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

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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.

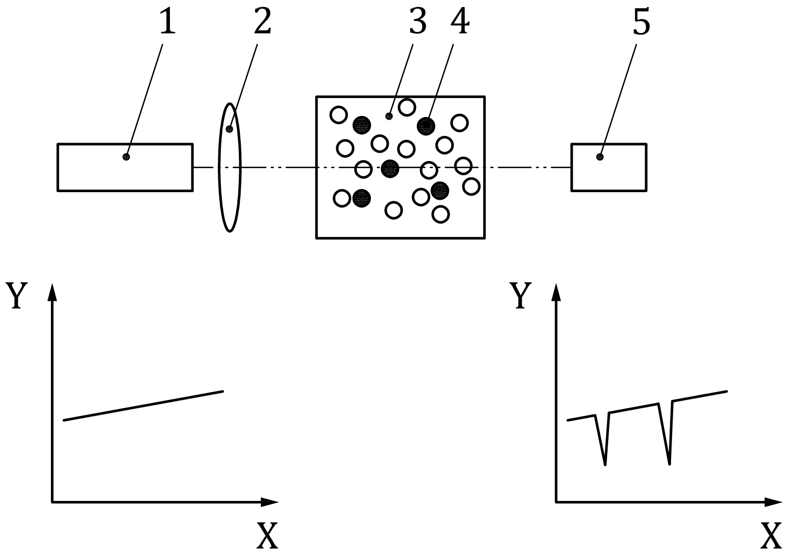
4.3 Common sensing technique and equipment using semiconductor lasers

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.



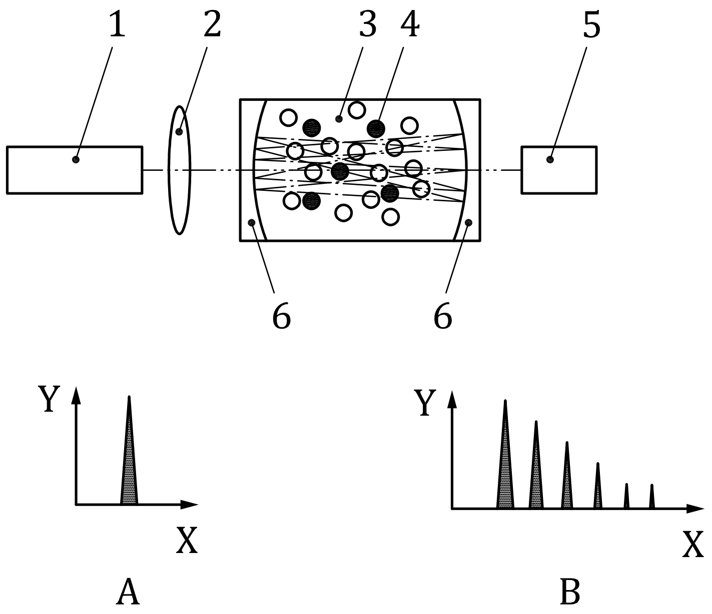
Key

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.



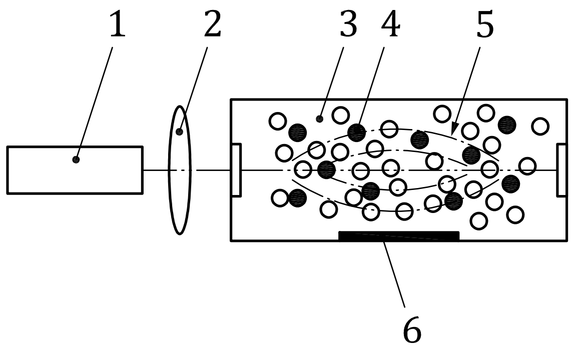
Key

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.