

PAM4 Evaluation by High-Saturation-Output-Power, Low-Noise 1.31 μm SOA *AA3TB10EY*

Table of Contents

1	Introduction	3
2	Market Trends	3
3	Evaluation Items.....	4
3.1	Saturation Output Power	4
3.2	Noise Figure	4
3.3	SECQ	4
4	SOA Specifications	6
4.1	Dimensions.....	6
4.2	Optical and Electrical Characteristics.....	6
5	SOA Evaluations	7
5.1	Saturation Output Power Characteristic.....	7
5.2	Gain Wavelength Characteristic	8
5.3	Signal Transmission Characteristic	8
6	Summary	9

1 Introduction

To meet the rapid growth in traffic driven by the dramatic advancement of AI technologies, continuous increases in the communication speeds of servers and networking equipment are required. To support these higher-speed networks, next-generation Ethernet standards are adopting PAM4 (four-level pulse amplitude modulation) in addition to conventional NRZ (non-return-to-zero) modulation, accelerating the realization of optical transmission systems with capacities exceeding 1 Tb/s.

At the same time, data center networks continue to expand at a remarkable pace. Optical transceiver modules are critical components for interconnecting network equipment, and SOAs are widely used to extend their transmission reach. Meanwhile, PAM4-based transmission schemes have been standardized to address the growing demand for higher transmission capacity, increasing the need for SOAs that combine high saturation output power with low noise while faithfully preserving signal quality. In response to these evolving requirements, Anritsu has developed the AA3TB10EY, a high-saturation-output-power, low-noise SOA, drawing on the optical device technologies it has cultivated through years of experience in the communications market.

2 Market Trends

IEEE 802.3 100GbE and 400GbE standards define transmission schemes (100GBASE-LR4, ER4, 400GBASE-LR8, and ER8) that use wavelength-division multiplexing of 25-Gbaud signals to achieve transmission distances of up to 40 km. To reduce costs by decreasing the number of optical lanes, the 100G Lambda MSA was established based on the expectation that a single 100-Gbps optical lane could reduce costs by approximately 40% compared with a four-lane 25-Gbps architecture, resulting in specifications such as 100G-LR1-20, -30, and -40, as well as 400G-LR4-10 and -30. In addition, products capable of transmitting 400G IM-DD signals over distances of up to 40 km have also emerged as de facto solutions. As a result, there is growing demand for high-saturation-output-power, low-noise SOAs capable of linearly amplifying 100-Gbps PAM4 signals in the 1.31- μ m wavelength band, where adjacent channels are spaced by approximately 2.3 nm, enabling long-reach transmission of IM-DD signals.

IEEE802.3 standards and 100G Lambda MSA

	No. of Lanes	Signaling Rate	2 km	6 km	10 km	20 km	30 km	40 km
100GbE	×1	IM-DD 100Gbps PAM4	100GBASE-FR1			100G-LR1-20	100G-ER1-30	100G-ER1-40
	×4	IM-DD 25Gbps NRZ			LWDM ^{*1} 100GBASE-LR4			LWDM ^{*1} 100GBASE-ER4
400GbE	×4	IM-DD 100Gbps PAM4	CWDM4 400GBASE-FR4	CWDM4 100GBASE-LR4-6	nWDM ^{*2} 400G-LR4-10	-	nWDM ^{*2} 400G-ER4-30	nWDM ^{*2} (400G-ER-40)
	×8	IM-DD 50Gbps PAM4	CWDM 400GBASE-FR8		LWDM ^{*1} 400GBASE-LR8			LWDM ^{*1} 400GBASE-ER8

*1: LWDM (LAN WDM) channel spacing approximately 4.5 nm (approximately 800 GHz)

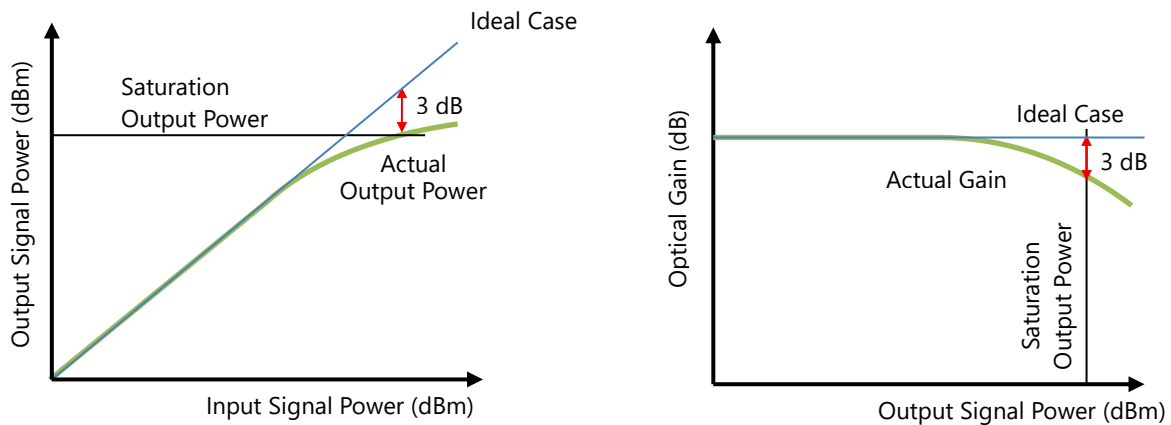
*2: nWDM (narrow WDM) channel spacing approximately 2.3nm (approximately 400GHz)

3 Evaluation Items

3.1 Saturation Output Power

In an SOA, carriers (electrons and holes) are injected into the active region by current, which allows amplification of the input optical signal. At sufficiently low input power, the SOA provides a constant gain. However, as the input optical power increases, carrier consumption gradually exceeds the carrier supply, resulting in gain compression. The output power at which the gain decreases by 3 dB from the small-signal gain is generally defined as the saturation output power. Once gain saturation occurs, the optical signal becomes distorted, which can lead to transmission errors.

The figure below illustrates the concept of saturation output power. In the left-hand graph, the horizontal and vertical axes represent the input and output optical power levels, respectively. In the right-hand graph, the horizontal axis represents the output optical power level, while the vertical axis represents gain.



Saturation Output Power Characteristics

3.2 Noise Figure

The noise figure (NF) represents the degradation in signal-to-noise ratio (SNR) caused by noise added by an optical amplifier and is defined by the following equation:

$$NF = \frac{S/N_{in}}{S/N_{out}}$$

The theoretical minimum noise figure of an SOA is 3 dB. Amplified spontaneous emission (ASE) generated by carrier injection acts as background noise and degrades the SNR of the amplified optical signal.

3.3 SECQ

Stressed Eye Closure Quaternary (SECQ) is an optical signal quality metric used in receiver conformance testing of PAM4 optical transceivers. It measures the degree of eye-pattern closure, which reflects signal quality degradation, with lower SECQ values indicating better signal quality. SECQ is defined by the following equation:

$$SECQ = 10 \log_{10} \frac{\sigma_G^2}{\sigma_s^2}$$

σ_s : Reference noise level of the measurement system

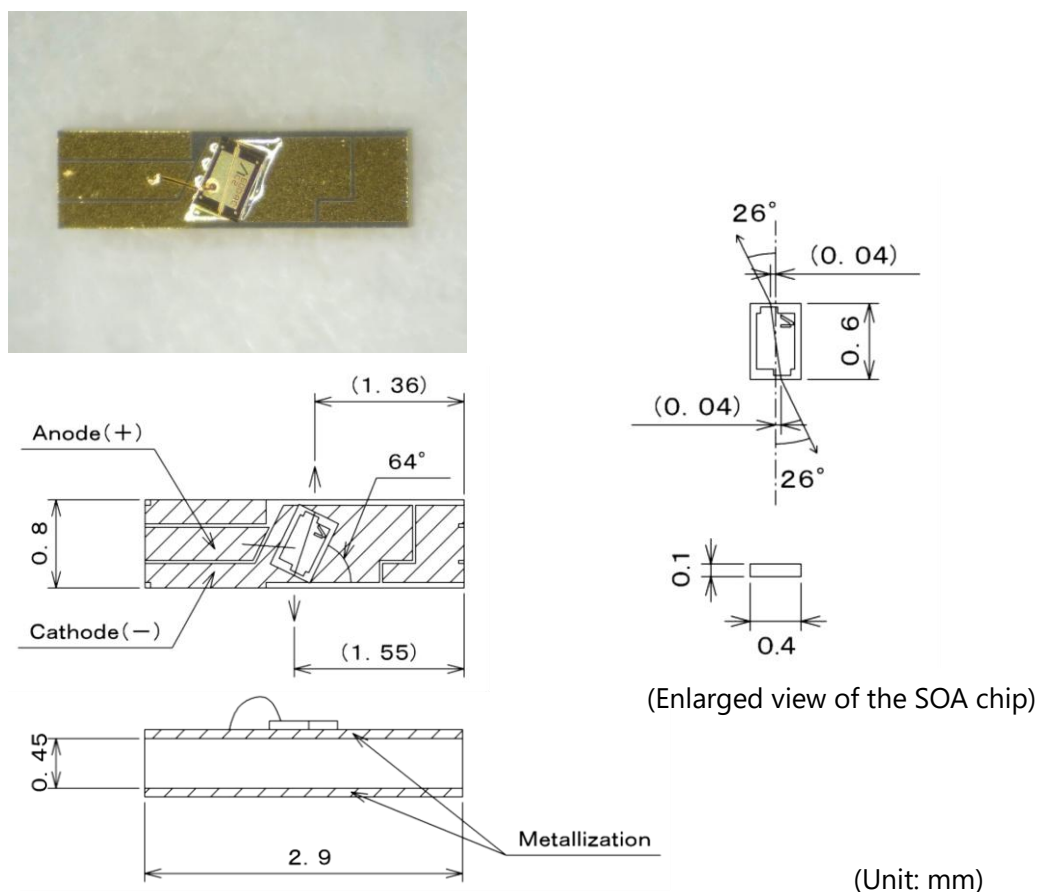
σ_G : Amount of additional Gaussian noise required to achieve the specified symbol error ratio

A similar signal quality metric, Transmitter Dispersion and Eye Closure Quaternary (TDECQ), is used to quantify the degradation of an optical signal transmitted from a PAM4 transmitter by measuring the degree of eye closure. Unlike SECQ, however, TDECQ does not take optical-fiber dispersion into account. As with SECQ, lower values indicate better signal quality.

4 SOA Specifications

4.1 Dimensions

The AA3TB10EY is a chip-carrier-type SOA product featuring a 1.31- μ m-band SOA chip mounted on a compact aluminum nitride carrier and is well suited for integration into photonic integrated circuits (PICs).



Dimensions

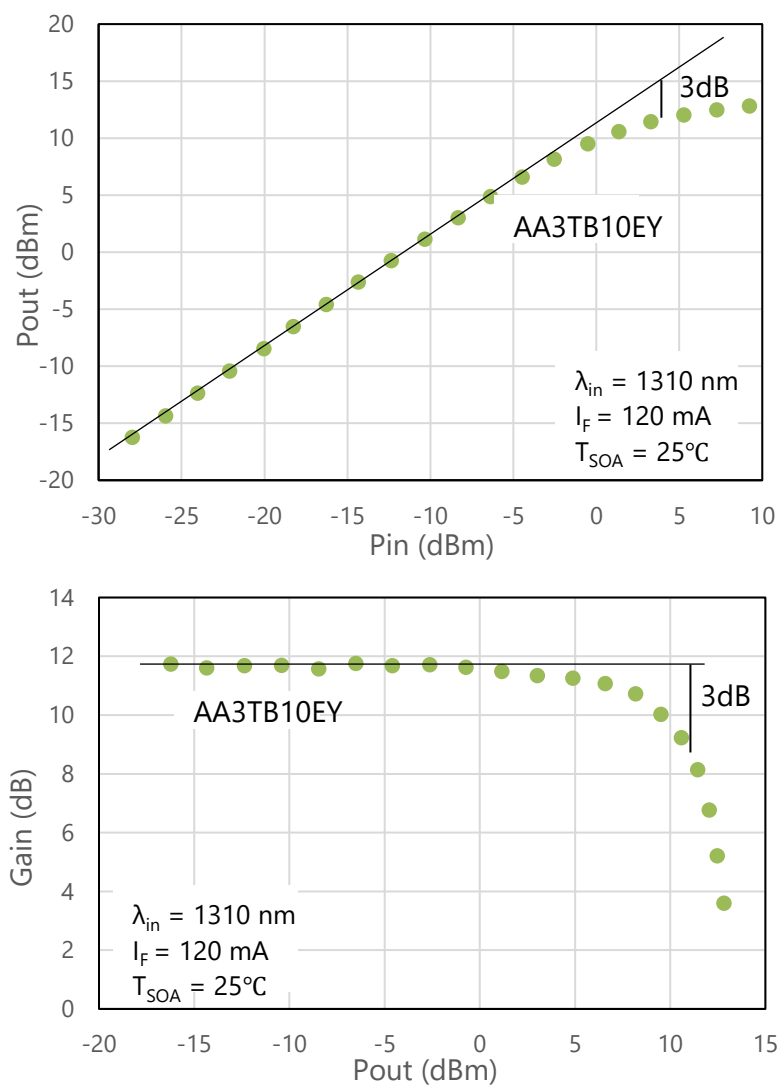
4.2 Optical and Electrical Characteristics

Item	Min.	Typ.	Max.	Unit
Gain	–	10	–	dB
Polarization Dependent Gain	–	1.5	–	dB
Saturation Power	–	11.5	–	dBm
Noise Figure	–	5.8	–	dB
Beam Divergence Angle Lateral (Parallel)	–	23	–	deg.
Beam Divergence Angle Transverse (Perpendicular)	–	23	–	deg.
Optical output	–	0.25	–	mW
Forward Voltage	1.0	1.2	1.5	V

5 SOA Evaluations

5.1 Saturation Output Power Characteristic

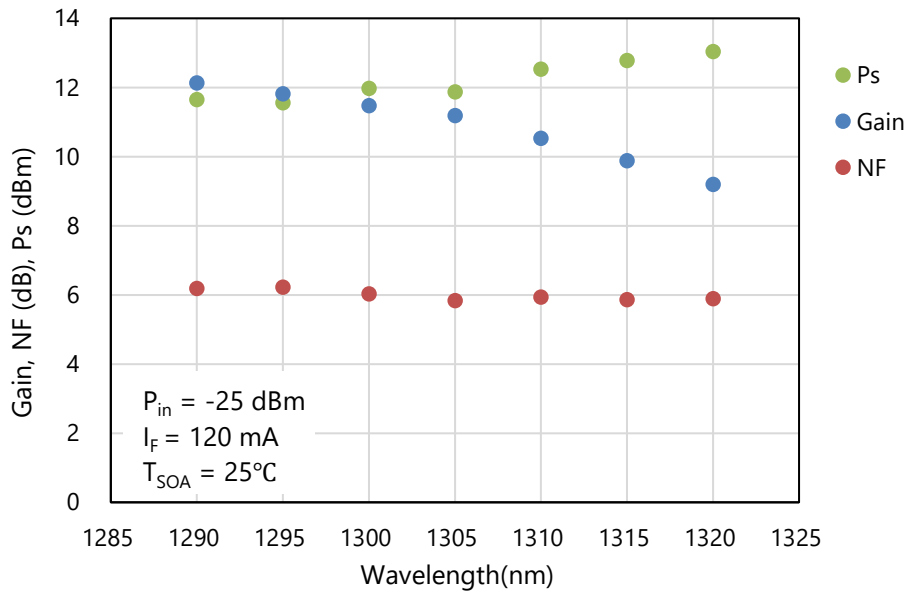
The figure below shows the saturation output power characteristics of the AA3TB10EY. Compared with Anritsu's conventional SOA, the gain is intentionally suppressed to achieve higher saturation output power. As a result, excellent waveform quality with minimal distortion can be expected.



Saturation Output Characteristics

5.2 Gain Wavelength Characteristic

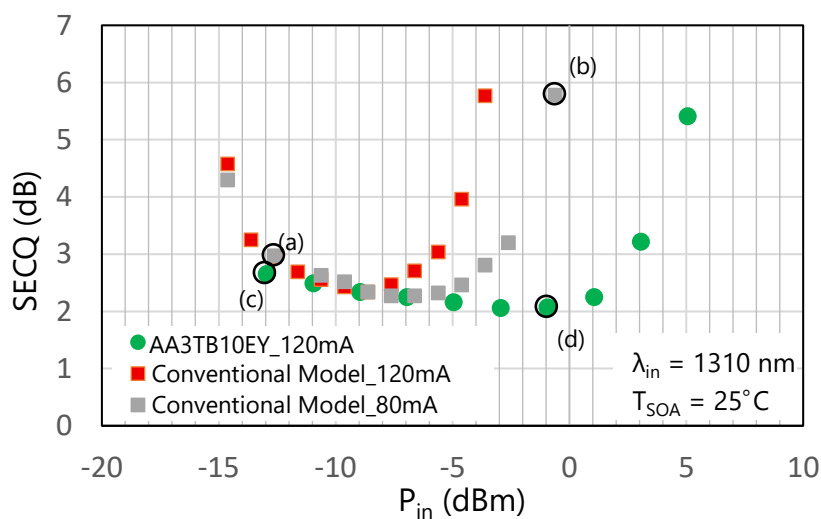
The AA3TB10EY improves both saturation output power and noise figure by suppressing the gain. It also provides a wider gain bandwidth than conventional products, offering sufficient gain over the 1295 nm to 1310 nm wavelength range used in LAN-WDM applications.



Wavelength Characteristic

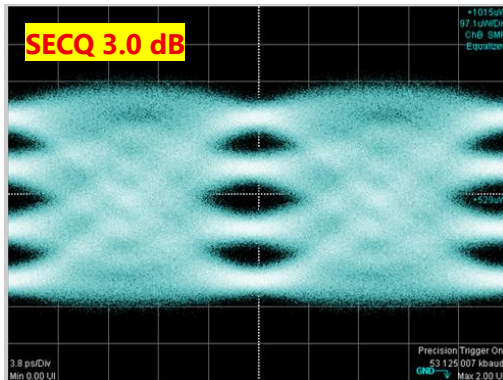
5.3 Signal Transmission Characteristic

The figure below shows the SECQ performance of the AA3TB10EY for a 53-Gbaud PAM4 input signal. Compared with the conventional product, the AA3TB10EY maintains excellent SECQ performance up to higher input optical power.

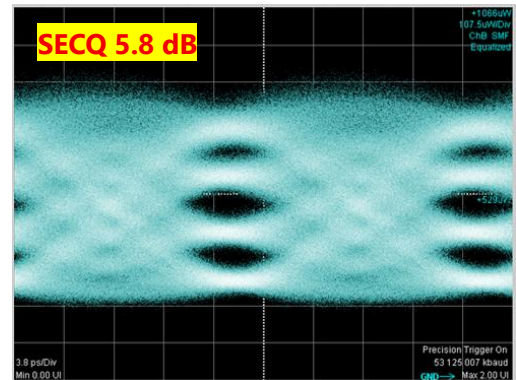


Signal Input Power vs. SECQ Characteristics

53 Gbaud PAM4

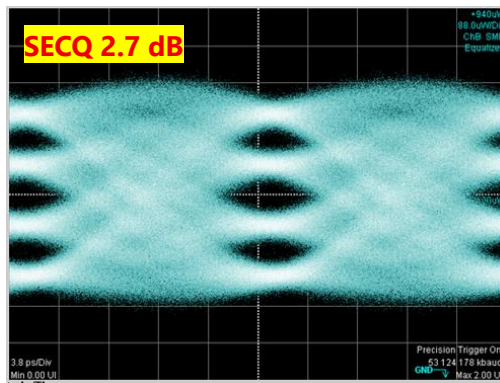


(a) $P_{in} = -13$ dBm

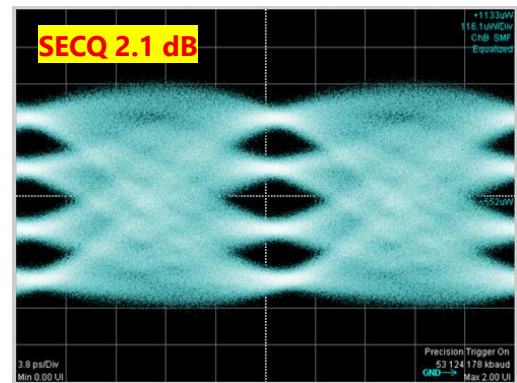


(b) $P_{in} = -1$ dBm

SECQ Evaluation Results of Conventional SOA ($I = 80$ mA)



(c) $P_{in} = -13$ dBm



(d) $P_{in} = -1$ dBm

SECQ Evaluation Results of AA3TB10EY ($I = 120$ mA)

6 Summary

The AA3TB10EY is a 1.31- μm chip-carrier-type SOA developed for the linear amplification of 100-Gbps PAM4 signals, combining high saturation output power with a low noise figure. Compared with conventional products, it suppresses waveform degradation due to gain saturation at higher input optical power and maintains excellent SECQ performance even with 53-Gbaud PAM4 input signals. Furthermore, it provides sufficient gain across the 1295-1310 nm wavelength range used in LAN-WDM and narrow-WDM applications.

The widespread adoption of AI is driving continued growth in communication capacity both within and between data centers. As a result, the importance of SOAs capable of amplifying PAM4 signals with high linearity is expected to increase further in long-reach IM-DD optical transceivers, including 100GbE and 400GbE systems. Combining high saturation output power, a low noise figure, and a wide gain bandwidth, the AA3TB10EY is well suited for 100G Lambda MSA and 400G ER/LR class optical transceivers, as well as compact photonic integrated circuits (PICs) with low power consumption.

Anritsu will continue to provide optical devices that contribute to the advancement of high-speed optical transmission systems.



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