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Optical amplifiers

Part 9: Semiconductor optical amplifiers (SOAs)

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

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

OPTICAL AMPLIFIERS –

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FOREWORD

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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.

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

Enquiry draft	Report on voting
86C/1148/DTR	86C/1183/RVC

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 publication 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.

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- withdrawn,
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INTRODUCTION

Optical amplifiers (OAs) are necessary components as booster, line and pre-amplifiers for current optical network systems. IEC TC86/SC86C, 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 technical report 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

IEC/TR 61292-9, which is a technical report, focuses on SOAs, especially the specific features and measurement of gain and PDG.

In this report, 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 Terms, definitions, abbreviations and symbols

2.1 Terms and definitions

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

2.1.1
SOA
generic term that includes the “SOA chip” and the “SOA module”

2.1.2
SOA chip
semiconductor chip which is the active component of the SOA module

2.1.3
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

2.2 Abbreviations

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

2.3 Symbols

G	optical gain
I_{F}	forward current
T_{TE}	TE mode confinement factor
T_{TM}	TM mode confinement factor
L	chip length
n_{eff}	effective refractive index
NF	noise figure
n_{sp}	spontaneous emission factor
λ	wavelength
$\Delta\lambda_{\mathrm{ripple}}$	period of gain ripple
$PDCE$	polarization dependence of coupling efficiency
PDG_{active}	polarization dependence of active layer gain
PDG_{total}	total polarization dependence of single pass gain

R	reflectivity
Ripple	peak to peak amplitude of gain ripple

3 Specific features of SOAs

3.1 SOA chips

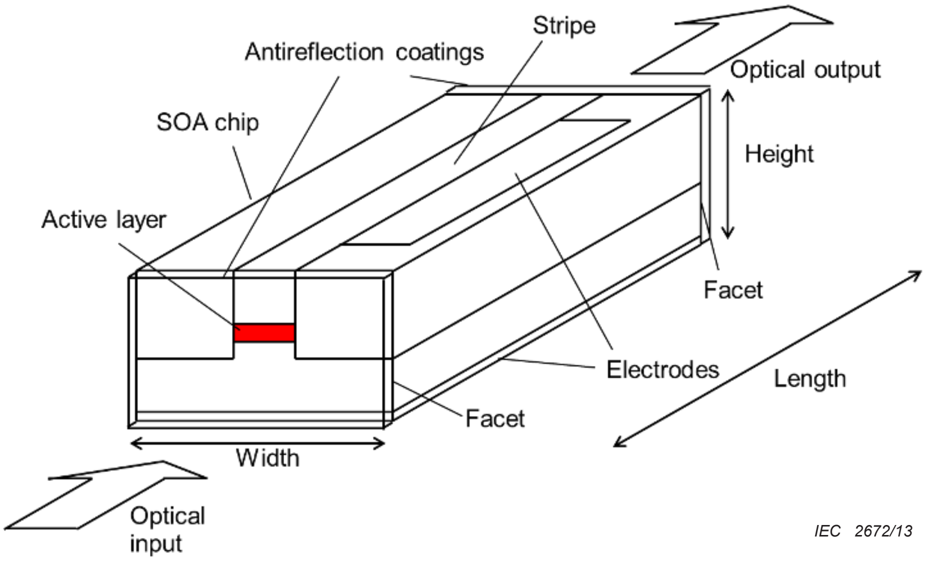


Figure 1 – Schematic diagram of the typical SOA chip

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_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.

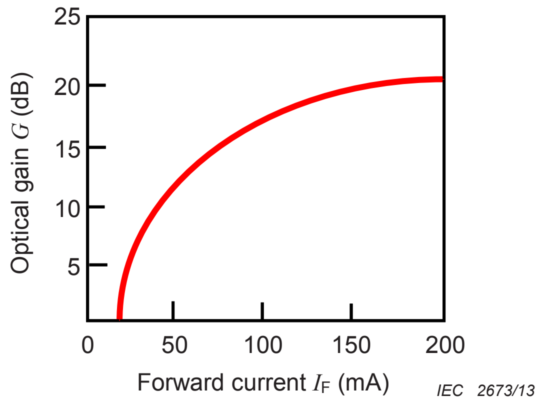


Figure 2 – Example of gain dependency on forward current of the SOA chip

Figure 2 shows the gain dependency on I_F, which is injected into electrodes at the top and bottom of the SOA chip as shown in Figure 1. The gain of the SOA chip is obtained and adjusted by simply applying the current. As shown in Figure 2, by increasing the I_F to greater than 150 mA, typical SOA chips can provide optical gain of greater than 20 dB with an input optical power of around –20 dBm.

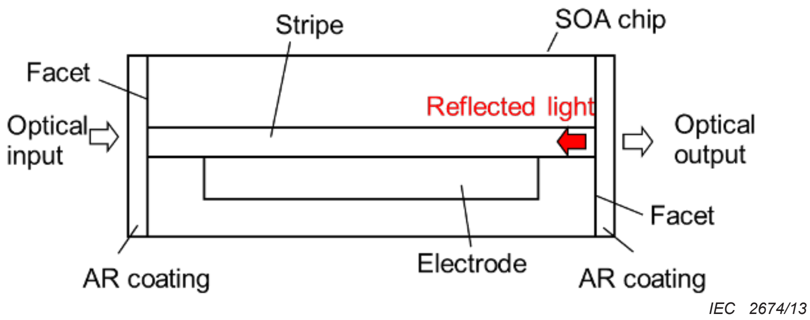


Figure 3a – Schematic top view of the conventional SOA chip

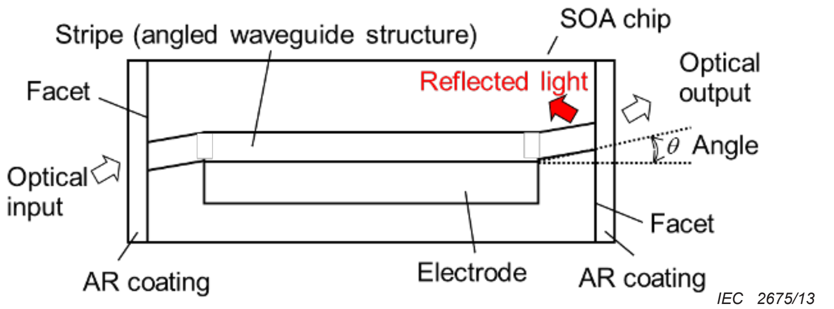


Figure 3b – Schematic top view of the SOA chip with angled waveguide structure

Figure 3 – Schematic top view of a typical SOA chip with and without an angled waveguide structure

Compared with LDs, the most distinctive feature of SOAs is that the SOA chip has an anti-reflection (AR) coating on both facets to avoid optical feedback between the facets. Since the semiconductor materials have a much higher refractive index (>3 is typical) than air, the facet has a reflectivity of 30 % or above. This feature is suitable for establishing a laser cavity but not for the SOA chip which requires facet reflectivity of less than 0,1 % over a wavelength range of greater than 30 nm. To achieve such a low reflectivity, AR coating is employed on both facets of the SOA chips as shown in Figure 3. Figures 3a and 3b show schematic top views of the conventional SOA chip and the SOA chip with an angled waveguide structure, respectively. As shown in Figure 3a, a conventional SOA chip has a straight stripe, which is normal to both facets where AR coating is applied. The AR coating consists of a multiple-layer thin film. Each thickness (a quarter wavelength, for example) of the film is controlled within ±4 %. The residual reflectivity will cause intra-cavity interference between the facets, which leads to gain ripple or laser oscillation. This is because the reflected light is easily coupled with the multiple reflections between the facets, since the angle (θ) between the stripe and the facet is 90°. One of the best ways to suppress intra-cavity feedback is the introduction of an angled waveguide structure. As shown in Figure 3b, the reflected light cannot be coupled by multiple reflection when using the angled stripe with $\theta = 7°$. This approach enables the SOA chip to have a low facet reflectivity of 0,2 %, and less than 0,1 % when combined with AR coating.

One of the other specific features of SOAs is that the gain-bandwidth of SOA chips can be varied by only changing the composition of the semiconductor materials using mature LD technologies (the band engineering technique). For example, long-wavelength (1 300 nm to 1 600 nm) SOA chips have an InGaAsP active layer on an InP substrate, and the peak wavelength of the gain is adjusted by changing the respective concentrations of In, Ga, As and P in InGaAsP. The typical gain bandwidth of SOA chips is greater than 40 nm.

Another specific feature of SOA chips is their integration with other semiconductor devices such as tuneable LDs, electro-absorption modulators and passive waveguides on a single chip. The integrated SOAs are used, for example, as booster amplifiers in tuneable LDs and line amplifiers (loss compensators) in photonic integrated circuits (PICs).

In summary, SOAs have completely different physical mechanisms for amplification and for the configuration of the device compared to OFAs.

3.2 SOA modules

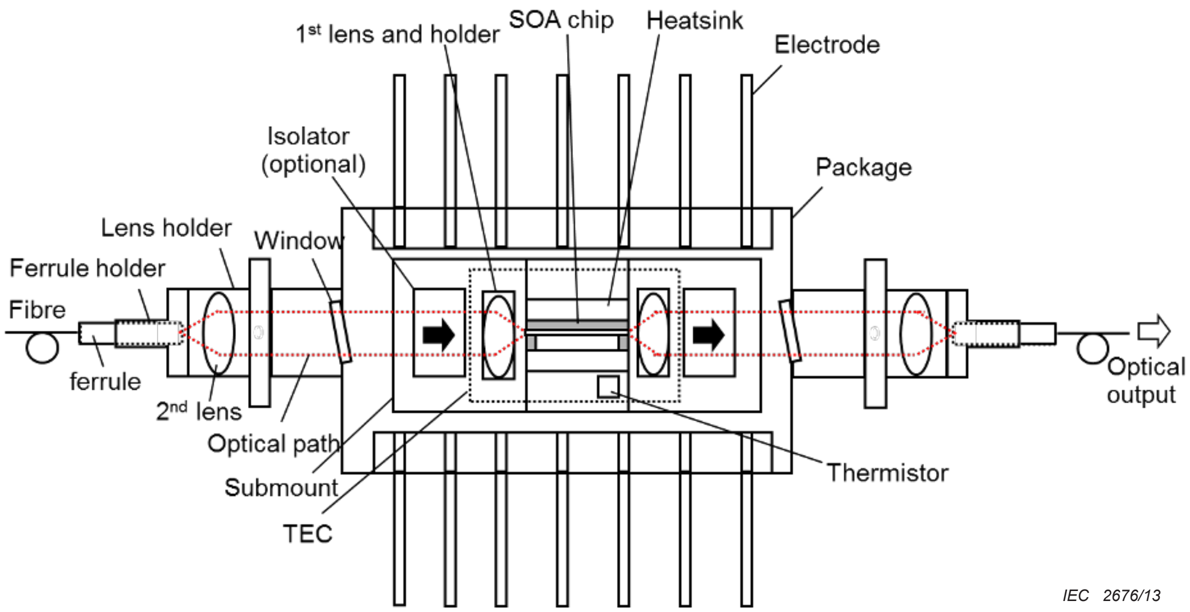


Figure 4 – Schematic top view of the typical SOA module

Figure 4 shows the schematic top view of the SOA module. An SOA chip, a TEC and optical lenses may be assembled in a butterfly package which has fibre pigtails for the input and output ports. This is the most common package for SOA modules and its size is almost the same as that of 14-pin butterfly LD modules. The use of optical isolators (input and/or output) may depend on the application. For example, optical isolators are not employed in SOA modules for bidirectional amplification. The TEC is used to stabilize the case (package) since more than 100 mA of electric current injected into the SOA chip will cause heat inside the chip to affect polarization characteristics. Similar to LD modules, SOA modules are also hermetically sealed with N_2 gas.

3.3 Gain ripple

Optical feedback inside the SOA chip, which is the residual reflections from the chip facets, may lead to round-trip resonances when an input optical signal is launched into the chip, as shown in Figure 5.

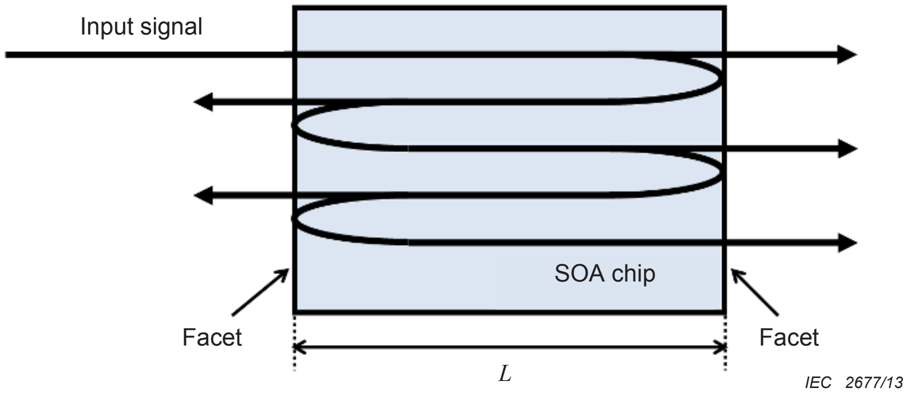


Figure 5 – Schematic diagram of the optical feedback inside the SOA chip

The round-trip paths will interfere constructively or destructively depending on the wavelength of the signal light. This gain dependence on the wavelength is called gain ripple, as shown in Figure 6.

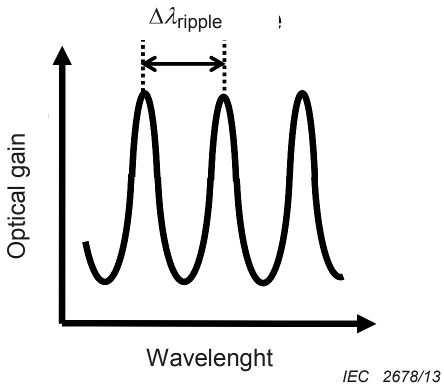


Figure 6 – Schematic diagram of gain ripple

With a chip gain G and facet reflectivity R, the peak to peak amplitude of the gain ripple $Ripple$ is shown as Equation (1).

$$Ripple = \frac{(1+G\times R)^2}{(1-G\times R)^2} \tag{1}$$

With a signal wavelength λ, chip length L, and effective refractive index n_{eff}, the period of the gain ripple $\Delta\lambda_{\mathrm{ripple}}$ is defined as Equation (2).

$$\Delta\lambda_{ripple} = \frac{\lambda^2}{2n_{eff}L} \tag{2}$$

For example, the SOA chip with n_{eff} = 3,4, L = 1,2 mm, and λ = 1 550 nm has the $\Delta\lambda_{\mathrm{ripple}}$ of 0,29 nm, approximately. Since the SOA chip has the birefringence between the parallel transverse electric (TE) and orthogonal transverse magnetic (TM) directions to the chip substrate, $\Delta\lambda_{\mathrm{ripple}}$ depends on the polarization mode of the input light.

3.4 Polarization dependent gain (PDG)

3.4.1 General

The PDG of the SOA chips is mainly caused by the difference of confinement factors between the TE and TM modes. Generally, the cross-section of the active layer has an anisotropic structure because the thickness of the active layer (e.g. 0,1 μm) is smaller than its width (e.g. 1,5 μm). This results in larger TE mode confinement factor (Γ_{TE}) than the TM mode confinement factor (Γ_{TM}), which means the TE mode gain will be larger.

PDG is one of the most significant characteristics of SOA modules. The total polarization dependence of single pass gain (PDG_{total}) in SOA modules is known to be the sum of the polarization dependence of the active layer gain (PDG_{active}) in SOA chips and the polarization dependence of the coupling efficiency (PDCE) between a fibre and a facet at both input and output ports in SOA modules.

In general, SOA chips have an elliptical mode field, so the PDCE will not be zero. Therefore, unless a specific design is implemented for the PDCE, SOA modules might have a certain amount of PDG_{total} even if the PDG_{active} is zero.

3.4.2 Polarization insensitive SOAs

3.4.2.1 General

As described in 4.3.1, the polarization sensitivity of SOA chips is mainly caused by the difference between the Γ_{TE} and Γ_{TM}. To achieve the polarization insensitivity, decreasing or compensation of the difference will be needed. It has been reported that the following techniques lead to a PDG_{total} of less than 0,5 dB.

3.4.2.2 Bulk active layer with square cross-waveguide structure

To reduce the difference between Γ_{TE} and Γ_{TM}, the thickness of the bulk active layer of the SOA chip is increased to obtain the isotropic cross-section waveguide structure in the active layer. This structure enables SOA chips to have not only low PDG_{active} but also low PDCE. However, the isotropic waveguide structure results in a high total confinement factor, which leads to a low saturation output power. The saturation output power is defined as the output power at which the gain decreases by 3 dB from the linear regime.

3.4.2.3 Active layer with strained multiple quantum wells (MQWs)

To compensate for the difference in Γ_{TE} and Γ_{TM}, the TM gain coefficients will be controlled by using strained MQWs in the active layer. The introduction of tensile strained MQWs into the active layer leads to a higher TM gain coefficient than the TE gain coefficient. This technique enables SOA chips to have an overall reduction in the PDG_{total}. Since the total confinement factor of this structure is smaller than that in an isotropic bulk active layer, the saturation output power is higher compared with SOA chips with isotropic bulk active layer.

3.5 Noise figure (NF)

Generally, the noise figure (NF) of SOAs depends on the spontaneous emission factor, n_{sp} and the coupling efficiency between the input fibre and the SOA. If n_{sp} = 1 and the coupling efficiency is 100 %, $NF = 2n_{sp}$ = 2 dB or 3 dB in the ideal case. The n_{sp} of practical SOA chips is more than unity because of the incomplete population inversion and the internal optical loss. In addition, the optical coupling between the SOA chip facet and fibre is achieved by using a two-lens system, which leads to the optical coupling loss of typically a few decibels at both facets because of the anisotropic structure of the active layer of the SOA chips (e.g. 1,5 μm and 0,1 μm in width and thickness, respectively). Therefore, the NF of SOA modules is typically more than 6 dB.

Since the NF depends on the coupling efficiency at the input, the NF of SOA modules with PDG_{active} = 0 will have high polarization dependence unless PDG_{total} is zero.

3.6 Lifetime of carriers

The lifetime of carriers in SOA chips is in the order of nanoseconds, leading to such as cross gain modulation (XGM) and a type of signal distortion called the pattern effect when used in gigabit-class optical signal systems.

3.7 Nonlinear effects

The SOA has nonlinear effects, such as cross phase modulation (XPM) and four-wave mixing (FWM). These effects are mainly caused by the carrier dynamics of SOA chips and lead to additional applications including wavelength conversion and wavelength demultiplexing. Since this technical report focuses on the amplification application, further details of these nonlinear effects are not addressed in this technical report.

4 Measurement of SOA output power and PDG

4.1 Narrow-band versus broadband light source

It is difficult to measure SOA output power and gain using a narrow-band light source for the input signal due to gain ripple. Gain ripple causes measurement errors of optical output power and polarization dependence. Since signal gain depends on temperature, input optical power, signal wavelength and forward current, measurement results may suffer from the lack of reproducibility. In this case, a wide-band optical light source has advantages. By averaging the signal gain in the SOA over a wide wavelength range, the optical power or polarization dependence can be accurately estimated. This is because the influence of gain ripple on the measurement results is drastically reduced.

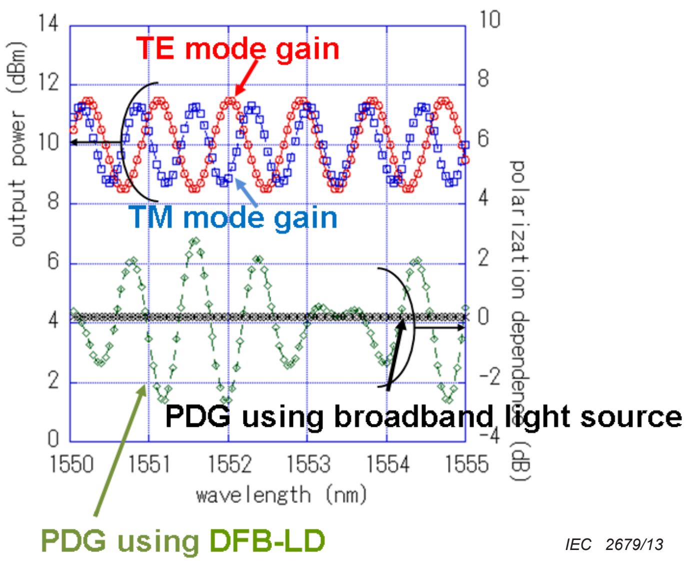


Figure 7 – Output power and PDG dependence on the wavelength of the SOA chip

Figure 7 shows an example of output power and polarization dependence on the wavelength of the SOA with a gain ripple of about 3 dB. The upper graph shows the optical power dependence on wavelength measured by using a distributed feedback (DFB) LD as an input light source. The red and blue lines are the TE and TM mode gains of the SOA respectively. The gain ripple is clearly observed because the DFB-LD has a linewidth much narrower than the period of the gain ripple. As shown in Figure 7, the amplitude of the gain ripple of the TE and TM modes are 3,2 dB and 3,0 dB, respectively, and the period of each mode is 0,8 nm and 0,7 nm, respectively. The bottom graph shows the PDG dependence on the wavelength of the SOA. The green and black lines are for the DFB-LD and the amplified spontaneous emission (ASE) light source, respectively. Although the use of the DFB-LD showed a large PDG of more than ±2 dB, the PDG measured by using the ASE light source was as only 0,2 dB.

NOTE An ASE source is one example of a broadband source.

The gain ripple can be estimated using an optical spectrum analyser. Since the gain ripple depends on several parameters, an accurate measurement is very difficult from the viewpoint of reproducibility. Including the information on the wavelength (frequency) resolution of the analyzer is preferable in the test report of gain ripple.

4.2 Recommended set-up for output power and PDG measurements

This subclause describes a test method for output power and PDG of SOAs by using a broadband light source and describes how the results will be different from those using a narrow-band light source (DFB-LD).

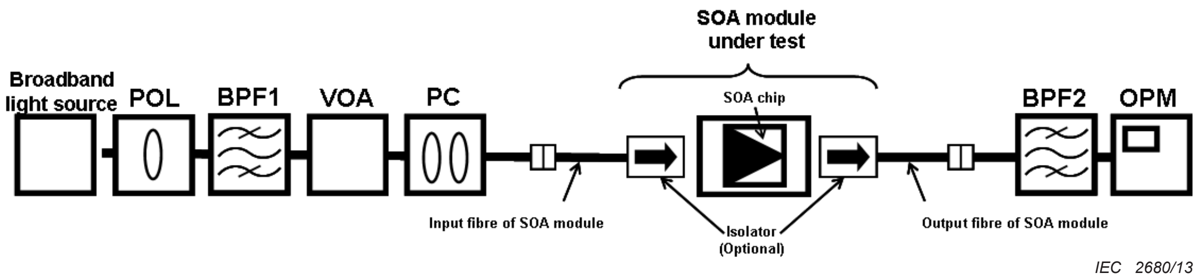


Figure 8 – Recommended measurement set-up for optical power and PDG of SOA modules

Figure 8 shows a recommended measurement set-up for SOA modules which incorporates a broadband light source. The broadband light source emits a continuous wave with a wavelength bandwidth (the full width at half maximum, FWHM), which must be wider than a gain ripple period (more than five-times wider if possible) of the SOA module under test. For example, superluminescent diodes (SLDs) and the ASE generated from OFAs or SOA modules are applicable as a broadband light source. Note that the ASE from the light source shall be a single polarization mode to measure the polarization dependence of the SOA characteristics. Thus, polarization maintaining OFAs, for example, with a polarization extinction ratio of larger than 15 dB are applicable. Alternatively, to enhance the ratio, the polarizer (POL) is used between the broadband light source and the band pass filter 1 (BPF1).

In Figure 8, the BPF1 is used to reduce the bandwidth of the broadband light source, and the reduced bandwidth shall be more than five times the period of the SOA module under test. Since there are no guarantees that the gain spectra of SOA and that of the input broad band light source are the same, spectral filtering is necessary. The bandwidth of the filter should be carefully chosen to obtain accurate measurement results. A variable optical attenuator (VOA) and polarization controller (PC) are employed to adjust the input power and the state of polarization, respectively. Another BPF (BPF2), which is inserted between the SOA and an optical power meter (OPM), is required to have the same bandwidth as the BPF1. As the SOA module under test has fibre pigtails, the measurement equipment is interconnected by using fibres.

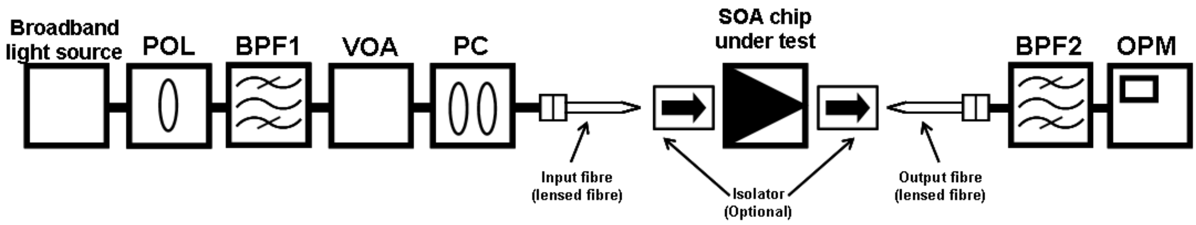


Figure 9 – Recommended measurement set-up for optical power and PDG of SOA chips

On the other hand, in Figure 9, which shows the recommended measurement set-up for SOA chips, the input and output lensed fibres are used for optical coupling with input and output of the SOA chip, respectively.

4.3 Examples of measurement results obtained by using the recommended set-up

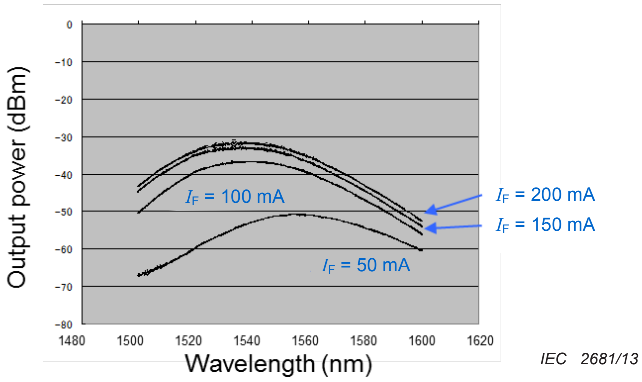


Figure 10a – SOA chip sample #1 with a negligibly small gain ripple at I_F = 100 mA

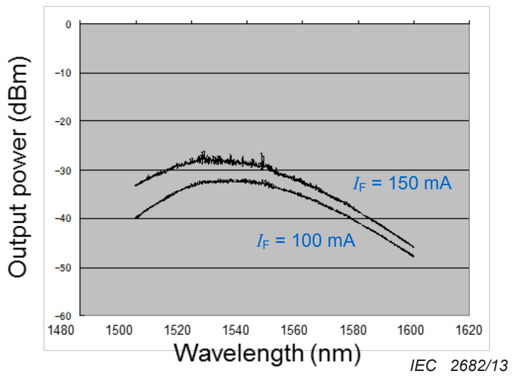


Figure 10b – SOA chip sample #2 with a gain ripple of about 1 dB at I_F = 100 mA

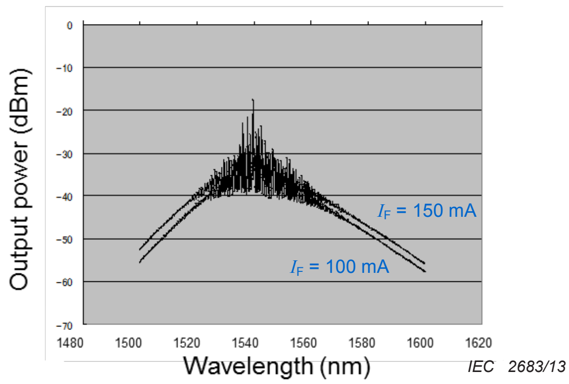


Figure 10c – SOA chip sample #3 with a gain ripple of more than 10 dB at I_F = 100 mA

Figure 10 – Optical power spectra of three different SOA chips

In this subclause, the advantage of using a broadband light source is described. Figure 10 shows the optical power spectra of three different SOA chips at various forward currents (I_F), and amplitude of the gain ripple. The period of the gain ripple of these SOA chips is less than 0,5 nm. In the output power and PDG measurements of the SOA chips, two input light sources were used for the comparison. One was the DFB-LD which with a linewidth of 2 MHz (16 fm in wavelength) approximately, and the other was the ASE generated from the polarization maintaining EDFA. The peak wavelength of both light sources was 1 540 nm, and the polarization extinction ratio of the ASE emitted from the EDFA was 20 dB. The measurement set-up using the EDFA was the same as shown in Figure 9, and the bandwidth of the BPF1 and BPF2 was set to be 5 nm which was more than ten times the gain ripple period of the

SOAs. The BPF1 was omitted when the DFB-LD was used as the input light source, and the bandwidth of the BPF2 was set to be 1 nm. The VOA adjusted the input power of both light sources to –20 dBm, and the polarization mode set to be the TE or TM modes with the PC.

Figures 11, 12, and 13 show the obtained results of the SOA chip sample #1, #2 and #3, respectively. In these figures, the lower graph is the output power of the TE and TM modes as a function of I_F, and the upper graph is the PDG dependence on I_F. The red and black lines are the ASE light source and DFB-LD, respectively for the comparison.

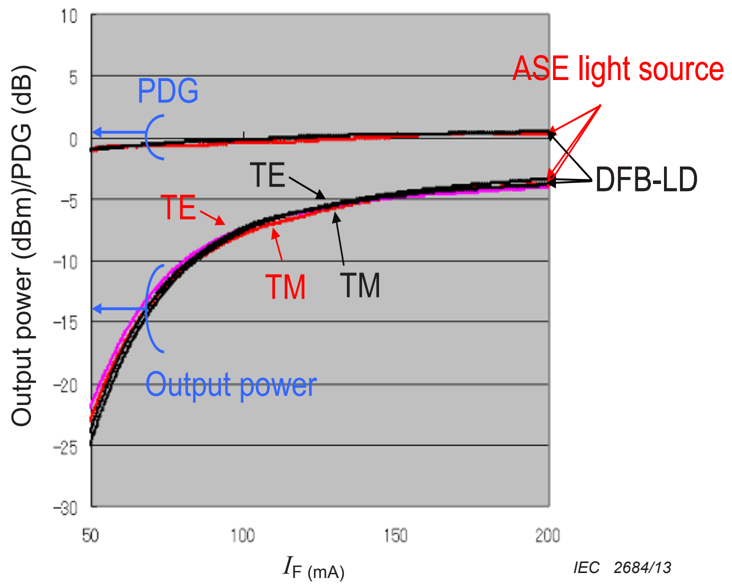


Figure 11 – Output power and PDG of the SOA chip sample no. 1 as a function of I_F

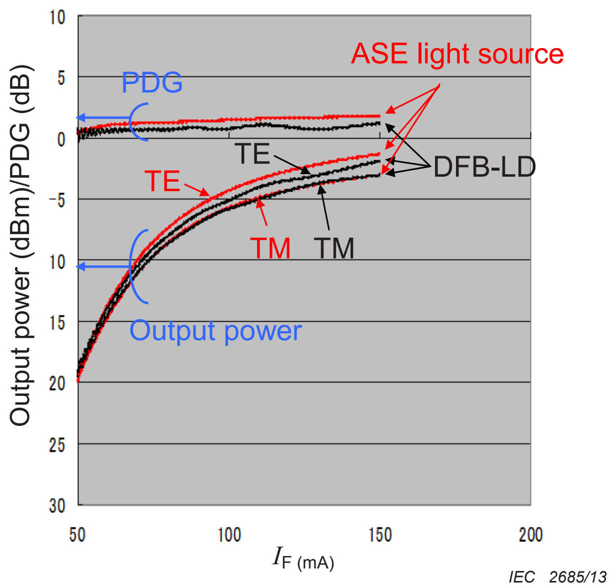


Figure 12 – Output power and PDG of the SOA chip sample no. 2 as a function of I_F

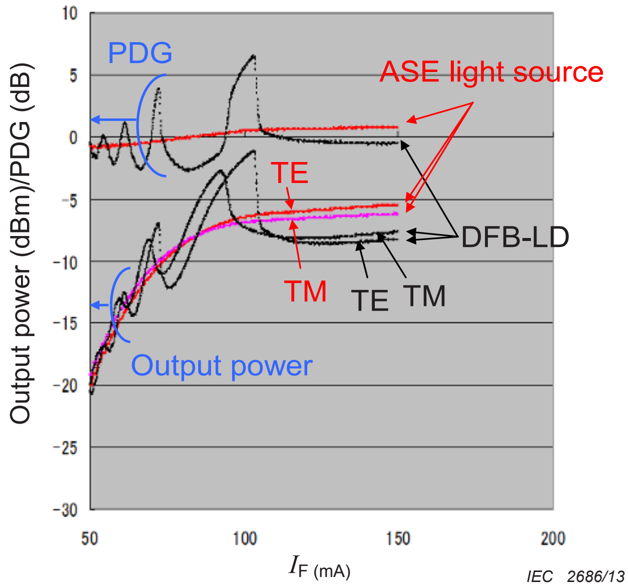


Figure 13 – Output power and PDG of the SOA chip sample no. 3 as a function of I_F

As shown in Figure 11, the difference in the results between the ASE light source and DFB-LD was almost negligible due to the small gain ripple of the SOA chip (sample no. 1). However, as shown in Figure 12, the PDG measured by using the ASE light source was about 1,0 dB larger than that when the DFB-LD was used. This difference was caused by the 1,0 dB gain ripple of the SOA chip (sample no. 2). Even if the gain ripple is as large as 10 dB, this method is applicable as shown in Figure 13. When the DFB-LD was used, the output power and the PDG extremely depended on the I_F due to the ripple. For example, the PDG was as large as 6 dB at I_F = 100 mA while almost 0 dB at I_F = 110 mA. On the other hand, the PDG obtained by using the ASE light source was still stable at the whole range of I_F, because of the averaged optical power over the sufficient bandwidth of 5 nm.

In summary, an SOA that has *x*-dB amplitude of the gain ripple results in variation of the PDG within ±*x* dB when a narrow-band light source is used for the measurement. For example, 3-dB amplitude of the gain ripple leads to ±3 dB variation of the PDG due to the difference of the gain ripple period between the TE and TM modes, as shown in Figure 7. Moreover, even if the amplitude of the gain ripple of the SOA is as small as 0,5 dB, it is still not practical to measure the PDG by using a narrow-band light source because ±0,5 dB variation of the PDG is comparable to the gain ripple. Thus, to avoid influence by the gain ripple, the output power and PDG shall be measured by using a broadband light source. In this case, the amplitude of the gain ripple of the SOA should be noted along with the measured results of the output power and PDG.

However, a narrow-band light source shall be applicable for the gain and saturation output power measurements if the gain ripple of SOAs is negligibly small. For example, if the amplitude of the gain ripple of the SOA is as small as 0,5 dB, the measurement error when the narrow-band light source is used would be ±0,25 dB, which is much smaller than the typical gain of >20 dB. Thus, if the users can accept this error, a narrow-band light source will be applicable for the gain and saturation output power measurements.

Annex A
(informative)

Applications of SOAs

A.1 General

Currently, discrete SOA modules are not commonly employed in commercial optical network systems. This is because several characteristics of SOAs, such as PDG and NF, do not meet the system requirements. Also, SOAs are not applicable for systems that require a large saturation output power because the gain length of SOAs is typically as short as 1,5 mm. On the other hand, since SOA chips can be integrated with other semiconductor devices, integrated SOA chips are widely used in PICs as boosters and line amplifiers. In this annex, current and proposed applications of discrete SOA modules and integrated SOA chips are briefly reviewed.

A.2 Polarization mode of SOAs

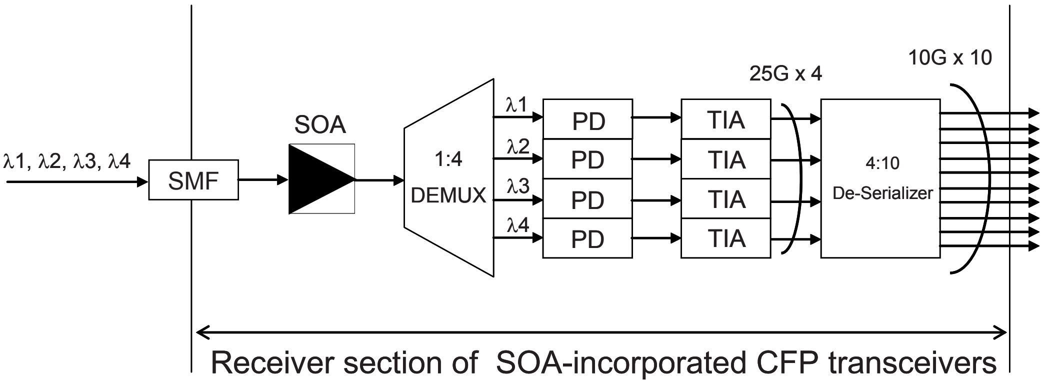
The polarization mode of SOA chips are designed by taking the application into account. Generally, integrated SOA chips used as booster amplifiers are TE-polarized because the LDs emit TE-polarized light. However, discrete SOA modules used as line amplifiers should be polarization independent because the polarization mode will be randomly changed by propagation in the fibre in optical links. SOAs for a pre-amplifier shall be discrete modules because the SOA modules need an optical filter to reduce the ASE noise between the SOA modules and photodiodes (PDs). To receive the signal light with various polarization modes, the SOA modules used as a pre-amplifier should be polarization independent.

A.3 Reach extender for GPON

Recently, the use of SOA modules was proposed as one of the examples of the OA-based reach extender for GPON in ITU-T Recommendation G.984.6. The reach extender is incorporated into the fibre link between the optical line termination (OLT) and optical network unit (ONU) to increase the reach to 60 km in both the upstream (λ = 1 310 nm) and downstream.(λ = 1 490 nm). The SOA chips can be easily adapted to both wavelengths by changing the composition of the semiconductor materials. For this application, an SOA chip, a TEC and optical lenses may be assembled in a butterfly package that has two fibre pigtails for the input and output ports, as shown in Figure 4. As a line amplifier in GPON, polarization independent SOA modules may be utilized for this application.

A.4 Pre-amplifier in transceivers for 100 GE

In the IEEE 802.3ba task force, installing an SOA module as a pre-amplifier into 40 km–100 GbE transceivers was proposed. The multi-source agreement (MSA) defined them as 100 G form factor pluggable (CFP) transceivers as described in CFP MSA Hardware Specification Revision 1.4.



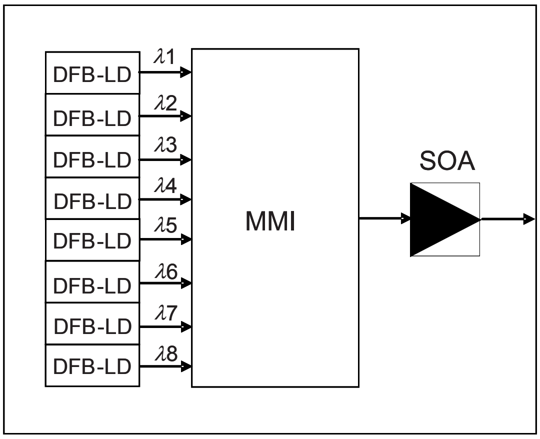
IEC 2687/13

Figure A.1 – Schematic diagram of the receiver section of SOA-incorporated CFP transceivers

Figure A.1 shows the schematic diagram of the receiver section of SOA-incorporated CFP transceivers. The input signal light in a single-mode fibre (SMF) is multiplexed by four wavelengths ($\lambda 1$, $\lambda 2$, $\lambda 3$, and $\lambda 4$) with the wavelength interval of about 5 nm in around 1 300 nm, and each wavelength has a signal bandwidth of about 25 Gbit/s. After the input port of the transceivers, the signal light launches into the SOA module. Since the signal light is multiplexed, four wavelengths are simultaneously amplified by the SOA module. Then, the amplified signal light is demultiplexed to four individual optical signal lines by the 1:4 demultiplexer (DEMUX). Demuliplexed signal lights are converted to 4×25 Gbit/s electric signals by PDs. The electric signals are amplified by transimpedance amplifiers (TIAs), and then converted to 10×10Gbit/s signal lines by the 4:10 de-serializer.

In this application, the SOA module is a butterfly package, which may be installed between the input port and 1:4 DEMUX. As a pre-amplifier, the SOA module shall be polarization independent.

A.5 Monolithic integration of SOAs



IEC 2688/13

Figure A.2 – Schematic diagram of the DFB-LDs-array type wavelength tuneable LD

Figure A.2 shows an example of the monolithic integration. Shown is a DFB-LDs-array wavelength tuneable LD, which consists of a DFB-LDs array, a multi-mode interference (MMI) device, and an SOA chip in one chip. In this PIC, the integrated SOA chip is used as the booster amplifier and amplifies a continuous wave light launched from the DFB-LDs array via the MMI device. SOA integrated tuneable LDs are used in tuneable optical transceivers, which are indispensable components in current telecommunication systems. Generally, the integrated booster SOA chips in tuneable LDs are polarization dependent (TE mode polarized) because the DFB-LDs emit the TE polarized light. In other PICs, if the polarization mode of the input light into the integrated SOA chips is random, the integrated SOA chips should be polarization independent.

A.6 Reflective SOAs (RSOAs)

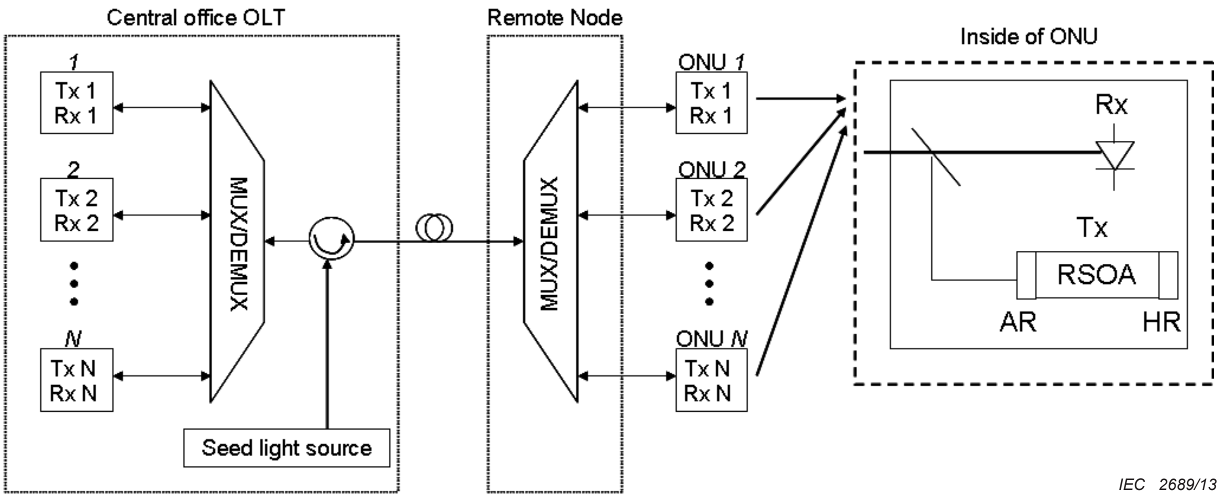


Figure A.3 – Schematic diagram of the seeded WDM-PON system

RSOAs have a high reflection mirror on one facet of the SOA and an anti-reflection coating on the other facet, while conventional SOA chips have anti-reflection coatings in both facets. This design can offer an amplification module with a single pigtailed fibre for the optical input/output. The input light launches into the input/output port of the RSOA chip, and is amplified and reflected by the mirror. Then, the amplified light propagating along the opposite direction is amplified again inside the chip and is emitted from the input/output port.

Recently, RSOAs have attracted attention as a promising candidate for an optical transmitter of ONUs for seeded WDM-PON systems as shown in Figure A.3. ITU-T G.698.3 defines and provides values for optical interface parameters of point-to-point seeded WDM applications. Since SOAs have a direct modulation bandwidth of approximately 2 GHz, RSOAs are considered suitable as reflective colourless amplifying modulators. In seeded WDM-PON systems, not only the signal light (downstream signal) but also the CW light of the seed light source are transmitted from the central office and ONUs receive both signals. The received signal in each ONU launches into the RSOA and then it is amplified and modulated by the RSOA. The modulated signal light is transmitted as the upstream signal from the ONU to the OLT in the central office.

Bibliography

IEC 61290-1 (all parts), *Optical amplifiers – Test methods – Power and gain parameters*

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

IEC 61291-2, *Optical amplifiers – Part 2: Digital applications – Performance specification template*

IEC/TR 61292-3, *Optical amplifiers – Part 3: Classification, characteristics and applications*

ITU-T Recommendation G.661, *Definition and test methods for the relevant generic parameters of optical devices and subsystems*

ITU-T Recommendation G.698.3, *Multichannel seeded DWDM applications with single-channel optical interfaces*

ITU-T Recommendation G.984.6, *Gigabit-capable passive optical networks (GPON): Reach extension*

CFP MSA Hardware Specification – Revision 1.4

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