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Microbeam analysis — Analytical electron microscopy — Vocabulary

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National foreword

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Microbeam analysis — Analytical electron microscopy — Vocabulary

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Contents

Page

Foreword

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

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The committee responsible for this document is ISO/TC 202, *Microbeam analysis*, Subcommittee SC 1, *Terminology*.

Introduction

Analytical electron microscopy (AEM) is a technique used to qualitatively determine and quantitatively measure the elemental composition and examine the electronic state of the small volume of solid material observed by transmission electron microscopy (TEM) and scanning transmission electron microscopy (STEM). AEM is based on the physical mechanism of electron-stimulated X-ray spectrometry and electron energy loss spectrometry (EELS). AEM also provides structural information from small regions by microdiffraction while still possessing the capability of high-resolution imaging.[9]

As a major sub-field of microbeam analysis (MBA), AEM is widely applied in diverse business sectors (high-technology industries, basic industries, metallurgy and geology, biology and medicine, environmental protection, trade, etc.) and has a wide business environment for standardization.

The standardization of terminology in a technical field is one of the basic prerequisites for the development of standards on other aspects of that field.

This International Standard is relevant to the international scientific and engineering communities that require an AEM vocabulary that contains consistent definitions of terms, as they are used in the practice of MBA combined with TEM and STEM.

This International Standard is one developed in a package of standards on scanning electron microscopy (SEM; ISO 22493), electron probe X-ray microanalysis (EPMA; ISO 23833), energy-dispersive X-ray spectrometry (EDS; ISO 22309), etc., which have been either already developed or are to be developed by ISO/TC 202, *Microbeam analysis*, to completely cover the field of MBA.

INTERNATIONAL STANDARD ISO 15932:2013(E)

Microbeam analysis — Analytical electron microscopy — Vocabulary

0 Scope

This International Standard defines terms used in the practice of AEM. It covers both general and specific concepts classified according to their hierarchy in a systematic order.

This International Standard is applicable to all standardization documents relevant to the practice of AEM. In addition, some parts of this International Standard are applicable to those documents relevant to the practice of related fields (e.g. TEM, STEM, SEM, EPMA, EDX) for the definition of those terms common to them.

NOTE See also the ISO online browsing platform (OBP): https://www.iso.org/obp/ui/

1 Abbreviated terms

AEM	analytical electron microscope/microscopy
CBED	convergent beam electron diffraction
CCD	charge-coupled device
CRT	cathode ray tube
EDS	energy-dispersive X-ray spectrometer/spectroscopy
EDX	energy-dispersive X-ray spectrometer/spectroscopy
EELS	electron energy loss spectrometer/spectroscopy
EPMA	electron probe microanalysis
FFT	fast Fourier transform
FIB	focused ion beam
FWHM	full width at half maximum
HAADF	high-angle annular dark field
HREM	high-resolution transmission electron microscope/microscopy
LAADF	low-angle annular dark field
MBA	microbeam analysis
SE	secondary electron
SEM	scanning electron microscopy
STEM	scanning transmission electron microscope/microscopy
TEM	transmission electron microscope/microscopy

2 Definitions of terms used in the physical basis of AEM

2.1
electron optics
science that deals with the trajectory of electrons as they pass through electrostatic and/or electromagnetic fields

[SOURCE: ISO 22493, modified]

2.1.1
electron source
device that generates electrons necessary for forming an electron beam in an electron optical system

2.1.1.1
energy spread
diversity of energy of electrons in the incident beam

[SOURCE: ISO 22493, modified]

2.1.1.2
effective source size
effective dimension of the electron source typically measured at the beam crossover

[SOURCE: ISO 22493, modified]

2.1.2
electron emission
ejection of electrons from the surface of a material under certain excitation conditions

[SOURCE: ISO 22493:2008, 3.1.2]

2.1.2.1
thermionic emission
electron emission which relies on the use of high temperature to enable electrons in the cathode to overcome the work function energy barrier and escape into the vacuum assisted by the application of an external electrostatic field

[SOURCE: ISO 22493, modified]

2.1.2.2
field emission
electron emission caused by the strong electric field on and near the surface of the material

[SOURCE: ISO 22493, modified]

2.1.2.2.1
cold field emission
field emission in which the emission process relies purely on the applied electric field to extract electrons from the cathode operating at ambient temperature

[SOURCE: ISO 22493, modified]

2.1.2.2.2
thermal field emission
field emission in which the emission process relies on both the elevated temperature of the cathode tip and an applied electric field of high voltage

[SOURCE: ISO 22493, modified]

2.1.3
electron lens
basic component of an electron optical system, using an electrostatic and/or electromagnetic field to change the trajectories of the electrons passing through it

2.1.3.1
electrostatic lens
electron lens employing an electrostatic field formed by a specific configuration of electrodes

2.1.3.2
electromagnetic lens
electron lens employing an electromagnetic field formed by a specific configuration of electromagnetic coils (or permanent magnets) and pole pieces

[SOURCE: ISO 22493:2008, 3.1.3.2]

2.1.4
focusing
converging an electron beam to a minimum diameter using an electron lens

[SOURCE: ISO 22493, modified]

2.1.5
demagnification
numerical value by which the diameter of the electron beam exiting a lens is reduced in comparison to the diameter of the electron beam entering the lens

[SOURCE: ISO 22493:2008, 3.1.5]

2.2
electron scattering
electron deflection with or without the loss of kinetic energy as a result of collision(s) with target atom(s) or electron(s)

[SOURCE: ISO 22493 and ISO 23833, modified]

2.2.1
elastic scattering
electron scattering in which energy and momentum are conserved in the collision system

[SOURCE: ISO 22493:2008, 3.2.1]

2.2.1.1
zero loss
unscattered and elastically scattered electrons (with only minimal loss of energy due to phonon excitation), giving rise to an intensity peak or the position of which defines zero in the electron energy loss spectrum

2.2.2
inelastic scattering
electron scattering in which energy and/or momentum are not conserved in the collision system

Note 1 to entry: For inelastic scattering, the electron trajectory is modified by plasmon loss, core loss, and other multiple scatterings

[SOURCE: ISO 22493, modified]

2.2.2.1
thermal diffuse scattering
electron scattering which is caused by electron-phonon scattering due to thermal vibration of the lattice

2.2.2.2
plasmon loss
type of energy loss in EELS in which the incident electron is affected by the collective oscillations of free electrons in the specimen and loses kinetic energy as a result

2.2.2.3
inner-shell ionization
excitation of an electron bound in an inner-shell (nonvalence) orbital to an unbound state in the continuum above the Fermi level

2.2.2.4
core loss
energy loss of an electron in the beam caused by excitation of an inner-shell electron

2.2.3
scattering cross-section
hypothetical area normal to the incident radiation that would geometrically intercept the total amount of radiation actually scattered by a scattering atom

Note 1 to entry: Scattering cross-section is usually expressed only as area (m^2).

[SOURCE: ISO 22493:2008, 3.2.3]

2.3
Bloch wave
wave function of an electron in a periodic crystal potential, which is written as the product of a plane wave envelope function and a periodic function that has the same periodicity as the crystal potential

2.3.1
anomalous absorption
absorption of Bloch wave in a crystalline material when the wave is symmetric and forms its antinodes at the nuclei

2.3.2
anomalous transmission
transmission of Bloch wave in a crystalline material when the wave is antisymmetric and forms its nodes at the nuclei

2.4
coherence
wave property exhibited by electron beams in which two waves share the same frequency and are in phase

Note 1 to entry: Phase shifts between two coherent beams result in interference and generate diffraction patterns.

2.5
TEM
microscopy technique or microscope where images of an ultrathin specimen are obtained by an electron beam that is transmitted through it

2.5.1
HREM
method for obtaining lattice and crystal structure images by interfering with a transmitted electron wave and diffracted electron waves using an electromagnetic lens with a small spherical aberration

2.5.2
STEM
transmission electron microscopy technique which rasters the focused electron beam over the specimen

2.5.3
HAADF-STEM
imaging mode in a scanning transmission electron microscope in which images are formed by collecting very high-angle, incoherently scattered electrons with an annular dark-field detector

2.5.4
LAADF-STEM
imaging mode in a scanning transmission electron microscope in which images are formed by collecting low-angle elastic and inelastic scattering electrons with an annular dark-field detector

2.5.5
ABF-STEM
imaging technique of acquiring a bright-field scanning transmission electron microscope image with an annular detector

2.6
electron holography
application of holography techniques to electron waves in which the coherent beam is split into at least two beams by using an electron biprism

2.6.1
electron prism
device which splits the coherent electron beam into several beams in order to obtain an interferogram or hologram

2.7
Lorentz electron microscopy
method for observing magnetic domain structures by use of the transmission electron microscope

2.8
phase-contrast electron microscopy
TEM technique in which small phase shifts in the transmitted beam resulting from interactions with the specimen are converted into amplitude or contrast changes in the image

2.9
electron tomography
reconstruction technique of a three-dimensional structure by the computer-assisted image processing of a series of projected images obtained by continuously tilting the specimen

3 Definitions of terms used in AEM instrumentation

3.1
electron gun
component that produces an electron beam with a well-defined kinetic energy

[SOURCE: ISO 22493:2008, 4.1]

3.1.1
Schottky emission
thermionic electron emission that takes place under an electric field that enhances the emission by lowering the surface barrier

[SOURCE: ISO 22493, modified]

3.1.2
field emission gun
electron gun employing field emissions sources, such as cold field electron emission or Schottky emission

3.1.2.1
cold field emission gun
electron gun employing cold field emission

3.1.2.2
extracting electrode
electrode applying the electrostatic potential to extract electrons from the electron source

[SOURCE: ISO 22493:2008, 4.1.1.1.1]

3.1.2.3
thermal field emission gun
electron gun employing thermal field emission

3.1.3
thermionic emission gun
electron gun employing thermionic emission

3.1.3.1
tungsten hairpin gun
thermionic emission gun employing a tungsten hairpin filament as its cathode

3.1.3.2
LaB_6 gun
thermionic emission gun employing a heated block of single-crystal LaB_6 as its cathode

[SOURCE: ISO 22493:2008, 4.1.2.2]

3.1.3.3
anode
electrode in an electron gun, to which a high positive voltage relative to the cathode is applied in order to accelerate the emitted electrons from the cathode

3.1.3.4
cathode
electrode that serves as the electron emitter in the electron gun, which is at a negative electric potential relative to the anode

3.1.3.5
accelerating voltage
electrostatic field between the cathode and the anode, which accelerates an electron beam in an electron gun

3.1.3.6
Wehnelt cylinder
cap-shaped electrode placed between the anode and the cathode in the electron gun, which acts to focus electrons inside the gun and to control the amount of electron emission

3.1.4
brightness
β
current density per unit solid angle in the beam at the focus position

Note 1 to entry: Brightness is given by the formula

$$\beta = 4i/(\pi^2 d^2 \alpha^2) \ [\mathrm{A/m^2 \cdot sr}]$$

where i is the beam current, in amps; d is the diameter of the beam crossover, in metres; and α is the beam half-angle, in rads.

3.1.5
reduced brightness
β'
brightness divided by the electron beam acceleration voltage

Note 1 to entry: Reduced brightness is given by the formula

$$\beta' = \beta/V$$

where V is the electron beam acceleration voltage and β is the brightness.

3.1.6
emission current
total electron current emitted from the cathode

3.1.7
saturation
specific cathode heating condition at which a change in the cathode heating current will result in only a small change in the electron beam current, which is close to its maximum

3.2
electron lens system
combination of various electron lenses to achieve specific electron optics functions

3.2.1
excitation current
electric current flowing in a coil of an electromagnetic lens, which is necessary for the generation of a magnetic field

3.2.2
aberration
divergence from ideal properties of an electron optical element, e.g. lens defects like spherical aberration, chromatic aberration, and diffraction, that degrade the lens optical function

[SOURCE: ISO 22493:2008, 4.2.1]

3.2.2.1
chromatic aberration
lens defect which arises because electrons from the same point in the specimen, but of slightly different energies, will be focused at different positions in the image plane

3.2.2.2
spherical aberration
C_S
lens defect arising from the varying strength of an electromagnetic lens with distance from the optic axis, which causes rays further from the optic axis to be focused more strongly than those nearer the optic axis

[SOURCE: ISO 22493, modified]

3.2.2.3
astigmatism
phenomenon in which electrons emerging from a point object are focused to form two separate focal lines at 90° to one another rather than a point focus as formed by a perfectly cylindrical lens

Note 1 to entry: It arises from the lens asymmetric magnetic field caused by machining errors, inhomogeneities in the pole pieces, asymmetry in the lens windings, and imperfect apertures.

[SOURCE: ISO 22493:2008, 4.2.3]

3.2.3
aperture
diaphragm with an axial opening that defines the transmission of the lens

3.2.3.1
aperture angle
half of the angle subtended by the diameter of the aperture at the point of beam focus

3.2.3.2
aperture diffraction
defect which arises at very small aperture diameters because the wave nature of electrons gives rise to a diffraction pattern instead of a point in the Gaussian image plane

3.2.3.3
condenser aperture
diaphragm that is used in a fixed or moveable manner in a condenser lens system in order to select a certain portion of the beam, thereby controlling the size of the illuminated specimen area and the electron beam dose and also enabling the electron beam convergence to be determined

3.2.3.4
objective aperture
diaphragm placed in the back focal plane of the objective lens in order to select an angular subset of electrons with which to form the image

3.2.3.5
selected-area (selector) aperture
moveable diaphragm that is used to select only radiation scattered from a specific area of the specimen to contribute to the formation of a diffraction pattern

3.2.4
stigmator
device that applies weak supplementary magnetic fields to correct astigmatism

3.2.5
condenser lens
electron lens located immediately below the electron gun, which is used to focus the electron beam to varying degrees to control the current and the convergence of the electron beam that passes down the electron column

3.2.5.1
cone angle
convergence angle of an incident electron beam

3.2.6
deflection coil
coil that generates a magnetic field to deflect the electron beam

3.2.7
C_S **corrector**
device that can vary the spherical aberration coefficient (C_S) of the objective lens

3.2.8
objective lens
first-stage lens in the imaging lens system of AEM, which is used to focus the electron image or probe

3.2.8.1
back focal plane
plane perpendicular to the optic axis of an AEM in which rays leaving the specimen at the same angle come to a focus

3.2.9
intermediate lens
lens inserted between the objective and projector lenses, which magnifies the objective image or diffraction pattern and forms the new image upon the objective plane of the projector lens

3.2.9.1
objective plane
plane where electron beams originating from an object converge to form an image of the object

3.2.10
projector lens
final lens in the imaging system, which magnifies the intermediate image and forms the final image on the recording device

3.3
scanning system
device incorporated in the electron optical system for achieving time-controlled one- or two-dimensional movement of the electron probe on the specimen surface and synchronized signal collection to generate line scans or images

3.4
specimen chamber
compartment in which the goniometer stage containing the specimen is accommodated

3.4.1
goniometer stage
device to move the specimen laterally and vertically and to tilt the specimen by tilting the specimen holder around the longitudinal holder axis

3.4.2
top-entry stage
specimen stage which is inserted from above the pole piece and has rotation symmetry about the optical axis

3.4.3
side-entry stage
specimen stage which is inserted from the side of the column and is useful for material science and tomography because of its large space above the specimen

3.4.4
electron beam-induced contamination
formation of a carbon-rich, polymerized film on a specimen surface as a result of radiation damage of adsorbed hydrocarbon molecules

3.4.5
anti-contamination device
device which suppresses the adsorption of hydrocarbon gas by condensing it using a cold trap chilled by liquid nitrogen

3.4.6
differential pumping
pumping method designed to achieve and maintain specified vacuum levels for chambers connected by diaphragms, which prevent the exchange of large amounts of gas

3.4.7
specimen drift
unintentional movement of the specimen image due to any source (thermal, mechanical, electrical, charging)

3.4.8
environmental TEM
type of TEM which enables the *in situ* observation of the specimen under various conditions, such as low vacuum or high temperature

3.5
fluorescent screen
viewing apparatus which visualizes TEM image and diffraction spots, using visible light emitted from fluorescent material excited by the electron impact

3.6
image wobbler
control for introducing an AC current into the objective lens in order to aid proper alignment of the electron optical elements

3.7
camera length
L
effective distance between the specimen and the plane where diffraction pattern is formed

3.7.1
camera constant
λL
product of the wavelength of the incident electron wave and camera length

Note 1 to entry: Because of the small Bragg angle, the Bragg condition can be given in the first-order approximation

$$d \approx \lambda L / r$$

where d is the lattice plane spacing and r is the distance of the diffraction spot from the primary beam.

4 Definitions of terms used in specimen preparation of AEM

4.1
ion milling
thinning technique of sputtering the specimen with an inert gas

4.2
chemical polishing
planarization technique that uses chemical dissolution of a specimen surface

4.3
mechanical polishing
planarization technique that uses abrasives to remove surface material from the specimen

4.4
jet polishing
electrolytic thinning technique for planarization of conductive materials by spraying jets of chemical etchants simultaneously on both sides of a specimen

4.5
supporting film
thin coating film on a grid utilized for holding the specimen for TEM observation

4.5.1
microgrid
specimen supporting film that features myriad micrometre-sized holes

4.6
FIB milling
site-specific thinning technique using abrasion by focused field-emitted gallium atoms accelerated to an energy of 1 keV to 40 keV to thin a particular region of the specimen

4.7
radiation damage
electron beam-induced structural deterioration of the specimen arising from ionization and electron knock-on

4.8
microtome
mechanical instrument used to slice specimens into electron transparent thin sections for TEM observation

4.9
dimple grinder
mechanical polishing instrument used to form a small dimple on a specimen which has been previously polished to a parallel-sided plate on the order of 100 μm

4.10
conductive coating
thin coating of conductive carbon or metal produced on the surface of non-conductive specimens to minimize charging problems during TEM observation

4.11
replica
duplication of specimen surface irregularities obtained by the exfoliation of a plastic or carbonaceous film from the specimen surface

4.12
extraction replica
replica which contains precipitates or inclusions fixed on a coated plastic or carbonaceous film created by stripping the film from the specimen surface

5 Definitions of terms used in AEM image formation and processing

5.1
Moiré effects
formation of Moiré fringes caused by the superposition of the periodicity of the specimen features and the grating of picture points forming the scanned image or by the superposition of interference patterns from crystals exhibiting different orientation or lattice spacing

5.2
contrast
C
difference in signal between two arbitrarily chosen points (P_1, P_2) of interest in the image field, normalized by the maximum possible signal available under the particular operating conditions

Note 1 to entry: Contrast is given by the formula

$$C = |S_2 - S_1|/S_{max} \quad (0 < C < 1)$$

where S_2 and S_1 are the signals of two arbitrarily chosen points (P_2 and P_1, respectively), and S_{max} is the maximum possible signal available under the particular operating conditions.

5.3
analogue image processing
operation of treating and manipulating the image information-carrying signals as continuously varying quantities

[SOURCE: ISO 22493:2008, 5.5]

5.4
digital image processing
operation in which the image information-carrying signals are treated and manipulated as discrete variables, i.e. digitized

[SOURCE: ISO 22493:2008, 5.6]

5.4.1
Fourier transform
mathematical operation that decomposes a signal into its constituent frequencies

5.4.1.1
fast Fourier transform
FFT
efficient algorithm to compute the discrete Fourier transform

5.4.1.2
inverse fast Fourier transform
IFFT
efficient algorithm to compute the inverse of the discrete Fourier transform

5.5
bright-field image
image formed using only the non-scattered beam, selected by observation of the back focal plane of the objective lens and using the objective aperture to cut out all diffracted beams

5.6
dark-field image
image formed by a diffracted beam only by using the objective aperture for selection or by collecting the diffracted beam with an annular dark-field detector

5.7
weak-beam method
image formed using a weakly excited diffracted beam, which can provide sharp contrast at dislocations because the highly strained areas contribute significantly to the beam intensity

5.8
lattice image
image formed by the interference of transmitted and diffracted beams from a very thin specimen and which corresponds to the periodic lattice structure of the specimen

5.9
defocus imaging
method of imaging under out-of-focus conditions, which is utilized when observing Fresnel fringes, lattice images, and structural images

5.9.1
underfocus imaging
imaging condition in which the objective lens current is weakened slightly from that of just focus to enhance contrast in bright/dark-field imaging

5.9.2
overfocus imaging
imaging condition in which the objective current is slightly strengthened from that of the focus to enhance contrast in bright/dark-field imaging

5.9.3
Scherzer focus
$\Delta f_{\text{Scherzer}}$
defocusing condition in which high-resolution images of the phase object are formed by shifting the phase of the diffracted beam by 0,5π which maximizes the spatial frequency of the first zero of the contrast transfer function

Note 1 to entry: $\Delta f_{\text{Scherzer}}$ is given by the formula

$$\Delta f_{\text{Scherzer}} = -1{,}2(C_s\lambda)^{1/2}$$

where C_s is the spherical aberration, and λ is the electron wavelength.

5.9.4
Fresnel fringe
interference fringes that appear near the specimen edge in Fresnel diffraction

5.9.5
structure image
image which is obtained by the interference of the transmitted and diffracted beams under Scherzer focus condition

5.9.6
through-focus method
imaging method of the lattice image and structure image in which a series of images are formed under slightly different defocus conditions

6 Definitions of terms used in AEM image interpretation and analysis

6.1
diffraction contrast
type of scattering contrast which arises from the spatial variation of the intensity of the diffracted beam due to the local variation of the diffraction condition

6.1.1
two-beam approximation
approximation for the calculation of an AEM image in which the transmitted wave and only one diffracted wave are presumed to be excited

6.1.2
bend contour
type of diffraction contrast which arises from the local variation of the excitation error in Bragg diffraction condition due to the bending of the specimen

6.1.3
thickness fringe
contrast observed in a wedge-shaped specimen under excitation of one Bragg diffraction due to the oscillation of the primary beam intensity and reflection intensity

6.1.4
Fresnel diffraction
type of diffraction which occurs when a wave passes through and diffracts in the near field, which creates interference fringes near the edge of the specimen under defocus condition

6.2
phase contrast
image contrast due to the phase shift of scattered waves, which provides high-resolution TEM image

6.2.1
weak phase object approximation
approximation in which the specimen does not change the amplitude of the incident wave but slightly shifts the phase

6.3
scattering contrast
image contrast which arises from the spatial variation of the intensity of atomic scattering due to the local variation of elemental composition

6.4
image simulation
calculation of the image theoretically expected to be formed by various AEM imaging techniques

6.4.1
multi-slice method
algorithm for the simulation of high-resolution TEM images, which treats electrons as incoming waves and treats the interactions with matter as occurring on multiple successive single slices of the specimen

6.4.2
Bethe's method
algorithm for the simulation of high-resolution TEM images, which finds the electron waves in the crystal by solving the Schrodinger equation considering the multiple scattering

6.4.3
contrast transfer function
CTF
function which provides phase shift of the electron wave as a function of a given spherical aberration, scattering angle, and defocus

6.5
lattice defect
crystallographic defect due to the irregularity in the atomic arrangement in the crystal

6.5.1
dislocation
crystallographic linear defect in a crystal structure, which strongly influences many of the properties of materials and has two primary types: edge dislocations and screw dislocations

6.5.1.1
edge dislocation
dislocation where an extra half-plane of atoms is inserted in the crystal, distorting nearby planes

6.5.1.2
screw dislocation
dislocation comprising a structure in which a helical path is traced around it

6.5.2
Burgers vector
vector that represents the magnitude and direction of the lattice distortion of dislocation in a crystal lattice, which is often denoted by ***b***

6.5.3
stacking fault
type of planar defect which arises from the irregularity in stacking sequence of closed-packed atomic planes and is commonly formed in close-packed structures, such as fcc and hcp

6.5.4
grain boundary
interface between two grains in a polycrystalline material

6.6
energy-dispersive X-ray spectroscopy
EDS
analytical technique which enables the elemental analysis or chemical characterization of a specimen by analysing characteristic X-rays emitted by the matter in response to electron irradiation

[SOURCE: ISO 23833, modified]

6.6.1
characteristic X-ray
emitted X-ray with a kinetic energy is characteristic of the element from which it is emitted

6.6.2
fluorescence yield
fraction of ionizations of a specific electron shell that result in characteristic X-ray emission

6.6.3
X-ray continuum
emitted X-rays resulting from the deceleration of electrons in the Coulomb field of the nucleus

6.6.4
Bremsstrahlung
electromagnetic radiation which gives a continuous spectrum due to the deceleration of a charged particle such as an electron

6.6.5
take-off angle
angle between the specimen plane and the axis of an EDS detector crystal

[SOURCE: ISO 22493, modified]

6.6.6
dead time
γ
time during which the system is unable to record a photon measurement because it is busy processing a previous event (frequently expressed as a percentage of the total time)

[SOURCE: ISO 23833, modified]

6.6.7
live time
time during which the pulse measurement circuitry is available for the detection of X-ray photons

Note 1 to entry: Live time equals real time for analysis minus dead time. Real time is the time that would be measured with a conventional clock. For X-ray acquisition, real time always exceeds live time.

6.6.8
ZAF correction method
correction method of the quantitative analysis in EDS in which the effect of absorption, fluorescence, and atomic number on characteristic X-ray emission by atoms in the specimen are corrected, while the effect is extremely small in the thin-film specimen in TEM/EDS

6.6.9
Cliff-Lorimer method
method for the quantitative EDS analysis of a thin specimen, in which proportionality factor, k, is used to relate spectral intensity to chemical composition

6.6.9.1
***k* factor**
correction factor used in Cliff-Lorimer method, which is experimentally or theoretically determined

6.6.10
EDS detector energy resolution
identifiable minimum energy separation in EDS analysis, which depends upon the detected X-ray energy, the type of detector, and the instrument on which the detector is installed

6.7
electron energy loss spectroscopy
EELS
microscopic elemental and electronic state analysis method using inelastically scattered electrons resulting from interaction with electrons and phonon in the specimen in which the energy loss is measured via an electron spectrometer and interpreted in terms of what caused the energy loss

6.8
energy filter
apparatus which passes electrons with a specific kinetic energy, which is effective for the subtraction of inelastic electron background in image and diffraction pattern formation, and also for the acquisition of energy-filtered images for analytical purposes

6.9
atomic-number effect
effect in which the yield of a characteristic X-ray depends upon the atomic numbers of elements in the specimen due to the back scattering of incident electrons

6.10
Imaging plate
two-dimensional detector which utilizes photostimulated luminescence of europium

6.11
slow-scan CCD camera
CCD camera which uses a lower refreshing rate than an ordinary CCD camera system to improve image quality by increasing the signal-to-noise ratio

6.12
EDS detector
solid-state detector which measures the intensity and the energy of X-rays emitted from the specimen

6.12.1
windowless EDS detector
EDS detector lacking a window material in front of the detector which increases the measurement sensitivity for soft X-rays (< 1 keV) enables the detection of elements with an atomic number larger than that of boron

6.12.2
ultrathin window (UTW) EDS detector
EDS detector which uses an aluminium-coated organic thin film as a window material in front of the detector, increasing the measurement sensitivity for soft X-rays (< 1 keV) and enabling the detection of light elements

6.12.3
beryllium window EDS detector
EDS detector fitted with a beryllium window of 8 μm to 10 μm in thickness, which is suitable for measuring hard X-rays (> 1 keV)

6.13
annular dark-field detector
ADF detector
detector used in STEM to collect a dark-field image by integrating the scattered intensity intercepted by an annulus around the transmitted beam

Note 1 to entry: Z-contrast due to Rutherford scattering is obtained with a high-scattering angle, while a dark-field image is obtained with a low-scattering angle.

7 Definitions of terms used in the measurement and calibration of AEM image magnification and resolution

7.1
image resolution
minimum spacing at which two features of an image can be recognized as distinct and separate; for an amorphous thin film, the resolution is obtained from the FFT pattern

[SOURCE: ISO 22493, modified]

7.2
image magnification
M
ratio of a linear dimension, *L*, on the recorded image of the specimen to the corresponding length, *l*, on the specimen itself

Note 1 to entry: Image magnification is given by the formula

$$M = L/l$$

[SOURCE: ISO 22493 and ISO 23833, modified]

7.2.1
calibration grating
standard reference grating with known pitch used to calibrate the TEM in order to obtain an absolute value of the magnification

[SOURCE: ISO 22493, modified]

7.2.2
diffraction grating replica
standard reference grating with a known pitch used to calibrate the TEM in order to obtain the absolute value of the camera constant

7.3
information limit
theoretical limit of the resolution of HREM, established by the observation of an amorphous specimen and used as a performance index of a TEM

7.4
diffraction limit
focusing limit of an electron optical system having no aberrations, which is dependent only upon the numerical aperture and the electron wavelength and is characterized by the size of the Airy disc

7.5
point resolution
resolution under Scherzer focusing, which is defined as the spatial frequency where the CTF crosses the abscissa for the first time

7.6
lattice resolution
resolution under imaging, which corresponds to the periodic lattice structure of the specimen

7.7
Airy disc
diffraction-limited probe size produced by a perfect lens with a circular aperture

7.8
reference material
RM
material or substance, one or more of whose property values are sufficiently homogeneous and well established to be used for the calibration of an apparatus, the assessment of a measurement method, or for assigning values to materials

Note 1 to entry: For the purpose of this International Standard, an RM possesses periodic pattern(s) with the desired range of periodic interval and accuracy to be used for the calibration of the image magnification or camera constant.

7.8.1
certified reference material
CRM
reference material, accompanied by a certificate, one or more of whose property values are certified by a procedure, which establishes its traceability to an accurate realization of the unit in which the property values are expressed, and for which each certified value is accompanied by an uncertainty at a stated level of confidence

7.9
excitation current
electric current applied to the coil of the magnetic lens

7.10
glass scale
ruler on which a fine scale is drawn and is utilized as the reference scale to measure the distance in the digitized image after digitizing it with an image scanner

8 Definitions of terms used in electron diffraction in AEM

8.1
transmitted wave
electron wave which is either unscattered or forward scattered by the specimen and is coincident with the optic axis

8.2
diffracted wave
electron wave which has undergone Bragg diffraction in the specimen

8.3
Bragg diffraction
physical process of particularly strong scattering of the incident electron beam at certain angles relative to the atomic planes in a crystal due to constructive interference in accordance with the Bragg diffraction relation

[SOURCE: ISO 22493, modified]

8.3.1
Bragg diffraction relation
mathematical expression which relates the wavelength of the incident radiation and the spacing of the atomic planes of a crystal to the angles, between the radiation beam and the atomic planes, at which diffraction takes place

Note 1 to entry: The relation is given by the formula

$$\lambda = 2d\sin\theta_B$$

where λ is the wavelength; d is the lattice spacing; and θ_B is the Bragg angle.

8.3.2
kinematical diffraction
diffraction process in which only one Bragg diffraction is excited in the thin specimen and absorption is negligible

8.3.3
dynamical diffraction
diffraction process in which multiple Bragg diffraction are excited in the specimen

8.3.3.1
double diffraction
Bragg diffractions doubly excited in a vertically stacked bicrystal

8.3.3.2
Kikuchi lines
structure observed in the background of the diffraction pattern, which is formed by a Bragg diffraction of inelastically scattered electrons

8.3.4
selected area electron diffraction
diffraction technique in which an area of the specimen is selected by using the selector diaphragm in front of the intermediate lens

8.3.5
microdiffraction
diffraction technique in which diffraction spots are obtained from micrometre-sized regions of the specimen by use of a small electron probe

8.3.6
convergent-beam electron diffraction
diffraction technique in which diffractions over several incident angles simultaneously take place by converging the electron trajectories in a cone onto the specimen

8.4
Miller index
notation system in crystallography for planes and directions in crystal lattices, in which a family of lattice planes or directions is determined by three integers *h, k, l*

8.5
reciprocal space
space defined by reciprocal lattice vectors that is useful for translating diffraction patterns into crystal structures

8.5.1
reciprocal lattice
set of all vectors $\boldsymbol{K}$ determined such that $\exp(i\boldsymbol{R}\cdot\boldsymbol{K})=1$ for all lattice point position vectors $\boldsymbol{R}$

8.5.2
Ewald sphere
sphere defined in the reciprocal lattice with a radius of $1/\lambda$ (λ; electron wavelength) and centre located along the incident electron beam direction at a distance of $1/\lambda$ from a particular reciprocal point

8.5.3
zone axis
crystallographic direction, designated [*uvw*], can be defined by the intersection of a number of crystal planes (*h1, k1 ,l1... hi, ki, li*) such that all of the planes satisfy the so-called Weiss zone law; $hu + kv + lw = 0$

8.5.3.1
Weiss zone law
law which permits crystallographic planes and directions to be determined by using the relationship $hu + kv + lw = 0$ when Miller plane (*hkl*) is parallel to direction (*uvw*)

8.5.4
extinction distance
periodicity in depth of the electron intensity oscillation between the primary beam and the Bragg reflected beam

8.5.5
excitation error
parameter describing the small deviation from the exact Bragg condition

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