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TECHNICAL REPORT

colour inside

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



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CONTENTS

FOREWORD 4
INTRODUCTION 6
1 Scope 7
2 Normative references 7
3 Terms, definitions, abbreviated terms and symbols 7
3.1 Terms and definitions 7
3.2 Abbreviated terms 8
3.3 Symbols 9
4 Specific features of SOAs 9
4.1 SOA chips 9
4.2 Gain ripple 12
4.2.1 General 12
4.2.2 Theoretical calculation of gain ripple 14
4.3 Polarization dependent gain (PDG) 17
4.3.1 General 17
4.3.2 Polarization insensitive SOAs 17
4.4 Noise figure (NF) 18
4.5 Lifetime of carriers 18
4.6 Nonlinear effects 18
5 Measurement of SOA output power and PDG 18
5.1 Narrow-band versus broadband light source 18
5.2 Examples of measurement results 19
Annex A (informative) Applications of SOAs 23
A.1 General 23
A.2 Polarization mode of SOAs 23
A.3 Reach extender for GPON 23
A.4 Pre-amplifier in transceivers for 100 Gbit Ethernet 23
A.5 Monolithic integration of SOAs 24
A.6 Reflective SOAs (RSOAs) 25
Bibliography 26

Figure 1 – Schematic diagram of the typical SOA chip 10
Figure 2 – Example of gain dependency of an SOA chip on forward current 10
Figure 3 – Schematic top view of a typical SOA chip with and without an angled waveguide structure 11
Figure 4 – Schematic top view of a typical SOA module 12
Figure 5 – Schematic diagram of the optical feedback inside the SOA chip 13
Figure 6 – Schematic diagram of gain ripple 13
Figure 7 – Illustrated model of a Fabry-Perot type SOA 14
Figure 8 – Illustrated model of ASE output from an SOA 15
Figure 9 – SOA output power and PDG dependence on wavelength 19
Figure 10 – Optical power spectra of three different SOA chips 20
Figure 11 – Output power and PDG of SOA chip sample 1 as a function of I_F 21
Figure 12 – Output power and PDG of SOA chip sample 2 as a function of I_F 21

Figure 13 – Output power and PDG of SOA chip sample 3 as a function of I_F 22
Figure A.1 – Schematic diagram of the receiver section of SOA-incorporated CFP transceivers 24
Figure A.2 – Schematic diagram of the DFB-LDs-array type wavelength tuneable LD 25
Figure A.3 – Schematic diagram of a seeded WDM-PON system 25

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OPTICAL AMPLIFIERS –

Part 9: Semiconductor optical amplifiers (SOAs)

FOREWORD

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

This third edition cancels and replaces the second edition published in 2017. This edition constitutes a technical revision.

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

a) revised definitions for SOAs in 3.1;
b) added more theoretical background on gain ripple measurements using amplified spontaneous emission (ASE) spectrum in 4.3;
c) removed the formerly preferred set-up for output power and PDG measurements in Clause 5.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
86C/1820/DTR	86C/1830/RVDTR

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

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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 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.

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INTRODUCTION

Optical amplifiers (OAs) are essential components for fibre optic communication systems, where they serve as booster amplifiers, in-line amplifiers, and pre-amplifiers. Numerous standards have been published for OAs (e.g., the IEC 61290 series and IEC 61291 series). However, most of these standards focus on optical fibre amplifiers (OFAs) because these are commonly deployed in commercial fibre optic networks. Recently, semiconductor optical amplifiers (SOAs) have attracted attention for applications in Gbit passive optical networks (GPONs) and Gbit Ethernet (GbE) systems, which operate at line rates of 100 Gbit/s and beyond. SOA chips are as small as laser diodes (LDs) and are directly driven by an electrical current.

Although SOAs operating in the 1 310 nm or 1 550 nm wavelength bands have been extensively studied since the 1980s, SOAs have mostly been used in laboratories or in field trials. This is due to certain performance limitations of SOAs, such as gain ripple and polarization dependent gain (PDG). As a result, there are few IEC documents addressing SOAs. One exception is IEC TR 61292-3, which is a Technical Report on classification, characteristics, and applications of OAs including SOAs. However, IEC TR 61292-3 presents only general information on SOAs and does not contain detailed information on test methods for measuring the particular performance parameters of SOAs.

IEC 61290-1-1:2020 describes test methods for power and gain parameters of OAs, which includes a method for gain ripple measurements on SOAs. This document has been revised to harmonize its content with IEC 61290-1-1 and with IEC 61291-2.

This document provides more detailed descriptions of the specific features of SOAs, including information on gain ripple and PDG.

OPTICAL AMPLIFIERS –

Part 9: Semiconductor optical amplifiers (SOAs)

1 Scope

This part of IEC 61292, which is a Technical Report, describes the characteristic features of semiconductor optical amplifiers (SOAs), including the specific features of gain ripple and polarization dependent gain (PDG).

This document focuses on amplifying applications of SOAs. Other applications, such as modulation, switching and non-linear functions, are not covered.

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

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.

IEC 61291-1:2018, *Optical amplifiers – Part 1: Generic specification*

IEC 61291-2:2016, *Optical amplifiers – Part 2: Single channel applications – Performance specification template*

3 Terms, definitions, abbreviated terms and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61291-1:2018, IEC 61291-2:2016, and the following 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
optical amplifier in which the active optical waveguide is formed by a semiconductor laser diode structure, which is electrically pumped

Note 1 to entry: SOAs have a similar structure to Fabry-Perot semiconductor laser diodes but with anti-reflection elements at the end surfaces. The optical signal is amplified through the stimulated emission phenomenon in the gain medium.

[SOURCE: IEC 61291-2:2016, 3.1.3, modified – Note 1 to entry has been added.]

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 optical fibre(s)

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 Γ, the optical gain g, and internal optical losses α of the optical waveguide of SOA chip. It is defined as:

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

Note 2 to entry: The carrier density N_0 at which the stimulated emission is equal to the stimulated absorption is often called "transparent carrier density".

3.2 Abbreviated terms

AR	anti-reflection
ASE	amplified spontaneous emission
BPF	band pass filter
CFP	100 G 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

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
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_F forward current
L chip length
n_{eff} effective refractive index
n_{sp} population inversion factor
PDG_{active} polarization dependence of active layer gain
PDG_{total} total polarization dependence of single pass gain
R reflectivity
ΔG_{ripple} peak to peak amplitude of gain ripple
$\Delta\lambda_{ripple}$ period of gain ripple
Γ_{TE} TE mode confinement factor
Γ_{TM} TM mode confinement factor
λ wavelength

4 Specific features of SOAs

4.1 SOA chips

Figure 1 shows the schematic diagram of a typical SOA chip. Similar to LDs, SOA chips are less than 1,5 mm in length, 0,5 mm in width, and 0,2 mm in height. Since SOA chips are made of III-V compound semiconductor materials and developed based on the technologies used for laser diodes (LDs), the basic physical mechanisms of generating optical gain in SOA chips are the same as those in LDs. Therefore, the population inversion inside the SOA chip is implemented by a forward current (I_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 a typical active layer is 1,5 µm in width and 0,1 µm in thickness (height).