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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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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 13695 was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 9, *Electro-optical systems*.

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 International Standard 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 International Standard specifies methods by which the spectral characteristics such as wavelength, bandwidth, spectral distribution and wavelength stability of a laser beam can be measured. This International Standard 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 optical instruments — Lasers and laser-related equipment — Vocabulary and symbols*

ISO 12005, *Lasers and laser-related equipment — Test methods for laser beam parameters — Polarization*

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

Guide to the expression of uncertainty in measurement (GUM), BIPM[1)], IEC, IFCC[2)], ISO, IUPAC[3)], IUPAP[4)], OIML[5)], 1993, corrected and reprinted in 1995

International vocabulary of basic and general terms in metrology (VIM). BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, Geneva, ISO

3 Terms and definitions

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

3.1
wavelength in vacuum
λ_0
wavelength of an infinite, plane electromagnetic wave propagating in vacuum

NOTE 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.

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1) International Bureau of Weights and Measures (Bureau International des Poids et Measures).

2) International Federation of Clinical Chemistry and Laboratory Medicine.

3) International Union of Pure and Applied Chemistry.

4) International Union of Pure and Applied Physics.

5) International Organization of Legal Metrology (Organization International de Metrologie Legale).

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 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 For the purpose of this International Standard, 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 $\mathrm{d}P(\lambda)$ [or energy $\mathrm{d}Q(\lambda)$ in the case of a pulsed laser] transferred by laser beam in the range of wavelength $\mathrm{d}\lambda$ 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 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

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:

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

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

See Figure 1.

NOTE 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 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 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 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.

See Figure 1.

NOTE For choosing of the integration limits λ_{min} and λ_{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

See Figure 1.

NOTE 1 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 2 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

See Figure 1.

NOTE Adapted from ISO 11145.

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 $\delta\lambda$

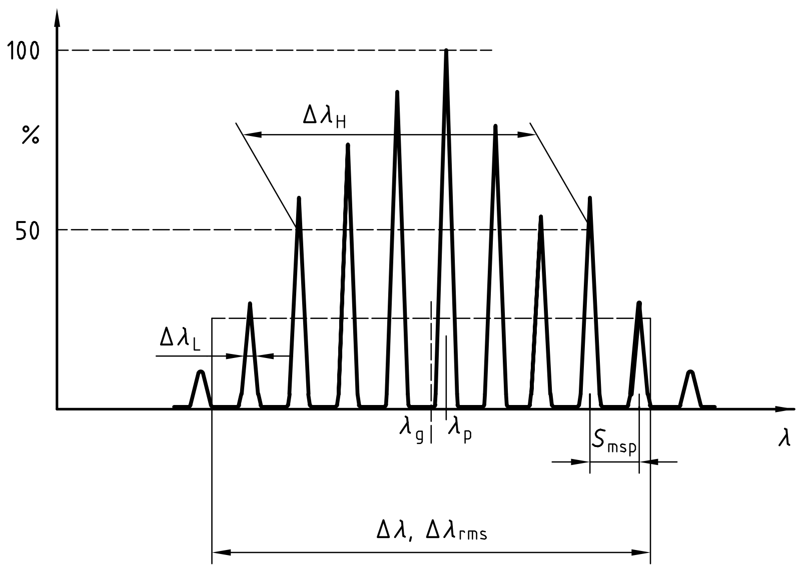
See Figure 1.

cf. **spectral bandwidth** (3.11), $\Delta\lambda_H$

NOTE 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})]

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 $\Delta\lambda_{rms}$

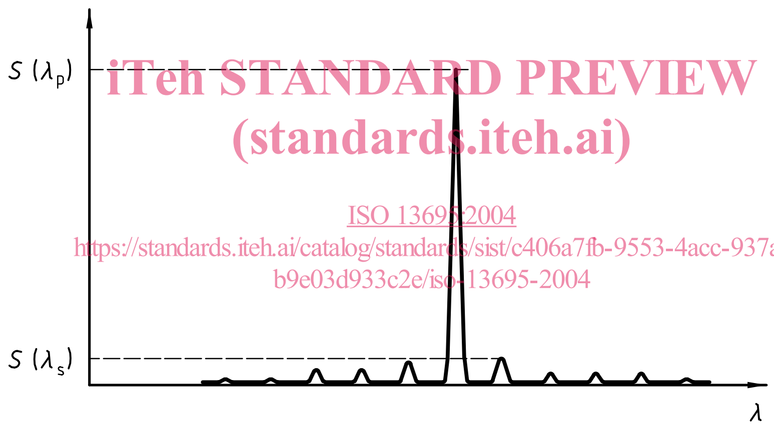
3.15
side-mode suppression ratio
SMS
ratio of the relative radiant power of the most intense mode, I_p, located at λ_p, to the relative radiant power of the second most intense mode, I_s, located at λ_s:

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

See Figure 2.

NOTE In practice the *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:

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



Key

λ wavelength

Figure 2 — Side-mode suppression ratio

3.16
pulse repetition rate
f_p
number of laser pulses per second of a repetitively pulsed laser

3.17
temperature dependence of wavelength
$\delta\lambda_T$
wavelength shift per change in temperature T of the laser:

$$\delta\lambda_T = \frac{d\lambda}{dT}$$