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Surface chemical analysis — Vocabulary —

Part 2: Terms used in scanning-probe microscopy

Analyse chimique des surfaces — Vocabulaire —

Partie 2: Termes utilisés en microscopie à sonde à balayage

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Foreword

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

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This document was prepared by Technical Committee ISO/TC 201, *Surface chemical analysis*, Subcommittee SC 1, *Terminology*.

This third edition cancels and replaces the second edition (ISO 18115-2:2013), of which it constitutes a minor revision.

The changes to the previous edition are as follows:

— the term "Kelvin-force microscopy" has been replaced with "Kelvin-probe force microscopy" and, where it occurred, the term "scanning-probe microscopy" has been replaced with "scanning probe microscopy".

A list of all parts in the ISO 18115 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

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

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

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

The terms are given in alphabetical order, classified under the following:

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

— Clause 4: Acronyms and terms for contact mechanics models;

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

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

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

In the terms in Clause 3, note that the final “M” or final “S” in the acronyms, given as “microscopy” or “spectroscopy”, may also mean “microscope” or “spectrometer”, respectively, depending on the context. For the definition relating to the microscope or spectrometer, replace the words “a method” by the words “an instrument” where that appears.

In contact mechanics, covered in Clause 4, the basic theories are often referenced by acronyms. To avoid confusion, these acronyms are defined below. These models all assume that the materials in contact are homogeneous and isotropic, and have a linear elastic constitutive behaviour. Various contact models for inhomogeneous, anisotropic, nonlinear, viscoelastic, elastoplastic, and other materials have been derived and can be found in the literature.

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

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

Surface chemical analysis — Vocabulary —

Part 2: Terms used in scanning-probe microscopy

1 Scope

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

2 Normative references

There are no normative references in this document.

3 Terms and definitions

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1 Terms related to scanning probe microscopy methods

3.1.1
apertureless Raman microscopy
<NSOM, SNOM> method of microscopy involving the acquisition of Raman spectroscopic data utilizing a *near-field* (5.88) optical source and based upon a metal *tip* (5.120) in close proximity to the sample surface illuminated with suitably polarized light

3.1.2
atomic-force microscopy
AFM
DEPRECATED: scanning force microscopy
DEPRECATED: SFM
method for imaging surfaces by mechanically scanning their surface contours, in which the deflection of a sharp *tip* (5.120) sensing the surface forces, mounted on a compliant *cantilever* (5.18), is monitored

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

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

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

Note 4 to entry: Many types of force can be measured, such as the *normal forces* (5.91) or the *lateral* (5.77), *friction* (5.62), or shear force. When the latter is measured, the technique is referred to as *lateral* (3.1.13), *frictional* (3.1.11), or *shear force microscopy* (3.1.37). This generic term encompasses all of the types of force microscopy listed in Annex A.

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

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

3.1.3
chemical-force microscopy
CFM
LFM (3.1.13) or *AFM* (3.1.2) mode in which the deflection of a sharp *probe tip* (5.120), functionalized to provide interaction forces with specific molecules, is monitored

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

3.1.4
conductive-probe atomic-force microscopy
CPAFM
DEPRECATED: CAFM
DEPRECATED: C-AFM
<AFM> *AFM* (3.1.2) mode in which a conductive *probe* (5.109) is used to measure both topography and electric current between the *tip* (5.120) and the sample

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

3.1.5
current-imaging tunnelling spectroscopy
CITS
<STM> method in which the STM tip is held at a constant height above the surface, while the bias voltage, *V*, is scanned and the tunnelling current, *I*, is measured and mapped

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

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

3.1.6
dynamic-mode AFM
dynamic-force microscopy
DFM
<AFM> *AFM* (3.1.2) mode in which the relative positions of the *probe tip* (5.120) and sample vary in a sinusoidal manner at each point in the *image* (5.69)

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

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

3.1.7
electrostatic-force microscopy
DEPRECATED: electric-force microscopy
<AFM> *AFM* (3.1.2) mode in which a conductive *probe* (5.109) is used to map both topography and electrostatic force between the *tip* (5.120) and the sample surface

3.1.8
electrochemical atomic-force microscopy
EC-AFM
<AFM> *AFM* (3.1.2) mode in which a conductive *probe* (5.109) is used in an electrolyte solution to measure both topography and electrochemical current

3.1.9
electrochemical scanning tunnelling microscopy
EC-STM
<STM> *STM* (3.1.34) mode in which a coated *tip* (5.120) is used in an electrolyte solution to measure both topography and electrochemical current

3.1.10
frequency modulation atomic-force microscopy
FM-AFM
dynamic-mode AFM (3.1.6) in which the shift in *resonance frequency* (5.134) of the *probe assembly* (5.20) is monitored and is adjusted to a set point using a feedback circuit

3.1.11
frictional-force microscopy
FFM
SPM (3.1.30) mode in which the *friction force* (5.62) is monitored

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

3.1.12
Kelvin-probe force microscopy
KPFM
DEPRECATED: KFM
dynamic-mode AFM (3.1.6) using a conducting probe tip to measure spatial or temporal changes in the relative electric potentials of the tip and the surface

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

3.1.13
lateral-force microscopy
LFM
SPM (3.1.30) mode in which surface contours are scanned with a *probe assembly* (5.20) while monitoring the lateral forces exerted on the *probe tip* (5.120) by observation of the torsion of the *cantilever* (5.18) arising as a result of those forces

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

3.1.14
magnetic dynamic-force microscopy
MDFM
DEPRECATED: magnetic AC mode
DEPRECATED: MAC mode
<AFM> *AFM* (3.1.2) mode in which the *probe* (5.109) is oscillated by using a *magnetic force* (5.80)

3.1.15
magnetic-force microscopy
MFM
AFM (3.1.2) mode employing a *probe assembly* (5.20) that monitors both atomic forces and magnetic interactions between the *probe tip* (5.120) and a surface

3.1.16
magnetic-resonance force microscopy
MRFM
<AFM> *AFM* (3.1.2) imaging mode in which magnetic signals are mechanically detected by using a *cantilever* (5.18) at resonance and the force arising from nuclear or electronic spin in the sample is sensitively measured

3.1.17
near-field scanning optical microscopy
NSOM
scanning near-field optical microscopy
SNOM
method of imaging surfaces optically in transmission or reflection by mechanically scanning an optically active *probe* (5.109) much smaller than the wavelength of light over the surface while monitoring the transmitted or reflected light or an associated signal in the *near-field* (5.88) regime

Note 1 to entry: See *scattering NSOM* (3.1.36), *scattering SNOM* (3.1.36).

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

Note 3 to entry: Where the extent of the optical probe is defined by an *aperture* (5.5), the aperture size is typically in the range of 10 nm to 100 nm, and this largely defines the resolution. This form of instrument is often called an aperture NSOM or aperture SNOM to distinguish it from a *scattering NSOM* (3.1.36) or *scattering SNOM* (3.1.36) [previously called *apertureless NSOM* (3.1.36) or *apertureless SNOM* (3.1.36)], although, generally, the adjective "aperture" is omitted. In the apertureless form, the extent of the optically active probe is defined by an illuminated sharp metal or metal-coated *tip* (5.120) with a radius typically in the range of 10 nm to 100 nm, and this largely defines the resolution.

Note 4 to entry: In addition to the optical *image* (5.69), NSOM can provide a quantitative image of the surface contours similar to that available in *AFM* (3.1.2) and allied scanning probe techniques.

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

3.1.18
non-contact atomic-force microscopy
NC-AFM
dynamic-mode AFM (3.1.6) in which the *probe tip* (5.120) is operated at such a distance from the surface that it samples the weak, attractive van der Waals or other forces

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

3.1.19
photothermal micro-spectroscopy
PTMS
SThM mode in which the *probe* (5.109) detects the photothermal response of a sample exposed to infrared light to obtain an absorption spectrum

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

3.1.20
scanning capacitance microscopy
SCM
SPM (3.1.30) mode in which a conductive *probe* (5.109) is used to measure both topography and capacitance between the *tip* (5.120) and sample

3.1.21
scanning chemical-potential microscopy
SCPM
SPM (3.1.30) mode in which spatial variations in the thermoelectric voltage signal, created by a constant temperature gradient normal to the sample surface, are measured and related to spatial variations in the chemical-potential gradient

3.1.22
scanning electrochemical microscopy
SECM
SPM (3.1.30) mode in which imaging occurs in an electrolyte solution with an electrochemically active *tip* (5.120)

Note 1 to entry: See *electrochemical atomic-force microscopy*, *EC-AFM* (3.1.8), *electrochemical scanning probe microscopy*, *EC-SPM* (6.5), *electrochemical scanning tunnelling microscopy*, *EC-STM* (3.1.9).

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

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

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

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

3.1.23
scanning Hall probe microscopy
SHPM
SPM (3.1.30) mode in which a Hall probe is used as the scanning sensor to measure and map the magnetic field from a sample surface

3.1.24
scanning ion conductance microscopy
SICM
SPM (3.1.30) mode in which an electrolyte-filled micropipette or nanopipette is used as a local *probe* (5.109) for insulating samples immersed in an electrolytic solution

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

3.1.25
scanning magneto-resistance microscopy
SMRM
SPM (3.1.30) mode in which a magneto-resistive sensor *probe* (5.109) on a *cantilever* (5.18) is scanned in the *contact mode* (5.35) over a magnetic sample surface to measure two-dimensional magnetic *images* (5.69) by acquiring magneto-resistive voltage

3.1.26
scanning Maxwell stress microscopy
SMSM
SPM (3.1.30) mode in which a conductive *probe* (5.109) is used to measure both topography and surface potential by utilizing the Maxwell stress

3.1.27
scanning near-field thermal microscopy
SNTM
SNOM method in which an infrared-sensing thermometer is used to detect the local emission collected by an optical *probe* (5.109) to measure both the topography and thermal properties

3.1.28
scanning near-field ultrasound holography
SNFUH
method for imaging surfaces and the subsurface regimes by mechanically scanning their surface contours and detecting the results of the interference of a high-frequency acoustic wave [of the order of MHz or higher and substantially greater than the *resonance frequency* (5.134) of the *cantilever* (5.18)] applied to the bottom of the sample while another wave is applied to the cantilever at a slightly different frequency

3.1.29
scanning non-linear dielectric microscopy
SNDM
SPM (3.1.30) mode in which a conductive *probe* (5.109) is used to measure both topography and dielectric constant (capacitance)

3.1.30
scanning probe microscopy
SPM
method of imaging surfaces by mechanically scanning a *probe* (5.109) over the surface under study, in which the concomitant response of a detector is measured

Note 1 to entry: This generic term encompasses *AFM* (3.1.2), *CFM* (3.1.3), *CITS* (3.1.5), *FFM* (3.1.11), *LFM* (3.1.13), SFM, *SNOM* (3.1.17), *STM* (3.1.34), TSM, etc. listed in Annex A.

Note 2 to entry: The resolution varies from that of STM, where individual atoms can be resolved, to *SThM* (3.1.33), in which the resolution is generally limited to around 1 µm.

3.1.31
scanning spreading-resistance microscopy
SSRM
SPM (3.1.30) mode in which a conductive *tip* (5.120) is used to measure both topography and spreading resistance

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

3.1.32
scanning surface potential microscopy
SSPM
SPM (3.1.30) mode in which a conductive *probe* (5.109) is used to measure both topography and surface potential

Note 1 to entry: *KPFM* (3.1.12) is SSPM conducted using an *AFM* (3.1.2) as defined in 3.1.13. Where this is appropriate, KPFM should be used to describe the method rather than the more generic term, SSPM.

3.1.33
scanning thermal microscopy
SThM
SPM (3.1.30) method in which a thermal sensor is integrated into the *probe* (5.109) to measure both topography and thermal properties

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

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

3.1.34
scanning tunnelling microscopy
STM
SPM (3.1.30) mode for imaging conductive surfaces by mechanically scanning a sharp, voltage-biased, conducting *probe tip* (5.120) over their surface, in which the data of the *tunnelling* (5.169) current and the tip-surface separation are used in generating the *image* (5.69)

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

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

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

3.1.35
scanning tunnelling spectroscopy
STS
STM (3.1.34) mode in which the *tunnelling* (5.169) current, *I*, between the *tip* (5.120) and the sample is measured as the voltage, V, between the tip and the sample is scanned

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

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

3.1.36
scattering NSOM/SNOM
s-NSOM
s-SNOM
DEPRECATED: apertureless NSOM
DEPRECATED: ANSOM
DEPRECATED: apertureless SNOM
DEPRECATED: ASNOM

method in which imaging at a resolution below the *Abbe diffraction limit* (5.1) is achieved by detecting light scattered or emitted in the vicinity of a sharp scanning *tip* (5.120)

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

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

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

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

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

3.1.37
shear force microscopy
ShFM
<AFM> *AFM* (3.1.2) mode using signals arising from a *probe tip* (5.120) oscillating laterally in proximity to the surface

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

3.1.38
spin-polarized scanning tunnelling microscopy
SP-STM
DEPRECATED: spin-resolved tunnelling microscopy
DEPRECATED: SRTM
<STM> *STM* (3.1.34) mode in which a magnetically ordered (ferromagnetic or antiferromagnetic) STM *tip* (5.120) is scanned over a sample surface to image two-dimensional magnetic structures on the nanometre scale by measuring the spin-dependent *tunnelling* (5.169) current

3.1.39
spin-polarized scanning tunnelling spectroscopy
SP-STS
STS (3.1.35) mode in which a magnetically ordered (ferromagnetic or antiferromagnetic) STM tip is scanned over a sample surface to perform spin-polarized *tunnelling* (5.169) spectroscopy to probe the magnetic and electronic structures of the sample surface on the nanometre scale

3.1.40
static-mode AFM
static AFM
<AFM> *AFM* (3.1.2) mode of scanning the *probe* (5.109) where a control parameter is maintained essentially constant or of scanning a control parameter at a fixed point in the raster array at the sample surface

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

3.1.41
tip-enhanced fluorescence spectroscopy
TEFS
<NSOM, SNOM> enhanced fluorescence observed with a metal *tip* (5.120) in close proximity to a sample surface illuminated with suitably polarized light

Note 1 to entry: See *tip-enhanced Raman spectroscopy* (3.1.42).

3.1.42
tip-enhanced Raman spectroscopy
TERS
<NSOM, SNOM> enhanced *Raman effect* (5.128) observed with a metal *tip* (5.120) in close proximity to a sample surface illuminated with suitably polarized light

Note 1 to entry: See *tip-enhanced fluorescence spectroscopy* (3.1.41), *surface-enhanced Raman scattering* (5.151).

3.1.43
ultrasonic force microscopy
UFM
<AFM> *AFM* (3.1.2) mode in which an ultrasonic wave is injected through the *probe* (5.109) to observe the surface or subsurface mechanical structure

4 Terms for contact mechanics models

4.1
Burnham-Colton-Pollock model
BCP
semi-empirical model of *tip* (5.120) and surface contact that assumes that long-range forces act only outside the contact area

Note 1 to entry: See Reference [1].