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Optics and photonics — Lasers and laser-related equipment — Test methods for the spectral characteristics of lasers

Optique et photonique — Lasers et équipement associé aux lasers — Méthodes d'essai des caractéristiques spectrales des lasers

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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 13595:2004) of which it constitutes a minor revision.

The main changes are as follows:

— editorial changes related to the new format;

— the symbol for side-mode suppression ratio was adapted from *SMS* to R_{SMS};

— lg was changed to $\log_{10}$ in 3.15;

— the title of the SC 9 was updated;

— intensity was adapted to irradiance;

— in the Bibliography Reference 2 was updated and replaced by References 2 and 3.

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 spectral characteristics of a laser, such as its peak wavelength or spectral linewidth, are important for potential applications. Examples are the specific application requirements of interferometry and lithography. This document gives definitions of key parameters describing the spectral characteristics of a laser, and provides guidance on performing measurements to determine these parameters for common laser types.

The acceptable level of uncertainty in the measurement of wavelength will vary according to the intended application. Therefore, equipment selection and measurement and evaluation procedures are outlined for three accuracy classes. To standardize reporting of spectral characteristics measurement results, a report example is also included.

Optics and photonics — Lasers and laser-related equipment — Test methods for the spectral characteristics of lasers

1 Scope

This document specifies methods by which the spectral characteristics such as wavelength, bandwidth, spectral distribution and wavelength stability of a laser beam can be measured. This document is applicable to both continuous wave (cw) and pulsed laser beams. The dependence of the spectral characteristics of a laser on its operating conditions may also be important.

2 Normative references

The following referenced documents are indispensable for the application 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 11145, *Optics and photonics — Lasers and laser-related equipment — Vocabulary and symbols*

ISO/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

IEC 60747-5-1, *Discrete semiconductor devices and integrated circuits — Part 5-1: Optoelectronic devices — General*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11145, ISO/IEC Guide 99 and IEC 60747-5-1, and the following apply.

ISO and IEC maintain terminology 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
wavelength in vacuum
λ_0
wavelength of an infinite, plane electromagnetic wave propagating in vacuum

Note 1 to entry: For a wave of frequency f, the wavelength in vacuum is then given by $\lambda_0 = c/f$, where c = 299 792 458 m/s.

3.2
wavelength in air
λ_{air}
wavelength of radiation propagating in the air and related to the wavelength in vacuum by the relationship:

$$\lambda_{air} = \lambda_0 / n_{air}$$

where n_{air} denotes the refractive index of ambient air (see 6.4)

Note 1 to entry: The specific properties of the ambient atmosphere, such as humidity, pressure, temperature and composition all influence n_{air}. Therefore it is better to report the wavelength in vacuum, or the wavelength in standard air. These can be calculated from λ_{air} and n_{air} using the equation given in 6.4.

3.3
wavelength in dry air under standard conditions
λ_{std}
wavelength of radiation propagating in dry air (0 % humidity) under standard conditions and related to the wavelength in vacuum λ_0 by the relationship:

$$\lambda_{std} = \lambda_0 / n_{std}$$

where n_{std} denotes the refractive index of air under standard conditions (see 6.4).

Note 1 to entry: For the purpose of this document, air under standard conditions is as defined in 6.4. Note that various other "standard conditions" have been reported in the literature. It is therefore necessary to quote the conditions in the test report.

3.4
spectral radiant power [energy] distribution
$P_\lambda(\lambda)$, $[Q_\lambda(\lambda)]$
ratio of the radiant power d$P(\lambda)$ [or energy d$Q(\lambda)$ in the case of a pulsed laser] transferred by laser beam in the range of wavelength dλ to that range

$$P_\lambda(\lambda) = \frac{\mathrm{d}P(\lambda)}{\mathrm{d}\lambda} \qquad \left[Q_\lambda(\lambda) = \frac{\mathrm{d}Q(\lambda)}{\mathrm{d}\lambda}\right]$$

Note 1 to entry: The radiant power (energy) delivered by the laser beam in any bandwidth λ_{low} to λ_{high} is then given by the integral:

$$P = \int_{\lambda_{low}}^{\lambda_{high}} P_\lambda(\lambda)\,\mathrm{d}\lambda \qquad \left[Q = \int_{\lambda_{low}}^{\lambda_{high}} Q_\lambda(\lambda)\,\mathrm{d}\lambda\right]$$

3.5
peak-emission wavelength
λ_p
wavelength at which the spectral radiant power (energy) distribution has its maximum value

Note 1 to entry: See Figure 1.

3.6
weighted average wavelength (first moment)
λ_g
wavelength representing the centre of gravity of the spectral radiant power (energy) distribution, as defined by:

$$\lambda_g = \frac{\int_{\lambda_{min}}^{\lambda_{max}} \lambda\, S(\lambda)\,\mathrm{d}\lambda}{\int_{\lambda_{min}}^{\lambda_{max}} S(\lambda)\,\mathrm{d}\lambda}$$

where $S(\lambda)$ is the spectral radiant power $P_\lambda(\lambda)$ in the case of a cw laser, or the spectral radiant energy distribution $Q_\lambda(\lambda)$ in the case of a pulsed laser

Note 1 to entry: See Figure 1.

Note 2 to entry: For choosing of the integration limits λ_{min} and λ_{max}, see 6.2.2.

3.7
central wavelength
$\bar{\lambda}$

weighted average of the wavelengths of spectral lines or modes:

$$\bar{\lambda} = \frac{\sum_{i=i_{\min}}^{i=i_{\max}} I_i \lambda_i}{\sum_{i=i_{\min}}^{i=i_{\max}} I_i}$$

where

λ_i	is the wavelength of the ith spectral line or the ith mode;
I_i	is the relative radiant power of the ith spectral line or the ith mode;
$i_{\min}$, $i_{\max}$	denote extreme spectral lines or modes below and above λ_p.

Note 1 to entry: Usually, the summation limits are chosen such that the relative radiant power of spectral lines or modes outside the limits remains less than 1 % of the relative radiant power of the strongest line or mode, located at λ_p.

Note 2 to entry: This definition is particularly useful in the case of a multi-mode laser.

3.8
average wavelength
λ_{av}
ratio of the light velocity c to the average optical emission frequency f_{av}

$$\lambda_{av} = c/f_{av}$$

Note 1 to entry: The average optical emission frequency f_{av} can be measured directly, e.g. by the heterodyne measurement method (see 6.6.5).

3.9
RMS spectral radiation bandwidth (second moment)
$\Delta\lambda$
second moment of the spectral radiant power (energy) distribution, as defined by:

$$\Delta\lambda = \sqrt{\frac{\int_{\lambda_{\min}}^{\lambda_{\max}} (\lambda - \lambda_g)^2 S(\lambda)\,d\lambda}{\int_{\lambda_{\min}}^{\lambda_{\max}} S(\lambda)\,d\lambda}}$$

where $S(\lambda)$ is the spectral radiant power $P_\lambda(\lambda)$ in the case of a cw laser, or the spectral radiant energy distribution $Q_\lambda(\lambda)$ in the case of a pulsed laser.

Note 1 to entry: See Figure 1.

Note 2 to entry: For choosing of the integration limits $\lambda_{\min}$ and $\lambda_{\max}$ see 6.2.2.

3.10
RMS spectral bandwidth
$\Delta\lambda_{rms}$
rms bandwidth is defined by:

$$\Delta\lambda_{rms} = \sqrt{\frac{\sum_{i=i_{\min}}^{i=i_{\max}} I_i (\lambda_i - \bar{\lambda})^2}{\sum_{i=i_{\min}}^{i=i_{\max}} I_i}}$$

where

λ_i is the wavelength of the ith spectral line or the ith mode;

I_i is the relative radiant power of the ith spectral line or the ith mode;

$\bar{\lambda}$ is the central wavelength;

i_{min}, i_{max} denote extreme spectral lines or modes below and above λ_p

Note 1 to entry: See Figure 1.

Note 2 to entry: Usually, the summation limits are chosen such that the relative radiant power of spectral lines outside the limits remains less than 1 % of the relative radiant power of the strongest line, located at λ_p.

Note 3 to entry: This definition is particularly useful in the case of a multi-mode laser.

3.11
spectral bandwidth
FWHM
$\Delta\lambda_H$
maximum difference between the wavelengths for which the spectral radiant power (energy) distribution is half of its peak value

Note 1 to entry: See Figure 1.

[SOURCE: ISO 11145:2018, 3.17, modified — The abbreviation “FWHM” has been added, “$\Delta\lambda$, $\Delta\nu$” has been replaced by “$\Delta\lambda_H$” and Note 1 to entry has been added.]

3.12
spectral linewidth
FWHM
$\Delta\lambda_L$
maximum difference between those wavelengths within $\delta\lambda$ for which the spectral radiant power (energy) distribution is half of its peak value found within $\delta\lambda$

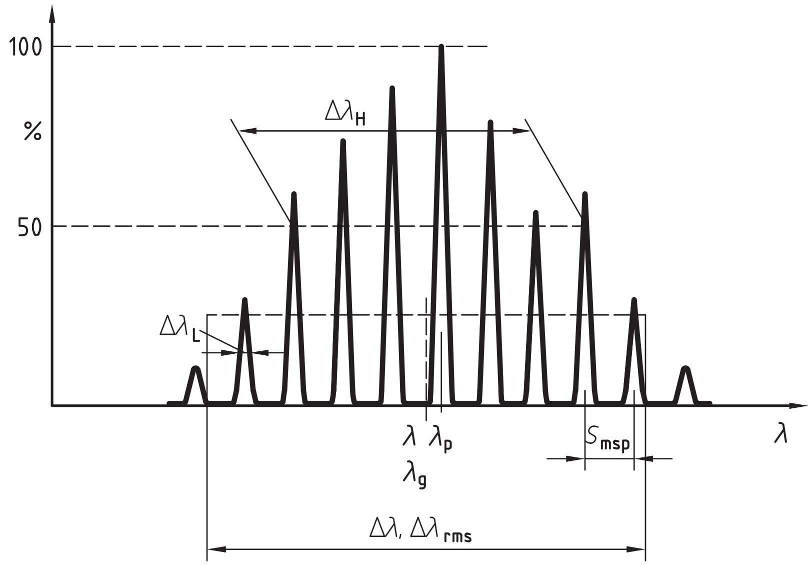
Note 1 to entry: See Figure 1.

Note 2 to entry: cf. *spectral bandwidth* (3.11), $\Delta\lambda_H$

Note 3 to entry: A spectral linewidth is analogous to a *spectral bandwidth* (3.11), but is defined for a single (longitudinal) mode or otherwise clearly distinguishable and labelled spectral feature contained within an interval $\delta\lambda$.

3.13
mode spacing
F_{msp} (S_{msp})
separation of two neighbouring longitudinal modes expressed in frequency (F_{msp}) (wavelength (S_{msp}))

Note 1 to entry: See Figure 1.



Key

λ wavelength

Figure 1 — Spectral characteristics of lasers — Illustration of defined parameters

3.14
number of longitudinal modes
N_m
number of longitudinal modes within a specified bandwidth, usually the rms spectral bandwidth $\Delta\lambda_{rms}$

3.15
side-mode suppression ratio
R_{SMS}
ratio of the relative radiant power of the most intense mode, I_p, located at λ_p, to the relative radiant power of the second most intense mode, I_s, located at λ_s:

$$R_{SMS} = 10\log_{10}\left(\frac{I_p}{I_s}\right)$$

Note 1 to entry: See Figure 2.

Note 2 to entry: In practice the R_{SMS} can be assumed to be equal to the ratio of the peak values of the spectral distribution for the most intense and second most intense modes:

$$R_{SMS} = 10\log_{10}\left[\frac{S(\lambda_p)}{S(\lambda_s)}\right]$$