrasonic force microscopy (see 3.43)

2 Format

2.1 Use of terms printed boldface in definitions

A term printed in italics in a definition or a note is defined in another entry in either part of this International Standard. However, the term is printed in italics only the first time it occurs in each entry.

2.2 Non-preferred and deprecated terms

A term listed lightface is non-preferred or deprecated. The preferred term is listed boldface.

2.3 Subject fields

Where a term designates several concepts, it is necessary to indicate the subject field to which each concept belongs. The field is shown lightface, between angle brackets, preceding the definition, and on the same line.

3 Definitions of the scanning-probe microscopy methods

NOTE The following are the definitions of scanned probe microscopy methods. In the list below, note that the final “M” or final “S” in the acronyms, given as “microscopy” or “spectroscopy”, may also mean “microscope” or “spectrometer”, respectively, depending on the context. For the definition relating to the microscope or spectrometer, replace the words “a method” by the words “an instrument” where that appears.

3.1
apertureless Raman microscopy

<NSOM, SNOM> method of microscopy involving the acquisition of Raman spectroscopic data utilizing a *near-field* (5.88) optical source and based upon a metal *tip* (5.120) in close proximity to the sample surface illuminated with suitably polarized light

3.2
atomic-force microscopy
AFM
DEPRECATED: scanning force microscopy
DEPRECATED: SFM
method for imaging surfaces by mechanically scanning their surface contours, in which the deflection of a sharp *tip* (5.120) sensing the surface forces, mounted on a compliant *cantilever* (5.18), is monitored

Note 1 to entry: AFM can provide a quantitative height *image* (5.69) of both insulating and conducting surfaces.

Note 2 to entry: Some AFM instruments move the sample in the x-, y- and z-directions while keeping the tip position constant and others move the tip while keeping the sample position constant.

Note 3 to entry: AFM can be conducted in vacuum, a liquid, a controlled atmosphere, or air. Atomic resolution may be attainable with suitable samples, with sharp tips, and by using an appropriate imaging mode.

Note 4 to entry: Many types of force can be measured, such as the *normal forces* (5.91) or the *lateral* (5.77), *friction* (5.62), or shear force. When the latter is measured, the technique is referred to as *lateral* (3.13), *frictional* (3.11), or *shear force microscopy* (3.37). This generic term encompasses all of the types of force microscopy listed in Clause 1.

Note 5 to entry: AFMs can be used to measure surface normal forces at individual points in the pixel array used for imaging.

Note 6 to entry: For typical AFM tips with radii < 100 nm, the normal force should be less than about 0,1 µN, depending on the sample material, or irreversible surface deformation and excessive tip wear occur.

3.3
chemical-force microscopy
CFM
LFM (3.13) or *AFM* (3.2) mode in which the deflection of a sharp *probe tip* (5.120), functionalized to provide interaction forces with specific molecules, is monitored

Note 1 to entry: LFM is the most popularly used mode.

3.4
conductive-probe atomic-force microscopy
CPAFM
DEPRECATED: CAFM
DEPRECATED: C-AFM
<AFM> *AFM* (3.2) mode in which a conductive *probe* (5.109) is used to measure both topography and electric current between the *tip* (5.120) and the sample

Note 1 to entry: CPAFM is a secondary imaging mode derived from contact AFM that characterizes conductivity variations across medium- to low-conducting and semiconducting materials. Typically, a DC bias is applied to the tip, and the sample is held at ground potential. While the z feedback signal is used to generate a normal-contact AFM topography *image* (5.69), the current passing between the tip and the sample is measured to generate the conductive AFM image.

3.5
current-imaging tunnelling spectroscopy
CITS
<STM> method in which the STM tip is held at a constant height above the surface, while the bias voltage, *V*, is scanned and the tunnelling current, *I*, is measured and mapped

Note 1 to entry: The constant height is usually maintained by gating the feedback loop so that it is only active for some proportion of the time; during the remaining time, the feedback loop is switched off and the applied tip bias is ramped and the current is measured.

Note 2 to entry: See *I-V spectroscopy* (5.74).

3.6
dynamic-mode AFM
dynamic-force microscopy
DFM
<AFM> *AFM* (3.2) mode in which the relative positions of the *probe tip* (5.120) and sample vary in a sinusoidal manner at each point in the *image* (5.69)

Note 1 to entry: The sinusoidal oscillation is usually in the form of a vibration in the *z*-direction and is often driven at a frequency close to, and sometimes equal to, the cantilever resonance frequency.

Note 2 to entry: The signal measured can be the amplitude, the phase shift, or the resonance frequency shift of the cantilever.

3.7
electrostatic-force microscopy
DEPRECATED: electric-force microscopy
<AFM> *AFM* (3.2) mode in which a conductive *probe* (5.109) is used to map both topography and electrostatic force between the *tip* (5.120) and the sample surface

3.8
electrochemical atomic-force microscopy
EC-AFM
<AFM> *AFM* (3.2) mode in which a conductive *probe* (5.109) is used in an electrolyte solution to measure both topography and electrochemical current

3.9
electrochemical scanning tunnelling microscopy
EC-STM
<STM> *STM* (3.34) mode in which a coated *tip* (5.120) is used in an electrolyte solution to measure both topography and electrochemical current

3.10
frequency modulation atomic-force microscopy
FM-AFM
dynamic-mode AFM (3.6) in which the shift in *resonance frequency* (5.134) of the *probe assembly* (5.20) is monitored and is adjusted to a set point using a feedback circuit

3.11
frictional-force microscopy
FFM
SPM (3.30) mode in which the *friction force* (5.62) is monitored

Note 1 to entry: The friction force can be detected in a static or frequency-modulated mode. Information on the tilt azimuthal variation of the frictional force needs the static mode.

3.12
Kelvin-probe force microscopy
KPFM
DEPRECATED: KFM
dynamic-mode AFM (3.6) using a conducting probe tip to measure spatial or temporal changes in the relative electric potentials of the tip and the surface

Note 1 to entry: Changes in the relative potentials reflect changes in the surface *work function* (4.487).

3.13
lateral-force microscopy
LFM
SPM (3.30) mode in which surface contours are scanned with a *probe assembly* (5.20) while monitoring the lateral forces exerted on the *probe tip* (5.120) by observation of the torsion of the *cantilever* (5.18) arising as a result of those forces

Note 1 to entry: The lateral forces can be detected in a static or frequency-modulated mode. Information on the tilt azimuth of surface molecules needs the static mode.

3.14
magnetic dynamic-force microscopy
MDFM
DEPRECATED: magnetic AC mode
DEPRECATED: MAC mode
<AFM> *AFM* (3.2) mode in which the *probe* (5.109) is oscillated by using a *magnetic force* (5.80)

3.15
magnetic-force microscopy
MFM
AFM (3.2) mode employing a *probe assembly* (5.20) that monitors both atomic forces and magnetic interactions between the *probe tip* (5.120) and a surface

3.16
magnetic-resonance force microscopy
MRFM
<AFM> *AFM* (3.2) imaging mode in which magnetic signals are mechanically detected by using a *cantilever* (5.18) at resonance and the force arising from nuclear or electronic spin in the sample is sensitively measured

3.17
near-field scanning optical microscopy
NSOM
scanning near-field optical microscopy
SNOM
method of imaging surfaces optically in transmission or reflection by mechanically scanning an optically active *probe* (5.109) much smaller than the wavelength of light over the surface while monitoring the transmitted or reflected light or an associated signal in the *near-field* (5.88) regime

Note 1 to entry: See *scattering NSOM* (3.36), *scattering SNOM* (3.36).

Note 2 to entry: Topography is important and the probe is scanned at constant height. Usually, the probe is oscillated in the shear mode to detect and set the height.

Note 3 to entry: Where the extent of the optical probe is defined by an *aperture* (5.5), the aperture size is typically in the range of 10 nm to 100 nm, and this largely defines the resolution. This form of instrument is often called an aperture NSOM or aperture SNOM to distinguish it from a *scattering NSOM* (3.36) or *scattering SNOM* (3.36) [previously called *apertureless NSOM* (3.36) or *apertureless SNOM* (3.36)], although, generally, the adjective “aperture” is omitted. In the apertureless form, the extent of the optically active probe is defined by an illuminated sharp metal or metal-coated *tip* (5.120) with a radius typically in the range of 10 nm to 100 nm, and this largely defines the resolution.

Note 4 to entry: In addition to the optical *image* (5.69), NSOM can provide a quantitative image of the surface contours similar to that available in *AFM* (3.2) and allied scanning-probe techniques.

Note 5 to entry: This generic term encompasses all of the types of near-field microscopy listed in Clause 2.

3.18

non-contact atomic-force microscopy

NC-AFM

dynamic-mode AFM (3.6) in which the *probe tip* (5.120) is operated at such a distance from the surface that it samples the weak, attractive van der Waals or other forces

Note 1 to entry: Forces in this mode are very low and are best for studying soft materials or avoiding cross-contamination of the tip and the surface.

3.19

photothermal micro-spectroscopy

PTMS

SThM mode in which the *probe* (5.109) detects the photothermal response of a sample exposed to infrared light to obtain an absorption spectrum

Note 1 to entry: The infrared light can be either from a tuneable monochromatic source or from a broadband source set up as part of a Fourier transform infrared spectrometer. In the latter case, the photothermal temperature fluctuations can be measured as a function of time to provide an interferogram which is Fourier-transformed to give the spectrum of sub-micron-sized regions of the sample.

3.20

scanning capacitance microscopy

SCM

SPM (3.30) mode in which a conductive *probe* (5.109) is used to measure both topography and capacitance between the *tip* (5.120) and sample

3.21

scanning chemical-potential microscopy

SCPM

SPM (3.30) mode in which spatial variations in the thermoelectric voltage signal, created by a constant temperature gradient normal to the sample surface, are measured and related to spatial variations in the chemical-potential gradient

3.22

scanning electrochemical microscopy

SECM

SPM (3.30) mode in which imaging occurs in an electrolyte solution with an electrochemically active *tip* (5.120)

Note 1 to entry: See *electrochemical atomic-force microscopy* (3.8), *EC-AFM* (3.8), *electrochemical scanning-probe microscopy* (6.5), *EC-SPM* (6.5), *electrochemical scanning tunnelling microscopy* (3.9), *EC-STM* (3.9).

Note 2 to entry: In most cases, the SECM tip is an ultramicroelectrode and the tip signal is a Faradaic current from electrolysis of solution species.

Note 3 to entry: The potential difference between the tip and either the sample or a reference electrode is usually monitored.

Note 4 to entry: The liquid is usually an ionic or polar liquid in which an electric double layer exists at the sample surface.

Note 5 to entry: The surface may be scanned with the tip at a constant height in the instrument frame to measure the convolution of topography and electrochemical activity, or if the sample is electrochemically homogeneous, in a feedback mode so that the tip is at a constant distance from the sample surface and the topography of the surface is recorded.

3.23
scanning Hall probe microscopy
SHPM
SPM (3.30) mode in which a Hall probe is used as the scanning sensor to measure and map the magnetic field from a sample surface

3.24
scanning ion conductance microscopy
SICM
SPM (3.30) mode in which an electrolyte-filled micropipette or nanopipette is used as a local *probe* (5.109) for insulating samples immersed in an electrolytic solution

Note 1 to entry: The distance dependence of the ion conductance provides the key to performing non-contact surface profiling.

3.25
scanning magneto-resistance microscopy
SMRM
SPM (3.30) mode in which a magneto-resistive sensor *probe* (5.109) on a *cantilever* (5.18) is scanned in the *contact mode* (5.35) over a magnetic sample surface to measure two-dimensional magnetic *images* (5.69) by acquiring magneto-resistive voltage

3.26
scanning Maxwell stress microscopy
SMSM
SPM (3.30) mode in which a conductive *probe* (5.109) is used to measure both topography and surface potential by utilizing the Maxwell stress

3.27
scanning near-field thermal microscopy
SNTM
SNOM method in which an infrared-sensing thermometer is used to detect the local emission collected by an optical *probe* (5.109) to measure both the topography and thermal properties

3.28
scanning near-field ultrasound holography
SNFUH
method for imaging surfaces and the subsurface regimes by mechanically scanning their surface contours and detecting the results of the interference of a high-frequency acoustic wave [of the order of MHz or higher and substantially greater than the *resonance frequency* (5.134) of the *cantilever* (5.18)] applied to the bottom of the sample while another wave is applied to the cantilever at a slightly different frequency

3.29
scanning non-linear dielectric microscopy
SNDM
SPM (3.30) mode in which a conductive *probe* (5.109) is used to measure both topography and dielectric constant (capacitance)

3.30
scanning-probe microscopy
SPM
method of imaging surfaces by mechanically scanning a *probe* (5.109) over the surface under study, in which the concomitant response of a detector is measured

Note 1 to entry: This generic term encompasses *AFM* (3.2), *CFM* (3.3), *CITS* (3.5), *FFM* (3.11), *LFM* (3.13), SFM, *SNOM* (3.17), *STM* (3.34), TSM, etc. listed in Clause 1.

Note 2 to entry: The resolution varies from that of STM, where individual atoms can be resolved, to *SThM* (3.33), in which the resolution is generally limited to around 1 µm.

3.31
scanning spreading-resistance microscopy
SSRM

SPM (3.30) mode in which a conductive *tip* (5.120) is used to measure both topography and spreading resistance

Note 1 to entry: While full-diamond or diamond-coated *probes* (5.109) are almost always used for the SSRM of Si samples, it is possible to perform SSRM with other conductive tips when (in cases such as the imaging of InP, which is soft) the use of a diamond tip could damage the sample.

3.32
scanning surface potential microscopy
SSPM

SPM (3.30) mode in which a conductive *probe* (5.109) is used to measure both topography and surface potential

Note 1 to entry: *KPFM* (3.12) is SSPM conducted using an *AFM* (3.2) as defined in 3.13. Where this is appropriate, KPFM should be used to describe the method rather than the more generic term, SSPM.

3.33
scanning thermal microscopy
SThM

SPM (3.30) method in which a thermal sensor is integrated into the *probe* (5.109) to measure both topography and thermal properties

Note 1 to entry: Examples of such thermal properties are temperature and thermal conductivity.

Note 2 to entry: This method is sometimes known as thermal-scanning microscopy or TSM. This expression and acronym are deprecated.

3.34
scanning tunnelling microscopy
STM

SPM (3.30) mode for imaging conductive surfaces by mechanically scanning a sharp, voltage-biased, conducting *probe tip* (5.120) over their surface, in which the data of the *tunnelling* (5.169) current and the tip-surface separation are used in generating the *image* (5.69)

Note 1 to entry: STM can be conducted in vacuum, a liquid, or air. Atomic resolution can be achieved with suitable samples and sharp probes and can, with ideal samples, provide localized bonding information around surface atoms.

Note 2 to entry: Images can be formed from the height data at a constant tunnelling current or the tunnelling current at a constant height or other modes at defined relative potentials of the tip and sample.

Note 3 to entry: STM can be used to map the densities of states at surfaces or, in ideal cases, around individual atoms. The surface images can differ significantly, depending on the *tip bias* (5.159), even for the same topography.

3.35
scanning tunnelling spectroscopy
STS

STM (3.34) mode in which the *tunnelling* (5.169) current, *I*, between the *tip* (5.120) and the sample is measured as the voltage, V, between the tip and the sample is scanned

Note 1 to entry: See *I-V spectroscopy* (5.74).

Note 2 to entry: The differential conductance, dI/dV, reflects the electronic local density of states (LDOS). If the sample is a superconductor, the energy gap around the Fermi level can be characterized.

3.36

scattering NSOM/SNOM
s-NSOM
s-SNOM
DEPRECATED: apertureless NSOM
DEPRECATED: ANSOM
DEPRECATED: apertureless SNOM
DEPRECATED: ASNOM
method in which imaging at a resolution below the *Abbe diffraction limit* (5.1) is achieved by detecting light scattered or emitted in the vicinity of a sharp scanning *tip* (5.120)

Note 1 to entry: ASNOM and ANSOM are both commonly used, and sometimes also mean apertured NSOM/SNOM and apertureless NSOM/SNOM. To reduce the potential confusion, scattering NSOM/SNOM is recommended, which is more descriptive of the technique than the earlier terms which describe what is not used.

Note 2 to entry: No *aperture* (5.5) defines the resolution of the instrument. Instead, the probed volume is defined by scattering within the near-field region around the tip or the localized optical field distribution around the tip.

Note 3 to entry: The sharp tip is usually metallic or metal coated, permitting measurements of *surface-enhanced Raman* (5.152) and *fluorescence* (5.52) spectroscopy and *second harmonic generation* (5.140). Raman signals of molecules in close proximity to silver can be enhanced by a factor of 10^{14}.

Note 4 to entry: The tip can be a single fluorescent molecule or *nanoparticle* (5.87).

Note 5 to entry: In the literature, the acronym ANSOM or ASNOM is occasionally used erroneously for aperture NSOM or aperture SNOM.

3.37

shear force microscopy
ShFM
<AFM> *AFM* (3.2) mode using signals arising from a *probe tip* (5.120) oscillating laterally in proximity to the surface

Note 1 to entry: The oscillation is usually sinusoidal and generated through a piezoelectric actuator.

3.38

spin-polarized scanning tunnelling microscopy
SP-STM
DEPRECATED: spin-resolved tunnelling microscopy
DEPRECATED: SRTM
<STM> *STM* (3.34) mode in which a magnetically ordered (ferromagnetic or antiferromagnetic) STM *tip* (5.120) is scanned over a sample surface to image two-dimensional magnetic structures on the nanometre scale by measuring the spin-dependent *tunnelling* (5.169) current

3.39

spin-polarized scanning tunnelling spectroscopy
SP-STS
STS (3.35) mode in which a magnetically ordered (ferromagnetic or antiferromagnetic) STM tip is scanned over a sample surface to perform spin-polarized *tunnelling* (5.169) spectroscopy to probe the magnetic and electronic structures of the sample surface on the nanometre scale

3.40

static-mode AFM
static AFM
<AFM> *AFM* (3.2) mode of scanning the *probe* (5.109) where a control parameter is maintained essentially constant or of scanning a control parameter at a fixed point in the raster array at the sample surface

Note 1 to entry: The control parameter can be, for example, force or height.

3.41

tip-enhanced fluorescence spectroscopy

TEFS

<NSOM, SNOM> enhanced fluorescence observed with a metal *tip* (5.120) in close proximity to a sample surface illuminated with suitably polarized light

Note 1 to entry: See *tip-enhanced Raman spectroscopy* (3.42).

3.42

tip-enhanced Raman spectroscopy

TERS

<NSOM, SNOM> enhanced *Raman effect* (5.128) observed with a metal *tip* (5.120) in close proximity to a sample surface illuminated with suitably polarized light

Note 1 to entry: See *tip-enhanced fluorescence spectroscopy* (3.41), *surface-enhanced Raman scattering* (5.151).

3.43

ultrasonic force microscopy

UFM

<AFM> *AFM* (3.2) mode in which an ultrasonic wave is injected through the *probe* (5.109) to observe the surface or subsurface mechanical structure

4 Acronyms and terms for contact mechanics models

NOTE In contact mechanics, the basic theories are often referenced by acronyms. To avoid confusion, these acronyms are defined below. These models all assume that the materials in contact are homogeneous and isotropic, and have a linear elastic constitutive behaviour. Various contact models for inhomogeneous, anisotropic, nonlinear, viscoelastic, elastoplastic, and other materials have been derived and can be found in the literature.

4.1

BCP

Burnham-Colton-Pollock model

semi-empirical model of *tip* (5.120) and surface contact that assumes that long-range forces act only outside the contact area[1]

Note 1 to entry: This simple semi-empirical approach matches many experimental AFM force-distance curves. It avoids both the severe discontinuity in the slope of the force curve at contact in *DMT* (4.3) theory and the adhesion hysteresis of *JKRS* (4.5) theory. It assumes that long-range forces act only outside the contact area and uses a Hertzian functional relationship between indentation depth and contact radius that gives no adhesion hysteresis.

4.2

COS

Carpick-Ogletree-Salmeron model

model of *tip* (5.120) and surface contact between a sphere and a flat surface giving a simple general formula that approximates Maugis' solution to within 1 % accuracy[2]

Note 1 to entry: The general formula is amenable to conventional curve-fitting routines and provides a rapid method of determining the approximate value of the parameter described by Maugis.

4.3

DMT

Derjaguin-Müller-Toporov model

model of *tip* (5.120) and surface contact in which adhesion forces are taken into account but the tip-sample geometry is constrained to be Hertzian[3]

Note 1 to entry: This approach applies to rigid systems with low adhesion and small radii of curvature. The adhesion forces are taken into account but the tip-sample geometry is constrained to be Hertzian, i.e. Hertzian mechanics with an offset to account for surface forces.

4.4
Hertzian model
model of *tip* (5.120) and surface contact between elastic solids that ignores any surface forces and adhesion hysteresis

Note 1 to entry: This approach, derived by Hertz and described in Reference,[4] describes the contact between elastic solids. It ignores any surface forces and adhesion hysteresis and applies at high loads where there are no surface forces present.

4.5
JKR(S) model
Johnson-Kendall-Roberts (-Sperling) model
model of *tip* (5.120) and surface contact in which adhesion forces outside the contact area are ignored and elastic stresses at the edge of the contact area are infinite[5]

Note 1 to entry: In this work, adhesion forces outside the contact area are ignored and elastic stresses at the edge of the contact area are infinite. At contact, short-range attractive forces suddenly operate, and the tip-sample geometry is not constrained to remain Hertzian. Adhesion hysteresis is described and loading and unloading are abrupt processes. This approach applies to highly adhesive systems with low *stiffness* (5.147) and high radii of curvature.

Note 2 to entry: The JKR and JKRS models are the same. The JKR acronym is very commonly used. The JKRS acronym extends the recognition to Sperling's earlier work.[6]

4.6
Maugis model
Maugis-Dugdale model
model of *tip* (5.120) and surface contact between a sphere and a flat surface incorporating the elastic modulus and *work of adhesion* (5.175)[7]

Note 1 to entry: This analysis is a complex mathematical description of the contact mechanics between a sphere and a flat surface which applies in all material possibilities through a parameter that is a function of reduced elastic modulus, reduced curvature radius, work of adhesion, and the tip-sample interatomic equilibrium distance. At the limits, when this parameter tends to infinity or zero, the Maugis mechanics tend to the *JKRS* (4.5) or *DMT* (4.3) mechanics, respectively.

5 Terms for scanning-probe methods

5.1
Abbe diffraction limit
far-field diffraction limit
<NSOM, SNOM> optimum resolution achievable for an optical system, governed by diffraction phenomena, at the limit of collection optics placed at a large number of wavelengths from the object under study

Note 1 to entry: In classical far-field diffraction theory, the optimum point-to-point resolution observed using a system with a particular *numerical aperture* (5.93), *NA* (5.93), is given by d, where $d = 0{,}61\lambda/\mathrm{NA}$, in which λ is the wavelength of the illuminating light. With a carefully defined illumination, the factor 0,61 can be reduced to as low as 0,36.

5.2
active length
length of the region of the *probe tip* (5.120) that can come into contact with the sample in a scan

[SOURCE: ASTM E1813-96]

Note 1 to entry: This length is set by the height of the tallest feature encountered.

Note 2 to entry: This length should be less than the *probe length* (5.112).

5.3

amplitude modulation detection

AM detection

<AFM> dynamic mode in which the change in *probe* (5.109) height required to keep the vibration amplitude of an oscillated *cantilever* (5.18) constant while it is scanning over the surface is monitored

Note 1 to entry: The oscillation frequency is usually set close to the *resonance frequency* (5.134), where the amplitude changes are strongest.

Note 2 to entry: The phase shift between the drive and the response can also be monitored and provides information on dissipated energy due to the tip-sample interaction.

Note 3 to entry: The detected signals can be used in a feedback system to keep one parameter constant.

5.4

anti-Stokes scattering

Raman effect (5.128) where the emitted photon has higher energy than the incident photon

Note 1 to entry: See *Stokes scattering* (5.148).

5.5

aperture

<NSOM, SNOM> hole, typically circular, in an opaque manifold

Note 1 to entry: Apertures are critical to the performance of optical (light, electron, or optical) instruments in defining their imaging or spectral resolution.

5.6

artefact

artifact

unwanted distortion or added feature in measured data arising from lack of idealness of equipment

5.7

atomic corrugation

regular undulations of the atoms on a low-index or vicinal surface of a single crystal, where the undulations are of atomic width or greater and have heights which are a significant fraction of the atomic size

Note 1 to entry: The corrugations can arise, for example, from the non-uniform distribution of the local density of states (LDOS) and the minimization of the *surface energy* (5.150) and can change, for example, as a result of changes in the *probe tip* (5.120) settings, the probe tip itself, the ambient temperature, or adsorbed species.

5.8

ballistic electron

electron that travels through a piece of material without significant scattering

Note 1 to entry: The energy of the electron is greater than that of any other electron in thermal equilibrium in the system.

Note 2 to entry: The electron's mean free path is larger than the characteristic dimension of the sample in the direction of transport.

5.9

barrier height

magnitude of the potential energy in a region restricting the movement of electrons

Note 1 to entry: In *STM* (3.34), the magnitude of the barrier height is related to the *tip* (5.120) and substrate *work functions* (4.487). In classical mechanics, an electron with an energy less than the barrier height would not be able to penetrate the barrier, whereas in quantum mechanics, there is a finite probability that the electron will tunnel across the barrier. In the quantum *tunnelling* (5.169) of an electron from a metal through a vacuum gap to a metal, the barrier height is the difference between the *Fermi energy* (4.211) in the first metal and the maximum of the potential distribution in the space between the two metals.

5.10

barrier height, local

potential energy of a *tunnelling barrier* (5.12) at a specified location

Note 1 to entry: When an *STM* (3.34)*tip* (5.120) is scanned across a sample, the potential energy can vary with tip position due to chemical inhomogeneities (e.g. impurities) of lower *work function* (4.487) at or close to the surface.

5.11

barrier height, tunnelling-

magnitude of the potential energy associated with the *tunnelling barrier* (5.12)

Note 1 to entry: See *barrier height* (5.9).

Note 2 to entry: In *STM* (3.34), the magnitude of the barrier height is related to the *tip* (5.120) and substrate *work functions* (4.487).

5.12

barrier, tunnelling

energy barrier with an associated height (i.e. energy), width (i.e. length), and shape (i.e. profile of energy versus length) across which electrons traverse by quantum-mechanical *tunnelling* (5.169)

Note 1 to entry: For electrons with an energy less than the *barrier height* (5.9), quantum mechanics dictates that there is a finite probability for the electrons to tunnel across the barrier, whereas classical mechanics would forbid electron transport.

Note 2 to entry: See *tunnelling-barrier height* (5.11), *tunnelling-barrier width* (5.13).

5.13

barrier width, tunnelling-

length associated with a potential-energy barrier that electrons traverse by quantum-mechanical *tunnelling* (5.169)

Note 1 to entry: When in the *STM* (3.34) tunnelling regime, the tunnelling-barrier width is equivalent to the tip-sample separation. The tunnelling current decreases approximately exponentially with increasing barrier width.

5.14

Bethe-Bouwkamp model

<NSOM, SNOM> model by Bethe and by Bouwkamp describing the wavefield for a sub-wavelength *aperture* (5.5) in an infinite perfectly conducting screen

Note 1 to entry: This may be a useful approximation for an aperture in *NSOM/SNOM* (3.17).

Note 2 to entry: The original model derives from References[9] to.[11]

5.15

blind reconstruction

reconstruction estimate of a sample's (or tip's) surface topography when the estimate is obtained from a measured *image* (5.69) without independent knowledge of the tip's (or sample's) surface topography

Note 1 to entry: See *dilation* (5.39), *erosion* (5.45).

5.16

bow

distance, measured at right angles, of the centre point of a sample surface from a reference plane defined by three equidistant points on the surface in a circle around that centre with a radius suitable to cover the surface defined

Note 1 to entry: See *flatness* (5.50), *warp* (5.173).

Note 2 to entry: A positive value indicates a surface that is convex and a negative value indicates a surface that is concave.

Note 3 to entry: This term is applied to surfaces whose out-of-flatness is essentially described as concave or convex, i.e. they have one extremity that is not at the perimeter of the reference plane.

Note 4 to entry: This term is often applied to wafers where the diameter of the circle might be 6,25 mm less than the wafer diameter.

5.17
Bückle’s rule

indentation to less than 10 % of the layer thickness when measuring the layer hardness directly

Note 1 to entry: This is an empirical rule established for measuring coating hardnesses and has been shown to apply to films greater than about 5 µm in thickness.

Note 2 to entry: This rule is often applied to the measurement of film moduli.

5.18
cantilever

thin force-sensing support for a *probe tip* (5.120), joined to the *cantilever chip* (5.26) at the end furthest from the probe tip

Note 1 to entry: Cantilevers are available in a number of shapes ranging from rectangular or diving board to “V” or “A” shapes where the probe tip is near the narrower end.

5.19
cantilever apex

end of the *cantilever* (5.18) furthest from the cantilever support structure

Note 1 to entry: See *probe apex* (5.120).

5.20
cantilever assembly
micro cantilever
probe assembly

structure comprising the *chip holder* (5.27), *chip* (5.26), *cantilever* (5.18), and *probe* (5.109)

5.21
cantilever back side

DEPRECATED: cantilever reflex side

cantilever (5.18) surface opposite to the surface on which the *probe tip* (5.120) is mounted

Note 1 to entry: See *detector side (of a cantilever)* (5.38).

Note 2 to entry: The reflex side has the same meaning as the back side but is only applicable to cantilevers with a reflection coating for use with an optical sensor. Reflex side is therefore deprecated.

5.22
capillary force

force exerted on an AFM cantilever or similar *probe* (5.109) due to capillary condensation at the junction between the probe and the surface

5.23
carbon nanotube probe

probe (5.109) with a carbon nanotube that forms both the *probe shank* (5.113) and the *probe tip* (5.120)

Note 1 to entry: The carbon nanotube is normally supported on a probe-like structure called the *probe support* (5.115). The nanotube and the support comprise a *composite probe* (5.30).

5.24
characterized length

region of the *probe* (5.109) that has been measured by a *probe characterizer* (5.110)

[SOURCE: ASTM E1813-96]

5.25
chemical force
force between atoms or molecular groups on the *probe tip* (5.120) and atoms or molecular groups on the surface

5.26
chip
cantilever chip
chip substrate
DEPRECATED: probe chip
small piece, usually of silicon, on which the *cantilever* (5.18) has been fabricated and to which it is still attached as a convenient supporting structure in the *probe assembly* (5.20)

5.27
chip holder
structure on which the *chip* (5.26), *cantilever* (5.18), and *probe* (5.109) are mounted

Note 1 to entry: The chip holder, chip, cantilever, and probe comprise the *probe assembly* (5.20).

5.28
closed-loop scanner
scanning system having a function sensor whose output is fed back into the scanning system to improve the accuracy of its settings

Note 1 to entry: This term often refers to function sensors that relate to position and *scanners* (5.136) that can then set their *x*- and *y*- and, sometimes, *z*-positions accurately. This is very important since position scanners are often based on piezoelectric components that exhibit significant hysteresis and creep in the absence of closed-loop control.

5.29
coarse-approach device
device that changes the initial *probe* (5.109) and sample separations by amounts significantly greater than the vertical (*z*) *scanner* (5.136) range

Note 1 to entry: Typical coarse-approach device ranges are 1 mm whereas the *z* scanner ranges are typically 1 µm to 100 µm. Coarse approaches are often made in steps similar to the *z* scanner range and are critical for the routine study of samples.

5.30
composite probe
structure at or near the *cantilever apex* (5.19) including a *probe support* (5.115) and a superimposed *probe* (5.109)

Note 1 to entry: For work where particular probe qualities, such as probe *tip radius,* (5.161)*probe stiffness* (5.114), and probe profile are required, a special probe such as a carbon nanotube can be affixed or grown on the end of a larger probe manufactured by traditional silicon foundry methods. This combination forms a composite probe with the larger probe being termed the probe support.

5.31
cone angle
<NSOM, SNOM> angle subtended between the optical-fibre axis and the wall of the tip in an optical-fibre NSOM probe

Note 1 to entry: See *included half-angle* (5.70), *cone half-angle* (5.70).

5.32
constant-current mode
<STM> mode of scanning the *probe tip* (5.120) over the sample surface at a constant current by adjusting the relative heights of the *probe* (5.109) and sample so that the current sensed does not change during the scan

5.33
constant-force mode

<AFM> mode of scanning the *probe tip* (5.120) over the sample surface at a constant *normal force* (5.91) by adjusting the relative heights of the *probe* (5.109) and sample so that the force sensed does not change during the scan

5.34
constant-height mode

mode of scanning the *probe tip* (5.120) over the sample surface at a constant height over the surface during the scan

Note 1 to entry: The height is constant relative to the instrument, not the sample surface.

5.35
contact mode

<AFM> mode of scanning the *probe tip* (5.120) over the sample surface, adjusting the relative heights of the *probe* (5.109) and sample, in which there is always a repulsive force between the probe and the sample

Note 1 to entry: See *intermittent contact mode* (5.73), *non-contact mode* (5.90), *tapping mode* (5.73).

Note 2 to entry: This mode can be, for example, either the *constant-height* (5.34) or *constant-force mode* (5.33).

5.36
contour length

<polymers> length of a segment of polymer at maximum extension

5.37
damping

<AFM> mechanical energy dissipated per unit time from a *cantilever* (5.18) oscillating with constant, maintained amplitude during *NC-AFM* (3.18) measurement

Note 1 to entry: See *dissipation* (5.41).

5.38
detector side (of a cantilever)

surface of a *cantilever* (5.18) facing the detector

Note 1 to entry: See *cantilever back side* (5.21).

Note 2 to entry: In the usual arrangement, the detector side and the reflex side are the same side of the cantilever.

5.39
dilation

<AFM> mathematical morphological operation by which two shapes, A and B, are combined to produce a third shape in accordance with

$$A \oplus B = \bigcup_{\boldsymbol{b} \in B} (A + \boldsymbol{b})$$

where

$\oplus$ is the customary symbol for dilation;

A is the set of all points within the first shape;

$\boldsymbol{b}$ is a vector which successively takes the values of all the points within the second shape (B);

$A + \boldsymbol{b} = \{\boldsymbol{a} + \boldsymbol{b} \mid \boldsymbol{a} \in A\}$ is the translation of A by $\boldsymbol{b}$.

Note 1 to entry: See *erosion* (5.45).

Note 2 to entry: Dilation is discussed in Reference.[12] To the extent that the *tip* (5.120) scans the sample in contact without compression, twisting, or bending, the shape, I, of an **AFM image** is a dilation given by $I = S \oplus (-T)$, where S and T are the sample and tip shapes, respectively, and $-T = \{-\boldsymbol{t} \mid \boldsymbol{t} \in T\}$.

Note 3 to entry: Dilation and convolution are both forms of mixing, but they are mathematically different. In some texts, the reader might find the term convolution used incorrectly.

5.40
dip pen nanolithography

method in which a scanning *tip* (5.120) is used to transfer specific material onto a substrate surface, via a solvent meniscus, for patterning a substrate at length scales below 100 nm

Note 1 to entry: Often the tip is an *AFM* (3.2) tip coated with specific molecules that are to be deposited on the surface in a layer that can be a *monolayer* (4.307). In other cases, the material to be deposited could be **nanoparticles**.

Note 2 to entry: Dip Pen Nanolithography1) is a registered trademark of NanoInk Inc.

5.41
dissipation

<AFM> energy transfer from the tip to the sample during the tip-sample interaction in *NC-AFM* (3.18)

Note 1 to entry: See *damping* (5.37).

5.42
dither

action, in the dynamic mode, of oscillating the *tip* (5.120)

5.43
elastic tunnelling

quantum-mechanical *tunnelling* (5.169) process in which electrons do not lose energy

Note 1 to entry: The energy in the initial and final states are the same.

5.44
electrostatic force

force generated by electrostatic effects between the *probe tip* (5.120) and the sample

5.45
erosion

<AFM> mathematical morphological operation by which two shapes, A and B, are combined to produce a third shape in accordance with

$$A \ominus B = \bigcap_{\boldsymbol{b} \in B} (A - \boldsymbol{b})$$

where

$\ominus$ is the customary symbol for erosion;

A is the set of all points within the first shape;

$\boldsymbol{b}$ is a vector which successively takes the values of all the points within the second shape (B);

$A - \boldsymbol{b} = \{\boldsymbol{a} - \boldsymbol{b} \mid \boldsymbol{a} \in A\}$ is the translation of A by $-\boldsymbol{b}$.

Note 1 to entry: See *dilation* (5.39).

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1) This information is given for the convenience of users of this document and does not constitute an endorsement by ISO TC 201/SC 1 of the product named. Equivalent products may be used if they can be shown to lead to the same results.

Note 2 to entry: Erosion is discussed in Reference.[12] To the extent that imaging is appropriately modelled as a *dilation* (5.39), erosion can be used to reconstruct a least outer-bound estimate of the sample's shape, S_r, given by $S_r = I \ominus (-T)$, where I and T are the *image* (5.69) and *tip* (5.120) shapes, respectively, and $-T = \{-\boldsymbol{t} \mid \boldsymbol{t} \in T\}$.

Note 3 to entry: Erosion is mathematically different from deconvolution. In some texts, the reader might find the term deconvolution used incorrectly.

5.46
etched tip

probe tip (5.120) generated by an etching process

Note 1 to entry: This term generally refers to STM tips generated by electrochemical etching, but ion sputter etching can also be used for manufacturing STM tips. This term also applies to optical-fibre tips for *NSOM/SNOM* (3.17), where etching in hydrofluoric acid is part of the forming process.

5.47
evanescent wave

part of a wave that extends beyond an interface between materials of differing refractive indexes where, in geometrical optics, the incident wave undergoes total internal reflection

Note 1 to entry: The intensity of evanescent waves decays exponentially with distance from the interface at which they are formed.

5.48
feedback-induced distortion

distortion of a scan trace arising from the inability of a *probe* (5.109) microscope feedback to maintain close proximity between the *tip* (5.120) and the surface

[SOURCE: ASTM E1813-96]

Note 1 to entry: This distortion can be caused by scanning too quickly and can change with scan speed and scan direction.

5.49
Fischer pattern
Fischer projection pattern

<NSOM, SNOM> patterned layer, typically of aluminium around 50 nm to 200 nm in thickness and typically evaporated on a glass or quartz cover slip on which monodispersed spheres, typically of latex or polystyrene and typically between 150 nm and 1 µm in diameter, have been deposited prior to evaporation and have been removed after evaporation

Note 1 to entry: The spheres form an almost perfect close-packed array, with row dislocations that are then reproduced in the aluminium layer. Fischer patterns have been found to be useful to practitioners of SNOM and confocal microscopy because they offer nanoscale features of known dimensions for *optical resolution* (5.94) tests, while the imperfect close-packing allows the identification of the areas imaged by these high-resolution techniques within the field of view available to, and at the lower resolutions available to, a conventional light microscope. Details are given in Reference.[13]

5.50
flatness

minimum distance between two parallel planes that contain the surface

Note 1 to entry: See *bow* (5.16), *warp* (5.173).

Note 2 to entry: This term is applied to surfaces whose out-of-flatness is more complex than described by bow and warp in that they have many extremities that are not at the perimeter.

5.51
flexing-induced distortion

distortion of a scan trace arising from flexing of the *probe tip* (5.120) or *probe shank* (5.113) during scanning

5.52
fluorescence

<NSOM, SNOM> phenomenon in which absorption of light of a given wavelength by a substance is followed by the emission of light at a longer wavelength

Note 1 to entry: In the case of multiphoton fluorescence, the emitted light may be of a shorter wavelength.

5.53
fluorescence quenching

<NSOM, SNOM> process that decreases the intensity of *fluorescence* (5.52) emission by energy transfer via a non-radiative relaxation mechanism

5.54
fluorescence resonant energy transfer
FRET

<NSOM, SNOM> *fluorescence* (5.52) resulting from energy exchange between a donor and acceptor molecule or different parts of the same molecule in close proximity with each other

Note 1 to entry: The close proximity is within a wavelength and may typically be less than 10 nm.

5.55
fluorescent tagging
fluorescent labelling

chemical attachment of a fluorescent molecule to a molecule being studied

Note 1 to entry: This permits the orientation, structure, distribution, or motion of the molecule being studied to be analysed optically.

Note 2 to entry: Fluorescent molecules are called *fluorophores* (7.11).

5.56
force-distance curve
force-displacement curve
DEPRECATED: force-deflection curve
DEPRECATED: force-extension curve

<AFM> pairs of force and distance values resulting from a mode of operation in which the probe is set at a fixed (x, y) position and the *probe tip* (5.120) is moved towards or away from the surface as the force is measured

Note 1 to entry: The force is usually monitored using the *cantilever* (5.18) deflection.

5.57
force sensor

sensor detecting forces applied to the *probe* (5.109)

5.58
force spectroscopy
FS

measurement of the interaction force between the *probe tip* (5.120) and the surface as a function of a control parameter such as tip-sample separation or tip-sample bias

5.59
force-volume mode

<AFM> mode of scanning the *probe* (5.109) at an array of $n \times m$ points across the surface, where a *force-distance curve* (5.56) is acquired at each point in the array

Note 1 to entry: See *pulsed-force mode* (5.125).

5.60

frequency modulation detection

FM detection

<AFM> detection mode in *dynamic-mode AFM* (3.6) where the change in the oscillation frequency is used in imaging and to control the tip-surface separation

Note 1 to entry: This mode was first described in Reference.[14]

5.61

friction, dynamic

phenomenon of two solids in contact in which sliding occurs between the solids and in which resistive mechanisms lead to a force in opposition to the applied force that caused the sliding, so leading to the *dissipation* (5.41) of energy

Note 1 to entry: If the applied force exceeds the opposing static frictional force, sliding occurs and the friction is dynamic. If not, no sliding occurs and the friction is static. The maximum frictional force in the static regime can exceed the frictional force in the dynamic regime.

Note 2 to entry: If the surfaces are not isotropic, the frictional force might not be in the opposite direction to the applied force. In dynamic friction, this can lead to movement at an angle to the direction of the applied force.

5.62

friction force

<AFM> *lateral force* (5.77) arising from *friction* (5.61) generated by the lateral movement between the *probe tip* (5.120) and the sample

Note 1 to entry: The lateral force causes torsional bending of the *cantilever* (5.18) that can be detected on an optical or other sensor.

Note 2 to entry: Microscopy in this mode is called *frictional-force microscopy (FFM)* (3.11).

5.63

friction, static

phenomenon of two solids in contact in which no movement occurs between the solids and in which resistive mechanisms lead to a force in opposition to the applied force that would, in the absence of friction, cause sliding between the solids

Note 1 to entry: If the applied force exceeds the opposing frictional force, sliding occurs and the friction is dynamic. If not, no sliding occurs and the friction is static. The maximum frictional force in the static regime can exceed the frictional force in the dynamic regime.

5.64

functionalized probe

functionalized tip

probe tip (5.120) with specific functional groups

Note 1 to entry: In general, the functionalization is achieved by grafting a *monolayer* (4.307) of specific molecules onto the *tip* (5.120) so that the presence of specific chemical groups on the sample surface can be detected by, for example, a specific attractive force between the chemical groups and the grafted molecules. The functionalization can also be achieved by fabricating the probe tip from material exhibiting such a property. In certain circumstances, unintended functionalization can contribute to measurements where functionalization was otherwise thought to be absent.

5.65

height tracking mode

topography tracking mode

mode in which data are recorded as the *tip* (5.120) traces a line at a given height above the surface defined by the pre-determined topography

Note 1 to entry: See *planar subtraction mode* (5.107).

Note 2 to entry: This mode is used to remove the effects of topography in a line scan. Typical data that can be recorded are forces in general [such as *magnetic forces* (5.80)], patch fields, etc.

Note 3 to entry: This mode is also referred to as the lift-off mode, lift mode, or path mode by different manufacturers.

5.66
Hertzian contact
form of contact between elastic solids only involving elasticity

Note 1 to entry: Hertzian contact ignores any surface forces and adhesion hysteresis and generally applies at high loads where there are no surface forces present.

5.67
illumination mode
<NSOM, SNOM> mode of operation of an optical scanning-probe instrument in which the optical excitation is limited so as to define the *optical resolution* (5.94) of the system

Note 1 to entry: The optical resolution can be defined, for example, by delivery of the optical excitation by an optical fibre.

Note 2 to entry: This mode is a common operating mode of *aperture* (5.5) SNOM systems.

5.68
illumination-collection mode
<NSOM, SNOM> mode of operation of an optical scanning-probe instrument in which the optical excitation and the optical response signal to this excitation are carried by the same *probe tip* (5.120)

Note 1 to entry: In SNOM, the illumination-collection mode helps avoid loss of resolution due to the drift of excited states or charge carriers that could occur if only one of either the primary exciting radiation or the detected radiation were to be limited to a small near-field region.

Note 2 to entry: In practice, the optical response is typically photoluminescence and the probe tip is often a drawn optical fibre.

5.69
image
map
two- or three-dimensional representation of the sample surface where the information at each point in the representation, given by a brightness or colour or as a length in a third dimension, is related to the output signal from a detector or processed intensity information from the available software

Note 1 to entry: Map intensities can be presented in a normalized fashion to have the maximum and minimum signal intensities set at, for example, full white and full black, respectively, or on a colour scale. The contrast scale should be defined.

5.70
included half-angle
cone half-angle
DEPRECATED: half tip angle
DEPRECATED: semi-vertical angle
<of an AFM probe> included angle between the *probe* (5.109) surface and the axis of symmetry for a cone-shaped probe

Note 1 to entry: For asymmetric probes, the included half-angles in different azimuths are not the same. These included half-angles need to be specified in defined azimuths, usually along and at right angles to the *cantilever* (5.18) axis.

5.71
inelastic tunnelling
<STM> process involving quantum-mechanical *tunnelling* (5.169) in which electrons lose energy

5.72

interfacial energy

quotient of the energy required to increase an interfacial area at thermodynamic equilibrium by that area

Note 1 to entry: This term should more precisely be the areic interfacial energy or the interfacial energy per unit area since the dimensions are those of energy per unit area. However, in the literature, the abbreviated term interfacial energy is in common usage.

5.73

intermittent contact mode

tapping mode

mode of scanning the *probe* (5.109) where the probe is operated with a sinusoidal *z*-displacement modulation such that the *probe tip* (5.120) makes contact with the sample for a fraction of the sinusoidal cycle

Note 1 to entry: See *contact mode* (5.35), *non-contact mode* (5.90).

Note 2 to entry: In this mode, the change in the amplitude arising from the intermittent contact can be used to control the relative heights of the sample and tip in the scanned *image* (5.69).

Note 3 to entry: TappingMode[2)] is a registered trademark of Veeco.

5.74

I-V spectroscopy

<STM> technique in which the STM tip is held at a constant position, while the bias voltage, *V*, is ramped and the *tunnelling* (5.169) current, *I*, is measured

Note 1 to entry: I-V spectroscopy is also known as I/V, I(V), and IV spectroscopy.

5.75

I-Z spectroscopy

<STM> technique in which the STM tip is held at a constant bias voltage, while the tip height, *Z*, is ramped and the *tunnelling* (5.169) current, *I*, is measured

Note 1 to entry: I-Z spectroscopy is also known as I/Z, I(Z), and IZ spectroscopy.

5.76

Kelvin probe

probe (5.109) designed to measure the relative potential between the surface and a conducting *tip* (5.120) by using the dynamic mode and determining the *tip bias* (5.159)for a null alternating current

Note 1 to entry: Kelvin probes operate without contact.

5.77

lateral force

<AFM> force applied to the *probe tip* (5.120) in a direction in the surface plane and at right angles to the *cantilever* (5.18)

Note 1 to entry: In *AFMs* (3.2), the lateral direction is in the plane of the surface and the vertical direction is in the plane normal to the surface. In practice, of course, the *SPM* (3.30) can be mounted so that the surface normal is horizontal and it should be remembered that these terms refer to the surface plane and not the laboratory floor plane.

5.78

lateral spring constant

k_x, k_y

DEPRECATED: probe lateral stiffness

quotient of the applied *lateral force* (5.77) on a *cantilever* (5.18) at the *probe tip* (5.120) position on the cantilever by the lateral deflection of the cantilever at that position

Note 1 to entry: See *normal spring constant* (5.92), *torsional spring constant* (5.166).

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2) This information is given for the convenience of users of this document and does not constitute an endorsement by ISO TC 201/SC 1 of the product named. Equivalent products may be used if they can be shown to lead to the same results.

Note 2 to entry: The symbols k_x and k_y refer to the lateral spring constants for lateral motion at right angles to and along the cantilever axis, respectively.

Note 3 to entry: In *lateral-force microscopy* (3.13), it is the torsional spring constant and not the lateral spring constant that is usually required for interpreting measurements.

5.79
linker molecule
DEPRECATED: tether
molecule that attaches a target molecule or particle to a surface with a chemical bond

5.80
magnetic force
force acting between magnetic dipoles in a magnetic field

Note 1 to entry: In *SPM* (3.30), the magnetic dipoles are usually incorporated as ferromagnetic material in the *probe tip* (5.120) and it is the magnetic field of the sample that is measured.

5.81
meniscus force
force between *tip* (5.120) and sample arising from the presence of a condensed liquid layer in contact with both the tip and the sample

5.82
molecular pulling
force pulling
application of a tensile force to a molecule attached to a second molecule, a particle, or a surface to measure bond strength or folding properties

5.83
multi-frequency mode
method in which more than one frequency oscillation is applied to an AFM cantilever

Note 1 to entry: The frequency or frequencies are usually harmonics of the fundamental frequency used.

5.84
nano-antenna
<NSOM, SNOM> antenna of nanoscopic dimensions which couples light from the far field to the *near field* (5.88) and/or *vice versa*

Note 1 to entry: The nano-antenna may be a metal *tip* (5.120) or an antenna structure defined on an SPM probe using lithography or FIB processing.

5.85
nanoindentation
indentation of a surface where the indentation depth or the depth of the plastic deformation is less than 100 nm

5.86
nanomechanics
mechanical analysis of materials where significant inhomogeneity in the force or stress field occurs with scales less than 100 nm

Note 1 to entry: This term applies equally to a number of widely differing situations, including materials with internal inhomogeneities of less than 100 nm, materials probed mechanically with *probes* (5.109) smaller than 100 nm, and single molecules being unravelled.

5.87
nanoparticle
particle with one or more dimensions of the order of 100 nm or less

5.88

near field

<NSOM, SNOM> region closer than about one wavelength to a source of electromagnetic radiation, typically light

Note 1 to entry: For a Hertzian dipole, in the near field the magnetic field is proportional to r^{-3}, while the near-field electric field is proportional to r^{-2}, where r is the distance from the dipole. In the far field, where r is very much larger than one wavelength, both electric and magnetic fields exhibit r^{-1} behaviour. Therefore, sufficiently close to a light source of sub-wavelength dimensions, the electric and magnetic field strengths are dominated by their near-field components.

Note 2 to entry: As a consequence of Note 1, there is the potential for more information to be acquired by sampling the near field than can be obtained from far-field measurements or imaging, beyond simply improving *optical resolution* (5.94).

5.89

near-field Raman microscopy

<NSOM, SNOM> acquisition of Raman spectra from a defined small region following excitation of a sample using a near-field optical source

Note 1 to entry: See *apertureless Raman microscopy* (3.1).

5.90

non-contact mode

<AFM> mode of scanning the *probe* (5.109) in which there is always an attractive force between the probe and the sample

Note 1 to entry: See *contact mode* (5.35), *intermittent contact mode* (5.73), *tapping mode* (5.73).

Note 2 to entry: This mode can be, for example, the *constant-height* (5.34) or *constant-force mode* (5.33).

Note 3 to entry: The spatial resolution in *AFM* (3.2) in the static non-contact mode is generally much poorer than in the contact mode.

Note 4 to entry: AFM in the dynamic or frequency-modulated (FM) non-contact mode under ultra-high-vacuum conditions is able to achieve atomic resolution.

5.91

normal force

<AFM> applied force on the *probe tip* (5.120) normal to the surface

Note 1 to entry: Depending on the circumstances, this force can be the force normal to the average surface or the force normal to a small element of that surface.

5.92

normal spring constant

spring constant

force constant

DEPRECATED: cantilever stiffness

k_z

<AFM> quotient of the applied *normal force* (5.91) at the *probe tip* (5.120) by the deflection of the *cantilever* (5.18) in that direction at the probe tip position

Note 1 to entry: See *lateral spring constant* (5.78), *torsional spring constant* (5.166).

Note 2 to entry: The normal spring constant is usually referred to as the spring constant. The full term is used when it is necessary to distinguish it from the lateral spring constant.

Note 3 to entry: The force is applied normal to the plane of the cantilever to compute or measure the normal force constant, k_z. In application, the cantilever in *AFM* (3.2) can be tilted at an angle, θ, to the plane of the sample surface and the plane normal to the direction of approach of the tip to the sample. This angle is important in applying the normal spring constant in AFM studies.

5.93
numerical aperture
NA
<NSOM, SNOM> product of the refractive index of the medium in which the lens is working, n, and the sine of one-half of the angular aperture of the lens, θ

Note 1 to entry: The numerical aperture is given by NA = $n\sin\theta$, where 2θ is the full angular aperture of the lens.

Note 2 to entry: Most optical lenses are operated in air, which has a refractive index of little more than unity. However, operation in immersion oils, which have a considerably higher refractive index, sometimes even up to about 1,56, provides superior resolution.

5.94
optical resolution
<NSOM, SNOM> spatial resolution of an optical instrument

5.95
patch charge force
force between two surfaces arising from the electrostatic attraction or repulsion between surface patch charges

Note 1 to entry: Patch charge force is discussed in Reference.[15]

5.96
phase contrast
<AFM> contrast in *phase imaging* (5.97)

5.97
phase imaging
imaging using the phase difference between the applied signal for the sinusoidal force or position modulation and the measured signal for the sinusoidal force or position modulation

Note 1 to entry: The definition of phase imaging for *SPM* (3.30) given in this part of ISO 18115 is very different from, and should not be confused with, that relevant to optical or electron microscopy.

5.98
photobleaching
loss of optical *fluorescence* (5.52) in a fluorescent molecule

5.99
piezo force
<AFM> contact-mode *AFM* (3.2) in which electrical contact is made via a conductive *tip* (5.120) to a piezoelectric sample surface, the response of which to the applied electric field is a displacement that is measured via the AFM cantilever tip deflection

5.100
piezoelectric force
force between the *probe tip* (5.120) and the sample generated by the piezoelectric effect

Note 1 to entry: This term is not commonly used except to describe the degree to which a *piezoelectric material* (5.101) can move a mass or load. It is also used to describe the way in which piezoelectric displacement deflects an AFM cantilever, which has a well-defined mechanical *stiffness* (5.147).

5.101
piezoelectric material
material with a non-centro-symmetric unit cell such that, under an externally applied mechanical stress, an electrical charge is produced across the faces of the material

Note 1 to entry: Conversely, an externally applied electrical field produces mechanical strain in the sample. Piezoelectric materials are used as sensors and actuators. Piezoelectricity is the generation of electricity as a result of a mechanical pressure. Mechanical strain in crystals belonging to certain classes produces electrical **polarization**, the polarization being proportional to the strain and changing sign with that strain.

5.102

piezoelectric sensor (cantilever)

sensor (cantilever) utilizing the piezoelectric effect for transduction

Note 1 to entry: These sensors usually convert mechanical stress to electrical charge.

5.103

piezoresistive

material property in which a mechanical stress or strain-induced stress produces a change in the resistance of the material

Note 1 to entry: Although most materials are piezoresistive, silicon is known for being highly piezoresistive when appropriately doped.

5.104

piezoresistive cantilever

cantilever (5.18) made of, or including, a *piezoresistive* (5.103) material or region

Note 1 to entry: These cantilevers, typically of doped Si, can be used in resistive bridges in order to determine stress or strain.

5.105

pile-up

flow of material around an indenting *probe* (5.109) leading to a build-up of excess material around the rim of the indent

5.106

pitch

mean distance between corresponding features in a regular array of features on a surface

5.107

planar subtraction mode

mode in which data are recorded as the *tip* (5.120) traces at a given height above a plane defined by a least-squares fit through the pre-determined topography

Note 1 to entry: See *height tracking mode* (5.65), *topography tracking mode* (5.65).

Note 2 to entry: This approximate mode is used to remove the effects of topography from an *image* (5.69). Typical data that can be recorded are forces in general (such as magnetic forces), patch fields, etc.

Note 3 to entry: This mode is also known as planar subtract mode.

5.108

polarization

electric dipole moment per unit volume

Note 1 to entry: The polarization, P_i, is related to electric displacement, D, through the linear expression $D_i = P_i + \varepsilon_0 E_i$, where ε_0 (usually called the permittivity of free space) equals 8,854 × 10^{-12} coulombs/volt metre and E_i is the electric field.

5.109

probe

structure at or near the end or apex of the *cantilever* (5.18) designed to carry the *probe tip* (5.120)

Note 1 to entry: See *composite probe* (5.30).

5.110

probe characterizer

tip characterizer

structure designed to allow extraction of the *probe tip* (5.120) shape from a scan of the characterizer

[SOURCE: ASTM E1813-96]

5.111

probe flank

side of the *probe* (5.109) in the region between the *probe apex* (5.120) and the *probe support* (5.115) or, if there is no probe support, the *cantilever* (5.18)

5.112

probe length

distance between the *probe apex* (5.120) and the *probe support* (5.115) or, if there is no probe support, the *cantilever* (5.18)

5.113

probe shank

structure between the *probe apex* (5.120) and the *probe support* (5.115) or, if there is no probe support, the *cantilever* (5.18)

Note 1 to entry: For a *composite probe* (5.30), such as a *carbon nanotube probe* (5.23), focused ion beam machined probe, or electron beam deposition probe, this term is applied to the fine structure produced on the probe support to analyse the sample. The shank of the probe support is called the *probe support shank* (5.118).

Note 2 to entry: For a *probe* (5.109) with a higher aspect ratio portion nearer to the probe apex than the portion closer to the cantilever, fabricated by a process such as oxide sharpening, this term is applied to the nanostructure of the probe near the apex. This is typically within a few hundred nanometres of the *tip* (5.120) end. In this example, the single material of the probe has been engineered into two parts: the probe and the probe support.

5.114

probe stiffness

resistance of the *probe* (5.109) to flexing caused by *lateral forces* (5.77), expressed as a *force constant* (5.92) describing the lateral flexing of the probe under an impressed force

[SOURCE: ASTM E1813-96]

5.115

probe support

structure at or near the end or apex of the *cantilever* (5.18) designed to carry the *probe* (5.109)

Note 1 to entry: For work where particular probe qualities, such as probe *tip radius* (5.161), *probe stiffness* (5.114), or probe profile, are required, a special probe such as a carbon nanotube can be affixed to or grown on the end of a larger probe manufactured by traditional silicon foundry methods. This combination forms a *composite probe* (5.30), with the larger probe being termed the probe support.

5.116

probe support flank

side of the *probe support* (5.115) in the region between the *probe* (5.109) and the *cantilever* (5.18)

5.117

probe support length

length of the *probe support* (5.115) in the region between the *probe* (5.109) and the *cantilever* (5.18)

5.118

probe support shank

structure of the *probe support* (5.115) in the region between the *probe* (5.109) and the *cantilever* (5.18)

5.119

probe tilt angle

angle between the axis of the *probe* (5.109) and the normal to the plane of the *cantilever* (5.18)

Note 1 to entry: The azimuth of the tilt needs to be specified. Where there is no specification, it is assumed that the tilt direction is in the azimuth of the cantilever axis and a positive tilt angle is in the azimuth direction away from the *chip* (5.26) end and towards the *cantilever apex* (5.19).

5.120
probe tip
tip
probe apex
structure at the extremity of a *probe* (5.109), the apex of which senses the surface

Note 1 to entry: See *cantilever apex* (5.19).

5.121
protein unfolding
separation of the folds of a protein molecule

Note 1 to entry: Proteins can fold naturally to lower the system energy. Such proteins, when deposited on a surface, can be mechanically unfolded using an AFM probe tip specially functionalized to bond to one end of the protein molecule.

5.122
pulled tip
structure formed by pulling a ductile material, such as a metallic wire or optical fibre, often at elevated temperature, until separation occurs, leaving at least one *tip* (5.120) with a radius of curvature below 1 µm, and ideally in the range 10 nm to 50 nm

Note 1 to entry: Pulled tips can be used for imaging by one of the *scanning-probe microscopy* (3.30) methods, such as *NSOM/SNOM* (3.17).

5.123
pull-in force
pull-on force
force exerted by the surface on the *probe tip* (5.120) at *snap-in* (5.144)

5.124
pull-off force
force required to pull the *probe* (5.109) free from the surface

Note 1 to entry: This force is generally measured from the *force-distance curve* (5.56) as the value between the force minimum and the zero of force as the probe moves away from the surface.

5.125
pulsed-force mode
mode of scanning the *probe* (5.109) where the probe is continually undergoing *force-distance curve* (5.56) cycles at a cycle frequency below the resonant frequency of the *cantilever* (5.18)

Note 1 to entry: See *force-volume mode* (5.59).

Note 2 to entry: The operating frequency can be in the 100 Hz to 2 000 Hz range, and data for the maximum adhesion force or the sample local *stiffness* (5.147) can be recorded rather than the whole force-distance curve for each pixel.

5.126
***Q*-control**
electronic feedback system in the dynamic mode designed to change the apparent Q-value for an AFM cantilever

Note 1 to entry: This control may be used to raise or lower the Q-factor of a cantilever used in AFM.

Note 2 to entry: In liquids, the cantilever Q-factor is reduced and so *phase imaging* (5.97) is degraded. Raising the Q-factor improves the phase imaging quality.

5.127

quality factor

Q

energy stored in a given resonator for a particular resonant peak divided by the average energy lost per radian of oscillation, this average being over one cycle

Note 1 to entry: The resonator in this context can be, for example, an AFM cantilever operating in the *non-contact mode* (5.90) or an optical-fibre *probe* (5.109) or tuning fork assembly used with shear force sensing in *NSOM/SNOM* (3.17).

Note 2 to entry: A practical method of measuring the quality factor is to record a resonance curve as a function of frequency. It can be shown that Q is approximately equal to the resonant frequency divided by the bandwidth of the resonance, and that this approximation is excellent for quality factors above about 4.

Note 3 to entry: The bandwidth of the resonance can be measured from a plot of the square of the amplitude against frequency. The bandwidth is the frequency interval between the two points 3 dB below the peak maximum on either side of the peak. This is, to an error of less than 0,25 %, the full width at half maximum height (FWHM) of this curve, so the FWHM can be judged a more convenient and sufficiently accurate measure of bandwidth for many practical purposes.

5.128

Raman effect

<NSOM, SNOM> emitted radiation, associated with molecules illuminated with monochromatic radiation, characterized by an energy loss or gain arising from rotational or vibrational excitations

5.129

Raman spectroscopy

<NSOM, SNOM> spectroscopy in which the *Raman effect* (5.128) is used to investigate molecular energy levels

5.130

raster scanning

<SPM> two-dimensional pattern generated by the movement of a *probe* (5.109)

Note 1 to entry: Commonly used rasters cover square or rectangular areas.

5.131

Rayleigh criterion

<NSOM, SNOM> condition where the centre of the Airy disc from one *image* (5.69) is superimposed on the minimum from another nearby image

Note 1 to entry: The Rayleigh criterion is usually applied to circular *apertures* (5.5), where the criterion for resolution is when the centre of one Airy disc pattern falls on the first minimum of the Airy disc pattern of the second image. The angular separation, θ, is then given by $\theta = 1{,}22\lambda/D$, where λ is the wavelength of light and D is the aperture diameter.

5.132

reconstruction

<AFM> estimate of the sample’s (or tip’s) surface topography determined by removing from the *image* (5.69) the effect of the tip’s (or sample’s) shape and other measurement *artefacts* (5.6)

[SOURCE: ASTM E1813-96]

Note 1 to entry: See *blind reconstruction* (5.15), *dilation* (5.39),*erosion* (5.45).

Note 2 to entry: Reconstruction is most commonly used to estimate the tip shape when using a *probe characterizer* (5.110).

Note 3 to entry: The estimate can be made by, for example, erosion or erosion with refinements in order to correct the effects of tip or *cantilever* (5.18) bending or dynamic tip-sample effects.

Note 4 to entry: This term should not be confused with surface reconstruction, which is concerned with the rearrangement of the atoms on a crystalline surface as a result of annealing or the adsorption of gases, deposited atoms, etc., or as a result of surface relaxation.

5.133
reflection mode
<NSOM, SNOM> mode in which the light reflected from the sample is collected as an optical signal

5.134
resonance frequency
natural frequency of resonance of the *probe* (5.109) and support structure

Note 1 to entry: The resonance frequency is lower in air than in vacuum, and in water or other liquids it is lower still. The resonance frequency for a probe in contact with a sample may be higher or lower than the resonance frequency in air.

5.135
sample bias
voltage applied to the sample relative to the *probe tip* (5.120)

5.136
scanner
mechanism that scans the *probe tip* (5.120) relative to the sample

5.137
scanner creep
slow drift in the position addressed by a *scanner* (5.136)

Note 1 to entry: This effect depends on the extent of the excursion of the scanner from its previous position. For scanners without closed-loop control, creep is often in the forward direction and can lead to significant *image* (5.69) distortion.

Note 2 to entry: Creep values for piezo tube scanners, without closed-loop control, are given by the ratio of the drift in position to the total change in position used. This ratio is usually expressed as a percentage. The extent of the drift following a change in position, D, can reach an asymptotic value, kD, in the range from 1 % up to 20 % of D, with an exponential time constant, t_0, in the range 10 s to 100 s. Thus, the position at time t becomes $D\{1 + k[1 - \exp(-t/t_0)]\}$.

5.138
scanner hysteresis
difference in position of the *scanner* (5.136) in a given direction between the forward and backward movements of that scanner

Note 1 to entry: See *scanner creep* (5.137).

Note 2 to entry: This effect leads to nonlinear scans, poor repeatability of *image* (5.69) registration, image distortion, and differences in positioning with scan direction that depends on the extent of the excursion of the scanner from its previous position. Scanner hysteresis can largely be corrected by using a closed-loop feedback system or compensated for, and so reduced, by using appropriate voltage waveforms.

Note 3 to entry: Hysteresis values for piezo tube scanners, without closed-loop control, are given by the ratio of the maximum of the deviations in position between the forward and reverse scans to the total scan length used. This ratio is usually expressed as a percentage. Typical hysteresis values are in the range up to 20 %. The nonlinearity is generally half of this value.

Note 4 to entry: Scanner hysteresis values are time-dependent and involve *scanner creep* (5.137).

5.139
scanning rate
rate of the raster scan driving an SPM tip

Note 1 to entry: It is expressed as the number of the lines of the image scanned per second or the frequency of repeating the line scan, in hertz.

5.140
second harmonic generation
SHG
non-linear effect in which light is scattered with twice the frequency of the incident light

Note 1 to entry: In *NSOM/SNOM* (3.17), *tip enhancement* (5.160) can lead to second harmonic generation when a metal *tip* (5.120) is used, or lead to an increase in second harmonic generation from the surface in close proximity to the tip.

Note 2 to entry: For incident light, the lack of symmetry at a surface or at a buried interface can lead to SHG.

5.141
set point
value of a parameter that an instrument tries to maintain constant when operating in a feedback mode by adjusting the *tip* (5.120) to sample distance

Note 1 to entry: When operating an *AFM* (3.2) in the *contact mode* (5.35) at constant force, the set point parameter is a force that is sometimes called the set force. In the dynamic mode, the set point could be for a vibrational amplitude, frequency, or phase.

5.142
sink-in
flow of material around an indenting *probe* (5.109), leading to a reduction of material around the rim of the indent

5.143
skin depth
<NSOM, SNOM> depth of penetration of the propagating electric field into the metal coating of the optical fibre in a fibre-based NSOM/SNOM probe

5.144
snap-in
snap-on
DEPRECATED: jump to contact
event that occurs when the *tip* (5.120) is brought close enough to the surface for the force gradient arising from surface attractive forces to exceed the *cantilever* (5.18) restorative force gradient, causing the tip to spring into contact with the surface

5.145
soft lithography
fabrication or replication of a structure using an elastomeric stamp, mould, or conformable photomask

5.146
stiction
phenomenon in which the surface adhesion forces between solids in contact, but unbonded, either exceed the mechanical force designed to separate the solids or significantly affect the separation behaviour

Note 1 to entry: Stiction occurs in MEMS device manufacture when components are removed from aqueous solutions. It is often overcome using suitable low *surface energy* (5.150) treatments that can involve *monolayer* (4.307) adsorption.

Note 2 to entry: This problem can be studied using *AFM* (3.2).

5.147
stiffness
resistance of an elastic material to deflection by an applied force

Note 1 to entry: The directions of the deflection and the applied force might not be the same. The relationship between these two vectors is characterized by the stiffness matrix.

5.148
Stokes scattering

Raman effect (5.128) where the emitted photon has lower energy than the incident photon

Note 1 to entry: See *anti-Stokes scattering* (5.4).

5.149
stretching length

amplitude of molecular strain just prior to bond failure

5.150
surface energy

quotient of the energy required to increase a surface area at thermodynamic equilibrium by that increase in area

Note 1 to entry: This term should more precisely be the areic surface energy or the surface energy per unit area since the dimensions are of energy per unit area. However, in the literature, the abbreviated term surface energy is in common usage.

Note 2 to entry: This term has no relation to surface energy approximation used in EIA (energetic-ion analysis) and RBS (Rutherford backscattering spectrometry).

5.151
surface-enhanced Raman scattering
SERS

enhanced *Raman effect* (5.128) observed for certain molecules close to appropriately prepared metal surfaces, where Raman scattering cross sections are many orders of magnitude greater than for the same molecules in the absence of an appropriately prepared metal surface

Note 1 to entry: The acronym SERS is used for both surface-enhanced Raman scattering and spectroscopy.

Note 2 to entry: The enhancement is particularly strong for gold and silver surfaces of appropriate topography when excited by a laser at the correct wavelength.

Note 3 to entry: Surface-enhanced Raman scattering is utilized in *TERS* (3.42).

5.152
surface-enhanced Raman spectroscopy
SERS

spectroscopy using *surface-enhanced Raman scattering* (5.151)

Note 1 to entry: The acronym SERS is used for both surface-enhanced Raman scattering and spectroscopy.

5.153
surface-enhanced resonant Raman scattering
SERRS

surface-enhanced *Raman effect* (5.128) in which the energy of the incident or scattered radiation is in resonance with an optical transition in the molecule

Note 1 to entry: The acronym SERRS is used for both surface-enhanced resonant Raman scattering and spectroscopy.

5.154
surface-enhanced resonant Raman spectroscopy
SERRS

spectroscopy using *surface-enhanced resonant Raman scattering* (5.153)

Note 1 to entry: The acronym SERRS is used for both surface-enhanced resonant Raman scattering and spectroscopy.

5.155
surface patch charge
local charge arising from variations in the local *work function* (4.487) of a solid surface

Note 1 to entry: The surface patch charge arises as a result of variations in the strengths of the surface dipole layer and its associated electrostatic field at the surface (patch field effect). Gauss's law implies that such a field will lead to the appearance of charges at the surface. These variations can arise from regions of a polycrystalline surface having different crystal orientations or from regions with adsorbed layers with different local morphologies or from regions with different local absorbed or adsorbed layers.

5.156
target group
molecular group with specific binding to a defined functional group

5.157
thermal drift
parameter change as a result of the effects of heat or temperature changes

5.158
tilt-compensated probe
<AFM> *cantilever* (5.18) with a *probe* (5.109) that is tilted with respect to the cantilever plane such that, when mounted, the probe addresses the surface normally

5.159
tip bias
voltage applied to the *tip* (5.120) measured relative to the sample

5.160
tip enhancement
<NSOM, SNOM> enhancement of an optical signal, usually in the *near-field* (5.88) regime, obtained through the interaction of the electrons at the *tip* (5.120) end and the illuminating light

Note 1 to entry: See *scattering NSOM/SNOM* (3.36), *surface-enhanced Raman scattering* (5.151).

Note 2 to entry: Enhancements are usually obtained using a metallized *AFM* (3.2) tip.

Note 3 to entry: Tip enhancement is important in techniques such as *near-field Raman microscopy* (5.89), where some tip materials and structures can lead to surface-enhanced Raman signals many orders of magnitude larger than would otherwise be expected.

5.161
tip radius
<excluding scattering NSOM/SNOM> radius describing the surface curvature in a region at the apex of a stylus or *probe tip* (5.120)

Note 1 to entry: It might be necessary to describe the tip by radii in different azimuths.

Note 2 to entry: In practice, tips can only approximate a sphere for a very small region at the tip.

5.162
tip radius
<scattering NSOM/SNOM> radius describing a circular region at the *probe tip* (5.120) from which evanescent light of a significant intensity is emitted

5.163
tip-sample contact radius
maximum radius of the contact area between the *tip* (5.120) and the sample at the maximum indentation depth

5.164

tip side (of a cantilever)

side of a *cantilever* (5.18) on which the *probe tip* (5.120) is mounted

Note 1 to entry: See *detector side (of a cantilever)* (5.38), *cantilever back side* (5.21).

5.165

topographic contrast

contrast in a *map* (5.69) or *image* (5.69) arising from the topography of the sample surface

Note 1 to entry: Topographic effects may modify the interaction between the *probe* (5.109) and the sample, making the interpretation of other data more complex than otherwise.

5.166

torsional spring constant

k_θ

<AFM> quotient of the applied torque at the *probe tip* (5.120) about the *cantilever* (5.18) axis by the torsional rotation about that axis at the probe tip position

Note 1 to entry: See *lateral spring constant* (5.78),*normal spring constant* (5.92).

5.167

transmittance

fraction of incident light that passes through a sample

Note 1 to entry: The transmittance is usually defined at a specified wavelength.

5.168

tuning fork detection

detection of the tip-sample distance using oscillations of amplitude driven by a quartz tuning fork attached to a *cantilever* (5.18) or optical-fibre *probe* (5.109)

5.169

tunnelling

quantum-mechanical transport of electrons across a region with a potential energy higher than the electron energy

5.170

tunnelling probability

probability that an electron will traverse the *tunnelling barrier* (5.12)

Note 1 to entry: In this quantum-mechanical phenomenon, the tunnelling probability is related to the electron energy, the *barrier height* (5.10), and the *barrier width* (5.13).

5.171

van der Waals force

attractive or repulsive force between molecular entities (or between groups within the same molecular entity) other than those due to bond formation or to the electrostatic interaction of ions or ionic groups with one another or with neutral molecules

[SOURCE: IUPAC]

Note 1 to entry: The term includes dipole-dipole, dipole-induced dipole, and London (instantaneous induced dipole-induced dipole) forces. The term is sometimes used loosely for the totality of non-specific attractive or repulsive intermolecular forces.

5.172

vector scanning

scanning method that drives the *probe tip* (5.120) on a defined vector trajectory in the *image* (5.69) plane

5.173
warp
distance between the upper and lower extremities of a sample surface measured at right angles to a reference plane that is defined either by three equidistant points on the surface in a circle around the centre of the sample surface with a radius suitable to cover the surface defined or by a least squares planar fit to the surface

Note 1 to entry: See *bow* (5.16), *flatness* (5.50).

Note 2 to entry: The method of defining the reference plane should be stated.

Note 3 to entry: This term is applied to surfaces whose out-of-flatness is more complex than concave or convex, i.e. they have more than one extremity from the reference plane that is not at the perimeter.

5.174
Wollaston wire
wire *probe* (5.109) comprising an electrically heated platinum *tip* (5.120) in which the electrical resistance is used to measure the temperature of the tip in order to conduct micro-thermal analysis

5.175
work of adhesion
energy required when two condensed phases, forming an interface of unit area, are separated reversibly to form unit areas of the free surfaces of those two phases

Note 1 to entry: This term is sometimes also known as the work of separation or the Dupré work of adhesion.

5.176
worm-like chain
<polymers> model of the polymer backbone with a continuous, random curvature

6 Definitions of supplementary scanning-probe microscopy methods

6.1
amplitude modulation atomic-force microscopy
AM-AFM
dynamic-mode AFM (3.6) in which the probe assembly is excited at a fixed frequency

Note 1 to entry: See *FM-AFM* (3.10).

Note 2 to entry: The tip-sample interaction force is detected as a reduction in the cantilever oscillation amplitude. A feedback loop varies the tip-sample separation to try to keep the amplitude of the cantilever oscillation constant.

6.2
amplitude modulation Kelvin-probe force microscopy
AM-KPFM
dynamic-mode KPFM in which the probe assembly is excited at a fixed frequency

Note 1 to entry: See *FM-KPFM* (6.6), *AM-AFM* (6.1).

Note 2 to entry: The tip-sample interaction force is detected as a reduction in the cantilever oscillation amplitude. A feedback loop varies the tip-sample separation to try to keep the amplitude of the cantilever oscillation constant.

6.3
ballistic electron emission microscopy
BEEM
STM (3.34) mode in which electrons are injected from the tip into the grounded metal base of a Schottky diode, some travelling ballistically through the metal to the metal-semiconductor interface where those with sufficient energy to surmount the Schottky barrier there are detected as the BEEM current

6.4
contact resonance force microscopy
CRFM
contact resonance atomic-force microscopy
CRAFM

contact-mode AFM in which the probe assembly is excited over a range of frequencies covering the free air resonance frequency or one of its harmonics and the resonant frequency or one of its harmonics in contact is determined

Note 1 to entry: The data provide the local stiffness at the sample surface and may be used to deduce the storage and loss moduli of viscoelastic materials as well as subsurface materials properties. To provide accurate local stiffness, the tip and the cantilever properties should be both carefully characterized, rather than using their nominal values.

6.5
electrochemical scanning-probe microscopy
EC-SPM

SPM (3.30) mode that includes the measurement of electrochemical activity of a surface

Note 1 to entry: EC-SPM includes *EC-AFM* (3.8), *EC-STM* (3.9), *SECM* (3.22), and SECM-AFM.

6.6
frequency modulation Kelvin-probe force microscopy
FM-KPFM

dynamic-mode KPFM in which the shift in resonant frequency of the probe assembly is monitored and is adjusted to a set point using a feedback circuit

Note 1 to entry: See *FM-AFM* (3.10).

6.7
hopping probe ion conductance microscopy
HPICM

SICM (3.24) mode in which, at each pixel, the surface is approached with the pipette until the ion current drops to a pre-determined set point, then the height of the pipette is recorded at this point and the pipette is retracted

Note 1 to entry: This technique does not rely on adjacent pixels to be measured consecutively, thus allowing different sections of an image to be mapped at different resolutions and with varying “hop heights” to decrease imaging times.

6.8
inelastic electron tunnelling spectroscopy
IETS

spectroscopy arising from the tunnelling current through a junction in which the tunnelling electrons, at a particular energy, have enhanced transmission as a result of the presence of vibrational states associated with molecules within the junction

Note 1 to entry: The effect is very small and occurs as a small step in the current/voltage curve for the junction. It is usually observed in the second derivative of this curve. In early work, junctions were formed over a significant area of oxidized aluminium by coating with an organic molecule to be studied and then applying a further electrode. More recent work uses tunnelling in the *STM* (3.34). In both cases, to obtain highly resolved spectra, very low temperatures are required.

6.9
metrological scanning probe microscope
metrological SPM

SPM (3.30) with one or more parameters calibrated at the highest level of accuracy

Note 1 to entry: Such SPMs are often used to provide traceability to other SPMs or to establish the scientific principles of nanoscale behaviour.

Note 2 to entry: The term "metrological SPM" may be used with any specific microscope in place of SPM, such as "metrological AFM" or "metrological SNOM", to deliver traceability through, for example, calibrated artefacts for the x-, y-, or z-scales or to measure, with high accuracy, relevant mechanical or optical properties of samples.

6.10
nano-impedance spectroscopy
NIS

SPM (3.30) mode in which a conductive probe is used to measure both topography and impedance between the tip and the sample

Note 1 to entry: See *SIM* (6.16).

Note 2 to entry: The conductive tip may be gold-coated silicon and the impedance may be measured in the usual way by an impedance analyser over a range of frequencies.

6.11
piezoresponse force microscopy
PFM

SPM (3.30) mode mapping the surface topography in contact mode whilst, simultaneously, measuring the piezoresponse force

Note 1 to entry: An alternating voltage bias is applied to the probe tip. The phase and amplitude of the AC component of the tip's motion give the piezoresponse of the sample and are collected by a phase-sensitive amplifier, allowing imaging of ferroelectric domains.

Note 2 to entry: Crucially, the technique depends on the use of "locking in" to the displacement response related to the applied oscillating voltage. Only in this way can picometre sensitivity currently be achieved.

6.12
polarization NSOM/SNOM

NSOM/SNOM (3.17) in which the intensity and/or polarization of the light in the interaction with the sample is measured

Note 1 to entry: The light polarization is important for measuring surfaces that exhibit optical anisotropy, e.g. the physical orientation of surface molecules. This can provide data not observed by other methods and can be coupled with optical spectroscopic methods.

6.13
scanning capacitance force microscopy
SCFM

mode of *AFM* (3.2) in which an alternating or constant electric field is applied between the conducting tip and the sample and the induced electrostatic force is used to map electrical properties such as the differential capacitance ($\partial C/\partial V$)

Note 1 to entry: SCFM is usually used for semiconducting samples.

Note 2 to entry: SCFM allows mapping of the differential capacitance ($\partial C/\partial V$) without an external capacitance sensor.

Note 3 to entry: If the alternating electric field is at an angular frequency ω, then the magnitude of the induced electrostatic force is proportional to the square of the magnitude of the applied electric field and the capacitance of the semiconducting sample is modulated at ω, and the amplitude and the phase of the induced electrostatic force oscillating at 3ω contain information on $\partial \mathrm{C}/\partial \mathrm{V}$. This mode eliminates topography more effectively than the similar mode using signals at 2ω.

Note 4 to entry: SCFM has been applied to the investigation of two-dimensional carrier (dopant) profiles in metal-oxide-semiconductor field effect transistors (MOSFETs).

6.14
scanning electrochemical microscopy - scanning ion conductance microscopy
SECM-SICM

SICM mode where the pipette has an additional electrode to monitor the electrochemical activity that is positioned near the tip aperture

Note 1 to entry: The ion current is used as the feedback parameter.

6.15
scanning gate microscopy
SGM

SPM (3.30) mode in which an electrically conductive probe is used as a movable gate that couples capacitively to the sample to measure the electrical conductance as a function of the probe's position and potential

6.16
scanning impedance microscopy
SIM

SPM (3.30) mode in which an electrically conductive probe is used to map the phase and amplitude of local potential with respect to an electric field applied across the sample

Note 1 to entry: See *NIS* (6.10).

Note 2 to entry: SIM can give quantitative imaging of AC and DC transport properties of electrically inhomogeneous materials.

6.17
scanning micropipette contact method
SMCM

mode of *SECM* (3.22) using a *double-barrelled micropipette* (7.6) filled with an electroactive species in an electrolyte solution that forms a liquid meniscus at the double-barrelled pipette apertures

Note 1 to entry: The surface that is probed does not require solution immersion but instead the surface forms the working electrode when the liquid meniscus makes contact with the surface.

6.18
scanning surface confocal microscopy
SSCM

method for acquiring simultaneous topographical and optical property imaging of a surface using a combined height-measuring *SPM* (3.30) and a scanning confocal microscope

Note 1 to entry: The SPM allows accurate height tracking of the surface whose reflections may otherwise lead to errors in a stand-alone confocal microscope. Additionally, the optical properties at the sample surface can be measured in one raster scan of the surface, compared to conventional scanning confocal microscope where multiple optical sections of the sample must be scanned to image the surface.

Note 2 to entry: The optical properties measured are usually either fluorescence or Raman intensities.

Note 3 to entry: If the SPM is a *SICM* (3.24), the confocal objective is focused at a point relative to the pipette aperture while, usually, the surface itself is displaced.

6.19
scanning tunnelling hydrogen microscopy
STHM

<STM> constant-height *STM* (3.34) mode that uses an STM tip with a single hydrogen molecule attached to the tip apex

Note 1 to entry: The STM tip is functionalised by exposing the tip to hydrogen gas at 10 K.

Note 2 to entry: The atomic resolution of planar molecules attached to a surface can be achieved with this technique.

Note 3 to entry: STHM should not be confused with SThM.

6.20
switching spectroscopy piezoresponse force microscopy
SS-PFM
PFM (6.11) mode in which point measurement of the piezoresponse as a function of voltage is mapped across the sample surface

6.21
vector PFM
3D-PFM
PFM (6.11) mode that combines, vectorially, the vertical piezoresponse and the two orthogonal components of the lateral piezoresponse

6.22
vertical PFM
PFM (6.11) mode in which the piezoresponse response is measured only in the cantilever direction normal to the sample plane

7 Definitions of supplementary terms for scanning-probe methods

7.1
active damping
electronic method of simulating the effects of damping in SPM systems usually to reduce vibrations, particularly resonant vibrations, originating in the scanner structure

7.2
Amonton's law
law in which the friction force is proportional to the load applied perpendicularly to the surface

Note 1 to entry: At the nanoscale, Amonton's law, which operates well for macroscopic samples with many minute asperities, was not expected to be valid. For non-adhering surfaces, it may still be a useful approximation.

7.3
AM-AM method
<EFM> method in which the control of the probe-to-sample distance and the detection of the electrostatic force both use amplitude modulation

7.4
contrast
<TERS> ratio of the optical intensity measured at a given wavelength with the tip present to that in the absence of the tip

Note 1 to entry: An alternative definition of the ratio of the optical intensity arising from the near-field to that arising from the far-field gives a value 1 less than that in the above definition and is deprecated.

7.5
corrected profile
profile deduced from the measured profile after full or partial removal of defined distortional effects

Note 1 to entry: The distortional effects may be dilating effects of the finite size of the scanning probe and/or inaccuracies of the scanner displacements, such as *bow* (5.16), *warp* (5.173), nonlinearity, non-orthogonality, and drift.

7.6
double-barrelled micropipette
pair of micropipettes aligned side by side

Note 1 to entry: Micropipettes have a bore at the tip greater than approximately 100 nm.

7.7
double-barrelled nanopipette
pair of nanopipettes aligned side by side

Note 1 to entry: Nanopipettes have a bore at the tip equal to or less than approximately 100 nm.

7.8
dual intermittent contact mode
dual AC mode
<AFM> mode of scanning the *probe* (5.109) where the probe is operated with a *z*-displacement modulation combined of two frequencies at or near the cantilever’s resonance modes such that the probe tip makes contact with the sample for a fraction of the cycle

Note 1 to entry: See *intermittent contact* (5.73).

Note 2 to entry: The modulation is usually applied to the first harmonic and with lower amplitude to the second harmonic.

7.9
enhancement factor
<TERS> ratio of the optical intensity measured at a given wavelength with the probe tip present to that in the absence of the probe tip, scaled to equal areas of emission

Note 1 to entry: The enhancement factor is the product of the *contrast* (7.4) and the ratio of the areas analysed without the probe tip and with the probe tip. An alternative definition involving scaling to equal volumes of emission is deprecated.

7.10
F-d curve
abbreviation of *force-displacement curve* (5.56)

7.11
fluorophore
molecular entity that emits *fluorescence* (5.52)

Note 1 to entry: The entity is often organic.

7.12
FM-AM method
<EFM> method in which the control of the probe-to-sample distance uses frequency modulation and the detection of the electrostatic force uses amplitude modulation

7.13
four-point probe
arrangement of four probes for measuring the conductivity, usually at semiconductor surfaces

7.14
four-tip STM
technique for measuring spatially-resolved conductivity at semiconductor surfaces by the *four-point probe* (7.13) method in which the contact of each probe is governed by a tunnelling measurement

Note 1 to entry: See *multi-probe SPM* (7.21).

7.15
Green’s function STM
multi-tip STM in which the tip spacing is comparable to the coherence length of the carriers in a semiconductor to provide real-space mapping of Green’s function

7.16
heterodyne detection

method detecting a signal of one frequency by non-linear mixing with a signal from a reference frequency

Note 1 to entry: In this mode, any high-frequency components and constant components are filtered out, leaving the intermediate (beat) frequency equal to the difference in the two frequencies. The amplitude of the beat frequency is proportional to the amplitude of the signal. The phase of the signal may be recovered as well.

7.17
ideal profile

profile expected from the fabrication of the artefact being measured and ignoring the distorting effects of the scanning probe

Note 1 to entry: See *true profile* (7.28).

Note 2 to entry: This profile may be a simple shape or a more complex shape depending on the knowledge of the roughness or other effects included in the fabrication.

7.18
lateral PFM

piezoresponse measured only in the surface plane

7.19
lift mode

mode in which the topography is first measured and then, in a second scan across the same line, one or more physical properties are measured while the tip and sample are kept at a constant separation using the topography data

Note 1 to entry: Commonly measured physical properties are electrical, magnetic, or optical.

7.20
measured profile

profile as measured for a stated property in a stated direction in the x-y plane of the scanning system after a stated data processing action

Note 1 to entry: The property measured is often height and the data processing may involve line-by-line levelling or removal of a general plane to level the data.

7.21
multi-probe SPM

SPM using several *probes* (5.109) and/or *cantilever* (5.18)

Note 1 to entry: See *four-point probe* (7.13).

7.22
nanolithography

deposition or removal of material on a surface, or local modification of surface properties, with positioning control at scales less than 100 nm

Note 1 to entry: Methods of depositing, removing, and modifying materials at very high spatial resolution include the use of the beam methods involving electrons, ions, and ultraviolet light. Such changes may also be made with many scanned probe methods involving localized electrochemistry to remove, deposit, or oxidize, the *AFM* (3.2) to physically remove or relocate material, and *dip pen nanolithography* (5.40).

7.23
nanotweezers

device for holding and manipulating nanoparticles at surfaces with positioning control at scales less than 100 nm

Note 1 to entry: Nanotweezers may use optical, mechanical, electrical, or other properties to effect the holding and manipulation.

7.24

PFM phase

phase angle, θ, of *PFM* (6.11) signal

Note 1 to entry: The phase angle, θ, is usually from a phase-sensitive (lock-in) amplifier and is measured in degrees.

7.25

roughness

*R*q

root mean square value of the difference between the measured profile and a reference profile

Note 1 to entry: This definition of roughness is not as complete as those in ISO 4287 and ISO 25178-2. There, one needs to consider the effective filters that are operational in the measurement. Depending on the filters used, the above may be a measure of the profile, *P*q, the roughness, *R*q, or the waviness, *W*q. SPM users do not currently do this and do not intentionally apply a filter. The shortness of the SPM scan, usually, in effect places a short filter to the data such that it is *R*q that is measured, rather than *P*q or *W*q. Furthermore, the flattening and other data processing usually applied to SPM images usually removes all roughness contributions with wavelengths longer than the scan length. The above definition is intended to give a clear description of how the roughness is calculated when using SPMs. These values will not necessarily compare with values determined by other methods for which the fuller definition is appropriate, not least because of the different spatial resolution available with SPMs.

Note 2 to entry: In general, in SPMs, it is assumed that any line scan is equivalent to any other and that if an area is used, the *R*q will be better defined. This area measurement is usually called *S*q (ISO 25178-2).

Note 3 to entry: For most surfaces studied in SPMs where roughnesses are assessed, the reference profile is the average height of the surface. In this case, a least-squares line may be fitted to a single-line trace and subtracted or a least squares surface is fitted to the whole data array and subtracted. In different situations, the line or surface may have no curvature, or a second order or higher curvature. If the roughness to be quoted concerns the quality of the finish of a shape, the reference profile may be the smoothed, ideal profile. The given profile should be stated where the average height of the surface is not used.

Note 4 to entry: In ISO 4287, other measures of roughness may be found but are seldom used in SPM studies.

7.26

torsional harmonic cantilever

rectangular cantilever for *tapping mode* (5.73) measurements with a hammerhead end to hold a laterally offset tip designed to oscillate torsionally such that effects at harmonic torsional frequencies may be measured

Note 1 to entry: This mode has been used to measure the elastic modulus of soft materials with high spatial resolution.

Note 2 to entry: Harmonics as high as 20 may be used.

7.27

torsional intermittent contact mode

torsional tapping mode

mode involving intermittent contact using a torsionally active *cantilever* (5.18)

7.28

true profile

actual profile of the sample for a stated property in a stated direction in the *x*-*y* plane of the sample with no distortions from measurement

Note 1 to entry: See *ideal profile* (7.17).

Note 2 to entry: True profiles exist in simulations but, of course, in practice any correction of a measured profile is only an approximation of the true profile. So a corrected result may be within, say, 1 nm of the true profile.

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