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AMENDMENT 2
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Surface chemical analysis — Vocabulary —

AMENDMENT 2

Analyse chimique des surfaces — Vocabulaire —

AMENDEMENT 2

Reference number
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Foreword

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

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

Amendment 2 to ISO 18115:2001 was prepared by Technical Committee ISO/TC 201, *Surface chemical analysis*, Subcommittee SC 1, *Terminology*.

Introduction

In ISO 18115:2001, 350 terms for surface chemical analysis are provided. However, from time to time new terms need to be defined and these will appear in Amendments to ISO 18115. In the first amendment, ISO 18115:2001/Amd.1, five abbreviations and 71 terms were added. Many of these terms covered concepts in glow discharge analysis. None of the previous terms were changed. In this second amendment, a further 87 terms, many for secondary-ion mass spectrometry, elastic peak electron spectroscopy and reflected electron energy loss spectroscopy, 76 acronyms for scanned probes, 33 definitions of techniques, six terms for contact mechanics and 147 terms for concepts in scanned probe analysis are included. Additionally, term 5.24, “attenuation length”, in ISO 18115:2001 has had a sentence added clarifying Note 2 and term 5.25, “attenuation length, effective”, has been revised to make it more general. The previous term 5.25 is still valid as one usage of the revised definition.

This Amendment has been prepared in conformance with the principles and style defined in ISO 1087-1, *Terminology work — Vocabulary — Part 1: Theory and application*, and ISO 10241, *International terminology standards — Preparation and layout*. It should be noted that, as in ISO 18115, a term printed boldface in a definition or a note is defined in another entry. However, the term is printed boldface only the first time it occurs in each entry. A term listed lightface is non-preferred or deprecated. The preferred term is listed boldface. 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, on the same line.

The abbreviations given here add to those given in Clause 2 of ISO 18115:2001. The terms given here form new Clauses 7, 8, 9 and 10. An alphabetical index for this Amendment is given after the terms and definitions. The indexes for ISO 18115:2001 and ISO 18115:2001/Amd.1:2006 are given immediately after this for convenience. To assist retrieval, compound terms may be found in these indexes in both natural and reverse word order. It is recommended that users searching for a term start with these indexes.

Surface chemical analysis — Vocabulary —

AMENDMENT 2

Page 1, following the title to Clause 2

Insert the following subclause title:

2.1 Abbreviations for analytical techniques

Page 2, at the end of the current list of acronyms

Insert the following subclause title and list of abbreviations:

2.2 Abbreviations for scanned probe microscopy

In the list below, note that the final “M” and the final “S”, given as “microscopy” and “spectroscopy”, may also mean “microscope” or “spectrometer”, respectively, depending on the context. Items defined later, or with key words defined, are indicated in brackets.

AFM	atomic force microscopy (see 8.4)
ANSOM	apertureless near-field scanning optical microscopy (see 8.2)
ASNOM	apertureless scanning near-field optical microscopy (see 8.2)
BEEM	ballistic electron emission microscopy (cf. 10.7)
BEES	ballistic electron emission spectroscopy (cf. 10.7)
CAFM	conductive atomic force microscopy (see 8.5)
CFM	chemical force microscopy (cf. 10.17)
CITS	current imaging tunnelling spectroscopy (see 8.6)
DFM	dynamic force microscopy (see 8.7)
DMM	displacement modulation microscopy
DTM	differential tunnelling microscopy
EC-AFM	electrochemical atomic force microscopy (see 8.9)
ECFM	electrochemical force microscopy
EC-SPM	electrochemical scanning probe microscopy
EC-STM	electrochemical scanning tunnelling microscopy (see 8.10)
EFM	electrostatic force microscopy (see 8.8)
FFM	frictional force microscopy (cf. 10.49)
FM-AFM	frequency modulation atomic force microscopy (cf. 10.43)

FMM	force modulation microscopy (cf. 10.43)
FRET	fluorescent resonance energy transfer (see 10.42)
FS	force spectroscopy
IC	intermittent contact (see 10.58)
IETS	inelastic electron tunnelling spectroscopy
IFM	interfacial force microscopy
KFM	Kelvin force microscopy (cf.10.61)
KPM	Kelvin probe microscopy (cf.10.61)
LFM	lateral force microscopy (cf.10.62)
LFMM	lateral force modulation microscopy (cf.10.62)
MDFM	magnetic dynamic force microscopy (see 8.11)
MDM	microwave dielectric microscopy
MFM	magnetic force microscopy (cf. 10.65)
MOKE	magneto-optic Kerr effect
MRFM	magnetic resonance force microscopy (see 8.12)
MTA	micro-thermal analysis
NC-AFM	non-contact atomic force microscopy (cf. 10.73)
NIS	nano-impedance spectroscopy
NSOM	near-field scanning optical microscopy (see 8.13)
PF-AFM	pulsed force atomic force microscopy (cf. 10.104)
PFM	piezoresponse force microscopy (cf. 10.82)
PSTM	photon scanning tunnelling microscopy
PTMS	photothermal micro-spectroscopy (see 8.14)
RNSOM	reflection near-field scanning optical microscopy
RSNOM	reflection scanning near-field optical microscopy (cf. 10.112)
SCM	scanning capacitance microscopy (see 8.15)
SCPM	scanning chemical potential microscopy (see 8.16)
SECM	scanning electrochemical microscopy (see 8.17)
SERRS	surface enhanced resonant Raman spectroscopy (see 10.128)
SERS	surface enhanced Raman scattering (see 10.126)
SFM	scanning force microscopy (see 8.4)
ShFM	shear-force microscopy (see 8.29)
SHG	second harmonic generation
SHPFM	second harmonic piezo force microscopy

SHPM	scanning Hall probe microscopy (see 8.18)
SICM	scanning ion conductance microscopy (see 8.19)
SIM	scanning impedance microscopy
SKPM	scanning Kelvin probe microscopy (cf. 10.61)
SMRM	scanning magneto-resistance microscopy (see 8.20)
SMSM	scanning Maxwell stress microscopy (see 8.21)
SNDM	scanning non-linear dielectric microscopy (see 8.22)
SNOM	scanning near-field optical microscopy (see 8.13)
SNTM	scanning near-field thermal microscopy
SPM	scanning probe microscopy (see 8.23)
SP-STM	spin polarized scanning tunnelling microscopy (see 8.30)
SP-STS	spin polarized scanning tunnelling spectroscopy (see 8.31)
SRTM	spin resolved tunnelling microscopy
SSM	scanning superconducting interference device (SQUID) microscopy
SSPM	scanning surface potential microscopy (see 8.25)
SSRM	scanning spreading resistance microscopy (see 8.24)
STM	scanning tunnelling microscopy (see 8.27)
SThM	scanning thermal microscopy (see 8.26)
STS	scanning tunnelling spectroscopy (see 8.28)
TERS	tip enhanced Raman scattering (cf. 10.134)
TNSOM	transmission near-field scanning optical microscopy
TSM	thermal scanning microscopy (deprecated, see 8.26)
TSNOM	transmission scanning near-field optical microscopy
UFM	ultrasonic force microscopy (see 8.33)

NOTE KFM is sometimes given as KPFM for Kelvin probe force microscopy, but this practice is deprecated. 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.

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In Note 2 to term 5.24, **attenuation length**, insert the following sentence between the existing first and second sentences: “Nevertheless, for some measurement conditions in **AES** and **XPS**, the signal intensity may depend approximately exponentially on path length, but the exponential constant (the parameter l) will then normally be different from the corresponding **inelastic mean free path**.” In addition, change “this” to “that” in the following sentence so that Note 2 reads:

> NOTE 2 For electrons in solids, the behaviour only approximates to an exponential decay due to the effects of **elastic scattering**. Nevertheless, for some measurement conditions in **AES** and **XPS**, the signal intensity may depend approximately exponentially on path length, but the exponential constant (the parameter l) will then normally be different from the corresponding **inelastic mean free path**. Where that approximation is valid, the term **effective attenuation length** is used.

Replace term 5.25, **attenuation length, effective**, by

5.25
attenuation length, effective
⟨AES, XPS⟩ parameter which, when introduced in place of the inelastic mean free path into an expression derived for AES and XPS on the assumption that elastic-scattering effects are negligible for a given quantitative application, will correct that expression for elastic-scattering effects

cf. **attenuation length**

NOTE 1 The effective attenuation length may have different values for different quantitative applications of AES and XPS. However, the most common use of effective attenuation length is the determination of overlayer-film thicknesses from measurement of the changes of substrate Auger-electron or photoelectron signal intensities after deposition of a film or as a function of emission angle. For emission angles of up to about 60° (with respect to the surface normal), it is often satisfactory to use a single value of this parameter. For larger emission angles, the effective attenuation length can depend on this angle.

NOTE 2 Since there are different uses of this term, it is recommended that users specify clearly the particular application and the definition of the parameter for that application (e.g. by giving an equation or by providing a reference to a particular source).

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Add the following new Clauses 7 to 10.

7 Definitions of supplementary terms for surface analysis

7.1
atomic mass unit (deprecated)
See Note 3 to "unified atomic mass unit".

cf. **unified atomic mass unit**

7.2
analyser blanking
⟨SIMS⟩ action to prevent **secondary ions** from travelling through the mass spectrometer and being detected

NOTE This action is usually made by pulsing one of the relevant electrode potentials in **time-of-flight** mass spectrometers to deflect ions of a selected mass range in which intense peaks occur, so that those masses are not detected and thus do not cause unwanted detector saturation.

7.3
angle resolved EPES
AREPES
⟨EPES⟩ a method involving **EPES** measurements as a function of the scattering angle

7.4
aperture, contrast
aperture in an ion or electron optical system designed to reduce unwanted background signal

NOTE This aperture may also govern the spatial resolution and other properties of the system.

7.5
background, metastable
⟨SIMS⟩ intensity in the mass spectrum arising from ions that spontaneously fragment between emission and detection

NOTE In reflectron **time-of-flight** mass spectrometers, the decay of **metastable ions** leads to broad peaks at a mass dependent on the drift energy and **reflector voltage**. Good design minimizes these background signals.

7.6
beam blanking
electrostatic or electromagnetic process designed to prevent any **beam particles** from impacting the sample

cf. **beam bunching**, **beam chopper**

NOTE For pulsed ion beams, the beam is usually deflected into a beam collector from which no particles can reach the sample and where the process of sputtering causes minimal effect on nearby components of the ion optical system. Typically, in **time-of-flight** static SIMS systems, a beam of between 0,2 pA and 2 pA may be on for between 0,6 ns and 30 ns and off for around 100 µs, with 10 000 repetitions per second.

7.7
beam bunching
⟨SIMS⟩ reduction in the spread of arrival times of an ion pulse by reduction in the speed of the leading ions or acceleration of those at the trailing edge of the pulse

cf. **beam blanking**, **beam chopper**

NOTE This procedure may degrade the optimum focus of the ion beam since different ions experience different fields.

7.8
beam source energy (deprecated)
See ISO 18115:2001, term 5.59, **beam energy**.

7.9
bond cleavage
bond scission
breakage of a molecular bond

NOTE 1 This breakage may lead to two fragments that may or may not be charged, or to a single rearranged product.

NOTE 2 For α- and β-cleavage, see Reference [7] or [11].

7.10
cationized ion
positively charged ion resulting from a neutral molecule combining with a cation, usually a metal ion

NOTE 1 Cationization with, for instance, Ag leads to high yields of some positive ion fragments or molecular ions. Each ion has a mass given by the sum of the mass of the parent molecule or fragment and the mass of the added metal atom or atoms. The Ag may be used either as the substrate upon which the molecules are deposited or in the form of a sub-monolayer sputtered onto the molecules already on a surface.

NOTE 2 NH_4^+ may be used as well as metals to cationize molecules.

7.11
charge compensation (deprecated)
charge stabilization (deprecated)
charge neutralization

7.12
chopper, beam
⟨SIMS⟩ electrostatic or electromagnetic device used to generate pulses of ions from a continuous ion beam

cf. **beam blanking**, **beam bunching**

NOTE The beam chopper may be used to define the pulse length and hence the mass resolution in a time-of-flight mass spectrometer and it may also be used to select particular ions in a beam that contains more than one species.

7.13
chromatic aberration
non-ideal focus of an electron or ion optical system for electrons or ions of different energies

7.14
cluster ion
ion composed of many atoms or chemical species

NOTE 1 The cluster may have a positive or negative charge.

NOTE 2 Cluster ions are used for primary ion sources with enhanced properties over those for monatomic ions. Examples of such sources are: Au_3^+, Au_5^+, Bi_3^+, Bi_5^+, C_{60}^+, $H_3O^+(H_2O)_n$, $[Os_3(CO)_{12}]^+$, SF_5^+.

7.15
cluster SIMS
〈SIMS〉 **SIMS** but utilizing a primary beam composed of **cluster ions**

NOTE Cluster ion sources are often used in **static SIMS** to enhance molecular signals and in **dynamic SIMS** to enhance **depth resolution**.

7.16
cross-section, damage
cross-section for the change in the number of particular entities observed as a result of the bombardment by defined ions, electrons or photons

NOTE 1 The observed entities may, for example, be specific molecules on a surface, specific observed ion fragments, atoms in a given chemical state or polymer cross-linking as inferred from spectral data.

NOTE 2 Generally, the larger the entity, the larger the damage cross-section.

NOTE 3 As a result of the break-up of larger entities, the observed entity may increase or decrease in intensity.

NOTE 4 Cross-sections are often expressed as an area per target entity (atom, molecule, etc.) for the relevant process.

NOTE 5 A cross-section of σ per atom for the removal of entities from a given state on a surface will lead to a reduction dN in the number of N of entities in that state in a time dt given by the relation:

$$dN = NJ\sigma\, dt$$

where J is the primary ion or electron dose rate density.

Integration leads to the relation:

$$N = N_0 \exp(-J\sigma t)$$

where N_0 is the initial value of N.

The observed value of the number of a given entity may also depend on sources creating that entity as discussed in Note 3.

7.17
cross-section, disappearance
〈SIMS〉 **cross-section** for the loss of intensity of an ion signal observed as a result of the bombardment by **primary ions**

cf. **cross-section**, **damage**

NOTE 1 The ion signal used is usually that for a large or characteristic fragment of the molecule such as a cationized, protonated or deprotonated ion from the molecule at a surface.

NOTE 2 Generally, the larger the molecule, the larger the disappearance cross-section.

7.18
damage limit
particle **fluence** above which significant changes in the spectrum or in a stated peak, arising from damage processes, are observed

cf. **static limit**

7.19
daughter ion
electrically charged product formed from a **parent ion** or neutral entity generally of a larger size

NOTE Formation of the product need not necessarily involve fragmentation. It could, for example, involve a change in the number of charges carried. Thus, all **fragment ions** are daughter ions, but not all daughter ions are necessarily fragment ions.

7.20
dendrimer
molecule comprising a multifunctional core molecule with a dendritic wedge of highly branched monomers regularly attached to each functional site, leading to a monodisperse, tree-like or generational structure

NOTE Dendrimer synthesis occurs in polymer chemistry and involves stepwise reactions in which the dendrimer is built up one monomer layer, or generation, at a time. The core molecule is referred to as "generation 0". Each successive repeat unit along all branches forms the next generation, "generation 1", "generation 2", and so on, until the terminating generation.

7.21
deprotonated ion
parent molecule or fragment from which a proton has been removed to form a negative ion

7.22
differential electron elastic reflection coefficient
⟨EPES⟩ ratio, per solid angle, of the number of electrons backscattered quasi-elastically from a solid surface at a given scattering angle to the number of incident electrons

NOTE The differential elastic reflection coefficient for electrons depends on the atomic composition of the surface layer of the solid, on the **differential elastic scattering cross-sections** of the different atoms for electrons, on the corresponding **IMFP**, on the energy of the incident electrons and on the scattering geometry.

7.23
dual beam profiling
⟨SIMS⟩ **sputter depth profiling** involving two ion guns

NOTE 1 Two similar ion guns may be used in opposite azimuths of the sample to reduce the development of topography.

NOTE 2 In **time-of-flight** mass spectrometers, one beam is used with a short on time for the SIMS analysis whilst a second is used during the period when the first is off and the mass analysis has been completed in each cycle. The second gun provides the ions for sputter removal of the sample to form the depth profile. This combination allows practical **sputtering rates** to be achieved and the profiling to be optimized separately from the optimization for the SIMS analysis.

7.24
efficiency
⟨SIMS⟩ quotient of the measured yield of an ion species per **primary ion** and the **disappearance cross-section**

7.25
elastic peak
quasi-elastic peak
peak in the electron spectrum, produced by quasi-elastically scattered electrons detected by an electron spectrometer

cf. **elastic peak electron spectroscopy**, **EPES, recoil effect**, **reflected electron energy loss spectroscopy**, **REELS**

NOTE 1 All electrons that are scattered by atoms may be elastically scattered in the centre-of-mass frame, but energy losses that are typically less than 1 eV may be observed in the laboratory frame. These losses are generally significantly less than the measured energy width of the electrons in a primary electron beam. Historically, and more generally, the scattering has been called "elastic"; however, the term quasi-elastic is now often used if the small change in energy that occurs on scattering is important.

NOTE 2 The energy and the energy broadening of the quasi-elastic peak are influenced by the recoil of the scatterer atoms, the energy distribution of the primary (incident) electrons, the scattering geometry, the acceptance geometry and the response function of the electron spectrometer. The intensity of the elastic peak depends on the electron differential elastic scattering cross-section and on the total cross-section for inelastic electron scattering at the particular primary electron beam energy and in the given scattering geometry, that includes the probability of surface excitations.

7.26
elastic peak electron spectroscopy
EPES
a method in which an **electron spectrometer** is used to measure the energy, intensity and/or energy broadening distribution of quasi-elastically scattered electrons from a solid or liquid **surface**

cf. **recoil effect**, **reflected electron energy loss spectroscopy**, **REELS**

NOTE 1 An electron beam in the energy range 100 eV to 3 keV is often used for this kind of spectroscopy.

NOTE 2 In general, electron sources with energy spreads that are less than 1 eV are required to provide adequate information.

NOTE 3 EPES is often an auxiliary method of **AES** and **REELS**, providing information on the composition of the surface layer. EPES is suitable for experimental determination of the **IMFP**, the electron **differential elastic scattering cross-section** and the **surface excitation parameter**.

7.27
energy acceptance window
range of energies accepted by a spectrometer, leading to a detected signal

7.28
enhancement factor
$K_{n,1}$
⟨SIMS, sputtering⟩ ratio of the ion or neutral sputtering yield using a primary ion cluster of n similar atoms to n times the ion or neutral sputtering yield using a primary ion of one of those atoms where the primary ion energy per atom is the same in each case

7.29
excited state
state of a system with energy higher than that of the ground state

NOTE This term is generally used to characterize a molecule in one of its electronically excited states, but can also refer to vibrational and/or rotational excitation in the electronic ground state.

7.30
extraction bias
⟨SIMS⟩ voltage between the electrodes used to define the **extraction field** occurring in the period between ion pulses in the pulsed extraction mode

NOTE 1 This term is used in **time-of-flight** SIMS instruments.

NOTE 2 The extraction bias may be set to zero or it may be set at a particular value to deflect low-energy electrons to the sample for charge neutralization or, in dual ion beam systems for **depth profiling**, to deflect **secondary ions** generated by the **sputter depth profiling** ion gun in order to prevent them from entering the mass spectrometer and generating background counts.

7.31
extraction field
⟨SIMS⟩ electric field above the sample, operational during ion emission from the sample

NOTE The extraction field may be pulsed or constant, depending on the type of instrument.

7.32
extractor voltage
⟨SIMS⟩ voltage, referenced to the sample, of the electrode defining the field above the sample and used to facilitate the introduction of emitted ions into the mass spectrometer

NOTE 1 In the pulsed extraction mode, the extractor voltage will be pulsed to the high value required to extract ions emitted from the sample by the primary ion pulse for at least the time period necessary for the heaviest ion to pass through the extractor electrode and will then be reduced to the **extraction bias** value until the next pulse is required.

NOTE 2 This voltage, together with the separation distance between the sample and the extractor electrode, defines the **extraction field**.

7.33
FAB-SIMS
〈SIMS〉 **SIMS** in which the primary-ion beam is replaced by a fast atom beam

7.34
FIB
focussed ion beam system
ion beam system used for machining small regions with sub-micron precision

NOTE 1 In general, FIBs use an **LMIS** to generate a finely focussed ion beam with diameters typically in the range 7 nm to 300 nm and of sufficient flux, typically 4 pA to 20 nA, to machine small items for study by AES, SIMS or TEM in an economic time. They are also used to manufacture **SPM** tips, those for **AFM** having radii down to 2 nm.

NOTE 2 FIB-machined surfaces may have an ion-damaged surface that needs to be removed.

7.35
fragment ion
charged dissociation product arising from ionic fragmentation

[IUPAC [11]]

cf. **daughter ion**, **metastable ion**

NOTE Fragment ions may dissociate further to form other electrically charged molecular or atomic moieties of successively lower mass.

7.36
fragmentation
breakdown of a molecule or ion to form one or more ions or neutrals of lower mass whilst conserving the total charge

7.37
G-SIMS
variant of **static SIMS** in which two spectra from the same area, recorded with different beam energies or different bombarding ions, are ratioed to each other and the result used to scale one of the spectra to generate a new spectrum

NOTE 1 As with static SIMS, the ion **areic dose** during measurement is restricted to less than 10^{16} ions/m^2 to an extent that depends on both the material of the sample and the size of the molecular fragments being analysed.

NOTE 2 The **G-SIMS** spectrum enables the whole mass of molecules on the surface to be determined more readily than in static SIMS.

7.38
impact energy per ion
kinetic energy of the **beam particles** on impact

cf. **beam impact energy**

7.39
information area
area of a region in the plane of the surface from which useful information is obtained

NOTE 1 The information area can be identified with the minimum surface area from which a specified percentage (e.g. 95 % or 99 %) of the detected signal originates.

NOTE 2 The information area may be determined from a measured, calculated or estimated measure of the signal intensity as a function of position on the sample surface.

7.40
information radius
maximum radius of a circular region in the plane of the surface from which useful information is obtained

NOTE 1 This definition is useful only for surface analyses of a homogeneous sample and for either normal incidence of the primary beam or normal detection of the signal particles, in which it is expected that the signal intensity as a function of position on the surface will depend only on the radial distance from the axis of symmetry. If these conditions are not met, it is more appropriate to make use of the information area.

NOTE 2 The information radius can be identified with the radius within which a specified percentage (e.g. 95 % or 99 %) of the detected signal originates.

NOTE 3 The information radius may be determined from a measured, calculated or estimated measure of the signal intensity as a function of radius.

7.41
ionization efficiency
ratio of the number of ions formed to the number of electrons, ions or photons used in an ionization process

[IUPAC [11]]

7.42
Langmuir-Blodgett film
LB film
film comprising one or more monolayers of organic molecules

NOTE The films are transferred from the surface of a liquid bath onto solid substrates and by repeated immersions many layers may be deposited. Control of the liquid surface tension during this process allows the molecular density of the monolayers to be controlled.

7.43
linear cascade
linear collision cascade
dilute **collision cascade** in which the number of atoms set in motion by an energetic primary particle is proportional to the amount of recoil energy deposited in the material

cf. **spike**, **thermal spike**

NOTE The sputtering of solids by monatomic primary ions in the energy range below 20 keV, usually used for surface analysis, is often assumed to be described by a linear collision cascade.

7.44
liquid metal ion gun
LMIG
ion gun utilizing a liquid metal Taylor cone as the source of the **primary ions**

NOTE The Taylor cone generates ion sources of very high brightness. This design enables the gun to provide **beam diameters** in the range 50 nm to 1 µm for ion **beam energies** in the range 5 keV to 30 keV, the lowest diameters generally being at the higher energies.

7.45
mass accuracy
systematic deviation of a measured mass from a reference value for that mass

NOTE The mass accuracy may be expressed as a fractional error (i.e. the ratio of the mass error to the mass at which that error is established) or as an absolute error (i.e. the mass error at a particular mass). Most commonly, the fractional error is used and is expressed in parts per million.

7.46
mass to charge ratio
modulus of the quotient of the particle mass in **u** and the particle charge in units of the electronic charge

7.47
matrix assisted laser desorption/ionization mass spectrometry
MALDI
a method in which a time-of-flight mass spectrometer is used to measure the mass-to-charge ratio and abundance of ions emitted, as a result of a short pulse of laser illumination, from a sample whose analyte is contained in an ion-assisting matrix

NOTE 1 The matrix used for assisting the ion emission needs a strong absorbance at the laser wavelength and a low enough mass to be sublimable. Examples of matrices for 337 nm wavelength laser light are 2,5-dihydroxybenzoic acid (DHB), 3,5-dimethoxy-4-hydroxycinnamic acid (sinapinic acid) and α-cyano-4-hydroxycinnamic acid (CHCA).

NOTE 2 MALDI is used to analyse non-volatile polar biological and organic macromolecules as well as polymers to masses of over 3 000 kDa.

7.48
metastable ion
ion that spontaneously fragments between emission and detection

cf. **background, metastable**

NOTE 1 In general, metastable ions have a lifetime less than 1 µs.

NOTE 2 In **reflectron time-of-flight** mass spectrometers, the decay of metastable ions leads to broad peaks at a mass dependent on the drift energy and **reflector voltage**. Good design minimizes these background signals.

7.49
molecular fragment
ion or neutral particle that was part of a larger molecular structure and contains information about that structure

7.50
molecular image
image of a surface formed from ions characteristic of a particular molecule

cf. **static limit**

7.51
molecular ion
ion formed by the removal from (positive ions) or addition to (negative ions) a molecule of one or more electrons without fragmentation of the molecular structure

[IUPAC [11]]

cf. **deprotonated molecular ion**, **protonated molecular ion**

NOTE Protonated and deprotonated molecular ions are often of greater intensity than the molecular ion.

7.52
molecular ion, deprotonated
molecular ion that has lost a proton to form a negative ion

7.53
molecular ion, protonated
molecular ion that has gained a proton to form a positive ion

7.54
nominal mass
particle mass in **u**, rounded to the nearest integer

7.55
oligomer molecule
molecule of intermediate relative molecular mass, the structure of which essentially comprises a small plurality of units derived, actually or conceptually, from molecules of lower relative molecular mass

[IUPAC [11]]

NOTE 1 A molecule is regarded as having an intermediate relative molecular mass if it has properties which vary significantly with the removal of one or a few of the units.

NOTE 2 If a part or the whole of the molecule has an intermediate relative molecular mass and essentially comprises a small plurality of units derived, actually or conceptually, from molecules of lower relative molecular mass, it may be described as oligomeric, or by oligomer used adjectivally.

7.56
parent ion
ion that subsequently fragments into smaller ions or neutral particles

7.57
polyatomic fragment
ion or neutral particle composed of three or more atoms

7.58
post-acceleration detector voltage
post-acceleration voltage
voltage applied to the front of the detector to increase the impact energy of incident electrons or ions

NOTE Voltages are often referred to reference points in the instrumental electronics, but here the reference zero is such that a post-acceleration detector voltage of 5 kV leads to an impact energy of 5 keV, etc. Post-acceleration detector voltages of 5 kV to 20 kV are generally used.

7.59
protonated ion
parent molecule to which a proton has been added to form a positive ion

7.60
pulse rate
〈SIMS〉 number of ion pulse cycles per second

cf. **repetition rate**

7.61
pulse width
〈SIMS〉 full width at half maximum of the time distribution of the pulse of ions generated by the **beam chopper** and, optionally, the use of **beam bunching**

NOTE The pulse width is usually measured using the H^+ ion. The velocity of H^+ ions, for a given **extraction field**, is larger than for other ions. The width in time of the H^+ pulse thus provides a more reliable value for the width of the extraction pulse.

7.62
pulsed extraction field
〈SIMS〉 **extraction field** around the sample that is pulsed to the working value for extracting ions for the time necessary for operation of a **time-of-flight** mass spectrometer but is otherwise at a low value

NOTE This is the usual mode in time-of-flight SIMS systems either for studying insulators, where the **charge neutralization** is established whilst the **extraction field** is off, or for **depth profiling** using a second ion beam whilst the extraction field is off.

7.63
random raster
digital raster array in which the coordinates of sequential ion pulses filling a frame is random

NOTE 1 The coordinates may be addressed in the same “random” sequence in each frame.

NOTE 2 A random raster, as opposed to a traditional or saw-tooth raster, may be used for analysing insulating samples to reduce the instantaneous accumulation of charge in any local region.

7.64
raw data file
unprocessed data file of information provided by an instrument

NOTE For **time-of-flight** SIMS instruments, this file usually contains the x- and y-coordinates of the ion beam raster address as well as the recorded flight times and signal intensities, since these files are used retrospectively to generate **secondary-ion** maps or spectra from the whole or selected parts of the map, or to generate these from the whole or selected time regions.

7.65
recoil effect
⟨EPES⟩ effect resulting from the change in movement of a scatterer atom as a result of quasi-elastic electron scattering

NOTE The energy shift and energy broadening of the **quasi-elastic peak** for a scattered electron beam due to atomic recoil depend on the mass of the scatterer atom, the energy of the primary electrons and the scattering angle. In addition, the energy broadening due to atomic recoil depends on the sample temperature. The quasi-elastic peak in **EPES** for multi-component materials contains contributions from each component. Recoil effects are most easily observable in electron spectra taken at high energy resolution with low atomic number scattering atoms. Hydrogen can be directly detected by its recoil shift.

7.66
reflector voltage
⟨SIMS⟩ voltage set on the reflector electrode of a **reflectron** mass spectrometer with the zero referenced such that an ion emitted from the sample with an energy numerically equal to the reflector voltage would just be on the point of reflection or transmission by the reflector electrode

7.67
reflection electron energy loss spectroscopy
REELS
a method in which an **electron spectrometer** is used to measure the energy distribution of electrons quasi-elastically scattered by atoms at or in a surface layer and the associated **electron energy loss spectrum**

cf. **elastic peak electron spectroscopy**, **EPES**

7.68
reflectron
⟨SIMS⟩ **time-of-flight** mass spectrometer in which ions are reflected through an angle approaching 180° in order to reduce the flight time dependence on the particular energy of the ions

7.69
relative instrument spectral response function
RISR
⟨AES, SIMS, XPS⟩ ratio of the **spectrometer response function** to the response function of a reference instrument or average of several such instruments as a function of energy (AES, XPS, etc.) or mass (SIMS)

NOTE The RISR can be used to relate spectra from one instrument to another when using similar excitation sources and geometries.

7.70
repeat unit, polymer
smallest structure that, repeated many times, describes the molecular structure of the polymer

7.71
repetition rate
⟨SIMS⟩ rate at which the whole cycle of primary-ion pulse, ion extraction, mass analysis and removal of slow ions is repeated to build up a mass spectrum in a **time-of-flight** mass spectrometer

7.72
sample bias
potential applied to the whole or part of the sample referenced to the potential of the sample holder

cf. **sample voltage**

7.73
sample voltage
voltage of the sample referenced to ground

cf. **sample bias**

NOTE 1 The sample voltage may be pulsed or constant, depending on the type of instrument.

NOTE 2 For insulators, the sample voltage is assumed to be the same as that of the sample holder if an effective **charge neutralizing** device is used.

7.74
self-assembled monolayer
SAM
film, one molecule thick, covalently assembled on a surface

7.75
shots per pixel
⟨SIMS⟩ number of ion pulses incident at each pixel in an image for one raster frame

7.76
spike
⟨SIMS, sputtering⟩ limited region in space and time within which the majority of atoms in an irradiated material are in rapid motion

cf. **thermal spike**

NOTE The term spike is usually applied to the region generated by a single primary particle. In SIMS, this primary particle may often be a **cluster ion**.

7.77
spin coating
coating of a thin layer of an organic material deposited from solution, under the action of high-speed rotation, on a flat substrate wetted by that solution

NOTE 1 Rotation speeds around 4 000 revolutions per minute are commonly used, producing films generally thinner than 100 nm.

NOTE 2 Some users place a drop of solution in the centre and some flood the whole sample, prior to the high-speed rotation that removes the solvent.

7.78
static limit
⟨SIMS⟩ ion fluence above which any significant changes in the spectrum, arising from beam damage, are observed

NOTE 1 Classically, a limit of 10^{12} ions/cm^2 or 10^{16} ions/m^2 is taken as the limit not to be exceeded in **static SIMS**. This limit is based on one incident ion for each 1 000 surface atoms.

NOTE 2 For imaging, the total molecular signal may be used, and here the limit may be higher and reach 100 times the limit in Note 1.

NOTE 3 For large molecules, the **damage cross-section** is generally larger than for small molecules, leading to a static limit lower than 10^{12} ions/cm^2.

7.79
stop event
⟨SIMS⟩ registration of a particle by a time-to-digital converter

NOTE The arrival time for each ion providing a pulse at the detector is registered by the time-to-digital converter (TDC). This is a stop event. TDCs may only record a fixed number of stop events during the time following each primary-ion pulse, for example 512 or 1 024, other events being lost.

7.80
surface excitation parameter
SEP
⟨AES, EPES, REELS, XPS⟩ characteristic parameter in the exponential attenuation describing the ratio of the intensity of a peak resulting from the presence of the surface, during a single crossing of a material surface, to that expected after traversing the same amount of material but in the absence of the surface

NOTE 1 If it is assumed that the SEP arises solely from surface excitations and that multiple surface excitations are governed by the Poisson stochastic process, the probability of experiencing n surface excitations is given by $(S^n/n!)[\exp(-S)]$, where S is the SEP. The SEP can then be interpreted as the average number of surface excitations during a single surface crossing, and the probability for not experiencing any surface excitation during that single surface crossing is given by $\exp(-S)$.

NOTE 2 The value of the SEP depends on the geometry of the experiment, and the contributions for incoming and for outgoing electrons in EPES and REELS may differ. The SEP decreases the intensities observed in REELS, EPES, AES, XPS and similar types of spectroscopy.

NOTE 3 Surface excitation decreases the intensity of the **quasi-elastic peak**. It is important in **REELS** and **EPES**.

7.81
surface plasmon
excitation of conduction or valence-band electrons in a solid or liquid, associated with the termination of the material at the surface, in which collective oscillations are generated

cf. **characteristic electron energy losses**, **plasmon**

NOTE 1 Plasmon excitations are often observed as characteristic energy loss peaks associated with other peaks or structures in the spectrum, such as those of any elastically scattered **primary electrons**, photoelectron peaks, Auger electron peaks and ionization edges. Surface plasmons are important for many optical measurements.

NOTE 2 Plasmons are prominent in some materials and not others.

NOTE 3 Two types of plasmon are commonly observed: bulk plasmons (often simply called plasmons) associated with material remote from a surface or interface and surface plasmons associated with a surface or interface. The bulk plasmon energy depends on the electronic structure of the material, and is generally roughly proportional to the square root of the density of the valence-band electrons. The surface plasmon energy for a surface (i.e. a material-vacuum interface) is often approximately $(1/\sqrt{2})$ of the bulk plasmon energy for a planar surface; the actual ratio of bulk and surface plasmon energies depends on the electronic structure of the material. The surface plasmon energy for an interface between two materials depends on the electronic properties of each material. For the case of a thin oxide film on a free-electron-like metal, the surface plasmon energy of the metal will be reduced compared to the value for the clean metal surface due to the presence of the oxide.

7.82
thermal spike
⟨SIMS, sputtering⟩ **spike** in which energy transport is the dominating process

NOTE Other processes proposed to generate spikes are pressure and shock waves.

7.83
time of flight
⟨SIMS⟩ total time taken for ions of a particular mass to move from the sample to the detector

NOTE Usually the clock timer is started with the beam chopper sequence selecting an ion pulse and so the recorded flight time may include the additional time for the **primary ion** to travel to the sample surface from the pulse-forming region of the ion gun.

7.84
ultra-shallow depth profile
⟨SIMS⟩ **depth profile** where the depth over which significant changes occur is less than 10 nm

7.85
unified atomic mass unit
u
unit equal to 1/12 of the mass of the nuclide ^{12}C at rest and in its ground state

NOTE 1 $1\ u \approx 1{,}660\ 538\ 86 \times 10^{-27}$ kg with a one-standard-deviation uncertainty of $\pm 0{,}000\ 000\ 28 \times 10^{-27}$ kg. [12] This is a non-SI unit accepted for use with the International System, whose value in SI units is obtained experimentally.

NOTE 2 In the field of biochemistry, the unified atomic mass unit is also called the Dalton, symbol Da.

NOTE 3 The above definition was agreed upon by the International Union of Pure and Applied Physics in 1960 and the International Union of Pure and Applied Chemistry in 1961, resolving a longstanding difference between chemists and physicists. The unified atomic mass unit replaced the atomic mass unit (chemical scale) and the atomic mass unit (physical scale), both having the symbol amu. The amu (physical scale) was one-sixteenth of the mass of an atom of oxygen-16. The amu (chemical scale) was one-sixteenth of the average mass of oxygen atoms as found in nature. In the 1998 CODATA, 1 u = 1,000 317 9 amu (physical scale) = 1,000 043 amu (chemical scale).

7.86
unimolecular dissociation
spontaneous dissociation of a molecule into two or more fragments

NOTE This term is often applied to the fragmentation of a metastable ion.

7.87
useful spatial resolution
⟨SIMS⟩ image resolution obtained in practice

NOTE The image resolution is poorer than the primary-ion beam diameter as a result of either the need to maintain the damage level below a limit set by the integrity of the data or the need to record sufficient signal when the sample is being consumed during analysis.

8 Definitions of the scanned probe microscopy methods

8.1 The following are the definitions of scanned probe microscopy methods. In the list below, note that the final "M" and the final "S" in the acronyms, given as "microscopy" and "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.

8.2
apertureless NSOM
ANSOM
apertureless SNOM
ASNOM
scattering NSOM/SNOM
a method in which imaging at a resolution below the **Abbe diffraction limit** is achieved by detecting light scattered or emitted in the vicinity of a scanned sharp **tip**

NOTE 1 No **aperture** 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 2 The sharp tip is usually metallic or metal coated, permitting measurements of **surface enhanced Raman** and **fluorescence** spectroscopy and **second harmonic generation**. Raman signals of molecules in close proximity to silver can be enhanced by a factor of 10^{14}.

NOTE 3 The tip may be a single fluorescent molecule or nanoparticle.

NOTE 4 In the literature, the acronym "ANSOM" or "ASNOM" is occasionally used erroneously for aperture NSOM or aperture SNOM.

8.3
apertureless Raman microscopy
⟨NSOM, SNOM⟩ a method of microscopy involving the acquisition of Raman spectroscopic data utilizing a **near-field** optical source and based upon a metal **tip** in close proximity to the sample surface illuminated with suitably polarized light

8.4
atomic force microscopy
AFM
scanning force microscopy
SFM
a method for imaging surfaces by mechanically scanning their surface contours, in which the deflection of a sharp **tip** sensing the surface forces, mounted on a compliant **cantilever**, is monitored

NOTE 1 AFM is also referred to as scanning force microscopy (SFM) (deprecated).

NOTE 2 AFM can provide a quantitative height image of both insulating and conducting surfaces.

NOTE 3 Some AFM instruments move the sample in the z-direction whilst keeping the tip position constant and others move the tip whilst keeping the sample position constant.

NOTE 4 AFM may 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 5 Many types of force may be measured, such as the **normal forces** or the **lateral, friction or shear force**. When the latter is measured, the technique is referred to as **lateral**, **frictional** or **shear force microscopy**. This generic term encompasses all of the types of force microscopy listed in 2.2.

NOTE 6 AFMs may be used to measure surface **normal forces** at individual points in the pixel array used for imaging.

NOTE 7 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 occurs.

8.5
conductive atomic force microscopy
CAFM
⟨AFM⟩ **AFM** mode in which a conductive **probe** is used to measure both topography and electric current between the **tip** and the sample

8.6
current imaging tunnelling spectroscopy
CITS
⟨STM⟩ a method in which the **STM tip** is held at a constant height above the surface, while the bias voltage (V) is fixed and the tunnelling current (I) is measured and mapped

cf. **I-V spectroscopy**

8.7
dynamic mode AFM
dynamic force microscopy
DFM
⟨AFM⟩ AFM mode in which the relative positions of the **probe tip** and sample vary in a sinusoidal manner

NOTE 1 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 The signal measured may be the amplitude, the phase shift or the resonance frequency shift of the cantilever.

8.8
electrostatic force microscopy
electric force microscopy (deprecated)
EFM
⟨AFM⟩ **AFM** mode in which a conductive **probe** is used to map both topography and electrostatic force between the **tip** and the sample surface

8.9
electrochemical atomic force microscopy
EC-AFM
〈AFM〉 **AFM** mode in which a conductive **probe** is used in an electrolyte solution to measure both topography and electrochemical current

8.10
electrochemical scanning tunnelling microscopy
EC-STM
〈STM〉 **STM** mode in which a coated **tip** is used in an electrolyte solution to measure both topography and electrochemical current

8.11
magnetic dynamic force microscopy
MDFM
magnetic AC mode
MAC mode
〈AFM〉 **AFM** mode in which the probe is oscillated by using a magnetic force

8.12
magnetic resonance force microscopy
MRFM
〈AFM〉 **AFM** imaging mode in which magnetic signals are mechanically detected by using a **cantilever** at resonance and the force arising from nuclear or electronic spin in the sample is sensitively measured

8.13
near-field scanning optical microscopy
NSOM
scanning near-field optical microscopy
SNOM
a method of imaging surfaces optically in transmission or reflection by mechanically scanning an optically active **probe** much smaller than the wavelength of light over the surface whilst monitoring the transmitted or reflected light or an associated signal in the **near-field** regime

cf. **apertureless NSOM, apertureless SNOM**

NOTE 1 Where the extent of the optical probe is defined by an **aperture**, the aperture size is typically in the range 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 an **apertureless NSOM** or **apertureless SNOM** 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** with a radius typically in the range 10 nm to 100 nm and this largely defines the resolution.

NOTE 2 In addition to the optical image, NSOM can provide a quantitative image of the surface contours similar to that available in **AFM** and allied scanned probe techniques.

NOTE 3 This generic term encompasses all of the types of near-field microscopy listed in 2.2.

8.14
photothermal micro-spectroscopy
PTMS
SThM mode in which the probe detects the photothermal response of a sample exposed to infra-red light to obtain an absorption spectrum

NOTE The infra-red light may be either from a tunable 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.

8.15
scanning capacitance microscopy
SCM
SPM mode in which a conductive **probe** is used to measure both topography and capacitance between the **tip** and sample

8.16
scanning chemical potential microscopy
SCPM
SPM 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

8.17
scanning electrochemical microscopy
SECM
SPM mode in which imaging occurs in an electrolyte solution with an electrochemically active **tip**

NOTE In most cases, the SECM tip is an ultra-microelectrode and the tip signal is a Faradaic current from electrolysis of solution species.

8.18
scanning Hall probe microscopy
SHPM
SPM mode in which a Hall probe is used as the scanned sensor to measure and map the magnetic field from a sample surface

8.19
scanning ion conductance microscopy
SICM
SPM mode in which an electrolyte-filled micropipette is used as a local probe for insulating samples immersed in an electrolytic solution

NOTE The distance dependence of the ion conductance provides the key to performing non-contact surface profiling.

8.20
scanning magneto-resistance microscopy
SMRM
SPM mode in which a magneto-resistive sensor **probe** on a cantilever is scanned in the **contact mode** over a magnetic sample surface to measure two-dimensional magnetic images by acquiring magneto-resistive voltage

8.21
scanning Maxwell stress microscopy
SMSM
SPM mode in which a conductive **probe** is used to measure both topography and surface potential by utilizing the Maxwell stress

8.22
scanning non-linear dielectric microscopy
SNDM
SPM mode in which a conductive **probe** is used to measure both topography and dielectric constant (capacitance)

8.23
scanning probe microscopy
SPM
a method of imaging surfaces by mechanically scanning a probe over the surface under study, in which the concomitant response of a detector is measured

NOTE 1 This generic term encompasses **AFM**, CFM, **CITS**, FFM, LFM, SFM, **SNOM**, **STM**, TSM, etc., listed in 2.2.

NOTE 2 The resolution may vary from that of **STM**, where individual atoms may be resolved, to **SThM** in which the resolution may be limited to around 1 µm.

8.24
scanning spreading resistance microscopy
SSRM
SPM mode in which a conductive diamond **tip** is used to measure both topography and spreading resistance

8.25
scanning surface potential microscopy
SSPM
SPM mode in which a conductive **probe** is used to measure both topography and surface potential

8.26
scanning thermal microscopy
SThM
SPM method in which a thermal probe is used to measure both topography and thermal information

NOTE 1 Examples of thermal information are temperature and thermal conductivity.

NOTE 2 This method is sometimes known as thermal scanning microscopy or TSM. This expression and acronym are deprecated.

8.27
scanning tunnelling microscopy
STM
SPM mode for imaging conductive surfaces by mechanically scanning a sharp, voltage-biased, conducting **probe tip** over their surface, in which the data of the tunnelling current and the tip-surface separation are used in generating the image

NOTE 1 STM may be conducted in vacuum, liquid or air. Atomic resolution may be achieved with suitable samples and sharp probes and may, with ideal samples, provide localized bonding information around surface atoms.

NOTE 2 Images may 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 STM may be used to map the densities of states at surfaces or around individual atoms in ideal cases. The surface images may differ significantly, depending on the **tip bias**, even for the same topography.

8.28
scanning tunnelling spectroscopy
STS
STM mode in which the tunnelling current (I) between tip and sample is measured as the voltage (V) between the tip and sample is scanned

cf. **I-V spectroscopy**

NOTE The differential conductance, $\mathrm{d}I/\mathrm{d}V$, reflects the electronic local density of states (LDOS). If the sample is a superconductor, the energy gap around the Fermi level may be characterized.

8.29
shear force microscopy
ShFM
〈AFM〉 **AFM** mode using signals arising from a **probe tip** oscillating laterally in proximity to the surface

NOTE The oscillation is usually sinusoidal and generated through a piezoelectric actuator.

8.30
spin-polarized scanning tunnelling microscopy
SP-STM
〈STM〉 **STM** mode in which a magnetically ordered (ferromagnetic or antiferromagnetic) STM **tip** is scanned over a sample surface to image two-dimensional magnetic structures on the nanometre scale by measuring the spin-dependent tunnelling current

8.31
spin-polarized scanning tunnelling spectroscopy
SP-STS
STS mode in which a magnetically ordered (ferromagnetic or antiferromagnetic) **STM tip** is scanned over a sample surface to perform spin-polarized tunnelling spectroscopy to probe the magnetic and electronic structures of the sample surface on the nanometre scale

8.32
static mode AFM
static AFM
〈AFM〉 **AFM** mode of scanning the probe 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 The control parameter may be, for example, force or height.

8.33
ultrasonic force microscopy
UFM
〈AFM〉 **AFM** mode in which an ultrasonic wave is injected through the probe to observe the surface or inside mechanical structure

9 Acronyms and terms for contact mechanics models

9.1 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, non-linear, viscoelastic, elasto-plastic and other materials have been derived and can be found in the literature.

9.2
BCP
Burnham-Colton-Pollock
semi-empirical model of **tip** and surface contact that assumes that long-range forces act only outside the contact area [13]

NOTE 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** theory and the adhesion hysteresis of **JKR(S)** 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.

9.3
COS
Carpick-Ogletree-Salmeron
model of **tip** and surface contact between a sphere and a flat surface giving a simple general equation that approximates Maugis' solution to within 1 % accuracy [14]

NOTE The general equation is amenable to conventional curve-fitting routines and provides a rapid method of determining the approximate value of the parameter described by Maugis.

9.4
DMT
Derjaguin-Müller-Toporov
model of **tip** and surface contact in which adhesion forces are taken into account but the tip-sample geometry is constrained to be Hertzian [15]

NOTE 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.

9.5
Hertzian
model of **tip** and surface contact between elastic solids that ignores any surface forces and adhesion hysteresis

NOTE This approach, derived by Hertz and described by K.L. Johnson [16], 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.

9.6
JKR(S)
Johnson-Kendall-Roberts-(Sperling)
model of **tip** 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 [17]

NOTE 1 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 and high radii of curvature.

NOTE 2 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 [18].

9.7
Maugis
Maugis-Dugdale
model of **tip** and surface contact between a sphere and a flat surface, incorporating the elastic modulus and work of adhesion [19]

NOTE 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** or **DMT** mechanics, respectively.

10 Terms for scanning probe methods

10.1
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 In classical far-field diffraction theory, the optimum point-to-point resolution observed using a system with a numerical aperture, NA, is given by d, where $d = 0{,}61\lambda/\mathrm{NA}$, and λ is the wavelength of the illuminating light. With a carefully defined illumination, the factor 0,61 may be reduced to as low as 0,36.

10.2
active length
length of the region of the **probe tip** that may come into contact with the sample in a scan

[ASTM E 1813-96 [20]]

NOTE 1 This length is set by the height of the tallest feature encountered.

NOTE 2 This length should be less than the probe length.

10.3
amplitude modulation detection
AM detection
⟨AFM⟩ dynamic mode in which the change in probe height required to keep the vibration amplitude of an oscillated **cantilever** constant while scanned over the surface is monitored

NOTE 1 The oscillating frequency is usually set close to the **resonance frequency**, where the amplitude changes are strongest.

NOTE 2 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 The detected signals may be used in a feedback system to keep one parameter constant.

10.4
aperture
⟨NSOM, SNOM⟩ hole, typically circular, in an opaque manifold

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

10.5
artefact
artifact
unwanted distortion or added features in measured data arising from lack of idealness of equipment

10.6
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 with heights which are a significant fraction of the atomic size

NOTE The corrugations arise from the non-uniform distribution of the local density of states (LDOS) and the minimization of the surface energy and may change with ambient temperature or adsorbed species.

10.7
ballistic electron
electron that travels through a piece of material without significant scattering

NOTE 1 The energy of the electron is greater than that of any electron in thermal equilibrium in the system.

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

10.8
barrier height
magnitude of the potential energy in a region restricting the movement of electrons

NOTE In **STM**, the magnitude of the barrier height is related to the **tip** and substrate **work functions**. In classical mechanics, an electron with 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 of an electron from a metal through a vacuum gap to a metal, the barrier height is the difference between the **Fermi energy** in the first metal and the maximum of the potential distribution in the space between the two metals.

10.9
barrier width, tunnelling
length associated with a potential energy barrier that electrons traverse by quantum mechanical tunnelling

NOTE When in the **STM** tunnelling regime, the tunnelling barrier width is equivalent to the **tip**-sample separation. The tunnelling current decreases approximately exponentially with increasing barrier width.

10.10
Bethe-Bouwkamp model
〈NSOM, SNOM〉 model by Bethe and by Bouwkamp describing the wavefield for a sub-wavelength aperture in an infinite perfectly conducting screen

NOTE 1 This may be a useful approximation for an **aperture** in **NSOM/SNOM**.

NOTE 2 The original model derives from References [21] to [23].

10.11
blind reconstruction
reconstruction estimate of the true surface using measurements from which the **tip** effects are intended to be removed by a mathematical process without manual intervention

cf. **dilation**, **erosion**

10.12
cantilever
thin force-sensing support for a **probe tip**, located on the equipment at the end furthest from the probe tip

NOTE 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 narrowest end.

10.13
cantilever apex
end of the **cantilever** furthest from the cantilever support structure

cf. **probe apex**, **tip apex**

10.14
capillary force
force exerted on an **AFM cantilever** or similar **probe** due to capillary condensation at the junction between the probe and the surface

10.15
carbon nanotube probe
probe with a carbon nanotube that forms both the **probe shank** and the **probe tip**

NOTE The carbon nanotube is normally supported on a probe-like structure called the probe support. The nanotube and the support comprise a **composite probe**.

10.16
characterized length
region of the probe that has been measured by a **probe characterizer**

[ASTM E 1813-96 [20]]

10.17
chemical force
force between atoms or molecular groups on the **probe tip** and atoms or molecular groups on the surface

10.18
chip
cantilever chip
chip substrate
probe chip (deprecated)
small piece, usually of silicon, on which the **cantilever** has been fabricated and to which it is still attached as a convenient supporting structure in the **probe assembly**

10.19
chip holder
structure on which the **chip**, **cantilever** and **probe** are mounted

NOTE The chip holder, chip, cantilever and probe comprise the **probe assembly**.

10.20
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 This term often refers to function sensors that relate to position and scanners that can then set their x and y and, sometimes, z positions accurately. This is very important since position scanners are often based on piezo-electric components that exhibit significant hysteresis and creep in the absence of closed-loop control.

10.21
coarse approach device
device that changes the initial probe and sample separations by amounts significantly greater than the vertical (z) scanner range

NOTE 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.

10.22
composite probe
structure at or near the **cantilever apex** involving a **probe support** and a superimposed **probe**

NOTE For work where particular probe qualities, such as probe **tip radius**, probe stiffness and probe profile, are required, a special probe such as a carbon nanotube may 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.

10.23
cone angle
⟨NSOM, SNOM⟩ angle subtended between the optical fibre axis and the wall of the **tip** in an optical fibre NSOM probe

cf. **included half-angle**, **cone half-angle**

10.24
constant current mode
⟨STM⟩ mode of scanning the **probe tip** over the sample surface at a constant current by adjusting the relative heights of the probe and sample so that the current sensed does not change during the scan

10.25
constant force mode
⟨AFM⟩ mode of scanning the **probe tip** over the sample surface at a constant normal force by adjusting the relative heights of the probe and sample so that the force sensed does not change during the scan

10.26
constant height mode
mode of scanning the **probe tip** over the sample surface at a constant height over the surface during the scan

NOTE The height is constant relative to the instrument, not the sample surface.

10.27
contact mode
⟨AFM⟩ mode of scanning the **probe tip** over the sample surface, adjusting the relative heights of the probe and sample, in which there is always a repulsive force between the probe and the sample

cf. **intermittent contact mode**, **non-contact mode**, **tapping mode**

NOTE This mode can be, for example, either the **constant height** or **constant force mode**.

10.28
damping
⟨AFM⟩ mechanical energy per unit time dissipated from a cantilever oscillating with constant, maintained, amplitude during NC-AFM measurement

cf. **dissipation**

10.29
dilation
⟨AFM⟩ process involved in mechanical stylus or **tip** tracing measurements which distorts the true form of the surface measured by adding part of the profile of the stylus or tip at each point

cf. **erosion**

NOTE Dilation is discussed by J.S. Villarubia [24]. This process is very different, mathematically, from convolution. In some texts, the reader may find the term convolution erroneously applied.

10.30
dissipation
⟨AFM⟩ energy transfer from the tip to the sample during the **tip**-sample interaction in NC-AFM

cf. **damping**

10.31
dither
action, in the dynamic mode, of oscillating the **tip**

10.32
elastic tunnelling
quantum mechanical tunnelling process in which electrons do not lose energy

NOTE The energy in the initial and final states is the same.

10.33
electrostatic force
force generated by electrostatic effects between the **probe tip** and the sample

10.34
erosion
mathematical process used in mechanical stylus or **tip** tracing measurements for reconstructing an estimate of the true form of the surface measured by removing the distorting effects of the stylus or tip

cf. **dilation**

NOTE Erosion is discussed in Reference [24]. This process is very different, mathematically, from deconvolution. In some texts, the reader may find the term deconvolution erroneously applied.

10.35
etched tip
probe tip (generated by an etching process)

NOTE This term generally refers to **STM** tips generated by electrochemical etching, but ion sputter etching may also be used for manufacturing STM tips as well. This term also applies to optical fibre tips for **NSOM/SNOM**, where etching in hydrofluoric acid is part of the forming process.

10.36
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 The intensity of evanescent waves decays exponentially with distance from the interface at which they are formed.

10.37
feedback-induced distortion
distortion of a scan trace arising from the inability of a probe microscope feedback to maintain close proximity between the **tip** and surface

[ASTM E 1813-96 [20]]

NOTE This distortion can be caused by scanning too quickly and may change with scan speed and scan direction.

10.38
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 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 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 [25].

10.39
flexing-induced distortion
distortion of a scan trace arising from flexing of the **probe tip** or **probe shank** during scanning

10.40
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

10.41
fluorescence quenching
⟨NSOM, SNOM⟩ process that decreases the intensity of **fluorescence** emission

10.42
fluorescence resonant energy transfer
FRET
⟨NSOM, SNOM⟩ **fluorescence** resulting from energy exchange between a donor and acceptor in close proximity

10.43
frequency modulation detection
FM detection
⟨AFM⟩ detection mode in **dynamic mode AFM** where the change in the oscillation frequency is used in imaging and to control the **tip**-surface separation

NOTE This mode was first described in Reference [26].

10.44
force-distance curve
force-displacement curve
force-deflection curve (deprecated)
force-extension curve (deprecated)
⟨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** is moved towards or away from the surface as the force is measured

NOTE The force is usually monitored by the cantilever deflection.

10.45
force sensor
sensor detecting forces applied to the probe

10.46
force-volume mode
⟨AFM⟩ mode of scanning the probe at an array of $n \times m$ points across the surface, where a **force-distance curve** is acquired at each point in the array

cf. **pulsed force mode**

10.47
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 of energy

NOTE 1 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 may exceed the frictional force in the dynamic regime.

NOTE 2 The surfaces may not be isotropic, and then the frictional force may not be in the opposite direction to the applied force. In dynamic friction, this may lead to movement at an angle to the applied force direction.

10.48
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 those solids

NOTE 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 may exceed the frictional force in the dynamic regime.

10.49
friction force
⟨AFM⟩ **lateral force** arising from **friction** generated by the lateral movement between the **probe tip** and the sample

NOTE 1 The lateral force causes torsional bending of cantilevers that may be detected on an optical or other sensor.

NOTE 2 Microscopy in this mode is called frictional force microscopy (FFM).

10.50
functionalized tip
tip with a thin added layer that changes the interactive property of the tip with a sample in a desired manner

NOTE In general, the functionalization is achieved by grafting a **monolayer** of specific molecules onto the tip so that the presence of specific chemical groups on the sample surface may be detected by, for example, a specific attractive force between the chemical groups and the grafted molecules.

10.51
height tracking mode
topography tracking mode
mode in which data are recorded as the **tip** traces a line at a given height above the surface defined by the pre-determined topography

cf. **planar subtraction mode**

NOTE 1 This mode is used to remove the effects of topography in a line scan. Typical data that may be recorded are forces in general (such as magnetic forces), patch fields, etc.

NOTE 2 This mode is also known as “lift off mode” or “path mode” by different manufacturers.

10.52
Hertzian contact
form of contact between elastic solids only involving elasticity

NOTE Hertzian contact ignores any surface forces and adhesion hysteresis and generally applies at high loads where there are no surface forces present.

10.53
illumination mode
⟨NSOM, SNOM⟩ mode of operation of an optical scanned-probe instrument in which the optical excitation is limited so as to define the optical resolution of the system

NOTE 1 The optical resolution may be defined, for example, by delivery of the optical excitation by an optical fibre.

NOTE 2 This mode is a common operating mode of aperture SNOM systems.

10.54
illumination-collection mode
⟨NSOM, SNOM⟩ mode of operation of an optical scanned-probe instrument in which the optical excitation and the optical response signal to this excitation are carried by the same **probe tip**

NOTE 1 In SNOM, the illumination-collection mode helps avoid loss of resolution due to the drift of excited states or charge carriers that may 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 In practice, the optical response is typically photoluminescence and the probe tip is often a drawn optical fibre.

10.55
included half-angle (of a probe)
cone half-angle (of a probe)
half tip angle (deprecated)
semi-vertical angle (deprecated)
⟨AFM⟩ included angle between the probe surface and the axis of symmetry for a cone-shaped probe

NOTE 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** axis.

10.56
inelastic tunnelling
⟨STM⟩ process involving quantum mechanical **tunnelling** in which electrons lose energy

10.57
interfacial energy
quotient of the energy required to increase an interfacial area at thermodynamic equilibrium and that area

NOTE 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.

10.58
intermittent contact mode
tapping mode
⟨AFM⟩ mode of scanning the probe where the probe is operated with a sinusoidal z-displacement modulation such that the **probe tip** makes contact with the sample for a fraction of the sinusoidal cycle

cf. **contact mode**, **non-contact mode**

NOTE 1 In this mode, the change in the amplitude arising from the intermittent contact may be used to control the relative heights of the sample and tip in the scanned image.

NOTE 2 TappingMode is a trade mark of Veeco.

10.59
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** current (I) is measured

NOTE I-V spectroscopy is also known as I/V, I(V) and IV spectroscopy.

10.60
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** current (I) is measured

NOTE I-Z spectroscopy is also known as I/Z, I(Z) and IZ spectroscopy.

10.61
Kelvin probe
probe designed to measure the relative potential between the surface and a conducting **tip** by using the dynamic mode and determining the tip bias for a null alternating current

NOTE Kelvin probes operate without contact.

10.62
lateral force
⟨AFM⟩ force applied to the **probe tip** in an AFM in a direction in the surface plane and at right angles to the **cantilever**

NOTE In AFMs, 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 may 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.

10.63
lateral spring constant
k_x, k_y
⟨AFM⟩ quotient of the applied **lateral force** at the **probe tip** by the deflection of the **cantilever** in that direction at the probe tip position

cf. **normal spring constant**, **torsional spring constant**

NOTE 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.

10.64
local barrier height
potential energy of a **tunnelling** barrier at a specified location

NOTE When an **STM tip** is scanned across a sample, the potential energy may vary with tip position due to chemical inhomogeneities (e.g. impurities) of lower **work function** at or close to the surface.

10.65
magnetic force
force acting between magnetic dipoles in a magnetic field

NOTE In SPM, the magnetic dipoles are usually incorporated as ferromagnetic material in the probe tip and it is the magnetic field of the sample that is measured.

10.66
meniscus force
force between **tip** and sample arising from the presence of a condensed liquid layer in contact with both the tip and the sample

10.67
nano-antenna
⟨NSOM, SNOM⟩ antenna of nanoscopic dimensions which couples light from the far field to the near field and/or *vice versa*

NOTE The nano-antenna may be a metal **tip** or an antenna structure defined on an **SPM probe** using lithography or **FIB** processing.

10.68
nano-indentation
indentation of a surface where the indentation depth or the depth of the plastic deformation is less than 100 nm

10.69
nanomechanics
mechanical analysis of materials where significant inhomogeneity in the force or stress field occurs with scales less than 100 nm

NOTE This term applies equally to a number of widely differing situations, including materials with internal inhomogeneities less than 100 nm, materials probed mechanically with probes smaller than 100 nm and single molecules being unravelled.

10.70
nanoparticle
particle with one or more dimensions of the order of 100 nm or less

10.71
near field
⟨NSOM, SNOM⟩ region closer than about one wavelength to a source of electromagnetic radiation, typically light

NOTE 1 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 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.

10.72
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

cf. **apertureless Raman microscopy**

10.73
non-contact mode
⟨AFM⟩ mode of scanning the probe in which there is always an attractive force between the probe and the sample

cf. **contact mode, intermittent contact mode, tapping mode**

NOTE 1 This mode can be, for example, the **constant height** or **constant force mode**.

NOTE 2 The spatial resolution in AFM in the static non-contact mode is generally much poorer than in the contact mode.

NOTE 3 AFM in the dynamic or frequency-modulated (FM) non-contact mode under ultra-high-vacuum conditions is able to achieve atomic resolution.

10.74
normal force
⟨AFM⟩ applied force on the **probe tip** normal to the surface

NOTE Depending on the circumstances, this force may be the force normal to the average surface or the force normal to a small element of that surface.

10.75
normal spring constant
spring constant
force constant
k_z
⟨AFM⟩ quotient of the applied **normal force** at the **probe tip** and the deflection of the **cantilever** in that direction at the probe tip position

cf. **lateral spring constant**, **torsional spring constant**

NOTE 1 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 2 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 an AFM may 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.

10.76
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 The numerical aperture is given by NA $= n\sin\theta$, where 2θ is the full angular aperture of the lens.

NOTE 2 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 around 1,56, provides superior resolution.

10.77
optical resolution
⟨NSOM, SNOM⟩ spatial resolution of an optical instrument

10.78
patch charge force
force between two surfaces arising from the electrostatic attraction or repulsion between surface patch charges

NOTE Patch charge force is discussed in Reference [27].

10.79
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

10.80
piezo force
⟨AFM⟩ contact mode AFM in which electrical contact is made via a conductive **tip** to a piezo-electric sample surface, the response of which to the applied electric field is a displacement that is measured via the AFM **cantilever** tip deflection

10.81
piezoelectric material
material with a non-centro-symmetric unit cell such that, under the application of externally applied mechanical stress, an electrical charge is produced across the faces of the material

NOTE 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.

10.82
piezoelectric force
force between the **probe tip** and the sample generated by the piezoelectric effect

NOTE This term is not commonly used except to describe the degree to which a piezoelectric material may 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.

10.83
piezoelectric sensor (cantilever)
sensor (cantilever) utilizing the piezoelectric effect for transduction

NOTE These sensors usually convert mechanical stress to electical charge.

10.84
piezoresistive
material property in which a mechanical stress or strain-induced stress produces a change in the resistance of the material

NOTE Although most materials are piezoresistive, silicon is known for being highly piezoresistive when appropriately doped.

10.85
piezoresistive cantilever
cantilever made of, or including, a **piezoresistive** material or region

NOTE These cantilevers, typically of doped Si, may be used in resistive bridges in order to determine stress or strain.

10.86
planar subtraction mode
mode in which data are recorded as the tip traces at a given height above a plane defined by a least squares fit through the pre-determined topography

cf. **height tracking mode, topography tracking mode**

NOTE 1 This approximate mode is used to remove the effects of topography from an image. Typical data that may be recorded are forces in general (such as magnetic forces), patch fields, etc.

NOTE 2 This mode is also known as the “planar subtract mode”.

10.87
polarization
electric dipole moment per unit volume

NOTE The polarization, P_i, is related to electric displacement, D, though 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.

10.88
probe
structure at or near the end or apex of the cantilever designed to carry the **probe tip**

cf. **composite probe**

10.89
probe assembly
structure comprising the **chip holder**, **chip**, **cantilever** and **probe**

10.90
probe characterizer
tip characterizer
structure designed to allow extraction of the **probe tip** shape from a scan of the characterizer

[ASTM E 1813-96 [20]]

10.91
probe flank
side of the probe in the region between the **probe apex** and the **probe support** or, if there is no probe support, the **cantilever**

10.92
probe length
distance between the **probe apex** and the **probe support** or, if there is no probe support, the **cantilever**

10.93
probe shank
structure between the **probe apex** and the **probe support** or, if there is no probe support, the **cantilever**

NOTE 1 For a **composite probe**, such as a **carbon nanotube probe**, 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**.

NOTE 2 For a **probe** 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 end. In this example, the single material of the probe has been engineered into two parts: the probe and the probe support.

10.94
probe stiffness
resistance of the probe to flexing caused by lateral forces, expressed as a force constant describing the lateral flexing of the probe under an impressed force

[ASTM E 1813-96 [20]]

10.95
probe support
structure at or near the end or apex of the cantilever designed to carry the **probe**

NOTE For work where particular probe qualities, such as probe **tip radius**, **probe stiffness** or probe profile, are required, a special probe such as a carbon nanotube may 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**.

10.96
probe support flank
side of the **probe support** in the region between the **probe** and the **cantilever**

10.97
probe support length
length of the **probe support** in the region between the **probe** and the **cantilever**

10.98
probe support shank
structure of the **probe support** in the region between the **probe** and the **cantilever**

10.99
probe tilt angle
angle between the axis of the probe and the normal to the plane of the **cantilever**

NOTE 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 end and towards the **cantilever apex**.

10.100
probe tip
tip
probe apex
structure at the extremity of a probe, the apex of which senses the surface

cf. **cantilever apex**

10.101
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 with a radius of curvature below 1 µm and ideally in the range 10 nm to 50 nm

NOTE Pulled tips may be used for imaging by one of the scanned probe microscopy methods, such as NSOM/SNOM.

10.102
pull-in force
pull-on force
force exerted by the surface on the **probe tip** at **snap-in**

10.103
pull-off force
force required to pull the probe free from the surface

NOTE This force is generally measured from the **force-distance curve** as the value between the force minimum and the zero of force as the probe moves away from the surface.

10.104
pulsed force mode
mode of scanning the probe where the probe is continually undergoing **force-distance curve** cycles at a cycle frequency below the **resonant frequency** of the **cantilever**

cf. **force-volume mode**

NOTE The operating frequency may be in the 100 to 2 000 Hz range and data for the maximum adhesion force or the sample local stiffness may be recorded rather than the whole force-distance curve for each pixel.

10.105
***Q* control**
electronic feedback system in the **dynamic mode** designed to change the apparent Q value for an **AFM cantilever**

NOTE 1 This control may be used to raise or lower the Q factor of a cantilever used in AFM.

NOTE 2 In liquids, the cantilever Q factor is reduced and so phase imaging is degraded. Raising the Q factor improves the phase imaging quality.

10.106
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 The resonator in this context may be, for example, an AFM **cantilever** operating in the **non-contact mode** or an optical fibre probe or tuning fork assembly used with shear force sensing in **NSOM/SNOM**.

NOTE 2 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 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 may be judged a more convenient and sufficiently accurate a measure of bandwidth for many practical purposes.

10.107
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

10.108
Raman spectroscopy
⟨NSOM, SNOM⟩ spectroscopy in which the **Raman effect** is used to investigate molecular energy levels

10.109
raster scanning
⟨SPM⟩ two-dimensional pattern generated by the movement of a **probe**

NOTE Commonly used rasters cover square or rectangular areas.

10.110
Rayleigh criterion
⟨NSOM, SNOM⟩ condition where the centre of the Airy disc from one image is superimposed on the minimum from another nearby image

NOTE Rayleigh's criterion is usually applied to circular apertures, 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 the aperture diameter.

10.111
reconstruction
⟨AFM⟩ estimate of the surface topography determined by eroding the image with the **probe tip** shape

[ASTM E 1813-96 [20]]

cf. **blind reconstruction**, **dilation**, **erosion**

NOTE 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, adsorption of gases or deposited atoms, etc.

10.112
reflection mode
⟨NSOM, SNOM⟩ mode in which the light reflected from the sample is collected as an optical signal

10.113
resonance frequency
natural frequency of resonance of the probe and support structure

NOTE The resonance frequency is lower in air than in vacuum, and in water or other liquids 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.

10.114
sample bias
voltage applied to the sample relative to the **probe tip**

10.115
scanner
mechanism that scans the **probe tip** relative to the sample

10.116
scanner creep
slow drift in the position addressed by a scanner

NOTE 1 For scanners without closed-loop control, creep is often in the forward direction and can lead to significant image distortion.

NOTE 2 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, may 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 $D\{1 + k[1 - \exp(-t/t_0)]\}$.

10.117
scanner hysteresis
position addressed by a scanner where the position lags on the position intended to an extent dependent on the excursion from the previous position

cf. **scanner creep**

NOTE 1 This effect leads to non-linear scans, poor repeatability of image registration, image distortion and differences in positioning with scan direction. It may largely be corrected by using a closed-loop feedback system.

NOTE 2 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 non-linearity is generally half of this value.

NOTE 3 Scanner hysteresis values are time-dependent and involve scanner creep.

10.118
scanning speed
rate of the raster scan driving an **SPM tip**, expressed as the number of lines of the image scanned per second or the frequency of repeating the linescan in Hz

10.119
second harmonic generation
SHG
non-linear effect in which light is scattered with twice the frequency of the incident light

NOTE 1 In **NSOM/SNOM**, **tip enhancement** can lead to second harmonic generation when a metal tip is used, or lead to an increase in second harmonic generation from the surface in close proximity to the tip.

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

10.120
set point
value of a parameter that an instrument tries to maintain constant when operating in a feedback mode by adjusting the **tip** to sample distance

NOTE When operating an AFM in the contact mode 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.

10.121
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

10.122
snap-in
snap-on
jump to contact (deprecated)
event that occurs when the **tip** is brought close enough to the surface such that the force gradient arising from surface attractive forces exceeds the **cantilever** restorative force gradient, causing the tip to spring into contact with the surface

10.123
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 Stiction occurs in MEMS device manufacture when components are removed from aqueous solutions. It is often overcome using suitable low surface energy treatments that may involve monolayer adsorption.

NOTE 2 This problem may be studied using **AFM**.

10.124
surface energy
quotient of the energy required to increase a surface area at thermodynamic equilibrium and that area

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

NOTE 2 This term has no relation to **surface energy approximation** used in EIA and RBS.

10.125
surface enhanced Raman scattering
SERS
enhanced **Raman effect** observed for certain molecules and appropriately prepared metal surfaces, where Raman scattering cross-sections are many orders of magnitude greater than for isolated molecules

NOTE The acronym SERS is used for both surface enhanced Raman scattering and spectroscopy.

10.126
surface enhanced Raman spectroscopy
SERS
spectroscopy using **surface enhanced Raman scattering**

NOTE The acronym SERS is used for both surface enhanced Raman scattering and spectroscopy.

10.127
surface enhanced resonant Raman scattering
SERRS
surface enhanced **Raman effect** in which the energy of the incident or scattered radiation is in resonance with an optical transition in the molecule

NOTE The acronym SERRS is used for both surface enhanced resonant Raman scattering and spectroscopy.

10.128
surface enhanced resonant Raman spectroscopy
SERRS
spectroscopy using **surface enhanced resonant Raman scattering**

NOTE The acronym SERRS is used for both surface enhanced resonant Raman scattering and spectroscopy.

10.129
surface patch charge
local charge arising from variations in the local **work function** of a solid surface

NOTE 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 may 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.

10.130
thermal drift
parameter change as a result of the effects of heat or temperature changes

10.131
tilt compensated probe
⟨AFM⟩ cantilever with a probe that is tilted with respect to the cantilever plane such that, when mounted, the probe addresses the surface normally

10.132
tip bias
⟨STM⟩ voltage applied to the **tip** measured relative to the sample

10.133
tip enhancement
⟨NSOM, SNOM⟩ enhancement of an optical signal, usually in the near-field regime, obtained through the interaction of the electrons at the **tip** end and the illuminating light

cf. **apertureless NSOM/SNOM**, **surface enhanced Raman scattering**

NOTE 1 Enhancements are usually obtained using a metallized AFM tip.

NOTE 2 Tip enhancement is important in techniques such as **near-field Raman microscopy**, where some tip materials and structures can lead to surface enhanced Raman signals many orders of magnitude larger than would otherwise be expected.

10.134
tip enhanced Raman scattering
TERS
⟨NSOM, SNOM⟩ enhanced **Raman effect** observed with a metal **tip** in close proximity to the sample surface illuminated with suitably polarized light

cf. **surface enhanced Raman scattering**

10.135
tip radius
⟨excluding apertureless NSOM/SNOM⟩ radius describing the surface curvature in a region at the apex of a stylus or **probe tip**

NOTE 1 It may be necessary to describe the tip by radii in different azimuths.

NOTE 2 In practice, tips may only approximate a sphere for a very small region at the tip.

10.136
tip radius
⟨apertureless NSOM/SNOM⟩ radius describing a circular region at the **probe tip** from which evanescent light of a significant intensity is emitted

10.137
torsional spring constant
k_θ
⟨AFM⟩ quotient of the applied torque at the **probe tip** about the cantilever axis and the torsional rotation about that axis at the probe tip position

cf. **lateral spring constant**, **normal spring constant**

10.138
transmittance
fraction of incident light that passes through a sample

NOTE The transmittance is usually defined at a specified wavelength.

10.139
tuning fork detection
detection of the **tip**-sample distance using oscillations of amplitude driven by a quartz tuning fork attached to a **cantilever** or optical fibre probe

10.140
tunnelling
quantum mechanical transport of electrons across a region with a potential energy higher than the electron energy

10.141
tunnelling barrier
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

cf. **tunnelling barrier height**, **tunnelling barrier width**

NOTE For electrons with energy less than the barrier height, quantum mechanics dictates that there is a finite probability for the electrons to tunnel across the barrier, whereas classical mechanics would forbid electron transport.

10.142
tunnelling barrier height
magnitude of the potential energy associated with the tunnelling barrier

cf. **barrier height**

NOTE In **STM**, the magnitude of the barrier height is related to the tip and substrate **work functions**.

10.143
tunnelling probability
probability that an electron will traverse the **tunnelling barrier**

NOTE In this quantum mechanical phenomenon, the tunnelling probability is related to the electron energy, **barrier height** and **barrier width**.

10.144
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 of ionic groups with one another or with neutral molecules

[IUPAC [11]]

NOTE 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.

10.145
vector scanning
scanning method that drives the **probe tip** on a defined vector trajectory in the image plane

10.146
Wollaston wire
wire probe comprising an electrically heated platinum **tip** in which the electrical resistance is used to measure the temperature of the tip in order to conduct micro-thermal analysis