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Optics and photonics — Lasers and laser-related equipment — Vocabulary and symbols

Optique et photonique — Lasers et équipements associés aux lasers — Vocabulaire et symboles

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Foreword

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

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 172, *Optics and photonics*, Subcommittee SC 9, *Electro-optical systems*.

This fourth edition cancels and replaces the third edition (ISO 11145:2006) which has been technically revised with the following changes:

a) in 3.5.3, a formula for beam ellipticity has been added;

b) in 3.53, the definition of relative intensity noise has been revised and a formula was added.

Optics and photonics — Lasers and laser-related equipment — Vocabulary and symbols

1 Scope

This International Standard defines basic terms, symbols, and units of measurement for the field of laser technology in order to unify the terminology and to arrive at clear definitions and reproducible tests of beam parameters and laser-oriented product properties.

NOTE The laser hierarchical vocabulary laid down in this International Standard differs from that given in IEC 60825–1. ISO and IEC have discussed this difference and agree that it reflects the different purposes for which the two standards serve. For more details, see informative Annex A.

2 Symbols and units of measurement

2.1 The spatial distribution of power (energy) density of a laser beam does not always have circular symmetry. Therefore, all terms related to these distributions are split into those for beams with circular and those with non-circular cross-sections. A circular beam is characterized by its radius, w, or diameter, d. For a non-circular beam, the beam widths, d_x and d_y, for two orthogonal directions have to be given.

2.2 The spatial distributions of laser beams do not have sharp edges. Therefore, it is necessary to define the power (energy) values to which the spatial terms refer. Depending on the application, different cut-off values can be chosen (for example 1/e, 1/e^2, 1/10 of peak value).

To clarify this situation, this International Standard uses the subscript u for all related terms to denote the percentage of the total beam power (energy) taken into account for a given parameter.

NOTE For the same power (energy) content, beam width $d_{x,u}$ and beam diameter d_u (= 2w_u) can differ for the same value of u (for example, for a circularly symmetric Gaussian beam $d_{86,5}$ is equal to $d_{x,95,4}$).

Table 1 lists symbols and units which are defined in detail in Clause 3.

Table 1 — Symbols and units of measurement

Symbol	Unit	Term
A_u or A_σ	m^2	Beam cross-sectional area
d_u or d_σ	m	Beam diameter
$d_{x,u}$ or $d_{\sigma x}$	m	Beam width in x-direction
$d_{y,u}$ or $d_{\sigma y}$	m	Beam width in y-direction
$d_{0,u}$ or $d_{\sigma 0}$	m	Beam waist diameter
$d_{\sigma 0}\cdot\Theta_\sigma/4$	rad m	Beam parameter product
E_u or E_σ	W/m^2	Average power density
f_p	Hz	Pulse repetition rate
H_u or H_σ	J/m^2	Average energy density
K	1	Beam propagation factor
l_c	m	Coherence length
M^2	1	Beam propagation ratio
p	1	Degree of linear polarization
P	W	Cw-power

Table 1 *(continued)*

Symbol	Unit	Term
P_{av}	W	Average power
P_{H}	W	Pulse power
P_{pk}	W	Peak power
Q	J	Pulse energy
$R(f)$	Hz^{-1} or dB/Hz	Relative intensity noise, RIN
w_u or w_σ	m	Beam radius
$w_{0,u}$ or $w_{\sigma 0}$	m	Beam waist radius
z_{R}	m	Rayleigh length
$\Delta\vartheta$	m	Misalignment angle
$\Delta\lambda$	m	Spectral bandwidth in terms of wavelength
$\Delta\nu$	Hz	Spectral bandwidth in terms of optical frequency
$\Delta_x(z')$	m	Beam positional stability in *x*-direction
$\Delta_y(z')$	m	Beam positional stability in *y*-direction
Δz_{a}	m	Astigmatic waist separation
Δz_{r}	1	Relative astigmatic waist separation
ε	1	Ellipticity of a power density distribution
η_{L}	1	Laser efficiency
η_{Q}	1	Quantum efficiency
η_{T}	1	Device efficiency
Θ_u or Θ_σ	rad	Divergence angle
$\Theta_{x,u}$ or $\Theta_{\sigma x}$	rad	Divergence angle for *x*-direction
$\Theta_{y,u}$ or $\Theta_{\sigma y}$	rad	Divergence angle for *y*-direction
λ	m	Wavelength
τ_{H}	s	Pulse duration
τ_{10}	s	10 %-pulse duration
τ_{c}	s	Coherence time

NOTE $R(f)$ expressed in dB/Hz equals 10 $\log_{10} R(f)$ with $R(f)$ given in Hz^{-1}.

When stating quantities marked by an index "*u*", "*u*" shall always be replaced by the concrete number, e.g. A_{90} for u = 90 %.

In contrast to these quantities defined by setting a cut-off value ["encircled power (energy)"], the beam widths and derived beam properties can also be defined based on the second moment of the power (energy) density distribution function (see 3.5.2). Only beam propagation ratios based on beam widths and divergence angles derived from the second moments of the power (energy) density distribution function allow calculation of the beam propagation. Quantities based on the second moment are marked by a subscript "σ".

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1 Beam axis

3.1.1
beam axis
straight line connecting the centroids defined by the first spatial moment of the cross-sectional profile of power (energy) at successive positions in the direction of propagation of the beam in a homogeneous medium

3.1.2
misalignment angle
$\Delta\vartheta$
deviation of the beam axis from the mechanical axis defined by the manufacturer

3.2 Beam cross-sectional area

3.2.1
beam cross-sectional area
A_u
⟨encircled power (energy)⟩ smallest completely filled area containing u % of the total beam power (energy)

Note 1 to entry: For clarity, the term "beam cross-sectional area" is always used in combination with the symbol and its appropriate subscript: A_u or A_{σ}.

3.2.2
beam cross-sectional area
A_σ
⟨second moment of power (energy) density distribution function⟩ area of a beam with circular cross-section

$$\pi \cdot d_\sigma^{\ 2} / 4$$

or elliptical cross-section

$$\left(\pi \cdot d_{\sigma x} \cdot d_{\sigma y}\right) / 4$$

Note 1 to entry: For clarity, the term "beam cross-sectional area" is always used in combination with the symbol and its appropriate subscript: A_u or A_{σ}.

3.3 Beam diameter

3.3.1
beam diameter
d_u
⟨encircled power (energy)⟩ smallest diameter of a circular aperture in a plane perpendicular to the beam axis that contains u % of the total beam power (energy)

Note 1 to entry: For clarity, the term "beam diameter" is always used in combination with the symbol and its appropriate subscript: d_u or d_{σ}.

3.3.2
beam diameter
d_σ
⟨second moment of power (energy) density distribution function⟩ smallest diameter of a circular aperture in a plane perpendicular to the beam axis, defined as

$$d_\sigma\left(z\right) = 2\sqrt{2}\sigma\left(z\right)$$

where the second moment of the power density distribution function $E(x,y,z)$ of the beam at the location z is given by

$$\sigma^2(z) = \frac{\iint r^2 \cdot E(r,\varphi,z) \cdot r\mathrm{d}r\mathrm{d}\varphi}{\iint E(r,\varphi,z) \cdot r\mathrm{d}r\mathrm{d}\varphi}$$

where

r is the distance to the centroid $(\bar{x}, \bar{y})$

φ is the azimuth angle

and where the first moments give the coordinates of the centroid, i.e.

$$\bar{x} = \frac{\iint x \cdot E(x,y,z)\mathrm{d}x\mathrm{d}y}{\iint E(x,y,z)\mathrm{d}x\mathrm{d}y}$$

$$\bar{y} = \frac{\iint y \cdot E(x,y,z)\mathrm{d}x\mathrm{d}y}{\iint E(x,y,z)\mathrm{d}x\mathrm{d}y}$$

Note 1 to entry: In principle, integration has to be carried out over the whole xy plane. In practice, the integration has to be performed over an area such that at least 99 % of the beam power (energy) is captured.

Note 2 to entry: The power density E has to be replaced by the energy density H for pulsed lasers.

Note 3 to entry: For clarity, the term “beam diameter” is always used in combination with the symbol and its appropriate subscript: d_u or d_σ.

3.4 Beam radius

3.4.1
beam radius

w_u

⟨encircled power (energy)⟩ smallest radius of an aperture in a plane perpendicular to the beam axis which contains u % of the total beam power (energy)

Note 1 to entry: For clarity, the term “beam radius” is always used in combination with the symbol and its appropriate subscript: w_u or w_σ.

3.4.2
beam radius

w_σ

⟨second moment of power (energy) density distribution function⟩ smallest radius of an aperture in a plane perpendicular to the beam axis, defined as

$$w_\sigma(z) = \sqrt{2}\sigma(z)$$

Note 1 to entry: For a definition of the second moment $\sigma^2(z)$, see 3.3.2.

Note 2 to entry: For clarity, the term “beam radius” is always used in combination with the symbol and its appropriate subscript: w_u or w_σ.

3.5 Beam widths

3.5.1
beam widths
$d_{x,u}$, $d_{y,u}$
⟨encircled power (energy)⟩ width of the smallest slit transmitting u % of the total beam power (energy) in two preferential orthogonal directions x and y which are perpendicular to the beam axis

Note 1 to entry: The preferential directions are given by the smallest beam width and the orthogonal direction.

Note 2 to entry: For circular Gaussian beams, $d_{x,95,4}$ equals $d_{86,5}$.

Note 3 to entry: For clarity, the term "beam widths" is always used in combination with the symbol and its appropriate subscripts: $d_{\sigma x}$, $d_{\sigma y}$ or $d_{x,u}$, $d_{y,u}$.

3.5.2
beam widths
$d_{\sigma x}$, $d_{\sigma y}$
⟨second moment of power (energy) density distribution function⟩ width of the smallest slit in two preferential orthogonal directions x and y which are perpendicular to the beam axis, defined as

$$d_{\sigma x}\left(z\right) = 4\sigma_x\left(z\right)$$

$$d_{\sigma y}\left(z\right) = 4\sigma_y\left(z\right)$$

where the second moments of the power density distribution function $E(x, y, z)$ of the beam at the location z are given by

$$\sigma_x^{\,2}\left(z\right) = \frac{\iint (x-\bar{x})^2 \cdot E(x,y,z)\mathrm{d}x\mathrm{d}y}{\iint E(x,y,z)\mathrm{d}x\mathrm{d}y}$$

$$\sigma_y^{\,2}\left(z\right) = \frac{\iint (y-\bar{y})^2 \cdot E(x,y,z)\mathrm{d}x\mathrm{d}y}{\iint E(x,y,z)\mathrm{d}x\mathrm{d}y}$$

where $\left(x-\bar{x}\right)$ and $\left(y-\bar{y}\right)$ are the distances to the centroid $\left(\bar{x},\bar{y}\right)$ and where the first moments give the coordinates of the centroid, i.e

$$\bar{x} = \frac{\iint x \cdot E(x,y,z)\mathrm{d}x\mathrm{d}y}{\iint E(x,y,z)\mathrm{d}x\mathrm{d}y}$$

$$\bar{y} = \frac{\iint y \cdot E(x,y,z)\mathrm{d}x\mathrm{d}y}{\iint E(x,y,z)\mathrm{d}x\mathrm{d}y}$$

Note 1 to entry: In principle, integration has to be carried out over the whole xy plane. In practice, the integration has to be performed over an area such that at least 99 % of the beam power (energy) are captured.

Note 2 to entry: The power density E has to be replaced by the energy density H for pulsed lasers.

Note 3 to entry: For clarity, the term "beam widths" is always used in combination with the symbol and its appropriate subscripts: $d_{\sigma\mathrm{x}}$, $d_{\sigma\mathrm{y}}$ or $d_{\mathrm{x,u}}$, $d_{\mathrm{y,u}}$.

3.5.3
beam ellipticity
$\varepsilon(z)$
parameter for quantifying the circularity or squareness of a power [energy] density distribution at z

$$\varepsilon(z) = \frac{d_{\sigma y}(z)}{d_{\sigma x}(z)}$$

Note 1 to entry: The direction of x is chosen to be along the major axis of the distribution so $d_{\sigma x} \geq d_{\sigma y}$.

Note 2 to entry: If $\varepsilon \geq 0{,}87$, elliptical distributions can be regarded as circular. In case of a rectangular beam profile, ellipticity is often referred to as aspect ratio.

3.5.4
circular power density distribution
power density distribution having an ellipticity greater than 0,87

[SOURCE: ISO 11146-1:2005, 3.7]

3.6
beam parameter product
product of the beam waist diameter and the divergence angle divided by 4

$$d_{\sigma 0} \cdot \Theta_{\sigma} \; / \; 4$$

Note 1 to entry: Beam parameter products for elliptical beams can be given separately for the principal axes of the power (energy) distribution.

3.7
beam propagation ratio

M^2
DEPRECATED: beam propagation factor
K
measure of how close the beam parameter product is to the diffraction limit of a perfect Gaussian beam

$$M^2 = \frac{1}{K} = \frac{\pi}{\lambda} \times \frac{d_{\sigma 0}\Theta_{\sigma}}{4}$$

Note 1 to entry: This is equal to the ratio of the beam parameter products for the actual modes of the laser and the fundamental Gaussian mode (TEM_{00}).

Note 2 to entry: The beam propagation ratio is unity for a theoretically perfect Gaussian beam, and has a value greater than one for any real beam.

Note 3 to entry: It is preferable to use M^2 because K is the symbol for the deprecated term and future editions will no longer use the term “beam propagation factor”.

3.8
beam position
displacement of the beam axis relative to the fixed mechanical axis of an optical system at a specified plane perpendicular to the mechanical axis of the optical system

Note 1 to entry: The mechanical axis is given by the straight line joining the centroids of the limiting apertures.

3.9
beam positional stability
$\Delta_x(z')$, $\Delta_y(z')$
four times the standard deviation of the measured beam positional movement at plane z'

[SOURCE: ISO 11670:2003, 3.6]

Note 1 to entry: These quantities are defined in the beam axis system x,y,z.

3.10
beam waist
portion of a beam where the beam diameter or beam width takes local minimum

3.11 Beam waist diameters

3.11.1
beam waist diameter
$d_{0,u}$
⟨encircled power (energy)⟩ diameter d_u of the beam at the location of the beam waist

Note 1 to entry: For clarity, the term "beam waist diameter" is always used in combination with the symbol and its appropriate subscripts: $d_{0,u}$ or $d_{\sigma 0}$.

3.11.2
beam waist diameter
$d_{\sigma 0}$
⟨second moment of power (energy) density distribution function⟩ diameter d_σ of the beam at the location of the beam waist

Note 1 to entry: For clarity, the term "beam waist diameter" is always used in combination with the symbol and its appropriate subscripts: $d_{0,u}$ or $d_{\sigma 0}$.

3.12 Beam waist radius

3.12.1
beam waist radius
$w_{0,u}$
⟨encircled power (energy)⟩ radius w_u of the beam at the location of the beam waist

Note 1 to entry: For clarity, the term "beam waist radius" is always used in combination with the symbol and its appropriate subscripts: $w_{0,u}$ or $w_{\sigma 0}$.

3.12.2
beam waist radius
$w_{\sigma 0}$
⟨second moment of power (energy) density distribution function⟩ radius w_σ of the beam at the location of the beam waist

Note 1 to entry: For clarity, the term "beam waist radius" is always used in combination with the symbol and its appropriate subscripts: $w_{0,u}$ or $w_{\sigma 0}$.

3.13 Beam waist widths

3.13.1
beam waist widths
$d_{x0,u}$, $d_{y0,u}$
⟨encircled power (energy)⟩ beam widths $d_{x,u}$ and $d_{y,u}$ at the locations of the beam waists in both the x and y directions

Note 1 to entry: For clarity, the term "beam waist widths" is always used in combination with the symbol and its appropriate subscripts: $d_{x0,u}$, $d_{y0,u}$ or $d_{\sigma x0}$, $d_{\sigma y0}$.

