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Optics and photonics — Measurement method of semiconductor lasers for sensing

Optique et photonique — Méthode de mesure des lasers semi-conducteurs pour la sensibilité

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

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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.*

This first edition cancels and replaces the Technical Specification ISO/TS 17915:2013, which has been technically revised.

The main changes compared to ISO/TS 17915:2013 are as follows:

— interband cascade semiconductor lasers have been included in 4.2.5.

— in A.3: Regarding the monitor photodiode, "option" has been inserted.

— Tables in Annex A have been separated for clarity.

Introduction

Sensing technologies for materials related to the environment or wellness, etc., by using lasers have been researched and developed in academic and industrial fields. Semiconductor lasers including quantum cascade semiconductor lasers have been widely used in sensing applications because of their advantages of compactness and wide selectivity of lasing wavelengths. The tunable laser absorption spectroscopy, the cavity ring down spectroscopy and the photoacoustic spectroscopy are commonly used sensing techniques. In those sensing techniques, wavelength and/or spectrum analysis by changing temperature or injected current is the key for determining the composition or element of the material or the mixture to be examined. Therefore measuring methods of semiconductor lasers for sensing applications are described with an informative annex for an example of essential ratings and characteristics.

Optics and photonics — Measurement method of semiconductor lasers for sensing

1 Scope

This document describes methods of measuring temperature and injected current dependence of lasing wavelengths, and lasing spectral line width in relation to semiconductor lasers for sensing applications.

This document is applicable to all kinds of semiconductor lasers, such as edge-emitting type and vertical cavity surface emitting type lasers, bulk-type and (strained) quantum well lasers, and quantum cascade lasers, used for optical sensing in e.g. industrial, medical and agricultural fields.

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 13695, *Optics and photonics — Lasers and laser-related equipment — Test methods for the spectral characteristics of lasers*

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at https://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

4 Optical sensing using semiconductor lasers

4.1 General

The methods described in this document shall be followed in accordance with ISO 13695.

Optical sensing using tunable semiconductor laser spectroscopy has been widely used in various engineering fields. For example, optical sensing is being used for bio-sensing and environmental monitoring. Semiconductor lasers are key devices for those applications and are indispensable for building sensing equipment. Semiconductor lasers and sensing techniques are described in 4.2 to 4.6.

4.2 Semiconductor laser

4.2.1 General

A semiconductor laser is an optical semiconductor device that emits coherent optical radiation in a certain direction through stimulated emission resulting from electron transition when excited by an electric current that exceeds the threshold current of the semiconductor laser. Here, the mechanism of coherent optical radiation is divided into the following two categories:

1) electron-hole recombination due to interband electron transition between conduction and valence band (bulk type) or between two quantized states (quantum well type, see 4.2.5) and

2) intraband electron transition between two quantized states (quantum cascade type, see 4.2.5).

Edge-emitting types with single lasing modes, such as distributed feedback (DFB) lasers, have been conventionally used in sensing equipment because of their high power and single lasing modes. Surface-emitting types are also widely used in sensing systems because they are easy to handle. Some names are given to those lasers from various aspects. Those lasers are briefly categorized in 4.2.2 to 4.2.5. Optical and electrical characteristics of semiconductor lasers are complicated and should be described precisely depending on the application (see Annex A for additional information).

4.2.2 Basic structure

a) Edge emitting type semiconductor laser: a semiconductor laser that emits coherent optical radiation in the direction parallel to the junction plane.

b) Surface emitting type semiconductor laser: a semiconductor laser that emits coherent optical radiation in the direction normal to the junction plane. A vertical cavity surface emitting semiconductor laser (VCSEL) is typical.

4.2.3 Transverse mode stabilizing structure

a) Gain guiding: a semiconductor laser in which emitted light propagates along the gain region generated by carrier injection and is amplified by stimulated emission along the gain region. Planar type lasers are typical in gain guiding.

b) Refractive index guiding: a semiconductor laser in which a stripe-shape active layer (light emitting layer) or junction is formed to introduce an effective refractive index difference between the stripe and the outer region. A buried heterostructure (BH) is typical in refractive index guiding.

4.2.4 Mode (wavelength) selection structure

a) Distributed feedback (DFB) semiconductor laser: a semiconductor in which stimulated emission is selected by a grating (equivalent to distributed mirror). This laser operates in single longitudinal mode.

b) Distributed Bragg reflector (DBR) semiconductor laser: a semiconductor laser in which stimulated emission is selected by a Bragg grating (equivalent to distributed mirror) jointed at a side or both sides of the light emitting layer. This laser operates in single longitudinal mode.

c) Fabry-Perot (FP) semiconductor laser: a semiconductor laser in which stimulated emission is generated between two mirror facets. This laser normally operates in multiple longitudinal modes.

d) External cavity controlled semiconductor laser: a semiconductor laser in which the optical cavity is composed of one mirror and an external mirror (external grating) set on the opposite side of the mirror. Stimulated emission is generated at the semiconductor part in the optical cavity. This laser normally operates in single longitudinal mode.

4.2.5 Active layer structure

a) Double heterostructure semiconductor laser: a semiconductor laser in which the active layer (light emitting layer) is sandwiched with two heterojunctions (pn- and iso-junction).

b) Quantum well semiconductor laser: a semiconductor laser that emits coherent optical radiation through stimulated emission resulting from the recombination of electrons and holes between two quantized states. Here, the light emitting layer is composed of a single quantum well layer or multiple quantum well layers. A quantum wire and quantum dot (box) semiconductor laser are included in this category but the light emitting area of the quantum wire and dot is a two-dimensional and three-dimensional structure, respectively.

c) Strained quantum well semiconductor laser: a semiconductor laser that emits coherent optical radiation through stimulated emission resulting from the recombination of free electrons and holes between two quantized states. Here, the light emitting layer is composed of a strained single quantum well layer or multiple quantum well layers.

d) Interband cascade semiconductor laser: a semiconductor laser that emits coherent optical radiation through stimulated emission resulting from the recombination of electrons and holes between two quantized states. Here, the light emitting layer is composed of type-II (broken gap) quantum well layers. Carriers are generated internally by a semimetallic interface.

e) Quantum cascade semiconductor laser: a semiconductor laser that emits coherent optical radiation through stimulated emission resulting from electron transition between two quantized states without any electron-hole recombination. The light emitting layer is composed of quantum cascade layers.

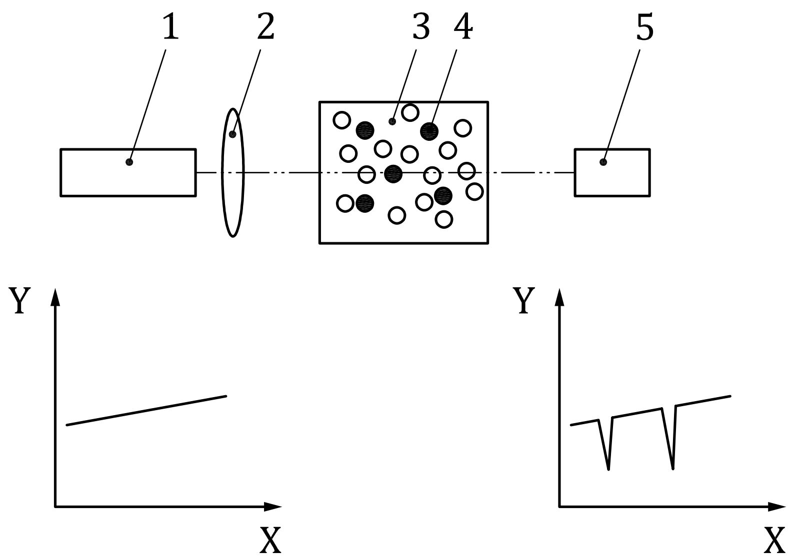
4.3 Common sensing technique and equipment using semiconductor lasers

4.3.1 General

Semiconductor lasers including quantum cascade semiconductor lasers have various advantages: compact size, light weight, low power consumption, easy controlling of wavelength by pulsed or continuous wave operation, etc. Sensing techniques and equipment using such semiconductor lasers have been researched and developed in academic and industrial fields. The main sensing techniques are described in 4.3.2 to 4.3.4.

4.3.2 Tunable laser absorption spectroscopy (TLAS)

An absorption spectrum is monitored by scanning repeatedly the wavelength of light emitted from the semiconductor laser as shown in Figure 1. The composition of material and mixture to be examined are qualitatively and quantitatively analysed based on the monitored spectrum (shape, peak wavelength and intensity). The lasing wavelength of the semiconductor laser is scanned by controlling the ambient temperature or injected current in this technique.



Key

X wavelength

Y optical intensity

1 tunable laser diode

2 lens

3 cell

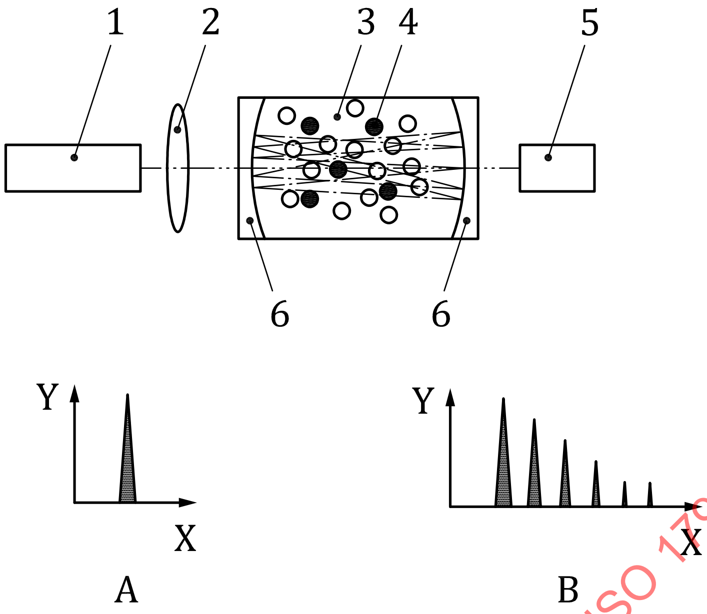
4 element to be detected

5 optical detector

Figure 1 — Basic concept of tunable laser absorption spectroscopy (two absorption peaks are observed)

4.3.3 Cavity ring down spectroscopy (CRDS)

This technique is usually used for detecting trace elements and originated from tunable semiconductor laser spectroscopy. Material to be analysed is introduced into the cavity built up with two mirrors as shown in Figure 2. A light pulse (with a certain wavelength) introduced to the cavity is repeatedly reflected between the mirror and passes through the material. A part of reflecting light escapes through the mirror, and a pulse train with a time interval determined with the cavity length is monitored. The trace element is qualitatively and quantitatively analysed with the decay time of the pulse train and the wavelength of the light.



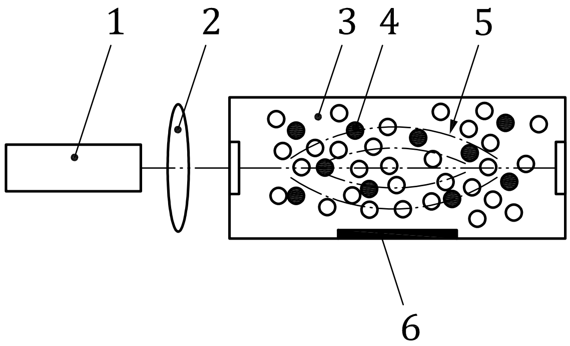
Key

X wavelength
Y optical intensity
A optical pulse
B optical pulse train
1 tunable laser diode
2 lens
3 cell
4 element to be detected
5 optical detector
6 mirror

Figure 2 — Basic concept of cavity ring down spectroscopy

4.3.4 Photoacoustic spectroscopy (PAS)

When material to be analysed is illuminated with laser light, the light is absorbed at the material. The light power absorbed induces a lattice vibration, and the vibration results in the emission of a supersonic wave as shown in Figure 3. The supersonic wave is detectable with a microphone, and the element contained in the material is quantitatively analysed by monitoring the frequency and intensity.



Key

1 tunable laser diode

2 lens

3 cell

4 element to be detected

5 supersonic wave

6 microphone

Figure 3 — Basic concept of photoacoustic spectroscopy

4.4 Temperature and current dependence of wavelength

The lasing wavelength of semiconductor lasers is changed by various methods.

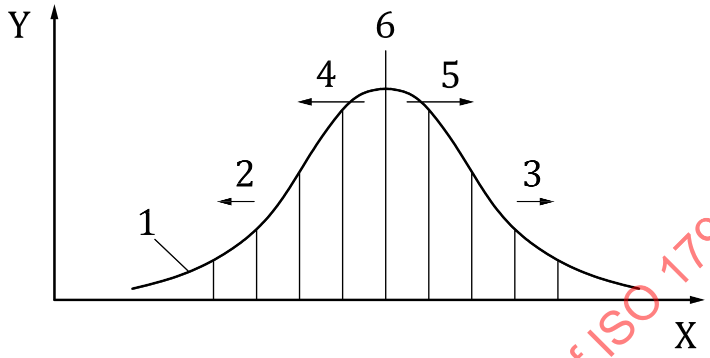
In normal semiconductor lasers, their lasing wavelength is ordinarily controlled by varying the ambient temperature and the injected current in tunable semiconductor laser spectroscopy. These variables correspond to a band-gap change due to ambient temperature and the band-filling effect induced by carriers injected into the active layer of semiconductor lasers. In addition, refractive index change of the active layer, which is induced by temperature and injected carrier density, takes an important role of changing the lasing wavelength. The changing rate of these physical properties determines the conventionally used temperature and current dependence of lasing wavelength. The physical mechanisms of temperature and current control of the lasing wavelength are explained in this subclause.

In external cavity controlled semiconductor lasers, the lasing wavelength can be selected by controlling the angle of grating if the grating is set as an external mirror. The lasing wavelength is widely scanned by controlling the grating angle.

Several factors govern the change in lasing wavelength of semiconductor lasers as shown in Figure 4. A decrease (an increase) in the refractive index of the active region originates from an increase (a decrease) in threshold carrier density and shortens (lengthens) the lasing wavelength of each Fabry-Perot (FP)-mode in FP semiconductor lasers. This phenomenon is induced by the plasma effect related to carrier density in semiconductors. In DFB semiconductor lasers, the lasing mode is shortened (lengthened) with a decrease (an increase) in effective grating pitch introduced by the decrease (increase) in the refractive index. The increase (decrease) in the refractive index is introduced by a rising (lowering) temperature. In addition, the rising (lowering) temperature shifts the envelope of FP-modes (gain envelope) to the longer (shorter) range. This is due to a reduction (an increase) of the band-gap energy.

Before lasing, the peak wavelength of FP-modes shortens due to the band-filling effect, and that of DFB-modes also shortens as the injected carrier density increases through the refractive index reduction. After lasing, the main factor is the thermal effect because threshold carrier density is fixed at the threshold value after lasing. Joule heating is generated and light output power changes in response to the injected current under the constant carrier density.

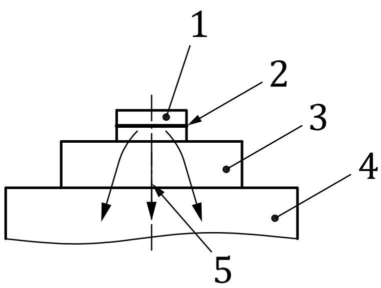
These are basic mechanisms for changing the lasing wavelength in semiconductor lasers. Among them, the change in lasing wavelength by controlling ambient temperature under a constant current is mainly generated by a band-gap change in FP semiconductor lasers and a refractive index change in DFB semiconductor lasers. Controlling the lasing wavelength with the magnitude of the injected current also occurs by the band-gap change due to Joule heating at the active layer (or pn-junction) because the injected carrier density is nearly constant after lasing. The temperature and current dependence of lasing wavelength is analysed in DFB semiconductor lasers from the viewpoint of thermal conductivity in the following parts.



Key

X wavelength
Y intensity
1 gain envelope
2 energy level change due to band filling
3 band gap change due to temperature increase
4 refractive index change due to carrier (plasma) effect
5 refractive index change due to heating
6 each lasing mode

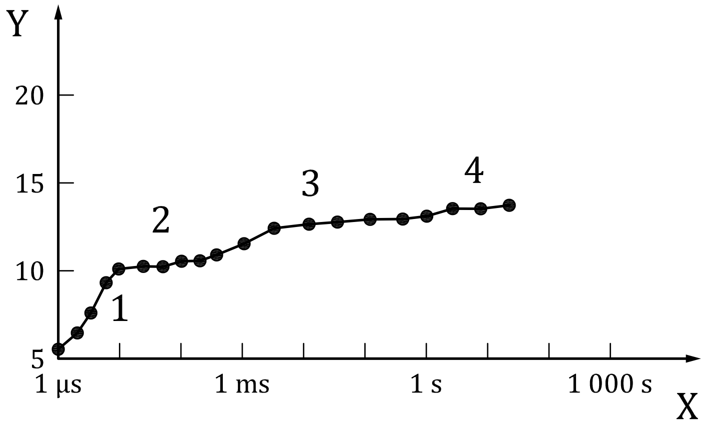
Figure 4 — Main factors of lasing-wavelength change



Key

1 semiconductor laser
2 active layer
3 heat sink
4 package stem
5 heat flow

Figure 5 — Sample configuration



Key

X current pulse width

Y active layer temperature, in ° C

1 LD chip

2 heat sink

3 package stem

4 package

NOTE 1 Pulse height: 100 mA.

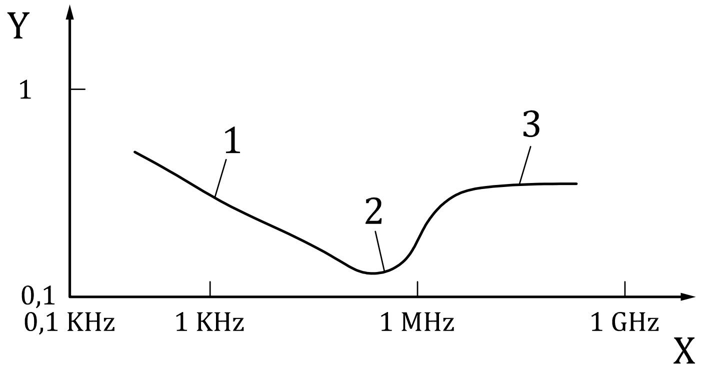
NOTE 2 The sample is a 1 300 nm-band FP semiconductor laser. The labels indicated by 1, 2, 3 and 4 indicate the responsible parts of heat conduction for the heat generated at the active layer.

Figure 6 — Estimated temperature rise in active layer as a function of pulse width

4.5 Effect of current injection on lasing wavelength

The rate of temperature change in the active layer depends on a transient phenomenon determined by heat conduction. As shown in Figure 5, the Joule heating generated at the active layer gradually diffuses from the active layer to the surrounding region, and thus the change rate in lasing wavelength strongly depends on the mounting configuration and packaging structure. Figure 6 shows an example of active layer temperature increase as a function of the current pulse width for a 1 300 nm-band FP semiconductor laser. The active layer temperature is estimated from the junction voltage because the junction voltage linearly decreases with temperature. The junction voltage at 1 mA is monitored just after turning off the 100 mA-pulsed current. The pulsed current and the monitoring current of the junction voltage is set at 100 mA and 1 mA, respectively. Here, the value of the monitoring current is determined so that the Joule heating due to the current is negligible. The temperature dependence of the junction voltage is about 1 mV/°C in the 1 300 nm-band semiconductor lasers. The Joule heating due to current injection diffuses within the laser chip and then towards the outside of the active layer, heat sink, package stem, package, and equipment, as the pulse width was widened. This heat conduction transient phenomenon governs the temperature of the active layer and is influenced by the laser-chip mounting configuration (configuration of the heat-conducting path).

These behaviours are closely related to the rate and range of wavelength change under current modulation. In Figure 7, the horizontal axis indicates modulation frequency and the vertical axis corresponds to the frequency deviation, which corresponds to the wavelength variation. As modulation frequency increases from 100 Hz, the frequency deviation decreases because the response to heat conduction is gradually small. This behaviour is also recognized in Figure 6, in which the current pulse width corresponds to the modulation frequency of the semiconductor laser from the viewpoint of heat conduction. A dip appears after 100 kHz in Figure 7. After the dip, the plasma effect is dominant and the lasing wavelength tends to be shortened (blue shift). This frequency deviation is called FM-response or chirping in the optical fibre communication field[4]. The frequency range used for tunable semiconductor laser spectroscopy is below the dip frequency and the frequency at which the influence of heat is dominant (red shift).



Key

X modulation frequency

Y frequency deviation, in GHz/mA

1 Joule heating (lengthening)

2 dip

3 plasma effect (shortening)

NOTE The modulation current was a 0,5 mA peak-to-peak sinusoidal wave and the DC bias was set at 60 mA.

Figure 7 — Lasing frequency (wavelength) deviation for a 1 300 nm-band DFB semiconductor laser as a function of frequency

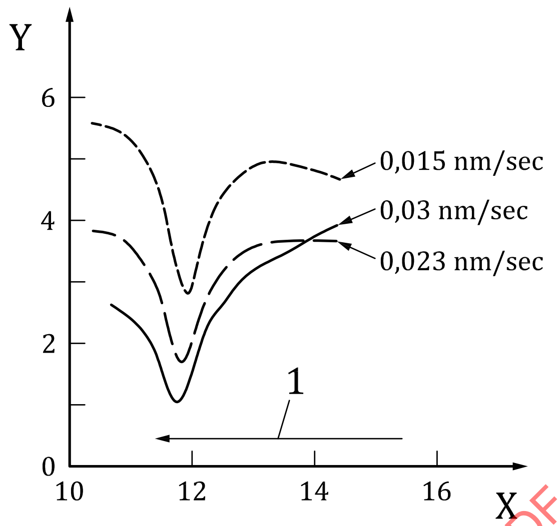
When the injected current is quickly changed, the increase in the temperature is not sufficient and the increase is not saturated. The temperature difference between the active layer and the package temperature becomes large or small in response to the magnitude of injected current when the package temperature is set at a constant temperature. The current dependence is, therefore, not constant and varies with the rate of current increase. Their dependences are, however, kept at fixed values if the time intervals of monitoring are fixed at the constant values and strongly influenced by the materials used and the chip-mount configuration.

4.6 Effect of ambient temperature on lasing wavelength

Heat is inversely transmitted from the ambient to the active layer of the semiconductor laser through the package when the ambient temperature or package temperature is changed. The heat conductance of the package, package stem, and heat sink is the same for the case of the diffusion of Joule heating at the active layer, and a certain time interval is needed until the temperature of the active layer is equal to the ambient temperature as shown in Figure 6.

The temperature dependence of wavelength and absorption peak wavelength vary depending on the time interval of monitoring after changing the ambient temperature. If the change rate of package temperature is set at values of more than 1 s, the temperature dependence is the same because the change in package temperature can diffuse to the active layer (see Figure 6). Figure 8 shows a set of changes in the absorption peak in the spectrum monitored at different scanning rate of the package the temperature for one of the CO_2-gas absorption peaks. (The CO_2-gas pressure is set at an atmospheric pressure, and the spectral width is broadened because of collisions and Doppler shift.) These scanning rates correspond to the package-temperature change rate of less than 1 s. As the rate is high, the peak position shifts to the direction of the temperature scan and the magnitude of the absorption peak tends to be small. These phenomena are caused by the time constant of heat diffusion between the package and active layer, and should be considered during measurement.

These dependences are governed by the change of each factor discussed in 4.4. When ambient temperature is changed, for example, threshold current density and band-gap energy vary simultaneously and lasing wavelength changes complicatedly. The dependences result from the overall change in the factors. Consequently, the dependences will vary with the material used, the mounting configuration, the monitoring time interval, etc. It can be said that the change rate of the injected current and ambient (package) temperature has to be constant during tunable semiconductor laser spectroscopy to eliminate wavelength error, although the dependence differs with the change rate.



Key

X package case temperature, in °C

Y light power, in a.u.

1 temperature scan

NOTE A 2 000 nm-band semiconductor laser was used in this experiment.

Figure 8 — Shape change in absorption spectrum monitored at different scanning rates of the package temperature for one of CO_2-gas absorption peaks

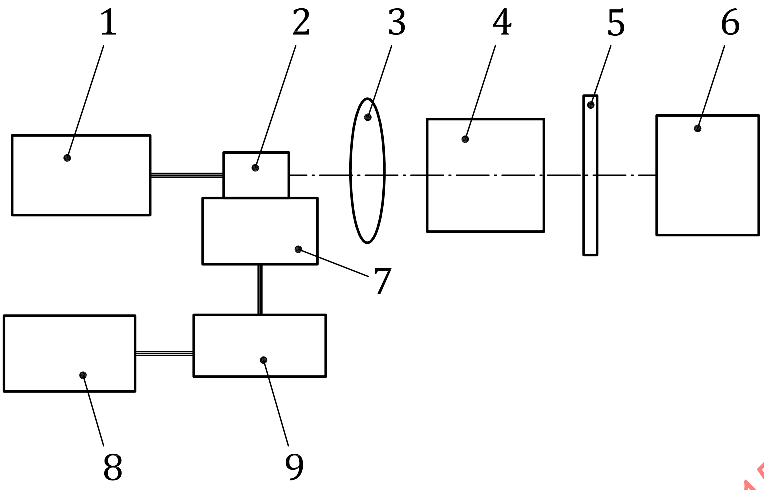
5 Measurement method for temperature dependence of wavelength

5.1 General

As described in Clause 4, the lasing wavelength of semiconductor lasers is scanned or fixed by temperature control when they are used for sensing application. The temperature dependence corresponds to the magnitude of lasing wavelength shift and is a measure of the lasing wavelength change with temperature. This characteristic is therefore important for semiconductor lasers for sensing. A semiconductor laser used for sensing is normally a single longitudinal mode laser, and the shift value of wavelength is, for instance, monitored with the amount of the change in peak-emission wavelength under temperature or current variation (see 4.2 and Figure 4). The measurement method of the temperature dependence is described in 5.2 to 5.4.

5.2 Description of measurement setup and requirements

The measurement setup is depicted in Figure 9.



Key

1 LD driver
2 device (semiconductor laser) being measured
3 lens
4 spectrometer
5 attenuator
6 optical detector
7 thermoelectric cooler
8 controller of power supply
9 power supply of thermoelectric cooler

Figure 9 — Basic measurement setup of temperature dependence of lasing wavelength

The Laser-Diode (LD) driver supplies current to the semiconductor laser, and if the laser is not capable of operating in continuous wave throughout measurement, supplies pulsed current to the lasers, such as quantum cascade ones.

The spectrometer (spectrophotometer or spectroscope) resolves the spectral components of input light in corresponding to the wavelength by wavelength-tunable optical filter and outputting light of the individual spectral components within a certain wavelength range. A diffraction grating or Fabry-Perot interferometer is used as the tunable optical filter.

The optical spectrum analyser is applicable to monitor, instead of the spectrometer and optical detector, if the spectrum analyser is corrected. Besides the diffraction-grating-based and Fabry-Perot interferometer-based optical spectrum analysers, a Michelson interferometer-based spectrum analyser, which outputs the autocorrelation function of the input light signal is also applicable.

5.3 Precautions to be observed

Care should be taken so that the optical output power does not exceed the linearity range of the optical detector.

The optical power sensitivity of the optical detector shall be calibrated over the required wavelength range.

The wavelength resolution and the bandwidth of the spectrometer shall be such that the measurement is carried out with adequate accuracy.

For measurement, light reflected into the laser shall be minimized to ensure that the spectral response is not significantly affected.

The temperature monitoring point should be set at the device being measured as close as possible.

The rate of temperature change has to be set at a constant value throughout measurement, unless the monitoring data are deviated and scattered. The constant rate should be determined under taking the time constant of heat conductance between the active layer and package of device being measured.

5.4 Measurement procedures

The specified current, cw or pulse, is applied to the device being measured.

The wavelength of the spectrometer is adjusted within the required range until the maximum reading on the optical detector has been achieved. The wavelength corresponding to this peak value is recorded. This is the peak-emission wavelength.

The temperature of the device being measured is changed with a constant rate. The peak-emission wavelength is continuously monitored with a constant temperature interval.

The change in the peak-emission wavelength is assumed to be linearly proportional to the temperature of the device being measured.

The slope of the change in the peak-emission wavelength to the temperature is calculated and the temperature dependence of the peak-emission wavelength is obtained. If the relationship is not linear, the calculation has to be performed within the linear range.

The wavelength temperature tuning range is determined and limited by the kink point or the point at which the linear relationship is deviated at the low and high temperature range.

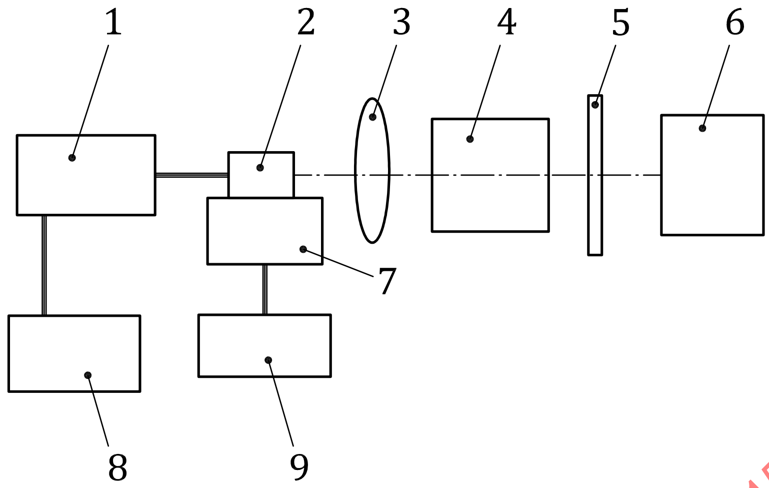
6 Measurement method for current dependence of wavelength

6.1 General

The lasing wavelength of semiconductor lasers is scanned with injected current when they are used for sensing application. The current dependence corresponds to the magnitude of lasing wavelength shift under current control and is a measure of the lasing wavelength change with current. This characteristic is therefore important for semiconductor lasers for sensing. The measurement method for the current dependence is described in 6.2 to 6.4.

6.2 Description of measurement setup and requirements

The measurement setup is depicted in Figure 10.



Key

1 LD driver
2 device (semiconductor laser) being measured
3 lens
4 spectrometer
5 attenuator
6 optical detector
7 thermoelectric cooler
8 controller of LD driver
9 power supply of thermoelectric cooler

Figure 10 — Diagram of measurement setup for current dependence of lasing wavelength

The LD driver supplies current to the semiconductor laser, and if the laser is not capable of operating in continuous wave throughout measurement, supplies pulsed current to the lasers, such as quantum cascade ones.

The spectrometer (spectrophotometer or spectroscope) resolves the spectral components of input light in corresponding to the wavelength by wavelength-tunable optical filter and outputting light of the individual spectral components within a certain wavelength range. The diffraction grating or Fabry-Perot interferometer is used as the tunable optical filter.

The optical spectrum analyser is applicable to monitor, instead of the spectrometer and optical detector, if the spectrum analyser is corrected. Besides the diffraction-grating-based and Fabry-Perot interferometer-based optical spectrum analysers, a Michelson interferometer-based spectrum analyser, which outputs the autocorrelation function of the input light signal is also applicable.

6.3 Precautions to be observed

Care should be taken so that the optical output power does not exceed the linearity range of the optical detector.

The optical sensitivity of the optical detector shall be calibrated over the required wavelength range.

The wavelength resolution and the bandwidth of the spectrometer shall be such that the measurement is carried out with adequate accuracy.

For measurement, light reflected into the semiconductor laser shall be minimized to ensure that the spectral response is not significantly affected.

The temperature monitoring point should be set at the device being measured as close as possible.

The rate of current change has to be set at a constant value throughout measurement, unless the monitoring data are deviated and scattered. The constant rate should be determined under taking the time constant of heat conductance between the active layer and package of device being measured.

6.4 Measurement procedures

6.4.1 Static current dependence

The specified injected current, cw or pulse, is applied to the device being measured.

The specified temperature is set to the device being measured.

The wavelength of the spectrometer is adjusted within the required range until the maximum reading on the optical detector has been achieved. The wavelength corresponding to this peak value is recorded. This is the peak-emission wavelength.

The injected current of the device being measured is changed with a constant rate. The peak-emission wavelength is monitored continuously or with a constant current interval.

The change in the peak-emission wavelength is assumed to be linearly proportional to the magnitude of the injected current of the device being measured.

The slope of the change in the peak-emission wavelength to the magnitude of the injected current is calculated and the current dependence of the peak-emission wavelength is obtained. If the relationship is not linear, the calculation has to be performed within the linear region.

The wavelength current tuning range is determined and limited by the kink point or the point at which the linear relationship is deviated at the small and large magnitude of injected current.

If the laser is not capable of operating in continuous wave near room temperature, the specified pulsed current is set to the device being measured. The current pulse height is changed with a constant pulse width and duty ratio. The other procedures are the same as described above.

6.4.2 Dynamic current coefficient

The specified injected current, cw, is applied to the device being measured.

The specified temperature is set to the device being measured.

An etalon plate or a Fabry-Perot etalon, replacing the spectrometer in Figure 10, is adjusted within the required finesse [free spectral range (FSR)/FWHM of resonance peak]. The optical detector can monitor cavity modes with the finesse.

A small signal current, sinusoidal wave, is biased to the laser under test in addition to the specified current.

The width of the peak deviation is divided with the peak height of injected current, and the dynamic current dependence is calculated in unit of Hz/mA.

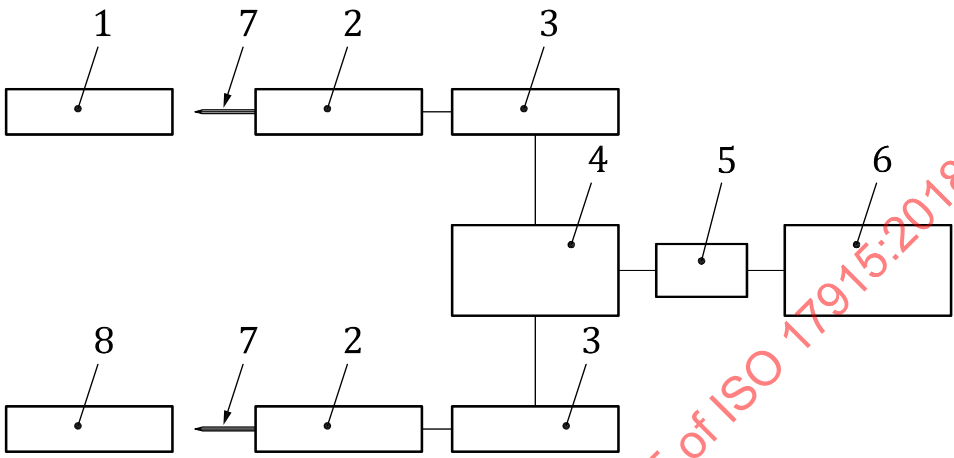
7 Measurement method of spectral line width

7.1 General

Lasing spectral line width is a device characteristic of semiconductor lasers with single mode, and therefore the measurement method is described only for semiconductor lasers operating under continuous wave. The lasing spectral line width is uncritical in most cases of sensing but is important when narrow absorbing lines at low pressure are monitored. If the spectral line width is wider than that of absorption line shapes, the line shape measured is broadened and vague. This characteristic is therefore important for semiconductor lasers for some sensing applications. The measurement method for lasing spectral line width is described in 7.2 to 7.4.

7.2 Description of measurement setup and requirements

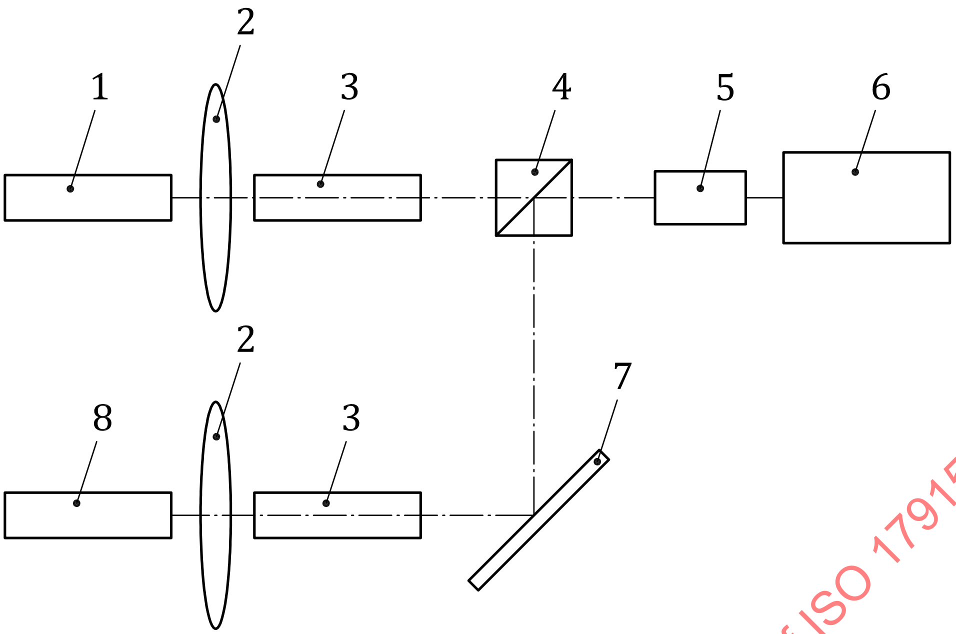
The measurement setup is depicted in Figure 11, Figure 12 and Figure 13.



Key

1 device being measured
2 optical isolator
3 polarization controller
4 single mode fibre coupler
5 optical detector
6 rf spectrum analyser
7 single mode optical fibre
8 local oscillator

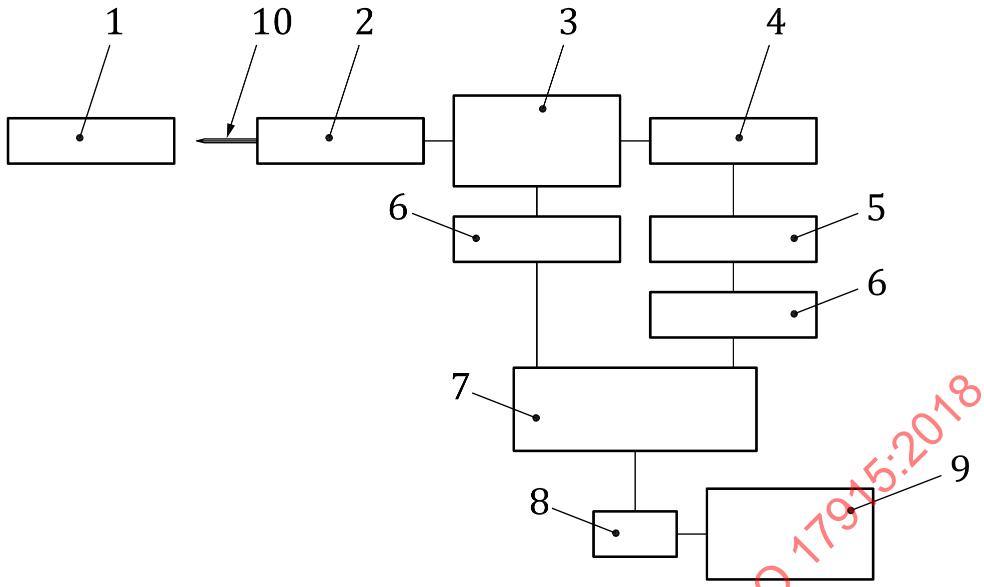
Figure 11 — Lasing spectrum line width measurement system: Optical heterodyne fibre system



Key

1 device being measured
2 lens
3 optical isolator
4 optical beam combiner
5 optical detector
6 rf spectrum analyser
7 mirror
8 local oscillator

Figure 12 — Lasing spectrum line width measurement system: Optical heterodyne system



Key

1 device being measured
2 optical isolator
3 single mode fibre coupler
4 optical fibre for phase delay
5 optical frequency modulator
6 polarization controller
7 single mode fibre coupler
8 optical detector
9 rf spectrum analyser
10 single mode optical fibre

Figure 13 — Lasing spectrum line width measurement system: Self-delayed optical heterodyne fibre system

Three heterodyne systems are depicted: Figure 11 shows a two-laser fibre system, Figure 12 a two laser system without fibre, and Figure 13 a self-delayed system. The systems shown in Figure 11 and 13 are composed of optical fibres; optical output power from semiconductor lasers is coupled into the fibre with lenses, etc. The equipment is connected to each other with the optical fibre. The fibres used here are single mode fibres.

The system depicted in Figure 12 is a beam optic system without fibre. The laser beam emitted from the semiconductor laser is converted to parallel beams with lenses and then passed through the optical components and equipment. In lasers emitting light in the wavelength range of more than 2 µm, the beam optic system is usually used.

The polarization controller is controlling the polarization direction of light transmitted through the fibre and is used for adjusting the polarization condition of the two input beams fed into the fibre coupler.

The optical fibre of phase delay delays the phase of transmitted light. The length of the fibre influences the monitoring resolution.

The optical frequency modulator modulates the frequency of light separated with the fibre coupler and differing the frequency from the light transmitted through the other fibre path for heterodyne detection. An acousto-optical modulator is usually used as the modulator.

7.3 Precautions to be observed

For measurement, light reflected into the semiconductor laser has to be eliminated or suppressed to less than −50 dB at least by using an optical isolator because spectral line width is strongly affected from the back-reflected light. In addition, anti-reflecting film should be coated on all optical parts indicated in Figure 10 to reduce the back-reflection.

If the setup is built with single mode optical fibres, the back-reflection at the connection point between fibres has to be suppressed to less than −50 dB by using suitable fibres.

The electrical source driving the semiconductor lasers has to be low noise to eliminate its influence on the spectral line width. For instance, a battery cell is favourable.

The optical isolation of the isolator has to be set at the value of less than −50 dB.

The spectral response of the optical detector should be calibrated.

The rf spectral analyser should be corrected.

The beat frequency of both semiconductor lasers or the frequency of the optical modulator should be relatively high to eliminate the influence of 1/f noise.

7.4 Measurement procedures

7.4.1 System employing two semiconductor lasers [shown in Figures 11 and 12]

The specified injected current is applied to the device being measured.

The specified temperature is set to the device being measured.

The specified wavelength is set to the device being measured, and the wavelength of the local oscillator is set at a required value which determines the beat frequency.

The frequency range of the rf spectrum analyser is adjusted within the required range for monitoring the beat frequency.

The polarization is controlled by the polarization controller so that the peak value of the beat signal on the rf spectrum analyser is the maximum in the case of a fibre system [Figure 11].

If the beam system is used [Figure 12], the polarization of both semiconductor lasers has to be adjusted.

The spectral line width is read on the rf spectrum analyser at 3 dB-down point or other values such as 20 dB-down point and calculated. Here, the spectral line width monitored on the rf spectrum analyser is the sum of the line width of both semiconductor lasers under consumption of Lorentzian line shapes.

Here, when the lasing wavelength of both semiconductor lasers is coincided with each other, this technique is called homodyne detection technique. The monitoring procedure is similar to that of the heterodyne technique. In this case, the beat spectrum is observed at 0 Hz and the spectral line width is directly obtained.

7.4.2 Self-delayed heterodyne [shown in Figure 13]

The specified injected current is applied to the device being measured.

The specified temperature is set to the device being measured.

The specified wavelength is set to the device being measured.

The frequency range of the rf spectrum analyser is adjusted within the required range for monitoring the beat frequency.

The light frequency modulation is performed with the optical frequency modulator.

The beat spectrum on the rf spectrum analyser is confirmed to appear at the modulation frequency.

The polarization is controlled by the polarization controller so that the peak value of the beat signal on the rf spectrum analyser is the maximum.

If a beam system without optical fibre is used, the polarization of the semiconductor laser has to be adjusted.

The spectral line width is read on the rf spectrum analyser at 3 dB-down point or other values such as 20 dB-down point and calculated. Here, the spectral line width monitored on the rf spectrum analyser is twice of the true value under consumption of a Lorentzian line shape.

Here, when the lasing wavelength of both semiconductor lasers is coincided with each other, this technique is called self-delayed homodyne detection technique, although the influence of 1/f noise is large. If the fibre system is employed, the optical modulator is omitted. The monitoring procedure is, however, the manner similar to those of heterodyne technique, although the beat spectrum is observed at 0 Hz and the spectral line width is obtained.

Annex A
(informative)

Essential ratings and characteristics

A.1 General

Device characteristics of semiconductor lasers are complicated, and many kinds of electrical and optical characteristics are explained in this document. Some examples of absolute maximum ratings, essential ratings and characteristics are, therefore, given for semiconductor lasers installed in Transistor Outline-(TO)-can packages and fibre-pigtail modules in Annex A.

A.2 Symbols (and abbreviated terms)

Table A.1 lists symbols (and abbreviated terms) and units which are used in A.3 and A.4

Table A.1 — Symbols (and abbreviated terms)

Symbol	Unit	Term
ϕ_e	W	radiant power
η_e	W/A	radiant power efficiency
η_{ed}, η_d	W/A	differential radiant power efficiency
η_s	W/A	slope efficiency
I_{th}	A	threshold current
$L_{\phi e}$	%	linearity (in current – radiant power relation)
λ_{air}	m	wavelength in air
$P_\lambda(\lambda)$	W/m	spectral radiant power distribution
ΔP_t	W	Radiant power variation across wavelength (frequency) tuning range [a]
λ_p	m	peak-emission wavelength
$\bar{\lambda}$	m	central wavelength
$\Delta\lambda$	m	spectral radiation bandwidth
$\Delta\lambda_{rms}$	m	rms spectral bandwidth
$\Delta\lambda_L$ or $\Delta\nu_L$	m or Hz	spectral line width FWHM
S_{msp}	m	mode spacing
N_m		number of longitudinal modes
SMS	dB	side mode suppression ratio
$\Delta\lambda_c$	m	spectral shift
$\delta\lambda_T$	m/K	temperature dependence of wavelength

[a] radiant power change over the defined temperature or current tuning range.

$\Delta P_t = P_{e1} - P_{e2}$,

here P_{e1} and P_{e2} is the end and the opposite end of the tuning range, respectively.

[b] maximum range of wavelength in which the ratio of wavelength to current or temperature is kept constant.

[c] required time at which the shift of lasing wavelength becomes constant or within a defined value just after changing in current or temperature.

Table A.1 *(continued)*

Symbol	Unit	Term
$\delta\lambda_c$	m/A	current dependence of wavelength
$\Delta\lambda_{tr}$	m	wavelength tuning range [b]
$\Delta\lambda_{tt}$	s	wavelength tuning time [c]
$R(f)$ or RIN	dB	relative intensity noise (RIN)
C/N	dB	carrier-to-noise ratio
$t_{d(on)}$	s	turn-on delay time
t_r	s	rise time
t_{on}	s	turn-on time
$t_{d(off)}$	s	turn-off delay time
t_f	s	fall time
t_{off}	s	turn-off time
f_c	Hz	cut-off (modulation) frequency

[a] radiant power change over the defined temperature or current tuning range.

$\Delta P_t = P_{e1} - P_{e2}$,

here P_{e1} and P_{e2} is the end and the opposite end of the tuning range, respectively.

[b] maximum range of wavelength in which the ratio of wavelength to current or temperature is kept constant.

[c] required time at which the shift of lasing wavelength becomes constant or within a defined value just after changing in current or temperature.

A.3 Essential ratings and characteristics of TO can laser devices

A.3.1 Type

The TO can laser device consists of the following basic parts:

— semiconductor laser;

— monitor photodiode (option).

A.3.2 Semiconductor material

The semiconductor materials used are:

— for the semiconductor lasers: InP, GaAs, InGaAs, InAlAs, InGaAsP, etc., and

— for the monitor photodiodes (option): Ge, Si, InGaAs, etc.

A.3.3 Structure

The structures employed are:

— in the semiconductor laser: Fabry Perot, Distributed feedback (DFB), buried heterostructure (BH), ridge waveguide, vertical cavity surface emitting (VCSEL), quantum well (QW), Multiple QW (MQW), strained MQW, quantum cascade, etc.;

— and in the monitor photodiode (option): pin photodiode (pin PD), avalanche photodiode (APD), etc.

A.3.4 Details of outline and encapsulation

A.3.4.1 ISO and/or IEC and/or national reference number of the outline drawing.

A.3.4.2 Method of encapsulation: glass/metal/plastic/other.

A.3.4.3 Terminal identification.

A.3.5 Limiting values (absolute maximum system) over the operating temperature range, unless otherwise stated

Tables A.2, A.3 and A.4 list characteristics and requirements of limiting values for general conditions, semiconductor lasers and monitor photodiodes, respectively.

Table A.2 — Characteristics and requirements of the limiting values — General conditions

Ref.	Characteristics	Symbol	Requirements		Unit
			Min.	Max.	
A.3.5.1	Storage temperature	T_{stg}	x	x	°C
A.3.5.2	Operating temperature	T_{case}	x	x	°C
A.3.5.3	Soldering temperature: (at specified soldering time and minimum distance to case	T_{sld}		x	°C

Table A.3 — Characteristics and requirements of the limiting values — Semiconductor laser

Ref.	Characteristics	Symbol	Requirements		Unit
			Min.	Max.	
A.3.5.4	Reverse voltage	V_R		x	V
A.3.5.5	Forward current	I_F		x	A
A.3.5.6	CW radiant output power at optical port	ϕ_e		x	W
A.3.5.7	Maximum radiant output power at specified pulse width and duty cycle	ϕ_{ep}		x	W
A.3.5.8	ESD-Voltage (both polarities) Human Body model	V_{ESD}		x	V

Table A.4 — Characteristics and requirements of the limiting values — Monitor photodiode (option)

Ref.	Characteristics	Symbol	Requirements		Unit
			Min.	Max.	
A.3.5.9	Reverse voltage	V_{mR}		x	V
A.3.5.10	Forward current	I_{mF}		x	A
A.3.5.11	ESD-Voltage (both polarities) Human Body model	V_{mESD}		x	V

A.3.6 Electrical and optical characteristics

Tables A.5 and A.6 list static electrical and optical characteristics of semiconductor lasers and optional monitor photodiodes, respectively. Table A.7 lists dynamic electrical and optical characteristics of semiconductor lasers. Table A.8 lists electrical and optical characteristics of semiconductor lasers and optional monitor photodiodes which should be specified over the operating temperature range.