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Integrated optics — Vocabulary —

Part 1: Optical waveguide basic terms and symbols

Optique intégrée — Vocabulaire —

Partie 1: Termes fondamentaux et symboles des guides d'onde optique

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Foreword

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This document was prepared by Technical Committee ISO/TC 172 *Optics and photonics*, Subcommittee SC 9, *Laser and electro optical systems,* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 123, *Lasers and photonics*, in accordance with the agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 11807-1:2001), which has been technically revised. The main changes compared to the previous edition are as follows:

— Terminologies that have not been frequently used over the last 5 to 10 years are revised to those matching to current trends.

— In the revision process, terminologies and definitions are compared to similar terminology definitions in IEC and harmonized.

A list of all parts of ISO 11807 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

The aim of this document is to clarify the terms of the field of "integrated optics" and to define a unified vocabulary. It is expected that this document will be revised periodically to adopt the requirements of customers and suppliers of integrated optical products. At a later stage, it is planned to add definitions from other International Standards which deal with integrated optics.

Some of the definitions are closely related to definitions given in IEC 60050-731. Wherever this can lead to misunderstanding, integrated optics or integrated optical waveguide should be used together with the defined term.

Integrated optics — Vocabulary —

Part 1:
Optical waveguide basic terms and symbols

1 Scope

This document defines basic terms for integrated optical devices, their related optical chips and optical elements which find applications, for example, in the fields of optical communications and sensors.

— The coordinate system used in Clause 3 is described in Annex A.

— The symbols and units defined in detail in Clause 3 are listed in Annex B.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 11807-2, *Integrated optics — Vocabulary — Part 2: Terms used in classification*

ISO 14881, *Integrated optics — Interfaces — Parameters relevant to coupling properties*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11807-2 and ISO 14881 and the following apply.

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

3.1.1
integrated optics
planar optical *waveguide* (3.2.1) structures, manufactured either in or on a *substrate* (3.2.6), including the optical components necessary for the input and output coupling of lightwaves

Note 1 to entry: In this context the term "planar" is used to include small deviations from planarity which are associated with Luneburg lenses, for example. By use of a suitable material, it is possible to integrate both optoelectronic and purely optical functions on the same substrate. The simplest case is electrodes, which can be used for controlling the properties of a waveguide. It is also possible to fabricate lasers and detectors using compound semiconductor materials.

Note 2 to entry: It is envisaged that integrated optical components will be combined with other microtechnologies, such as microelectronics and micromechanics, to build more complex systems. However, such systems are beyond the scope of this document, which will be concerned only with the integrated optical component and its immediate interfaces (see IEC 60050-731:1991, 06-43).

3.2 Waveguide structures

3.2.1
waveguide
transmission line designed to guide optical power consisting of structures which guide lightwaves on the basis of a higher refractive index in the *core* (3.2.4) and a lower refractive index in the surrounding material

Note 1 to entry: The lightwaves in a waveguide propagate in modes.

3.2.2
slab waveguide
waveguide (3.2.1) which confines the optical field between two light guiding parallel surfaces

Note 1 to entry: See Figure A.1 where the Cartesian coordinate system is indicated for defining the several terminologies relating to waveguides.

Note 2 to entry: In the previous edition "planar waveguide" was used as a synonym.

3.2.3
strip waveguide
channel waveguide
waveguide (3.2.1) which confines the optical field in a two-dimensional cross-sectional area perpendicular to the lightwave propagating direction (wave vector) along a one-dimensional path

3.2.4
core
region(s) of an integrated optical *waveguide* (3.2.1), in which the optical power is mainly confined

3.2.5
cladding
material surrounding the *waveguide* (3.2.1) *core* (3.2.4)

Note 1 to entry: In contrast to optical fibres for integrated optical waveguides, the cladding often consists of more than one material. Normally, it is necessary to distinguish between lower cladding and upper cladding due to the planar fabrication process of integrated optical waveguides.

3.2.6
substrate
carrier onto or within which the integrated optical *waveguide* (3.2.1) is fabricated

3.2.7
superstrate
cladding (3.2.5) medium or layer structure with which the *core* (3.2.4) of the integrated optical *waveguide* (3.2.1) is covered

Note 1 to entry: An electrode, for example, should not be considered as a superstrate. Although it covers the waveguide, it does not influence the optical properties of the waveguide due to an optically insulating layer of sufficient thickness.

3.3 Modes in integrated optical waveguides

3.3.1
mode
eigenfunction of Maxwell's equations, representing an electromagnetic field in a certain space domain and belonging to a family of independent solutions defined by specific boundary conditions

Note 1 to entry: Each mode is defined according to its order in the vertical and horizontal directions and its polarization, the latter being separated into TE- and TM-modes. The mode order is given by indexing TE_{ij} and TM_{ij}, where TE and TM represent the *y*- and *x*-direction of polarization, respectively. The symbols, *i* and *j* define the mode indices (the order) along *x* (horizontal) and *y* (vertical) respectively.

3.3.2
guided mode
electromagnetic wave whose electric field decays monotonically in the transverse direction everywhere outside the *core* (3.2.4) and which does not lose power

3.3.3
TE mode
transverse electromagnetic wave, where the electric field vector is normal to the direction of propagation; i.e., the electric field vector lies in the transverse plane (*xy*-plane)

Note 1 to entry: Strictly speaking, in strip waveguides, hybrid modes having a non-zero component of the electric and magnetic field in the direction of propagation do exist. Pure TE- and TM-modes are only found in waveguides with a corresponding geometry — for example in slab waveguides. For integrated optical waveguides in planar substrates, the polarization state is usually defined relative to the substrate surface. In slab waveguides, the electric field vector of TE modes lies in the *y*-direction, as a result of the choice of the coordinate system.

3.3.4
TM mode
transverse electromagnetic wave, where the magnetic field vector is normal to the direction of propagation; i.e., the magnetic field vector lies in the transverse plane (*xy*-plane)

Note 1 to entry: In slab waveguides, the magnetic field vector of TM mode lies in the *y*-direction, as a result of the choice of the coordinate system.

3.3.5
evanescent field
time varying electromagnetic field in an integrated optical *waveguide* (3.2.1) whose field amplitude decays very rapidly and monotonically in the transverse direction outside the *core* (3.2.4), but without an accompanying phase shift

3.3.6
leaky mode
mode (3.3.1) having an *evanescent field* (3.3.5) in the transverse direction outside the *core* (3.2.4) for a finite distance but with an oscillating field in the transverse direction beyond that distance

Note 1 to entry: A leaky mode is attenuated due to radiation losses along the waveguide.

3.3.7
radiation mode
mode (3.3.1) which transfers power in the transverse direction everywhere external to the *core* (3.2.4)

3.3.8
single-mode waveguide
waveguide (3.2.1) which supports only one *guided mode* (3.3.2)

Note 1 to entry: The waveguide mode may consist of two orthogonal states of polarization.

3.3.9
multimode waveguide
waveguide (3.2.1) which supports more than one *guided mode* (3.3.2)

3.3.10
waveguide cutoff
transition of propagation *mode* (3.3.1) from being guided to being leaky or radiative

3.3.11
cutoff wavelength
<guided mode> vacuum wavelength above which a given *mode* (3.3.1) is cutoff

Note 1 to entry: Due to the generally short length of integrated optical waveguides, the measured value strongly depends on the waveguide structure. Therefore, special waveguide structures have to be fabricated to measure the cutoff wavelength. The measurement methods known for optical fibres cannot be applied to integrated optical waveguides.

Note 2 to entry: In fibre optics, the term cutoff wavelength is used to describe the cutoff wavelength of the second-order mode. The reason is that the fundamental mode of a symmetrical dielectric waveguide has no cutoff and the cutoff wavelength of the second order mode determines the single mode condition.

3.3.12
effective refractive index
DEPRECATED: equivalent refractive index
n_{eff}
ratio of the speed of light in vacuum to the phase velocity of the *guided mode* (3.3.2)

Note 1 to entry: The effective refractive index is determined by the waveguide dimensions and the refractive index profile of the waveguide, including the medium adjacent to the core of the waveguide and the wavelength. Each mode capable to propagate is characterized by its individual effective or equivalent refractive index.

Note 2 to entry: The term "effective refractive index" is defined by

$$n_{eff} = \frac{\beta}{k_0}$$

where

β is the propagation constant of a mode in a waveguide;

k_0 is the propagation constant of a plane wave in vacuum.

Note 3 to entry: The term "equivalent refractive index" is currently used just for expressing the quantity similar to "group index" defined by

$$n_{eq} = n + k_0 \frac{dn}{dk_0} = n - \lambda \frac{dn}{d\lambda}$$

which is defined for a bulk material with the refractive index n. This quantity determines the free spectral range or the spacing of the adjacent peak wavelength $\Delta\lambda$ of resonators, such as Fabry-Perot resonators, given by

$$\Delta\lambda = -\frac{{\lambda_0}^2}{2Ln_{eff}}$$

where

L is the length of cavity;

λ_0 is the centre wavelength of the resonator.

3.4 Refractive index distribution in integrated optical waveguides

3.4.1
refractive index profile
refractive index $n(x, y)$ across a cross-section of the *waveguide* (3.2.1) as a function of position

3.4.2
step index profile
refractive index profile (3.4.1) which is characterized by an almost constant refractive index within the *waveguide* (3.2.1) *core* (3.2.4) and a sharp drop in refractive index at the boundary between the *core* (3.2.4) and the *cladding* (3.2.5) (*substrate* (3.2.6) or *superstrate* (3.2.7))

Note 1 to entry: The width of the index transition is small in comparison with the wavelength.

3.4.3
graded index profile
index profile in which the refractive index varies continuously in the *core* (3.2.4) as a function of distance from the axis

Note 1 to entry: The width of the index variation is large in comparison with the wavelength.

3.4.4
relative refractive index difference
Δ
relative difference of the refractive index of the *waveguide* (3.2.1) *core* (3.2.4) and *cladding* (3.2.5)

$$\Delta = \frac{n_{\mathrm{max}}^2 - n_{\mathrm{cl}}^2}{2 n_{\mathrm{cl}}^2}$$

where

n_{max} is the maximum refractive index of the *core* (3.2.4);

n_{cl} is refractive index of the *cladding* (3.2.5);

3.4.5
acceptance angle
θ
<step index profile> maximum half angle of all in- and out-coupled directions of radiation for one plane of incidence, which experience total internal reflection at the core-cladding interfaces in the *waveguide* (3.2.1)

$$\theta = \arcsin\sqrt{n_{\mathrm{co}}^2 - n_{\mathrm{cl}}^2}$$

where

n_{co} is the refractive index of the *core* (3.2.4);

n_{cl} is the refractive index of the *cladding* (3.2.5);

Note 1 to entry: The horizontal and vertical acceptance angles of a non-circular symmetrical waveguide can be different.

Note 2 to entry: The acceptance angle is, according to IEC 60050-731:1991, 03-84, defined as half the angle of the coupled radiation bundle. In contrast, the divergence angle of laser radiation is defined as the full angle (see ISO 11145).

3.4.6
numerical aperture
NA
sine of the *acceptance angle* (3.4.5) multiplied by the refractive index of the medium outside the *waveguide* (3.2.1)

Note 1 to entry: See notes to 3.4.5.

Note 2 to entry: The numerical aperture of a waveguide with step index profile against ambient air is given by

$$NA = \sqrt{{n_{\text{co}}}^2 - {n_{\text{cl}}}^2}$$

where

n_{co} is the refractive index of the core;

n_{cl} is the refractive index of the cladding.

3.4.7
V-number
dimensionless *waveguide* (3.2.1) parameter, which is defined in an analogous way to the procedure used for step-index optical fibres

$$V_x = \frac{2\pi a_x}{\lambda} NA$$

$$V_y = \frac{2\pi a_y}{\lambda} NA$$

where

a_x is the half width of the *core* (3.2.4) region in the x-direction;

a_y is the half width of the *core* (3.2.4) region in the y-direction;

λ is the vacuum wavelength;

NA is the *numerical aperture* (3.4.6).

Note 1 to entry: The V-number allows the dimensionless calculation of the waveguide modes.

3.4.8
launch angle
angle between the direction of maximum power of the input beam and the optical axis of the *waveguide* (3.2.1)

3.4.9
output angle
angle between the direction of maximum power of the output beam and the optical axis of the *waveguide* (3.2.1)

3.4.10
near-field pattern
distribution of the optical power density along a perpendicular cross-section at or very close to the end facet of the *waveguide* (3.2.1)

Note 1 to entry: Due to the close distance to the end facet, diffraction is negligible and therefore the near-field pattern also is assumed to represent the distribution of the power density inside the waveguide, called as mode-field distribution. The full width at which this distribution is reduced to half the maximum value is called the full width at half maximum FWHM (of the mode).

Note 2 to entry: In most cases, an integrated optical waveguide has an asymmetrical refractive index profile in the vertical direction, in contrast to a fibre. Therefore, the near-field distribution is symmetrical in the horizontal, y-direction, and asymmetrical in the vertical, x-direction.

3.4.11
near-field centre
position of the maximum of the *near-field pattern* (3.4.10)

3.4.12
spot size (half width)
w_{x1}, w_{x2}, w_{y1}, w_{y2}
<single-mode waveguides> distances between the *near-field centre* (3.4.11) of the fundamental *mode* (3.3.1) and the point where the Gaussian intensity profile approximated from the actual profile falls to $1/e^2$ of the maximum value at the centre in either side of the *x*- and *y*-directions

Note 1 to entry: (w_{x1}, w_{x2}), and (w_{y1}, w_{y2}) are the spot sizes determined in the (negative, positive) regions in the *x*- and *y*- directions, respectively.

Note 2 to entry: When the field profile is symmetric in the *x*-direction, the spot size w_x is approximately given by:

$$w_x = \left[\frac{4\int_{-\infty}^{\infty} x^2 f^2(x)\mathrm{d}x}{\int_{-\infty}^{\infty} f^2(x)\mathrm{d}x} \right]^{1/2}$$

where

$f(x)$ is the field profile;

$f^2(x)$ is the intensity (power) profile;

3.4.13
mode field width
W_x, W_y
sum of w_{x1} and w_{x2} in *x*-direction respectively the sum of w_{y1} and w_{y2} in *y*-direction

3.4.14
near-field asymmetry
$A_{x,y}$
measure of the deviation from a symmetrical *near-field pattern* (3.4.10)

$$A_x = \frac{|w_{x1} - w_{x2}|}{|w_{x1} + w_{x2}|}$$

$$A_y = \frac{|w_{y1} - w_{y2}|}{|w_{y1} + w_{y2}|}$$

where w_{x1}, w_{x2}, w_{y1} and w_{y2} are the *spot sizes* (3.4.12) on either side of the *x*- and *y*-directions

3.4.15
mode field diameter
<symmetrical circular core waveguides> for Gaussian distributions in *single-mode* fibres and *waveguides* (3.3.8) it is the diameter at the $1/e^2$ points of the optical power distribution for Gaussian distributions in *single-mode* fibres and *waveguides* (3.3.8)

Note 1 to entry: See also IEC 60050-731:1991, 03-65.

3.4.16
far-field pattern
radiation pattern which describes the relative distribution of the optical power density as a function of angle at the position where the radiation pattern does not vary with the distance from the *waveguide* (3.2.1) end facet

Note 1 to entry: For integrated optical waveguides, the far-field distribution is influenced by the shape and position of the edge surface relative to the near field centre.

3.5 Properties of integrated optical waveguides

3.5.1
chromatic dispersion
wavelength dispersion
dependence of the *effective refractive index* (3.3.12) of a waveguide *mode* (3.3.1) on the wavelength as a combination of *material dispersion* (3.5.2) (and *waveguide dispersion* (3.5.3))

Note 1 to entry: The relationship between refractive index and wavelength can be directly transferred to the phase velocity. The transfer to the group velocity is more complex and leads to the concept of group velocity dispersion (GVD).

Note 2 to entry: In optical fibres, the chromatic dispersion is defined as the dependence of group velocities of the modes on the wavelength.

Note 3 to entry: The term dispersion is used for describing the wavelength dependence of some physical properties. In all sections of this subclause, when properties having a wavelength dependence are described, the wavelength under consideration is to be stated.

3.5.2
material dispersion
dependence of the refractive index of the material on the wavelength

3.5.3
waveguide dispersion
dependence of the *effective refractive index* (3.3.12) of a particular *mode* (3.3.1) on the *refractive index profile* (3.4.1) and the wavelength

3.5.4
mode dispersion
difference of phase velocity of *modes* (3.3.1) with different order at the same wavelength

3.5.5
waveguide birefringence
B
difference between the effective or equivalent refractive indices of orthogonal polarized *TE modes* (3.3.3) and *TM modes* (3.3.4) of the same order

$$B = n_{\text{eff,TE}} - n_{\text{eff,TM}}$$

Note 1 to entry: There are several causes of waveguide birefringence:

— the substrate material itself may be birefringent;

— birefringence may occur due to mechanical stress resulting from the waveguide fabrication process;

— geometrical birefringence may occur due to a spatial asymmetry of the refractive index profile;

— surface-induced birefringence may occur when the propagation of orthogonal polarized modes is influenced by the boundary between lower and upper cladding, for example, at the substrate-air interface.

3.6 Loss or attenuation in integrated optical waveguides

3.6.1
attenuation
loss
diminution of optical power in integrated optical devices

Note 1 to entry: For integrated optical elements, the power loss is related to two cross-sectional areas of the corresponding waveguide.

Note 2 to entry: Generally, for integrated optical devices, the input and output configuration which is used to measure the attenuation has to be specified. If the device is assembled with optical fibres, the power is launched into one fibre and the output power is measured at another fibre.

3.6.2
waveguide loss
α_W
reduction in the optical power P between two cross-sectional areas 1 (input) and 2 (output) of a waveguide on a logarithmic scale

$$\alpha_W = -10 \lg(P_2 / P_1)\ \mathrm{dB};\ P_2 < P_1$$

where

P_1 is the power at the cross-sectional area 1;

P_2 is the power at the cross-sectional area 2;

Note 1 to entry: Waveguide loss is expressed in decibels.

3.6.3
waveguide propagation loss
α
ratio of the *waveguide loss* (3.6.2) in a uniform *waveguide* (3.2.1) to the distance between two cross-sectional areas

$$\alpha = \frac{\alpha_W}{L}$$

Note 1 to entry: Waveguide propagation loss is expressed in decibels per metre (centimetre, millimetre, or micrometre).

3.6.4
insertion loss
α_I
loss (3.6.1) resulting from the insertion of an integrated optical device in an optical transmission path on a logarithmic scale

$$\alpha_I = -10 \lg(P_2 / P_1)\ \mathrm{dB};\ P_2 < P_1$$

where

P_1 is the output power before the insertion of the component;

P_2 is the output power after the insertion of the component;

Note 1 to entry: Insertion loss is expressed in decibels.

3.6.5
coupling loss
α_C
loss (3.6.1) of optical power obtained when the lightwave is coupled from the output endface of one optical element 1 (e. g. fibre *core* (3.2.4) or chip endface) into the input endface of another optical element 2

$$\alpha_C = -10 \lg(P_2 / P_1)\ \mathrm{dB}$$

where

P_2 is the optical power in optical element 2 at the input endface;

P_1 is the optical power from optical element 1 at the output endface;

Note 1 to entry: Coupling loss is expressed in decibels.

3.6.6
directivity
near-end crosstalk
α_D
ratio on a logarithmic scale of the optical power emitted from an unlaunched input port P_2 of an integrated optical device to the optical power launched to an input port P_1, of an integrated optical device

$$\alpha_D = -10 \lg(P_2 / P_1) \, \text{dB}$$

where

P_1 is the power launched into an input port of multi-port *waveguide* (3.2.1);

P_2 is the output power measured at another input port;

Note 1 to entry: Directivity or near-end cross talk is expressed in decibels.

3.6.7
crosstalk
far-end crosstalk
α_F
ratio of the optical power $P_{\text{out},j}$ on a logarithmic scale at an output port j of an integrated optical device from which no power should be emitted, to the sum of the optical power $P_{\text{out},i}$ at output ports with intended output powers

$$\alpha_F = -10 \lg\left(P_{\text{out},j} / \sum_i P_{\text{out},i} \right) \text{dB}$$

where

$P_{\text{out},i}$ is the power in addressed output port i;

$P_{\text{out},j}$ is the power from unaddressed output port j

Note 1 to entry: Crosstalk is expressed in decibels.

3.6.8
return loss
α_R
ratio of the optical power P_2 reflected from an input port of an integrated optical device to the launched power P_1 into the same input port

$$\alpha_R = -10 \lg(P_2 / P_1) \, \text{dB}$$

where

P_1 is the power launched into an input port of an integrated optical device;

P_2 is the power reflected from the same input port of the integrated optical device;

Note 1 to entry: Return loss is expressed in decibels.

3.6.9
excess loss
α_E
ratio of the sum of the optical power at all output ports $P_{out,i}$ to the optical power in the input port P_{in} on a logarithmic scale

$$\alpha_E = -10 \lg \left(\sum_i P_{out,i} / P_{in} \right) dB$$

where

P_{in} is the power in the input *waveguide* (3.2.1);

$P_{out,i}$ is the power in the output *waveguide* (3.2.1) *i*;

Note 1 to entry: Excess loss is expressed in decibels.

3.6.10
deviation of uniformity
α_U
ratio of the lowest optical power $P_{out,\,min}$ emitted from an output *waveguide* (3.2.1) of an integrated optical device with several output ports to the highest power $P_{out,\,max}$

$$\alpha_U = 10 \lg \left(P_{out,\,min} / P_{out,\,max} \right) dB$$

where

$P_{out,\,min}$ is the lowest output power;

$P_{out,\,max}$ is the highest optical power emitted from the output *waveguide* (3.2.1) of the multi-port *waveguide* (3.2.1);

Note 1 to entry: Deviation of uniformity is expressed in decibels.

3.6.11
deviation of polarization dependent loss
α_{PDL}
ratio of the lowest power $P_{out,\,min}$ transmitted at any state of polarization to the highest optical power $P_{out,\,max}$ transmitted at any state of polarization at the port *i*, on a logarithmic scale

$$\alpha_{PDL} = -10 \lg \left(P_{out,\,min} / P_{out,\,max} \right) dB$$

where

$P_{out,\,min}$ is the lowest power transmitted at any state of polarization;

$P_{out,\,max}$ is the highest power transmitted at any state of polarization;

Note 1 to entry: Deviation of uniformity is expressed in decibels.