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# TECHNICAL REPORT

colour inside



## Optical amplifiers –
## Part 9: Semiconductor optical amplifiers (SOAs)



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## Part 9: Semiconductor optical amplifiers (SOAs)



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

# OPTICAL AMPLIFIERS –

## Part 9: Semiconductor optical amplifiers (SOAs)

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IEC TR 61292-9, which is a technical report, has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

This second edition cancels and replaces the first edition published in 2013. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) addition of new terms;
b) clarification of noise figure definition.

The text of this technical report is based on the following documents:

| Draft TR | Report on voting |
|---|---|
| 86C/1465/DTR | 86C/1481/RVDTR |

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 61292 series, published under the general title *Optical amplifiers*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.



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# INTRODUCTION

Optical amplifiers (OAs) are necessary components as booster, line and pre-amplifiers for current optical network systems. IEC TC 86/SC 86C has published many standards for OAs, and most of them are focused on optical fibre amplifiers (OFAs), which are commonly deployed in commercial optical network systems. Recently, semiconductor optical amplifiers (SOAs) have attracted attention for applications in gigabit passive optical network (GPON) and 100 Gbit Ethernet (GbE) systems. This is because SOA chips are as small as laser diodes (LDs) and only require an electrical current.

Although SOAs for the 1 310 nm or 1 550 nm bands have been extensively studied since the 1980s, the use of SOAs is still limited to laboratories or field trials. This is due to specific performance features of SOAs such as gain ripple and polarization dependent gain (PDG). Thus, there are very few IEC standards addressing SOAs. One example is IEC TR 61292-3, which is a technical report for classification, characteristics and applications of OAs including SOAs. However, it only deals with general information on SOAs and does not contain the detail information on test methods that are necessary to measure precisely the particular parameters of SOAs.

This part of IEC 61292 provides a better understanding of specific features of SOAs as well as information on measuring gain and PDG. It is anticipated that future standards will address performance and test methodology.

# OPTICAL AMPLIFIERS –

# Part 9: Semiconductor optical amplifiers (SOAs)

## 1 Scope

This part of IEC 61292, which is a Technical Report, focuses on semiconductor optical amplifiers (SOAs), especially the specific features and measurement of gain and polarization dependent gain (PDG).

In this document, only the amplifying application of SOAs is described.

Other applications, such as modulation, switching and non-linear functions, are not covered.

Potential applications of SOAs, however, such as reflective SOAs (RSOAs) for the seeded wavelength division multiplexing passive optical network (WDM-PON), are briefly reviewed in Annex A.

## 2 Normative references



There are no normative references in this document.

## 3 Terms, definitions, abbreviated terms and symbols



### 3.1 Terms and definitions

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

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

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

**3.1.1**
**SOA**
semiconductor optical amplifier that includes the "SOA chip" and the "SOA module"

**3.1.2**
**SOA chip**
semiconductor chip that is the active component of the SOA module

**3.1.3**
**SOA module**
fibre-pigtailed optical component that consists of the SOA chip, lenses, optical isolators (if necessary), a thermoelectric cooler (TEC), a thermistor, a package, and fibres

**3.1.4**
**population inversion factor**
$n_{sp}$
ratio of the injected carrier density $N$ to the subtraction of the carrier density $N_0$ where the stimulated emission is equal to the stimulated absorption from $N$

$$n_{sp} = \frac{N}{N - N_0}$$

Note 1 to entry: In the semiconductor optical amplifier (SOA) field, the population inversion factor is composed of not only carrier density parameters but also combination of the confinement factor $\Gamma$, the optical gain $g$, and internal optical losses $\alpha$ of the optical waveguide of SOA chip. It is defined as:

$$n_{sp} = \frac{N}{N - N_0} \times \frac{\Gamma g}{\Gamma g - \alpha}$$

Note 2 to entry: The carrier density $N_0$ where the stimulated emission is equal to the stimulated absorption may be called "transparent carrier density".

## 3.2 Abbreviated terms

| | |
|---|---|
| AR | anti-reflection |
| ASE | amplified spontaneous emission |
| BPF | band pass filter |
| CFP | 100G form factor pluggable |
| CW | continuous wave |
| DEMUX | demultiplexer |
| DFB | distributed feedback |
| EDFA | erbium-doped fibre amplifier |
| FWM | four-wave mixing |
| GbE | gigabit Ethernet |
| GPON | gigabit capable passive optical network |
| LD | laser diode |
| MSA | multi-source agreement |
| MMI | multi-mode interference |
| MQWs | multiple quantum wells |
| NF | noise figure |
| OA | optical amplifier |
| OFA | optical fibre amplifier |
| OLT | optical line termination |
| ONU | optical network unit |
| OPM | optical power meter |
| PC | polarization controller |
| PD | photodiode |
| PDCE | polarization dependence of coupling efficiency |
| PDG | polarization dependent gain |
| PIC | photonic integrated circuit |
| POL | polarizer |
| PON | passive optical network |

| | |
|---|---|
| RSOA | reflective semiconductor optical amplifier |
| SLD | superluminescent diode |
| SMF | single mode fibre |
| SOA | semiconductor optical amplifier |
| TE | transverse electric |
| TEC | thermoelectric cooler |
| TIA | transimpedance amplifier |
| TM | transverse magnetic |
| VOA | variable optical attenuator |
| WDM | wavelength division multiplexing |
| XGM | cross gain modulation |
| XPM | cross phase modulation |

### 3.3 Symbols

| | |
|---|---|
| $G$ | optical gain |
| $I_{\mathrm{F}}$ | forward current |
| $\Gamma_{\mathrm{TE}}$ | TE mode confinement factor |
| $\Gamma_{\mathrm{TM}}$ | TM mode confinement factor |
| $L$ | chip length |
| $n_{\mathrm{eff}}$ | effective refractive index |
| $NF$ | noise figure |
| $n_{\mathrm{sp}}$ | population inversion factor |
| $\lambda$ | wavelength |
| $\Delta\lambda_{\mathrm{ripple}}$ | period of gain ripple |
| $PDCE$ | polarization dependence of coupling efficiency |
| $PDG_{\mathrm{active}}$ | polarization dependence of active layer gain |
| $PDG_{\mathrm{total}}$ | total polarization dependence of single pass gain |
| $R$ | reflectivity |
| $\Delta G_{\mathrm{ripple}}$ | peak to peak amplitude of gain ripple |



## 4 Specific features of SOAs

### 4.1 SOA chips

Figure 1 shows the schematic diagram of the SOA chip. Similar to LDs, SOA chips are less than 1,5 mm, 0,5 mm, and 0,2 mm in length, width and height, respectively. Since SOA chips are made of III-V compound semiconductor materials and developed based on the technologies used for LDs, the basic physical mechanisms of SOA chips are the same as those of LDs. Therefore, the population inversion inside the SOA chip is implemented by a forward current ($I_{\mathrm{F}}$), and the input optical signals are amplified by the stimulated emission of photons in the active layer of the chip. The cross section of the typical active layer is 1,5 μm and 0,1 μm in width and thickness (height), respectively.