Development of 1.3-μm Band Polarization Independent Semiconductor Optical Amplifier Module

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[Summary] Due to the recent explosive increase in communications traffic, attention is focusing on applying of semiconductor optical amplifiers for use as optical amplifiers at communications between data centers. Consequently, we leveraged our experience in optical device fabrication technologies to prototype a polarization independent Semiconductor Optical Amplifier (SOA) for the 1.3-μm band. We confirmed that the fabricated SOA has low polarization dependency and sufficiently high gain characteristics. Additionally, we also confirmed that elements in the small fabricated module had good reliability. As a result, the module has good characteristics as an optical amplifier for signals between data centers and is sufficiently small and reliable for building into current mainstream CFP/CFP2 modules.

1 Introduction

Recently, communications network operators are experiencing tight bandwidth capacity due to the popularity of wideband applications, such as video streaming. In addition, data center to data center communications volumes are increasing exponentially due to changes from communications between people to communications between machines. Communications both within and between data centers use Ethernet standardized by IEEE802.3ba. As part of this, 100GBASE-LR4/ER4[1)] uses four wavelengths in the 1.3-μm band suffering only small wavelength dispersion (λ0: 1294.53 to 1296.59 nm, λ1: 1299.02 to 1301.09 nm, λ2: 1303.54 to 1305.63 nm, and λ3: 1308.09 to 1310.19 nm). Data transfer is performed via a Single Mode Fiber (SMF) by multiplexing laser light. Using LR4 over a 10-km transfer distance eliminates the need for an amplifier at the receiver. However, since ER4 is specified for use for long distance transmissions of 40 km, an optical amplifier is built into the receiver to compensate for losses in the transmission path. Although the fiber loss is small at about 0.5 dB/km, a compensating preamplifier is required because signals are attenuated as the transmission distance becomes longer. Most trunk transmission and video streaming systems use an Erbium Doped optical Fiber Amplifier (EDFA) to amplify the optical signal with a 1480-nm light source (such as the AF4B150FA75L manufactured by Anritsu Devices Co., Ltd.) used to pump the EDFA. However, EDFAs for the 1.55-μm wavelength band cannot be used for the 1.3-μm band used between data centers. On the other hand, although the Praseodymium Doped Fiber Amplifier (PDFA) is known to support the 1.3-μm band, it has yet to be commercialized. Under these circumstances, attention is focusing on Semiconductor Optical Amplifier (SOA) rather than optical fiber amplifiers from the viewpoints of supported wavelength bands and smaller module size.

The CFP and CFP2[2)] optical transceivers used between data centers are specified in the Multi Source Agreement (MSA); CFP is the first generation with a size of 82(W) × 13.6(H) × 144.8 (D) mm, while the second-generation CFP2 is smaller at 41.5(W) × 12.4(H) × 107.5(D) mm. Under these conditions, conventional SOA modules are too large to incorporate in CFP modules, so they must be reduced in size.

A small SOA module can amplify a wide wavelength band. In addition, they can be fabricated using much the same manufacturing process as existing Laser Diodes (LD)[3)]. Therefore, Anritsu can leverage its experience in compound semiconductor fabrication technologies[4)] to manufacture SOA. Not only does the SOA have excellent Gain (G), Saturation Power (Ps), and Noise Figure (NF) characteristics for use in preamplifiers, but it also has the necessary low Polarization Dependent Gain (PDG).

This article introduces a prototype polarization independent SOA for 1.3 μm manufactured using LD fabrication technology and reports on the small developed SOA module characteristics.

2 SOA Chip Characteristics

The fabricated SOA chip was built into a carrier as a Chip on Carrier (CoC) and the amplifier characteristics (gain, NF, PDG) were measured. The amplifier characteristics were calculated[5] from the optical input (Pin) and optical output (Pout), each measured using an optical spectrum analyzer. A Tunable Laser Source (TLS) was used at Pin and the characteristics at each wavelength were monitored using the Anritsu optical spectrum analyzer MS9740A. Figure 1 shows the gain vs current characteristics for the 1310-nm wavelength band. The solid line indicates gain and the dashed line indicates NF; the black lines are measured in the TE mode, and the red lines are measured in the TM mode. Gain means the gain between fibers.

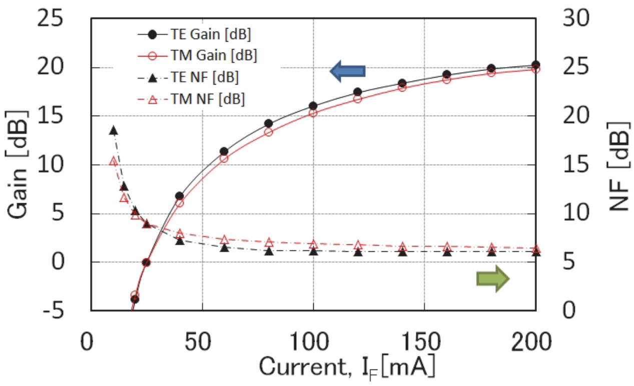


Figure 1 Current vs Gain Characteristics

The maximum gain between fibers was 20 dB at an input of one wavelength (λin) of 1310 nm at an input power of −25 dBm; the PDG (TE Gain − TM Gain) at this time was 0.45 dB. Almost no polarization dependency was found by confirming the PDG was less than 1.0 dB across the entire band at a current of less than 200 mA. Additionally, at drive current of 100 mA or more, the NF was a constant fixed value and was 6.5 dB at a current of 200 mA.

We settled on using drive current of 120 mA based on the trade-off between gain and power consumption. At a gain of 15 dB or more, the power consumption was about 1 W, offering a balanced operating condition in actual use.

Figure 2 shows the saturation characteristics indicating the change in gain between fibers with change in optical output power at a SOA drive current of 120 mA and λin of 1310 nm, where the horizontal axis is the optical output and the vertical axis is the gain between fibers. The black line indicates the TE mode and the red line the TM mode. The optical gain drops 3 dB from the initial gain to become the saturated optical output Ps. The saturated optical output Ps at this time is +8.4 dBm in the TE mode and +8.8 dBm in the TM mode, offering adequate saturated optical output for pre-amplifier operation.

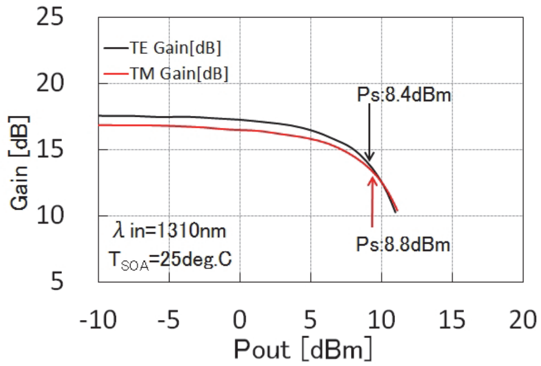


Figure 2 Saturation Characteristics

Figure 3 shows the gain vs PDG for the change in input wavelength at drive current of 120 mA, and Figure 4 shows the Ps vs NF.

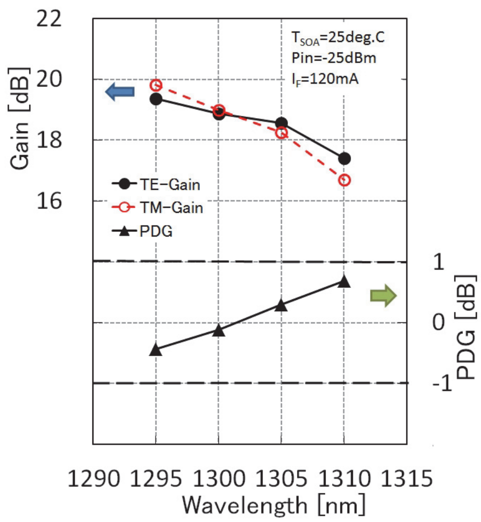


Figure 3 Gain vs PDG Wavelength Characteristics

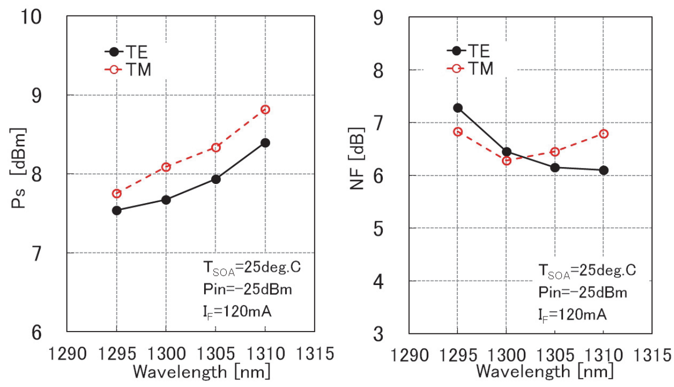


Figure 4 Ps vs NF Wavelength Characteristics

The gain was better than 16 dB under four wavelength inputs and the NF was less than 7.5 dB. Both gain and NF showed a tendency to become higher at shorter wavelengths. This characteristic is thought to be a correct result since the Amplified Spontaneous Emission (ASE) center wavelength is 1290 nm. Moreover, a Ps of +7.5 dBm or more was obtained, showing a tendency to increase at longer wavelengths. The PDG of the developed SOA was less than 1.0 dB at 4-wavelength input, with almost no polarization dependency in the usage range.

3 Module Characteristics

3.1 Module (Model: AA3F215CA)

Since meeting the need for small size was difficult using conventional 14-pin butterfly packages, we have developed a new 6-pin small package. The lens and SOA carrier are installed at a predetermined position on the Thermo-Electric Cooler (TEC) due to the size reduction limitations and were connected directly using an adhesive. In the installation procedure, the TEC was incorporated in the small package and then the SOA carrier was secured using heat-cured silver paste before the lens was secured using UV-cured adhesive (Figure 5). Additionally, a single-lens system tight-bend fiber, and one-side pin layout was used due to the small space. The dimensions of the fabricated small SOA are 35(W) × 9.6(H) × 5.7(D) mm (excluding fiber, connectors, and leads), which is sufficiently small for installation in a CFP2 module (Figure 6).

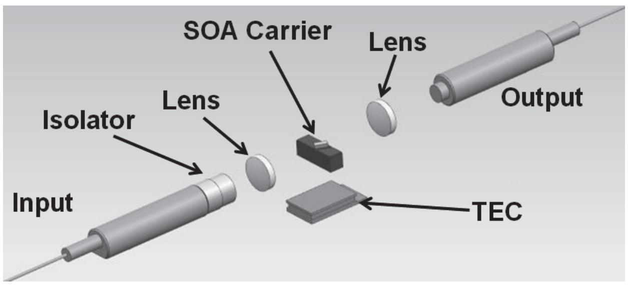
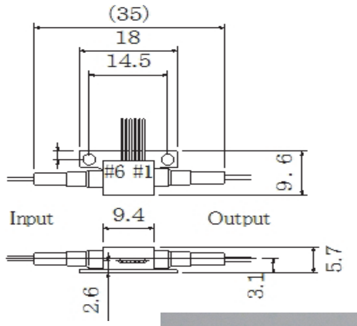


Figure 5 SOA Module Assembly



No.	Functions
1	Cooler cathode
2	Cooler anode
3	Thermistor
4	Thermistor
5	SOA cathode
6	SOA anode

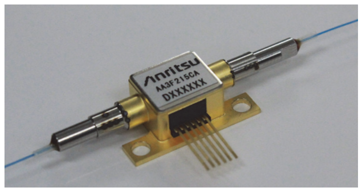


Figure 6 External View of SOA Module

Table 1 shows the SOA module characteristics, and these values are excellent enough for 100GBASE-ER4.

Table 1 Electrical and Optical Characteristics (AA3F215CA)

(T_{SOA} = 25°C, T_C = 25°C)

Item	Code	Measurement Conditions	Min.	Typ.	Max.	Units
Optical Gain	G	I_F = 120 mA, Pin = −25 dBm	15			dB
Polarization Dependent Gain	PDG	I_F = 120 mA, Pin = −25 dBm			1.5	dB
Forward Current	I_F		100		150	mA
Forward Voltage	V_F	I_F = 120 mA			2	V
Wavelength Range	λ	I_F = 120 mA	1294		1311	nm
Saturation Power	P_S	I_F = 120 mA		7		dBm
Noise Figure	NF	I_F = 120 mA, Pin = −25 dBm		7		dB
Power Consumption	P	I_F = 120 mA, T_C = 75°C		1	1.8	W
Thermistor Resistance	R_{th}	T_{SOA} = 25°C, B = 3435 ±105K	9.5	10	10.5	kΩ

Actual operation for 100GBASE-ER4 was confirmed using 4-wavelength simultaneous input. Four wavelengths of –25 dBm each were input to the SOA (Figure 7) and the signal amplification characteristics were good with no remarkable drop in gain at each wavelength.

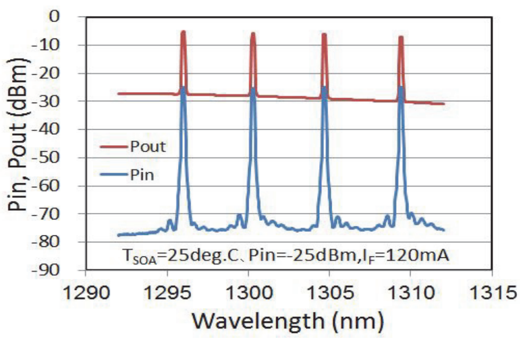


Figure 7 4-Wavelength Simultaneous Input Characteristics

3.2 Reliability Tests

Reliability was evaluated by testing 19 items (Table 2) based on Telcordia GR468-CORE and MIL-STD-883 standards. Good results were obtained, with all items passing the standards.

Table 2 Reliability Test Items

Reliability Item	Standard and Evaluation Condition	Result
Vibration	MIL-STD-883 Method 2007 20G, 20 Hz to 2000 Hz 4 min/cycle	Pass
Mechanical Shock	MIL-STD-883 Method 2002 4900 m/s^2 (500 g), 1 ms 5 times/axis	Pass
Thermal Shock	MIL-STD-883 Method 1011 ΔT = 100°C, 15 cycles	Pass
Temperature Cycle	Telcordia GR-468-CORE Ta = −40° to 85°C, 30/30 min., 500 cycles	Pass
Low-Temperature Storage	Telcordia GR-468-CORE Ta = −40°C, 72 h	Pass
High-Temperature Storage	Telcordia GR-468-CORE Ta = 85°C, 2000 h	Pass
Damp Heat	Telcordia GR-468-CORE Ta = 85°C/85%RH, 500 h	Pass
High-Temperature Operation	Telcordia GR-468-CORE Tc = 85°C, Tsoa = 25°C, Isoa = 150 mA, 2000 h	Pass
High-Temperature Operation (SOA CoC)	Telcordia GR-468-CORE Tsoa = 70°C, Isoa = 150 mA, 5000 h	Pass
Cable Retention	Telcordia GR-468-CORE 4.9 N (500 g), 1 min., 1 time	Pass
Fiber Twist	Telcordia GR-468-CORE 10 cycles from 0° to 90° to −90°~0°	Pass
Internal moisture	MIL-STD-883 Method 1018	Pass
ESD (HBM)	MIL-STD-883 Method 3015 C = 100 pF, R = 1500 Ω, ±500 V Discharge Interval: 5 s, Five Discharges, forward and reverse stress	Pass
ESD (CDM)	JESD22-C101E ±500 V, Five Discharges, forward and reverse stress	Pass
Die Shear (SOA CoC)	MIL-STD-883 Method 2019	Pass
Wire- Pull	MIL-STD-883 Method 2011	Pass

The CoC high-temperature operation test was run 25 times (N) for 5000 hours continuously at an ambient temperature (Ta) of 70°C using Auto Current Control (ACC) of 150 mA. The results are shown in Figure 8 with elapsed time on the x-axis and output optical power relative to start value on the y-axis. The figure shows the SOA chip experienced no extreme deterioration and confirmed stable operation. Assuming a 1 dB drop in ASE output from the initial value at a fault and a life until cumulative faults reach 50%, the SOA chip estimated life is 130,000 hours at an ACC of 150 mA and a Ta of 70°C. Converting this estimated lifetime for Ta of 25°C gives an estimated life of 1,050,000 hours, or a failure rate of 31 FITs over 10 years of operation, and 192 FITs over 20 years, confirming the high reliability of the fabricated SOA chip.

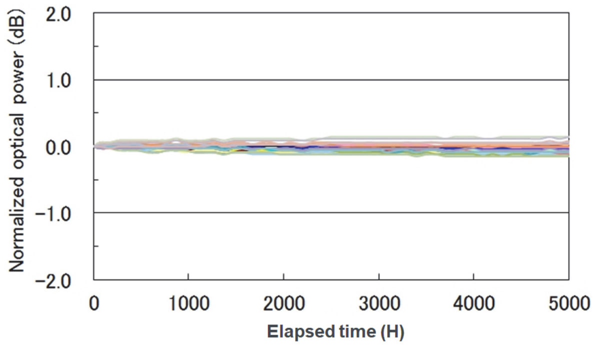


Figure 8 SOA Chip High-Temperature Operation Test

4 Conclusions

We developed a semiconductor optical amplifier for the 1.3-μm band used by 100GBASE-ER4.

For a CoC at 25°C and drive current of 120 mA, the gain between fibers was better than 16 dB, the PDG was less than 1.0 dB, the NF was less than 7.5 dB, and the Ps was better than +7.5 dBm. The wavelength dependency was also excellent in the range used by 100GBASE-ER4. In addition, although the lens and SOA carrier in the fabricated module were secured on the TEC directly with adhesive, the Telcordia GR468-CORE mechanical test items were all passed at reliability testing.

Based on the above, the developed SOA module has sufficiently good characteristics for amplifying optical signals passing between data centers, as well as small size and high reliability. Consequently, it can be built-into CFP2 modules currently becoming mainstream.

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