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Surface chemical analysis — Vocabulary —

Part 3:
Terms used in optical interface analysis

Analyse chimique des surfaces — Vocabulaire —

Partie 3: Termes utilisés dans l'analyse des interfaces optiques

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Contents

Page

Foreword

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

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

Optical spectroscopies and surface chemical analysis, in general, are important areas which involve interactions between people with different backgrounds and from different fields. Those conducting optical spectroscopy on surfaces can be materials scientists, chemists, physicists or biologists and might have a background that is primarily experimental or primarily theoretical. Those making use of the data and results extend beyond this group into other disciplines.

ISO 18115-1 extend from the techniques of electron spectroscopy and mass spectrometry to general spectrometry terms and X-ray analysis. The terms covered in ISO 18115-2 relate to scanning-probe microscopy.

This document covers terms used in optical spectroscopies. This includes terms related to general terms, properties of light and optical properties of materials. In terms of techniques, there is a focus on terms related to Raman spectroscopy, ellipsometry and nonlinear optical techniques.

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 3.1 general terms, 3.2 properties of light, 3.3 optical properties of materials, 3.4 ellipsometry terms, 3.5 Raman spectroscopy terms and 3.6 nonlinear optical technique terms. The terms in each clause are not always mutually exclusive and some terms placed in one clause can equally belong in another.

Surface chemical analysis — Vocabulary —

Part 3:
Terms used in optical interface analysis

1 Scope

This document defines terms for surface chemical analysis in the area of optical interface analysis including ellipsometry, Raman spectroscopy and nonlinear optical techniques as well as general optical terms.

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 General terms

3.1.1
background signal
signal present at a particular position, energy, mass or wavelength due to processes or sources other than those of primary interest

3.1.2
CCD detector
semiconductor device that converts light into an electrical signal

Note 1 to entry: When a photon is absorbed by the detector, a single electron is released. Electrodes covering the chip surface hold these electrons in place in an array of wells, or pixels, such that during exposure to light, a pattern of charge builds up that corresponds to the pattern of light.

3.1.3
compensator
retardation plate of fixed or variable optical path length difference used for introducing a light path difference between two beams or to compensate the optical path length that can cause unwanted dispersion or time-delay

Note 1 to entry: See also *retardation plate/wave plate* (3.1.34).

[SOURCE: ISO 10934:2020, 3.1.27, adapted]

3.1.4
confocal optical microscopy
optical microscopy in which, light is suppressed from out-of-focus planes using one or more pinholes such that only light from a confocal volume is detected

Note 1 to entry: An image of an extended area is formed via scanning.

Note 2 to entry: The confocal principle leads to improved contrast and axial resolution by suppression of light from out-of-focus planes.

3.1.5
confocal volume
effective volume that is in focus around a point in the object which gives rise to the detected signal or image in confocal microscopy

[SOURCE: ISO 10934:2020, 3.3.10.8, modified — The phrase "detected signal or" has been added.]

3.1.6
depth of field
region where the sharpness of the edges of the images reaches a pre-set optimum

[SOURCE: ISO 26824:2013, 8.16, modified — "the" has been replaced by "a" prior to "pre-set optimum".]

3.1.7
depth of focus
axial depth of the space on both sides of the focal plane, within which the image or signal appears acceptably sharp, while the positions of the object plane and of the objective are maintained

Note 1 to entry: The method to determine when the image or signal is acceptably sharp depends on the microscopy or spectroscopy method. For example, in confocal Raman microscopy, the depth of focus can be determined as when the signal does not decrease by more than 87 % ($1/e^2$) compared to the maximum signal exactly at the object position.

[SOURCE: ISO 19262:2015, 3.68, modified — Note 1 to entry has been added.]

3.1.8
diffraction grating
set of regularly repeating structures which, when illuminated, produce, by reflection or transmission, maxima and minima of intensity as a consequence of interference

Note 1 to entry: These maxima and minima vary in position according to wavelength. Radiation of any given wavelength may thus be selected from interference pattern allowing the grating to be used for producing monochromatic light.

[SOURCE: ISO 10934:2020(en), 3.1.42, modified — "diffraction" has been deleted as a consequence and Note 1 has been reworded slightly.]

3.1.9
dipole moment
vector quantity describing the separation of electric charges where the direction is from negative to positive charge

Note 1 to entry: When an atom or molecule interacts with an electromagnetic wave, it can undergo a transition from an initial to a final state of energy difference through the coupling of the electromagnetic field to the transition dipole moment. When this transition is from a lower energy state to a higher energy state, this results in the absorption of a photon. A transition from a higher energy state to a lower energy state results in the emission of a photon.

3.1.10
edge filter
optical filter that rejects light above or below a specific wavelength but transmits light outside that criterion

Note 1 to entry: Depending on whether the transmitted part contains the longer or shorter wavelengths, the edge filter is called a long wave pass (LWP) or a short-wave pass (SWP) filter, respectively.

Note 2 to entry: In Raman spectroscopy, an edge filter is used to reject *Rayleigh scattering* (3.3.38) but permit measurement of either *Stokes* (3.5.25) or *anti-Stokes* (3.5.1) Raman scattering.

Note 3 to entry: In reality, edge filters have a narrow transition width. Edge filters with a very narrow transition width are also available and are known as razor edge filters.

3.1.11
fluorophore
molecular entity that emits fluorescent light when excited by a specific range of wavelengths of light

3.1.12
goniometer
instrument that either measures an angle or allows an object to be rotated to a precise angular position

3.1.13
half-wave plate
half-wave compensator
optical device which alters the polarization state of light travelling through the device by π

3.1.14
Jones matrix
two by two matrix that is used to represent the operation of an optical element such as a polarizer on the polarization state of light

Note 1 to entry: Fully polarized light is represented by a *Jones vector* (3.2.17).

3.1.15
lock in amplifier
type of amplifier that extracts a signal from a complex waveform at the same frequency as that of a second carrier wave

3.1.16
monochromator
optical device that transmits a light beam with a certain wavelength within a wider range of wavelengths available at the input

Note 1 to entry: The bandwidth is defined by the *spectral purity* (3.1.33)

3.1.17
neutral density filter
filter having uniform absorption throughout the range from near ultraviolet to near infrared radiation, thus reducing the light intensity without altering spectral distribution

[SOURCE: ISO 6196-6:1992, 06.01.13]

3.1.18
notch filter
optical filter that attenuates light with a specific narrow frequency range while passing all other frequencies unaltered

Note 1 to entry: In Raman spectroscopy, a narrow notch is used to reject *Rayleigh scattering* (3.3.38) but permit measurement of both *Stokes* (3.5.25) and *anti-Stokes Raman scattering* (3.5.1).

3.1.19
numerical aperture
NA
product of the refractive index of the medium in which the lens is working, n, and the sine of one-half of the angular aperture of the lens, θ

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

[SOURCE: ISO 18115-2:2021, 5.93, modified — Note 2 has been deleted.]

3.1.20
objective lens
combination of several lenses in a common mounting which, together with the focusing lens, projects a real reversed image of the object in the image plane

[SOURCE: ISO 9849:2017, 3.2.20]

3.1.21
optical modulator
optical device that imposes modulation on a light beam

Note 1 to entry: This modulation can be for example in phase, frequency or amplitude.

Note 2 to entry: Examples include electro-optical modulator or photo acoustical modulator.

3.1.22
peak height
distance between the peak maximum and the background

Note 1 to entry: The method used to determine the background should be carefully considered and specified.

[SOURCE: ISO 7941:1988, 4.3.2, modified — Reworded slightly.]

3.1.23
peak shape
form of a spectral feature that can typically be described by a mathematical function and parameters such as spectral position, height, and width

Note 1 to entry: Examples of the mathematical function include Gaussian, Lorentzian, PearsonVII and Voigt functions.

3.1.24
peak width
width of a peak at a defined fraction of the peak height

Note 1 to entry: Any background subtraction method used should be specified.

Note 2 to entry: The most common measure of peak width is the full width of the peak at half maximum (FWHM) intensity.

Note 3 to entry: For asymmetrical peaks, convenient measures of peak width are the half-widths of each side of the peak at half maximum intensity. Other parameters that can be measured are skewness, the amount and direction of skew or departure from horizontal symmetry and kurtosis which is a measure of how tall and sharp a peak is.

3.1.25
photobleaching
loss of optical *fluorescence* (3.2.15) in a fluorescent molecule due to overexposure with irradiating light

3.1.26
photodetector
device that converts light into an electrical signal

Note 1 to entry: Examples include photodiode, photomultiplier, CCD and CMOS.

3.1.27
photomultiplier tubes
photomultipliers
PMTs
electronic device for amplifying and converting light pulses into measurable electrical signals

Note 1 to entry: They can be used for the collection of, for example, confocal Raman, *CARS* (3.5.3), two photon fluorescence, TPEF *(two photon excitation fluorescence)* (3.2.46) and *second harmonic generation* (3.6.27).

[SOURCE: ISO 772:2011(en), 1.163, modified — Note 1 has been added.]

3.1.28
polarizer
material which only transmits the component of a light wave which is oscillating in a particular direction

[SOURCE: ISO 23713:2005, 3.2, modified]

3.1.29
quarter-wave plate
optical device which changes the polarization state of light travelling through the device by $\pi/2$

3.1.30
selection rules
set of restrictions governing the allowedness of transitions of a system from one quantum state to another

Note 1 to entry: The selection rules may differ according to the technique used to observe the transition for example between infrared spectroscopy and Raman spectroscopy.

3.1.31
silicon diode detector
photodiode that converts the light into electrical current

Note 1 to entry: These types of detectors can be used for *SRS* (3.5.24) and it is a type of *photodetector* (3.1.26).

3.1.32
solid angle
$\Omega = A/r^2$

where

    A   is the area of the included surface of a sphere in a cone with its apex at the centre of the sphere;

    r   is the radius of the sphere.

Note 1 to entry: The solid angle is the three-dimensional angle, e.g. the cone of light from a point source.

Note 2 to entry: Solid angles are expressed in steradians (sr).

[SOURCE: ISO 80000-3:2006, 3-6 and notes adapted from ISO 4007:2018, 3.4.13

3.1.33
spectral purity
indication of the monochromaticity of a given light sample

3.1.34
wave plate
retardation plate
optical device generally consisting of a piece, or pieces, of optically anisotropic material with plane faces, to produce a specific polarization state change of the light when travelling through the device

Note 1 to entry: Waveplates are constructed out of a birefringent material (for example quartz, mica, or certain polymers), for which the index of refraction is different for light linearly polarized along one or the other of two certain perpendicular crystal axes.

3.2   Terms related to properties of light

3.2.1
airy disc
central spot of light in the diffraction pattern of a point light source

3.2.2
bandwidth
range of frequencies within a given band

Note 1 to entry: A common way to calculate bandwidth is to use the full width at half maximum. It is typically measured in hertz.

3.2.3
beam diameter
diameter of an electromagnetic beam along any specified line that is perpendicular to the beam axis and intersects it.

Note 1 to entry: The beam diameter can be defined in several ways, such as full-width at half-maximum (FWHM), $1/e$, $1/e^2$ or 4σ based on the measured intensity as a function of lateral distance.

Note 2 to entry: This usually refers to a beam of circular cross section, but not necessarily so it can be, for example, elliptical in which case the orientation of the major and minor axis needs to be specified.

3.2.4
beam divergence
angular measure of the increase in beam diameter or radius with distance from the optical aperture or antenna aperture from which the beam emerges

Note 1 to entry: As the *wavevector, k* (3.2.49) is a vector it is dependent on both the spectral purity and angular divergence of a source.

3.2.5
candela
luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of $1/683$ W per steradian (a unit of solid angle)

Note 1 to entry: Candela (cd) is the unit of luminous intensity in the International System of Units (SI).

3.2.6
chromaticity
property of a colour stimulus defined by its chromaticity coordinates, or by its dominant or complementary wavelength and purity taken together

Note 1 to entry: Chromaticity coordinates specifies a colour regardless of its luminance.

[SOURCE: ISO 9241-302:2008(en), 3.3.9, modified — Note 1 to entry has been added.]

3.2.7
circular polarization
polarization state in which, at each point, the electric field of the wave has a constant magnitude, but its direction rotates with time at a steady rate in a plane perpendicular to the direction of the wave

Note 1 to entry: Circularly polarized light can be produced by passing linearly polarized light through a quarter-wave plate at an angle of 45° to the optical axis of the plate.

Note 2 to entry: As the electric field can rotate clockwise or anti-clockwise as it propagates, circularly polarized waves exhibit chirality.

3.2.8
coherence
characteristic of a beam of electromagnetic radiation where there is a deterministic (not random) phase relationship between each pair of points in the beam

Note 1 to entry: There are two types of coherence; *spatial coherence* (3.2.40) and *temporal coherence* (3.2.45)

[SOURCE: ISO 11145:2018, 3.11.1, modified — Note 1 has been added.]

3.2.9
coherence length
propagation distance in a dispersive medium over which an electromagnetic wave maintains a specified degree of coherence

Note 1 to entry: Practically, it is used for quantifying the degree of *temporal coherence* (3.2.45) as the propagation length (and thus propagation time) over which coherence degrades significantly.

3.2.10
colour temperature
temperature of a Planckian radiator whose radiation has the same chromaticity as that of a given stimulus

[SOURCE: ISO 9241-6:1999, 3.5]

3.2.11
depolarization
act of randomizing the polarization of an electromagnetic wave

Note 1 to entry: A depolarizer is the device used to depolarise light regardless of the input wave. In reality a depolariser will produce a pseudo-random output.

3.2.12
diffraction limit
maximum spatial resolution achievable for an optical system, governed by diffraction phenomena

Note 1 to entry: The Abbe diffraction limit, is defined as $\lambda/(2NA)$ in which λ is the wavelength of the illuminating light and NA is the *numerical aperture* (3.1.19).

3.2.13
elliptical polarization
polarization state in which, the electric field vector describes an ellipse in any fixed plane intersecting, and normal to, the direction of propagation

Note 1 to entry: An elliptically polarized wave may be resolved into two linearly polarized waves in phase quadrature, with their polarization planes at right angles to each other. Circular and linear polarization can be considered to be special cases of elliptical polarization.

Note 2 to entry: As the electric field can rotate clockwise or anti-clockwise as it propagates, elliptically polarized waves exhibit chirality.

3.2.14
extinction coefficient
imaginary part of a complex refractive index of a material which describes the amount of attenuation when the electromagnetic wave propagates through the material

3.2.15
fluorescence
phenomenon in which absorption of light of a given frequency by a substance is followed by the emission of light at a lower frequency (longer wavelength) from the excited states with the same degeneracy

Note 1 to entry: Generally, the emission is from singlet excited state to singlet ground state.

Note 2 to entry: In the case of multiphoton fluorescence, the emitted light may be of a shorter wavelength.

3.2.16
frequency
reciprocal of the period

Note 1 to entry: The unit of frequency is the hertz (Hz), which corresponds to one cycle of periodic motion per second.

[SOURCE: ISO 2041:2018, 3.3.33]

3.2.17
Jones vector
two by one matrix that describes the polarization state of light where the two parts represent the amplitude and phase of the electric field in the x and y directions

Note 1 to entry: An optical element is represented by a *Jones matrix* (3.1.14).

3.2.18
irradiance
power of electromagnetic radiation incident on a surface per unit surface area

Note 1 to entry: The SI unit is watt per square metre (Wm^{-2}).

Note 2 to entry: This can also be expressed as the incident flux per area incident on a given surface.

[SOURCE: ISO 29464:2017, 3.6.7, modified — Note 1 has been modified. Note 2 to entry has been added.]

3.2.19
linear polarization
plane polarization
polarization state in which, the electric field vector is confined to a given plane along the direction of propagation

Note 1 to entry: The two orthogonal linear polarization states that are most important for reflection and transmission are referred to as p- and s-polarization.

3.2.20
lumen
SI derived unit of *luminous flux* (3.2.22), whereby one lumen is the luminous flux emitted within a unit solid angle (one steradian) by a point source having a uniform luminous intensity of one candela

Note 1 to entry: If a light source that emits one candela of luminous intensity uniformly across a solid angle of one steradian, the total luminous flux emitted into that angle is one lumen (1 cd·1 sr = 1 lm).

Note 2 to entry: Lumen (symbol: lm) is the SI derived unit of luminous flux, a measure of the total quantity of visible light emitted by a source.

3.2.21
luminescence
emission, of optical radiation by atoms, molecules or ions in a material, which for certain wavelengths or regions of the spectrum is in excess of the radiation due to thermal emission from that material at the same temperature, as a result of these particles being excited by energy other than thermal agitation

[SOURCE: IEC 60050 845:1987, 04-18, modified — Reordered the text of the definition.]

3.2.22
luminous flux
quantity derived from the radiant flux, by evaluating the radiation in accordance with its action upon the CIE standard photometric observer

[SOURCE: ISO 4007:2018,3.4.4]

3.2.23
luminous intensity
quantity of visible light that is emitted in unit time per unit solid angle

Note 1 to entry: The candela (one of the SI base units, abbreviation cd), is the unit of luminous intensity.

Note 2 to entry: The unit for the quantity of light flowing from a source in any one second (the luminous power, or luminous flux) is called the lumen.

3.2.24
monochromatic radiation
radiation consisting of only a single wavelength, or of only a very narrow band of wavelengths of which the central wavelength is quoted

[SOURCE: ISO 10934:2020, 3.1.123.2]

3.2.25
optical constants
quantities that describe the optical behaviour of a substance for a specified wavelength

Note 1 to entry: Typical properties are *refractive index* (3.3.43), *absorption coefficient* (3.3.1), or *reflectivity* (3.3.41).

3.2.26
period
smallest interval of time for which a periodic function repeats itself

Note 1 to entry: If no ambiguity is likely, the fundamental period is called the period.

[SOURCE: ISO 2041:2018, 3.3.32]

3.2.27
phosphorescence
photoluminescence (3.2.28) delayed by storage of energy in an intermediate energy level

Note 1 to entry: The emission is generally from triplet excited state to singlet ground state.

[SOURCE: ISO 17724:2003, 53]

3.2.28
photoluminescence
luminescence (3.2.21) caused by absorption of optical radiation

[SOURCE: IEC 60050 845:1987, 04-19]

3.2.29
photometry
method for the measurement of light, in terms of electromagnetic radiation weighted by the human eye's response

Note 1 to entry: This response changes with wavelength, and to an extent, from person to person. Internationally agreed standard observer functions are therefore used in order to provide a consistent measurement base for photometry.

Note 2 to entry: The word 'luminous' is used to indicate that measurements have been made using a detection system (called a photometer) that has a spectral response similar to that of a human eye.

3.2.30
photon
particle representing a quantum of light or other electromagnetic radiation that carries energy proportional to the radiation frequency, has zero rest mass and travels at the speed of light in a vacuum

3.2.31
polarizability
ratio of induced dipole moment of a material to the electric field that induces it

Note 1 to entry: Polarizability is a measure of how easily an electron cloud is distorted by an electric field.

Note 2 to entry: The SI units of polarizability are $C\ m^2\ V^{-1}$.

3.2.32
polarizability tensor
tensor used to describe the *polarizability* (3.2.31) of *anisotropic media* (3.3.3)

3.2.33
polarization
property of transverse waves that specifies the geometrical orientation of the oscillations with respect to the propagation vector

Note 1 to entry: For light, polarization is normally defined by the direction, or time-dependent direction, of the electric field vector.

3.2.34
power spectral density
magnitude of a signal in the frequency domain expressed in terms of the power per unit frequency as a function of frequency

Note 1 to entry: For optical signals the units of power spectral density are typically W/Hz.

3.2.35
p-polarized light
linear polarized light that has an electric field polarized parallel to the plane of incidence

3.2.36
propagation matrix
mathematical matrix that is used in optics to analyse the propagation of electromagnetic waves through a stratified medium

3.2.37
radiance
radiant intensity of an element of the surface, at a point on a surface and in a given direction, divided by the area of the orthogonal projection of this element on a plane perpendicular to the given direction

Note 1 to entry: The unit of radiance is the watt per steradian per square metre ($W \cdot sr^{-1} \cdot m^{-2}$)

[SOURCE: ISO/TS 19101-2:2018, 3.30, modified — Note 1 has been added.]

3.2.38
radiant flux
power emitted, transformed or received in the form of radiation

Note 1 to entry: radiant flux is expressed in watts (W)

[SOURCE: CIE 17.4-1987]

3.2.39
radiometry
set of techniques for characterizing the distribution of electromagnetic radiation's power

3.2.40
spatial coherence
characteristic of a beam of electromagnetic radiation to have a degree of phase correlation between different spatial points in the beam at the same moment in time

[SOURCE: ISO 11145:2018, 3.11.3]

3.2.41
spectral irradiance
irradiance of a surface per unit frequency or wavelength

Note 1 to entry: Spectral irradiance of a frequency spectrum is measured in watts per square metre per hertz (W·m^{-2}·Hz^{-1}), while spectral irradiance of a wavelength spectrum is measured in watts per square metre per metre (W·m^{-3}).

3.2.42
spectral radiance
radiance of a surface per unit frequency or wavelength

Note 1 to entry: Spectral radiance in frequency is measured in watts per steradian per square metre per hertz (W·sr^{-1}·m^{-2}·Hz^{-1}) while spectral radiance in wavelength is measured in watts per steradian per square metre, per metre (W·sr^{-1}·m^{-3}).

3.2.43
s-polarized light
linear polarized light that has an electric field polarized perpendicular to the plane of incidence

3.2.44
Stokes vector
4 x 1 column matrix which characterizes possible states of polarization of a quasi-monochromatic or monochromatic transverse-electromagnetic wave

3.2.45
temporal coherence
characteristic of a beam of electromagnetic radiation to have a degree of phase correlation between different moments in time at the same spatial point in the beam

[SOURCE: ISO 11145:2018, 3.11.2]

3.2.46
two photon fluorescence
two photon excitation fluorescence
TPEF
fluorescence that arises from the excitation by the simultaneous absorption of two photons

Note 1 to entry: This uses the simplest form of *multi-photon absorption* (3.6.14) such that a single fluorescent photon is emitted for every 2 photons being absorbed.

[SOURCE: ISO 10934:2020, 3.3.29.1.1]

3.2.47
wavelength
λ
distance in the direction of propagation of a sinusoidal wave between two successive points where at a given instant in time the phase differs by 2π

[SOURCE: ISO 80000-3:2006, 3-17]

3.2.48
wavenumber
σ
inverse of the wavelength (λ) of electromagnetic radiation

[SOURCE: ISO 19702:2015, 3.6]

3.2.49
wavevector
k
vector in reciprocal space describing the direction of propagation of electromagnetic wave and equal in magnitude to $2\pi/\lambda$, where λ is the *wavelength* (3.2.47)

Note 1 to entry: In different fields of study, the wave vector is taken as $2\pi/\lambda$ or as $1/\lambda$ for crystallography. For electromagnetic waves the former is usually used.

[SOURCE: ISO 18115-1:2013, 7.36, modified — The definition has been modified to apply to more general waves.]

3.3   Terms related to optical properties due to interactions with media

3.3.1
absorption coefficient
coefficient that indicates the degree of absorption of light per unit length in a certain medium and depends on the wavelength/energy of the incident wave

Note 1 to entry: In practice, the absorption coefficient indicates how deep into a material light of defined wavelengths will get before being absorbed.

Note 2 to entry: Attenuation coefficient is defined in ISO 18115-1:2013, 4.33.

3.3.2
absorption edge
sharp discontinuity in the absorption spectrum of a substance that occurs at wavelengths where the energy of an absorbed photon corresponds to an electronic transition or ionization potential

3.3.3
anisotropic media
<optics> media in which electromagnetic waves behave differently depending on which direction the wave is propagating

Note 1 to entry: Crystals are examples of anisotropic media. Here, the polarization field is not necessarily aligned with the electric field of light.

3.3.4
anomalous dispersion
dispersion (3.3.16) characterized by a decreasing index of refraction in the medium, as the frequency of the propagating light increases and the wavelength decreases

Note 1 to entry: A medium will have anomalous dispersion where the real part of permittivity decreases with frequency.

Note 2 to entry: Anomalous dispersion occurs in regions in which the material absorbs light.

Note 3 to entry: For a wave group, a related term is negative group-velocity dispersion which is sometimes referred to as anomalous dispersion. This is strictly speaking not correct. Negative group-velocity dispersion is characterized by a short-wavelength or high frequency pulse traveling faster than a long-wavelength, or low frequency pulse.

3.3.5
birefringence
property of a material which causes incident light waves of different polarizations to be refracted differently by the material

Note 1 to entry: Lyot filter is a type of optical filter that uses birefringence to produce a narrow bandpass of transmitted wavelengths.

[SOURCE: ISO/IEC 10885:1993, 4.3.3, modified — Note 1 to entry has been added.]

3.3.6
blackbody radiation
intensity and spectral distribution of the optical and infrared power emitted by a completely absorbing material at a uniform temperature

3.3.7
Brewster angle
angle of incidence at which light with a particular polarization is perfectly transmitted through a transparent dielectric surface, with no reflection

Note 1 to entry: When unpolarized light is incident at this angle, the light that is reflected from the surface is perfectly polarized.

3.3.8
Cauchy coefficients
constant parameters in *Cauchy's equation* (3.3.9) that characterize the index of refraction as a function of the wavelength for transparent materials

3.3.9
Cauchy's equation
empirical relationship between the index of refraction and wavelength of light for transparent materials

3.3.10
complex refractive index
refractive index for a medium with absorption expressed as a real and an imaginary (absorption) part

Note 1 to entry: The complex refractive index can be expressed mathematically as $\underline{n} = n + iK$ where i is the square root of −1; K is the imaginary (absorption coefficient) part of the refractive index; n is the real part of the refractive index. For an anisotropic medium, n is a tensor.

[SOURCE: ISO 13320:2020, 3.1.5 modified — Wording from ISO 80000-7:2008, 7-5 has been included.]

3.3.11
critical angle
angle between the incident beam and the specimen surface, at which the reflectivity is at the first point of inflexion

Note 1 to entry: In practical cases, the critical angle is often taken as the angle at which the reflected intensity has fallen to 50 % of that in the total external reflection condition. The error here is generally small. It is also the angle between the incident beam and the specimen surface above which the transmitted electric field becomes real. Its value depends on the energy and material properties.

Note 2 to entry: The critical angle for a given specimen material or structure can be found by using simulation software, or by calculation where refractive indices of the two mediums are known.

3.3.12
dichroism
property of some anisotropic materials of having different *absorption coefficients* (3.3.1) for light polarized in different directions

Note 1 to entry: Dichroism is in most cases related to the linear polarization directions, however there is also circular dichroism, where the difference in optical properties occurs for different circular polarization direction.

3.3.13
dielectric constant
relative permittivity
material property given as the ratio of the permittivity of the material to the permittivity of the vacuum

Note 1 to entry: For isotropic materials this is a unitless dimensionless quantity.

3.3.14
dielectric function
optical property of a material where the complex dielectric constant depends on the frequency and wave vector of the field

Note 1 to entry: This is generally a complex function.

3.3.15
dielectric tensor
dielectric function in anisotropic medium expressed as a 3 × 3 tensor

3.3.16
dispersion
change in phase velocity of a wave group as a function of its wavelength (or frequency) when passing from one medium to another which causes a separation of the monochromatic components of electromagnetic radiation

Note 1 to entry: The refractive index of a transparent material is the same as the phase velocity divided by the speed of light in a vacuum, thus dispersion can also be defined as the variation in refractive index of a medium which causes a separation of the monochromatic components of electromagnetic radiation.

Note 2 to entry: There are two types of dispersion, *normal dispersion* (3.3.27) and *anomalous dispersion* (3.3.4).

[SOURCE: ISO 10934:2020, 3.1.46, modified — "complex" has been replaced with "electromagnetic" and Note 1 added has been added.]

3.3.17
elastic scattering
interaction between a photon and matter, where the total kinetic energy is conserved, as a result, the energies of the incident and scattered photons are identical

3.3.18
electric susceptibility
dimensionless proportionality constant that indicates the degree of polarization of a dielectric material in response to an applied electric field

3.3.19
emissivity
ratio of the radiance emitted by a radiant source to the radiance that would be emitted by a black body radiant source at the same temperature

Note 1 to entry: Emissivity is dimensionless.

[SOURCE: ISO 13943:2017, 3.89, modified]

3.3.20
Fresnel coefficients
coefficients that give the amount an electromagnetic wave is reflected or transmitted from or through a dielectric for transverse electric field and transverse magnetic field radiation

Note 1 to entry: Since electromagnetic waves are transverse, there are separate coefficients in the polarization directions perpendicular to and parallel to the plane of incidence.

3.3.21
Fresnel equations
formulae that calculate the ratio of the reflected and transmitted electric field amplitude to the initial electric field for electromagnetic radiation incident on an interface between different optical media

Note 1 to entry: The formulae assume the interface between the media is flat and that the media are homogeneous. The incident light is assumed to be a plane wave, and effects of edges are neglected.

3.3.22
group velocity
speed and direction at which the amplitude of an overall envelope shape of a group of waves propagates in a medium

Note 1 to entry: Compare with *phase velocity* (3.3.29).

3.3.23
inelastic light scattering
interaction between a photon and matter, where the total kinetic energy is not conserved, as a result, the energy of the incident and scattered photons are not identical

3.3.24
isotropic media
<nonlinear optics> medium in which electromagnetic permeability and permittivity are uniform in all directions

3.3.25
Kramers-Kronig relationship
bidirectional mathematical relations, connecting the real and imaginary parts of a dielectric function based on the principle of causality

Note 1 to entry: These relations are often used to calculate the real part from the imaginary part or vice versa.

Note 2 to entry: All functions used to model vibrational spectra obey the Kramers-Kronig transforms as long as the real parts are even functions of wavenumber and the imaginary parts are odd functions of wavenumber so that the Kramers-Kronig transforms are equivalent to the Hilbert transforms.

3.3.26
nonlinear susceptibility
tensor that describes the nonlinear response of material system upon the strength of an applied optical field

Note 1 to entry: When this is a second order term it describes processes such as second harmonic generation *(SHG)* (3.6.27) and a third-order nonlinear optical susceptibility describes processes, such as *third-harmonic generation* (3.6.34) and the intensity-dependent refractive index.

3.3.27
normal dispersion
dispersion characterized by an increasing index of refraction in the medium, as the frequency of the propagating light increases and the wavelength decreases

Note 1 to entry: A medium will have normal dispersion where the real part of permittivity increases with frequency. Compare with *anomalous dispersion* (3.3.4).

Note 2 to entry: Normal dispersion occurs in most transparent media.

Note 3 to entry: For a wave group, a related term is positive group-velocity dispersion which is sometimes referred to as normal dispersion. This is strictly speaking not correct. Positive group-velocity dispersion is characterized by a long wavelength or low frequency pulse traveling faster than a short wavelength or high frequency pulse.

3.3.28
permittivity
mathematical scalar or tensor that describes the degree of polarization of a dielectric material in response to an applied electric field

3.3.29
phase velocity
speed and direction at which the phase of any individual wave of a given frequency in a group of waves, propagates in a medium

Note 1 to entry: 1 to entry: Compare with *group velocity* (3.3.22).

3.3.30
phonon
quantum mechanical description of an elementary vibrational motion in which a periodic elastic lattice of atoms or molecules collectively oscillates at a single frequency

3.3.31
photoacoustic effect
generation of sound in a material following the absorption of light

Note 1 to entry: Photo-acoustic imaging is the imaging technique based on the photoacoustic effect.

3.3.32
photoelasticity
phenomena that describes changes in the optical properties of a material when a mechanical stress is applied

Note 1 to entry: It is observed in all dielectric materials and is used to experimentally determine the stress distribution in a material.

3.3.33
photorefractive effect
nonlinear optical effect seen in particular materials that respond to light by altering their refractive index

Note 1 to entry: Materials that show this effect include barium titanate, lithium niobate, vanadium doped zinc telluride, organic photorefractive materials, certain photopolymers, and some multiple quantum well structures.

3.3.34
photothermal lensing
deflection of light caused by local changes in refractive index due to a temperature gradient resulting from local absorption of light energy

Note 1 to entry: Photothermal lensing can be used to detect small, strongly absorbing particles in a transparent sample, such as metal nanoparticles.

3.3.35
photothermal lens spectroscopy
spectroscopy using the photothermal lensing via a pump-probe technique that measures the influence of the temperature induced by a laser beam on the refractive index of a transparent sample

3.3.36
plasmon resonance
resonant excitation of plasmons by external electromagnetic fields

[SOURCE: ISO/TS 80004-12:2016, 3.11, modified — The word "surface" as been omitted.]

3.3.37
polarization density
density of dipole moments in a given volume and describes how a material responds to an applied electric field

Note 1 to entry: In nonlinear media the polarization density responds nonlinearly to the electric field of light.

3.3.38
Rayleigh scattering
elastic scattering of light or other electromagnetic radiation by particles much smaller than the wavelength of the radiation

Note 1 to entry: Rayleigh scattering is a *parametric process* (3.6.23). Photon energies of the scattered photons are not changed. Scattering in which the scattered photons have either a higher or lower photon energy is called *Raman scattering* (3.5.16).

Note 2 to entry: For frequencies well below the resonance frequency of the scattering particle (*normal dispersion* (3.3.27) regime), the amount of scattering is inversely proportional to the fourth power of the wavelength.

3.3.39
reflectance
<for incident radiation of given wavelength, polarization, and angle of incidence> ratio of the reflected radiant or luminous flux to the incident flux in the given conditions

[SOURCE: ISO 15368:2021, 3.5]

Note 1 to entry: This is the square of the magnitude of the Fresnel reflection coefficient.

3.3.40
reflection
process by which radiation is returned by a surface or medium, without change of frequency of its monochromatic components

Note 1 to entry: Part of the radiation falling on a medium is reflected at the surface of the medium (surface reflection); another part can be scattered back from the interior of the medium (volume reflection).

Note 2 to entry: Surface reflection can be a combination of specular (regular) and scattered (diffuse) reflection.

[SOURCE: ISO 4007:2018, 3.10.1.19]

3.3.41
reflectivity
property of reflecting light or radiation, especially *reflectance* (3.3.39) as measured independently of the thickness of a material

3.3.42
refraction
process by which the direction of a radiation is changed as a result of changes in its velocity of propagation in passing through an optically non-homogeneous medium, or in crossing a surface separating different media

[SOURCE: IEC 60050 845:1987]

3.3.43
refractive index
<of a medium, for a monochromatic radiation of wavelength λ in a vacuum> ratio of the velocity of the electromagnetic waves in a vacuum to the phase velocity of the waves of the monochromatic radiation in the medium

Note 1 to entry: For technical applications, the refractive index in air is given instead of the refractive index in a vacuum.

[SOURCE: IEC 60050 845:1987]

3.3.44
Sellmeier equation
empirical relationship between the refractive index and wavelength for a particular transparent medium

Note 1 to entry: The Sellmeier equation is used to determine the dispersion of light in the medium.

3.3.45
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

Note 1 to entry: See also definitions of characteristic electron energy losses and plasmon in ISO 18115-1.

Note 2 to entry: 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 3 to entry: Plasmons are prominent in some materials and not in others.

Note 4 to entry: 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 the bulk and surface plasmon energies depends on the electronic structure of the material. For an interface between two materials, the surface plasmon energy depends on the electronic properties of each material. In 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.

Note 5 to entry: Surface plasmon polariton is synonymous with surface plasmon.

[SOURCE: ISO 18115-1:2013, 4.462]

3.3.46
surface plasmon resonance
SPR
resonant excitation of *surface plasmons* (3.3.45) by external electromagnetic fields

[SOURCE: ISO/TS 80004-12:2016, 3.11]

3.3.47
transmittance
<for incident radiation of given spectral composition, polarization and geometrical distribution> ratio of the transmitted radiant or luminous flux to the incident flux in the given conditions

[SOURCE: ISO 15368:2021, 3.1]

3.4 Terms related to ellipsometry

3.4.1
amplitude reflection coefficient
complex quantity which is the ratio of the component of the electric field, perpendicular (parallel) to the plane of incidence, of light reflected from a surface to the perpendicular (parallel) component, respectively, of the electric field of the incidence light

3.4.2
analyser
<ellipsometry> polarizer that is used to determine the state of polarized light

3.4.3
delta
Δ
<ellipsometry> one of the two ellipsometric parameters which is equal to the change in phase difference of the complex reflectance ratio of amplitude reflection coefficients of s- and p-polarized light

3.4.4
Drude model
classic model that describes free carrier effects on the dielectric response

3.4.5
ellipsometry
measurement method that uses polarized light for the measurement of the thickness of transparent surface films, layers and microstructure and for the refractive index of a reflecting material

Note 1 to entry: Radiation that is linearly polarized oblique to the surface becomes elliptically polarized after reflection at non-normal incidence. The ellipticity is obtained from measurements of the intensity and polarization of the incident and reflected radiation.

Note 2 to entry: Ellipsometry may utilize monochromatic light while spectroscopic ellipsometry employs a range of frequencies.

[SOURCE: IUPAC orange book 4th Ed. Ch. 10, 35, modified]

3.4.6
effective medium approximation
EMA
analytical or theoretical model that describes the macroscopic properties of composite materials

3.4.7
EMA, Bruggeman
EMA model that treats equally and symmetrically the constituent materials according to their volume fractions and dielectric functions

3.4.8
EMA, linear
EMA model that simply interpolates between the constituent dielectric functions to obtain the dielectric function of the composite

3.4.9
EMA, Maxwell-Garnett
EMA model that asymmetrically treats the effective medium as consisting of spherical inclusions of component materials in a host matrix of another material

3.4.10
imaging ellipsometry
ellipsometry for quantification and visualization of surface property variations of a solid surface

Note 1 to entry: Typical properties are film or substrate thickness

3.4.11
IR ellipsometry
ellipsometry that uses light in the infrared range

3.4.12
Lorentz oscillator model
classical model that describes the interaction between light and matter characterized by an oscillator with the frequency-dependent polarization due to bound charge

Note 1 to entry: The bindings between electrons and nuclei are assumed similar to that of a mass-spring system.

3.4.13
Mueller matrix
4 x 4 matrix that completely describes the response of medium to excitation by polarized light in either reflection or transmission in the absence of nonlinear effects

3.4.14
null ellipsometry
type of ellipsometry based on finding a set of azimuth angles for its polarization components (polarizer, compensator, and analyser) such that the light flux falling on the photodetector is extinguished

3.4.15
psi
Ψ
one of the two ellipsometric parameters which is equal to the change in amplitude difference of the complex reflectance ratio

3.4.16
single wavelength ellipsometry
laser ellipsometry
ellipsometry technique that uses a monochromatic light source. The light source is usually a laser in the visible spectral region

3.4.17
spectroscopic ellipsometry
ellipsometry that employs broad band light sources that cover a certain spectral range in the infrared, visible or ultraviolet spectral region

3.4.18
straight line measurement
<ellipsometry> measurement with the angle of incidence of 90 degrees

3.4.19
Tauc-Lorentz oscillator model
optical dispersion function that uses the Lorentzian line shape with zero absorption below a defined band gap energy

3.4.20
terahertz ellipsometry
ellipsometry technique with the spectral range in the terahertz region

3.4.21
VUV ellipsometry
ellipsometry technique with spectral range from the vacuum ultraviolet to near infrared region

3.5   Terms related to Raman spectroscopy

3.5.1
anti-Stokes Raman scattering
Raman scattering (3.5.16) in which the emitted photon has higher energy than the incident photon

3.5.2
backscattering configuration
optical configuration where the collected scattered light is in the opposite direction of the incident light

Note 1 to entry: This is the typical configuration of a Raman spectrometer coupled with a microscope.

3.5.3
coherent anti-Stokes Raman scattering
CARS
multi-photon, third order nonlinear, wave mixing process that enhances the anti-Stokes Raman signal

Note 1 to entry: CARS signal is generated in samples due to third-order nonlinear susceptibility and requires three laser beams. A Stokes beam with frequency ω_s, a pump beam with frequency ω_p and a probe beam with frequency ω_{pr}. When the photons of the beams interact, they produce an anti-Stokes frequency ($\omega_{pr} + \omega_p - \omega_s$), when the term ($\omega_p - \omega_s$) matches the vibrational frequency of the Raman resonance then the anti-Stokes frequency is enhanced producing an orders stronger Raman signal comparing to spontaneous Raman spectroscopy.

Note 2 to entry: See also *anti-Stokes Raman scattering* (3.5.1).

Note 3 to entry: It is a third order process as it is the cubic component of the Taylor series expansion of the nonlinear susceptibility.

Note 4 to entry: *coherent -Stokes Raman scattering (CSRS)* (3.5.5) is the opposite of CARS.

3.5.4
coherent Raman scattering microscopy
CRS
family of multi-photon microscopy techniques which use Raman active scattering modes of molecules

Note 1 to entry: Under the family of CRS are the techniques of *coherent anti-Stokes Raman scattering (CARS)* (3.5.3), *CSRS* (3.5.5) and *stimulated Raman scattering (SRS)* (3.5.24).

3.5.5
coherent Stokes Raman scattering
CSRS
multi-photon, third order nonlinear, wave mixing process that enhances the Stokes Raman signal

Note 1 to entry: CSRS requires three laser beams, the anti-Stokes beam with frequency ω_{As}, a pump beam with frequency ω_p and a probe beam with frequency ω_{pr}. When the photons of the beams interact they produce a Stokes frequency $(\omega_{pr} + \omega_p - \omega A_s)$, when the term $(\omega_p - \omega A_s)$ matches the vibrational frequency of the Raman resonance then the Stokes frequency is enhanced producing an orders stronger Raman signal comparing to spontaneous Raman spectroscopy.

Note 2 to entry: See also *Stokes Raman scattering* (3.5.25).

Note 3 to entry: It is a third order process as it is the cubic component of the Taylor series expansion of the nonlinear susceptibility.

Note 4 to entry: CSRS is pronounced as "scissors".

3.5.6
confocal Raman microscopy
Raman spectroscopy performed via a confocal optical microscopy set-up, in which a well-characterized mono-chromatic light is used to excite a sample and Raman scattered light is collected

3.5.7
depolarization ratio
intensity ratio of the *Raman scattering* (3.5.16) perpendicular to the plane of polarization of the incident laser light to the polarization component of Raman scattering parallel to the polarization component

3.5.8
electronic Raman scattering
Raman scattering (3.5.16) caused by electronic transitions of materials

3.5.9
enhancement factor
<TERS, SERS> ratio of the Raman signal intensity measured at a given wavenumber with the metallic probe or surface present to that in the absence of the probe or surface, scaled to equal numbers of scatterers

Note 1 to entry: The enhancement factor is the product of the contrast and the ratio of the volumes analysed without the probe and with the probe.

Note 2 to entry: In TERS the enhancement is due to the presence of the probe and in SERS it is due to the presence of a surface that is typically metallic and contains nanoscale features.

3.5.10
hyper-Raman scattering
Raman scattering caused by two-photon excitation where two photons of the source (probe laser) are practically converted to one photon of Raman scattered light and one phonon when interacting with matter

3.5.11
polarized Raman spectroscopy
Raman spectroscopy (3.5.17) where special attention is paid to the polarization state of the excitation and/or scattered light

Note 1 to entry: This is typically achieved using combinations of *retardation plates* (3.1.34), scrambler and *polarizers* (3.1.28) in the optical path.

3.5.12
Raman amplification
optical amplifiers based on Raman gain

Note 1 to entry: See *CARS* (3.5.3) and *SRS* (3.5.24) as examples of Raman amplification.

3.5.13
Raman depth profiling
acquisition of Raman spectra as a function of depth or material removed by sputtering in order to obtain a depth representation of the spatial distribution of a particular molecular species (as indicated by the *Raman effect* (3.5.16))

[SOURCE: adapted from ISO 14606:2015, 3.6]

3.5.14
Raman mapping
Raman imaging
operation whereby the signal intensity or signal energy (band position) of a particular Raman vibrational mode or the intensity ratio of two Raman vibrational modes are mapped by undertaking *Raman spectroscopy* (3.5.17) while pointwise scanning the sample surface and subsequently evaluating each pixel of the image

Note 1 to entry: Raman spectral mapping and Raman spectral imaging are terms that are also used.

3.5.15
Raman optical activity
ROA
vibrational spectroscopic method that measures the small difference in intensity of Raman scattered right and left circularly polarized light due to molecular chirality

Note 1 to entry: The method probes biomolecular structure and behaviour in aqueous liquids.

3.5.16
Raman scattering
Raman effect
inelastic scattering of electromagnetic radiation, characterized by a loss or gain in energy of the incident photons corresponding to an energy transition within the scatterer

Note 1 to entry: Typically, monochromatic optical radiation is used to probe vibrational or rotational energy levels in a molecular or crystalline sample.

3.5.17
Raman spectroscopy
spectroscopy in which the radiation scattered from a sample illuminated with monochromatic radiation is characterized by an energy loss or gain arising from rotational, or vibrational mode excitations

[SOURCE: ISO/TS 80004-13:2017, 3.3.1.6, modified replaced emitted by scattered]

3.5.18
Raman tensor
tensor that describes the relationship between the electric field vectors of incident and Raman scattered light for a specific Raman-active vibrational mode where the symmetry of the Raman tensor is related to the symmetry of the underlying vibrational mode

3.5.19
Raman shift
energy difference between inelastically scattered photon and incident photon resulting via *Raman effect* (3.5.16) which is equal to the energy of the associated vibrational or rotational mode

Note 1 to entry: Raman shift is typically expressed in wavenumbers.

3.5.20
resonance Raman spectroscopy
RR
Raman spectroscopy (3.5.17) conducted under resonant conditions, where the incident or scattered light wavelength matches an optical absorption band of the sample, under these conditions the Raman scattering cross-section of particular modes are enhanced

3.5.21
rotational Raman spectroscopy
Raman scattering (3.5.16) caused by rotational transitions of molecules

3.5.22
spontaneous Raman spectroscopy
Raman spectroscopy that relies on random *Raman scattering* (3.5.16) of a proportion of incident photons

Note 1 to entry: There is no enhancement of sensitivity. This is in contrast to *stimulated Raman scattering* (3.5.24).

3.5.23
spatially offset Raman spectroscopy
SORS
variant of Raman spectroscopy using multiple Raman measurements from sample locations spatially offset from one another that are scaled and subtracted from one another to produce and collect/acquire Raman spectra representing subsurface and surface molecular species

Note 1 to entry: The method is used for chemical analysis at a sub-surface level for example inside biological material or inside packaging.

3.5.24
stimulated Raman scattering
SRS
third order nonlinear phenomenon involving a second photon where the difference in the frequency of the coinciding photons matches the vibrational/rotational frequency to be excited

Note 1 to entry: The difference frequency sometimes called as "beat frequency".

Note 2 to entry: The SRS signal strength is linearly proportional to the concentration.

3.5.25
Stokes Raman scattering
Raman scattering (3.5.16) in which the scattered photon has lower energy than the incident photon

Note 1 to entry: See *anti-Stokes Raman scattering* (3.5.1).

3.5.26
surface-enhanced Raman spectroscopy
SERS

spectroscopy using *surface-enhanced Raman scattering* (3.5.27)

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

3.5.27
surface-enhanced Raman scattering
SERS

enhanced *Raman scattering* (3.5.16) observed for molecules in close proximity to a nano-scale roughened plasmonic metal surface or to metallic nanoparticles, where Raman scattering cross-sections are many orders of magnitude greater than for the same molecules in the absence of the rough plasmonic metal surface

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

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

Note 3 to entry: Surface-enhanced Raman scattering is utilized via a tip-enhancement in *TERS* (3.5.30).

3.5.28
surface-enhanced resonant Raman scattering
SERRS

surface-enhanced Raman scattering in which the energy of the incident or scattered radiation is in resonance with an optical transition in the molecule

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

3.5.29
surface-enhanced resonant Raman spectroscopy
SERRS

spectroscopy using *surface-enhanced resonant Raman scattering* (3.5.28)

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

3.5.30
tip-enhanced Raman spectroscopy
TERS

spectroscopy using enhanced *Raman scattering* (3.5.16) with a plasmonically active metallic probe tip in close proximity to a sample surface illuminated with suitably polarized monochromatic light of appropriate wavelength

Note 1 to entry: TERS provides higher scattering cross-section and higher spatial resolution than confocal Raman microscopy.

3.5.31
tip-enhanced resonance Raman spectroscopy
TERRS

spectroscopy involving a combination of tip-enhanced Raman scattering with *resonance Raman spectroscopy* (3.5.20)

3.5.32
transmission Raman spectroscopy
Raman spectroscopy whereby one side of a sample is illuminated, and the transmitted light is collected on the other side

Note 1 to entry: This can be used for samples up to approximately 10 mm thick with the collected Raman signal representative of the bulk material. The thickness depends on the transmittance of the sample to the excitation light.

3.5.33
resonant excitation profile
relationship between intensity of Raman scattering for a particular vibrational or rotational mode and the photon energy (wavelength) of the incident light

3.5.34
transmission configuration
optical configuration where the collected light propagates in the same direction as the incident light

Note 1 to entry: Compare with *backscattering configuration* (3.5.2).

3.5.35
vibrational-rotational spectroscopy
branch of molecular spectroscopy techniques, measuring signals caused by vibrational transitions of molecules

Note 1 to entry: Raman and Infrared spectroscopy are the main representative techniques of this family, each technique being sensitive to different type of vibrations and provide complementary vibrational spectra.

3.6   Terms related to nonlinear optical technique terms

3.6.1
Brillouin scattering
Note 1 to entry: inelastic interaction between an electromagnetic wave and low frequency material lattice waves represented by phonons, polaritons or magnons, resulting in the transmitted electromagnetic wave gaining or losing a set amount of momentum (and thus its frequency and energy)

Note 2 to entry: Brillouin scattering can be used to measure material's properties on a large scale – such as its elastic behaviour compared to Raman scattering.

3.6.2
cross phase modulation
XPM
third-order nonlinear optical effect by which a light source at one wavelength can affect the phase of a light source at another wavelength through the *optical Kerr effect* (3.6.19)

Note 1 to entry: It is a third order effect as it is the cubic component of the Taylor series expansion of the nonlinear susceptibility.

3.6.3
difference-frequency generation
DFG
nonlinear, optical frequency mixing process generating light with a frequency that is the difference between the frequencies of the two pump beams through a nonlinear optical process

Note 1 to entry: It is a second order process as it is through the quadratic component of the Taylor series expansion of the nonlinear susceptibility.

Note 2 to entry: It is a parametric process, thus photons satisfy the energy conservation.

Note 3 to entry: This process requires an efficient phase matching of the contributing beams.

3.6.4
electro-optic effect
change in the optical properties of a material in response to an electric field that varies slowly compared with the frequency of light

Note 1 to entry: This encompasses several distinct phenomena related to change of the absorption or change of the refractive index and permittivity (e.g. *Kerr effect* (3.6.10)).

3.6.5
four-wave mixing
FWM
third-order nonlinear optical process in which three frequency components (photons) add-or-subtract to produce new frequency components (photon)

Note 1 to entry: Two of the incident frequency components may have the same frequency, degenerate four-wave mixing), or all frequency components may be unique, non-degenerate four-wave mixing. The combination of input frequencies can generate one or two new frequency components.

Note 2 to entry: It is a parametric nonlinear process, in that the energy of the incoming photons is conserved. It is also a phase-sensitive process, in that the efficiency of the process is strongly affected by phase matching conditions.

Note 3 to entry: It is applied for spectroscopy, most commonly in the form of *coherent anti-Stokes Raman spectroscopy (CARS)* (3.5.3).

3.6.6
half harmonic generation
nonlinear optical process whereby a photon is split to produce two photons with half frequency

3.6.7
heterodyne detection
method detecting a signal of one frequency by nonlinear mixing with a signal from a reference signal of different frequency

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

3.6.8
high harmonic generation
phenomenon where high harmonics of a generator beam are produced when a target is illuminated by an intense laser pulse

Note 1 to entry: This typically occurs at optical intensities of the order of 10^{14} Wcm^{-2} or higher. The target is typically a gas but can be a solid or plasma.

3.6.9
homodyne detection
method detecting a signal of one frequency by nonlinear mixing with a signal from a reference signal of the same frequency

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

3.6.10
Kerr effect
induced change in a material's *refractive index* (3.3.43) in response to an external electric field.

Note 1 to entry: A third-order nonlinear effect; thus, the change in refractive index is proportional to the square of the applied electric field amplitude

Note 2 to entry: two special cases are normally considered; the *Kerr electro-optic effect* (3.6.11) and the *optical Kerr effect* (3.6.19)

3.6.11
Kerr electro-optic effect
DC Kerr effect

particular *electro-optic effect* (3.6.4) and a special case of the *Kerr effect* (3.6.10) in which an externally applied DC (or slowly varying) electric field is applied to the material, inducing birefringence

3.6.12
Kerr-lens mode locking

method of mode locking lasers via the optical *Kerr effect* (3.6.10) allowing generation of pulses of light with a few femtosecond duration

3.6.13
modulational instability

phenomenon whereby deviations from a periodic waveform are reinforced by nonlinearity, leading to the generation of spectral-sidebands and the eventual breakup of the waveform into a train of pulses

3.6.14
multi-photon absorption

nonlinear absorption processes where multiple photons are absorbed simultaneously at high optical intensity

Note 1 to entry: The simplest variant is two-phonon absorption, where only two photons are required.

3.6.15
nonlinear optics

branch of optics that describes the behaviour of light in media in which the dielectric polarization P responds nonlinearly to the electric field *E* of the light

Note 1 to entry: Nonlinearity is typically observed only at very high light intensities (values of the electric field comparable to interatomic electric fields, typically 10^8 V/m) such as those provided by lasers.

3.6.16
optical frequency conversion

conversion of input light at one or more frequencies to light of other frequencies using optical nonlinear techniques and vice versa

Note 1 to entry: These techniques include frequency doubling, sum-frequency generation, and optimal parametric generation.

3.6.17
optical frequency multiplier

nonlinear optical device in which photons interacting with a nonlinear material are effectively "combined" to form new photons with greater energy, and thus higher frequency

3.6.18
optical harmonic generation

nonlinear optical device in which photons interacting with a nonlinear material are effectively combined to form new photons with greater energy, and thus higher frequency and shorter wavelength

Note 1 to entry: The two characteristic techniques of this harmonic generation are the *second harmonic generation* (3.6.27) and the *third harmonic generation* (3.6.34).