High Power AlGaInAs/InP Widely Wavelength Tunable Laser

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ABSTRACT Recently, a power consumption reduction is required for optical components used in optical communications. For a light signal source module that uses temperature control components for a precision control of wavelength, semi-cooled performance is useful for the purpose of low power consumption, because the semi-cooled performance raises the operation temperature range of the laser chips higher than ever before. In this case, since the laser chip is required to show superior performances at high temperature, using AlGaInAs-based materials, which are suitable for the performances at high temperature, in an active layer of the signal light source is a promising technology for the reduction of power consumption. On the other hand, a photonic integrated circuit (PIC) is a key technology to achieve both a size reduction and a low power consumption in the development of the next-generation of the optical communication systems. Here with the aim of realizing a high-performance photonic integrated circuit, we are reporting our development of a 1550 nm AlGaInAs buried-heterostructure laser and also the fabrication of a 1550 nm wavelength tunable laser, as the first for an AlGaInAs/InP-based laser, which is integrated with a 12 channel-DFB (Distributed feedback) laser array and a semiconductor optical amplifier (SOA).

1. INTRODUCTION

Recently, the reduction of power consumption is required in the optical components that are used in optical communications. In a light signal source module using temperature control components for a precision control of wavelength, semi-cooled performance, which raises the operation temperature range of the laser chips higher than ever before is useful for the low power consumption. In this case, since the laser chip is required to show superior performances at high temperature, using AlGaInAs-based materials, which are suitable for the performances at high temperature, in an active layer of the signal light source is a promising technology for the reduction of the power consumption. On the other hand, PIC is a key technology to achieve both a size reduction and a low power consumption in the development of the next-generation of the optical communication systems. An AlGaInAs/InP-based BH laser has been reported as the light source that has a low power consumption and a high-speed modulation for discrete devices[1)].

Although there are many reports of GaInAsP/InP-based materials for integrated devices, no photonic integrated circuit using AlGaInAs/InP-based material BH lasers has been reported. That is because it is difficult to control a re-growth buried interface which is concerned to influence the reliability.

Here, we are reporting that, toward the realization of a high-performance PIC, we have developed, a discrete 1550 nm AlGaInAs quantum well BH laser and have fabricated a 1550 nm widely wavelength tunable laser, as the first case for an AlGaInAs/InP-based laser, which is integrated with a 12 channel-DFB (Distributed feedback) laser array and a semiconductor optical amplifier (SOA).

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2. 1550 nm AlGaInAs/InP BH LASER

2.1. Device Structure and Static Characteristics

Since AlGaInAs-based materials have larger band offset of a conduction band as comparing to GaInAsP-based materials and since an overflow of electrons can be controlled, the improvement of the characteristics at high temperature range is expected. Therefore, we have fabricated a discrete 1550 nm AlGaInAs/InP quantum well BH laser, and then evaluated its characteristics and confirmed the impact, before fabricating a photonic integrated circuit. The structure of the fabricated device in this time is a conventional BH structure that has an active layer that consists of the AlGaInAs compressive strain quantum well layer, and the mesa stripe (including the active layers) buried with InP layers of p-type and n-type. The crystal growth has been implemented by MOCVD (metal organic chemical vapor deposition). The device used for the evaluation is a fabry-perot (FP) laser which has 300 μm of cavity length and cleavage planes at the both end facets.

The injection current-to-optical power output (L-I) characteristics of the device fabricated this time are shown in Figure 1. Operation temperatures are 25, 45, 65 and 85℃ respectively. From this result, threshold currents are obtained as 7.9 mA at 25℃ and 20 mA at 85℃, and threshold current density at 25℃ is approximately 1.5 kA/cm^2, and then an equivalent values to the GaInAsP/InP-based BH laser in same design (for optical confinement factor and such) is obtained. Therefore, this can be considered that a good re-growth interface is obtained.

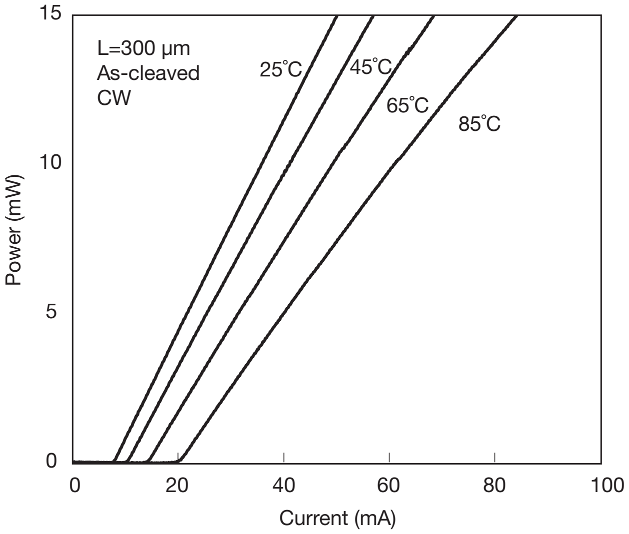

Figure 1 L-I characteristics of the 1550 nm AlGaInAs/InP BH laser.

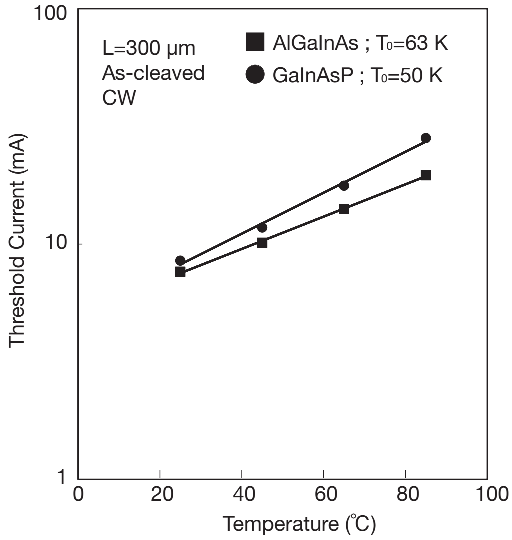

Figure 2 Temperature dependence of the threshold current.

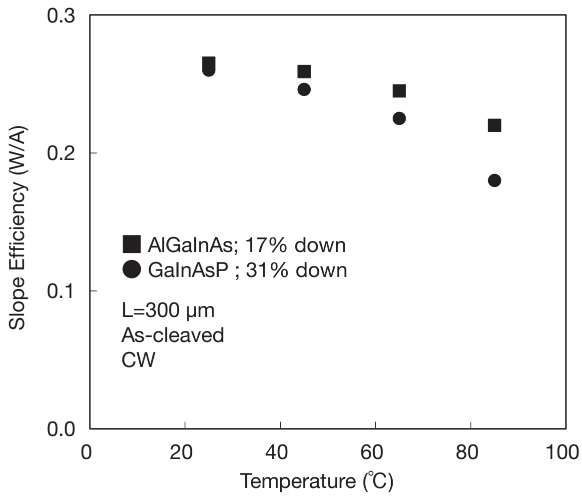

Figure 3 Temperature dependence of the slope efficiency.

Temperature dependences of the threshold current and the slope efficiency are shown in Figure 2 and Figure 3, respectively. For comparison, the result of a GaInAsP/InP-based BH laser fabricated in much the same design with a quantum well number and an optical confinement factor. From this result, the characteristic temperature (T_0) was 63 K for the AlGaInAs-based BH laser and 50 K for the GaInAsP-based BH laser, therefore, AlGaInAs-based material offered better result. Also, degradations of the slope efficiency at the temperature range of 25 – 85℃ were -17% for the AlGaInAs-based BH laser and -31% for the GaInAsP-based BH laser, therefore, the AlGaInAs-based material offered better result. With those results, improvements of the temperature characteristics by using the AlGaInAs-based material were confirmed.

2.2. Reliability Test

It is generally considered that materials which include Al are easily oxidized by oxygen or moisture in the air and a control of the re-growth interfaces is difficult. In the case of the BH laser this time, since the active layer which consists of AlGaInAs-based materials is processed to mesa shape by etching, the side surfaces of the AlGaInAs active layer are exposed in the air, and therefore influences on the reliability due to defects on the re-growth interface during burying and growing is of concern.

This time, we have made a control of re-growth interfaces by optimizing mesa treatment before burying and growing of the mesa. The results of the APC (auto power control mode) test for the AlGaInAs/InP-based BH laser fabricated this time are shown in Figure 4. The device used for the test is a fabry-perot (FP) laser which has 300 μm of cavity length and cleavage planes at the both end facets. The test condition is 20 mW of optical output power at 85℃ at an ambient temperature.

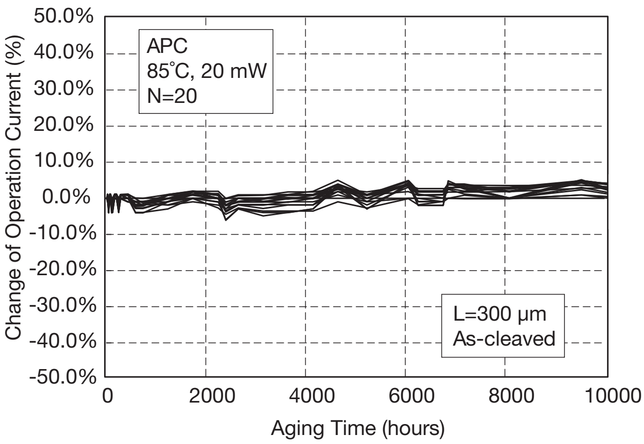

Figure 4 Result of the reliability test.

From this result, noticeable changes of the operation current have not been observed after 10,000 hours elapsed. The increase rate of the operation current is approximately 5% or less and the same result as in the GaInAsP/InP-based BH laser is obtained. The result observed of the sample by plan view TEM (transmission electron microscope) after 2500 hours elapsed is also shown in Figure 5. In the area of approximately 100 μm of the mesa stripe direction, which is observed this time, no dislocation occurred to an active layer or the mesa side wall. That is, we conclude that the influence initially feared on the reliability of the re-growth interface could be reduced.

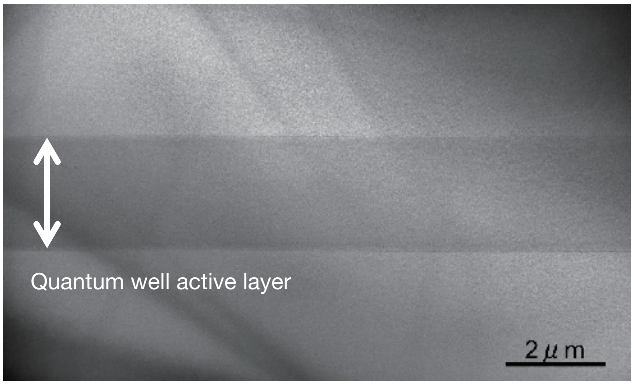

Figure 5 Plan view TEM image.

3. 1550 nm AlGaInAs / InP BH WAVELENGTH TUNABLE LASER

3.1 Advantages of Using the AlGaInAs-based Materials for Achieving a Low Power Consumption

We have commercialized a 1550 nm widely wavelength tunable laser module using GaInAsP/InP-based materials. The wavelength tunable light source, being the key component, consists of a 12-channel DFB laser array, bending waveguides, a multi-mode interference (MMI) coupler and a semiconductor optical amplifier (SOA), and produces more than 40 nm of wavelength tunable range in total by changing channels with approximately 4 nm wavelength variability par channel by heat[2]. In this case, the range of temperature variation required for wavelength tuning is approximately 40℃.

From the above, in the construction of tuning wavelength by heat, the temperature of DFB laser is controlled by a thermoelectric cooler (TEC), therefore, a power consumption for the laser module includes a power consumption of the TEC as well as a power consumption of the chip. The illustration of the relations between the total power consumption of the laser module, the ambient temperature and the temperature of the laser chip is shown in Figure 6. When an external ambient temperature is low, the chip temperature is increased by the TEC, thus the total power consumption increases with an increasing of the predefined operation temperature of the chip. On the other hand, when an external ambient temperature is high, the chip temperature is decreased by the TEC, thus the total power consumption increases with a decreasing of the predefined operating temperature of the chip. As seen from the above, the total power consumption of the module is in a trade-off relation that is it is related to the external ambient temperature, however, the total power consumption of the module is lager indeed when the external ambient temperature is high and the predefined operation temperature of the chip is low, because of the influence of the temperature increasing by the self-heating of the chip. In the case of our current products, the predefined operation temperature of the chip is controlled within the range of 15-55℃. This is because a degradation of the laser characteristics is large, related to an increase of the operation temperature for the chip with GaInAsP-based materials. That is, by using AlGaInAs-based materials superior at high-temperature characteristics and by specifying a predefined operation temperature range of the chip as high as 30-70℃, it is possible to reduce the total power consumption of the module.

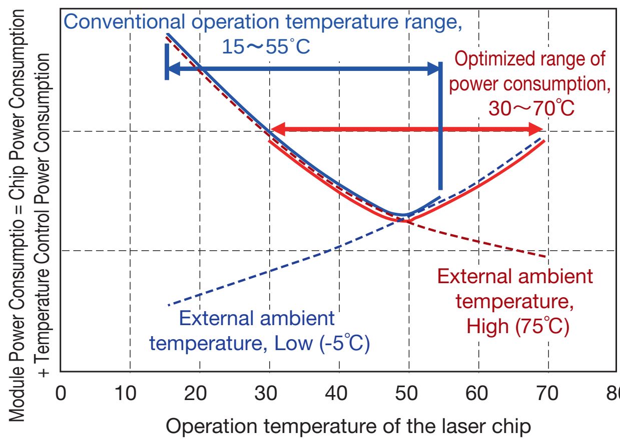

Figure 6 Power consumption of the laser module.

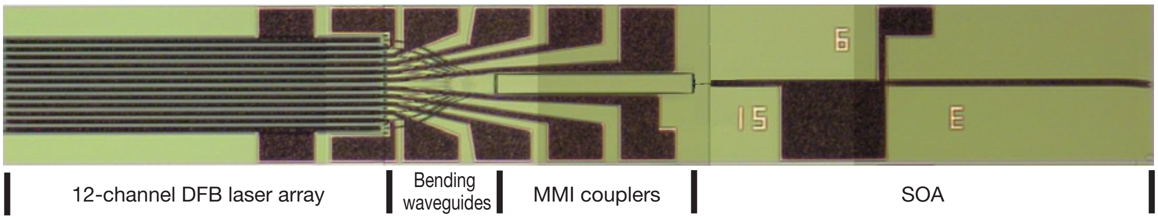

Figure 7 Picture of a 1550 nm AlGaInAs/InP wavelength tunable laser.

3.2 Structure and Characteristics of the 1550 nm AlGaInAs/InP BH Wavelength Tunable Laser

As an application to the optical integrated devices of the AlGaInAs/InP-based BH laser, we have fabricated a wavelength tunable laser. The picture of the wavelength tunable laser device fabricated this time is shown in Figure 7. The construction of the device consists of a 12-channel DFB laser array of AlGaInAs-MQW (Multiple Quantum Well) BH, bending waveguides, a multi-mode interference (MMI) coupler and a SOA of AlGaInAs-MQW BH[3), 4)].

The device size is 500 μm x 3600 μm, the length of the DFB laser is 1200 μm and the length of the SOA is 1400 μm. The reflection at the end faces is inhibited by bending waveguides and an anti-reflection coating on the end facets. Also, the laser is designed so that it can be used over a wide wavelength range over 36 nm or more by adjusting the pitch of the gratings of each of the DFB lasers and a temperature control.

In the wavelength tunable laser fabricated, the DFB laser is driven by a constant current and an optical output is controlled by the SOA current. The temperature control of the wavelength tuning is predefined at 30-70℃ with taking into account the low power consumption. The injection current-to-optical power output characteristics of the wavelength tunable laser are shown in Figure 8. Here, it shows the characteristics of three typical devices (short, middle and long wavelengths) of the 12-channel DFB lasers for each temperature. With all DFB lasers in the integrated device, optical output of more than 90 mW at 30℃ and of more than 50 mW at 70℃ was obtained[5), 6)].

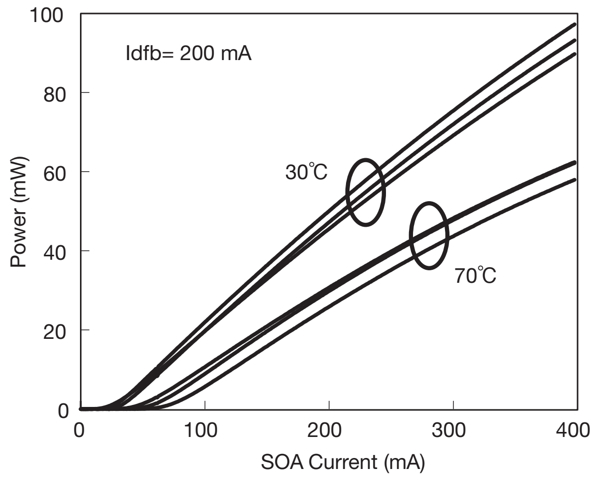

Figure 8 L-I characteristics of the wavelength tunable laser.

Also, the result of the temperature dependence of the SOA operation current is shown in Figure 9. DFB operation current is 200 mA constant and the SOA operation current is controlled as maintaining optical output constant at 40 mW. For comparison, the result of the GaInAsP-based wavelength tunable laser is also shown. From this result, it is confirmed that there is no difference of the SOA operation currents in both laser at the low temperature range of 20-30℃, however the SOA operation current can be lower with the AlGaInAs-based materials at the operation temperature of 30-70℃. Especially at the operation temperature of 70℃, it is confirmed the 14% of reduction of the SOA operation current.

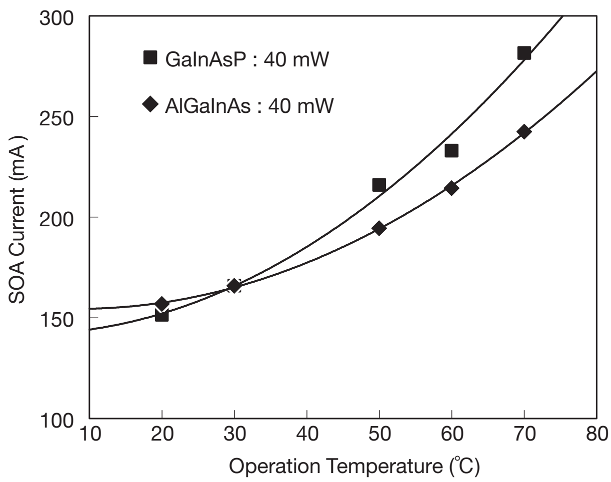

Figure 9 Temperature dependence of the SOA operation current.

Figure 10 shows the output saturation characteristics with 200 mA of DFB current at the 70℃ of operation temperature. For comparison, it also shows the result of the GaInAsP-based wavelength tunable laser. From this result, superior values, such that saturation current and saturation output are 750 mA and 90 mW respectively with the AlGaInAs-based wavelength tunable laser, are obtained compared to 700 mA and 75 mW with the GaInAsP-based wavelength tunable laser[5)]. This is the highest optical output in the previous reports for DFB array integrated type of wavelength tunable laser. Moreover, in the integrated devices, this can demonstrate the superior characteristics of AlGaInAs-based materials at high temperature and high current.

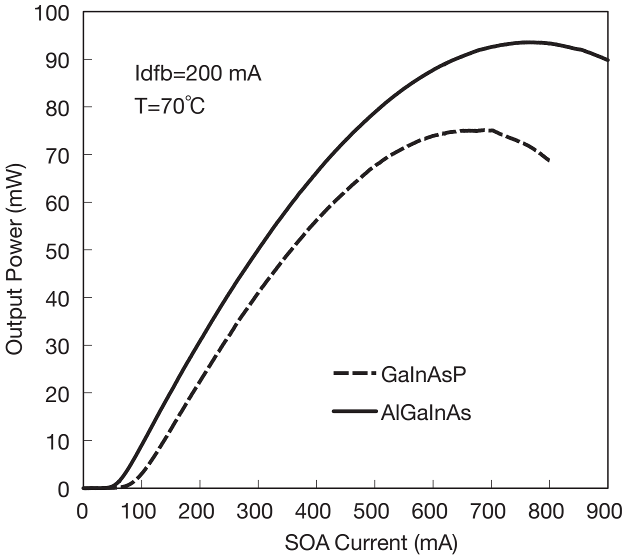

Figure 10 Comparison of the L-I characteristics at 70℃ .

Next, we will explain the important aspect of the wavelength characteristics the light signal source. The oscillation spectrum of the wavelength tunable laser is shown in Figure 11. Side mode suppression ratio (SMSR) can be obtained at a high value of more than 45 dB over wide wavelength range of approximately 40 nm. The DFB current dependency of the spectrum line width of the three typical devices is shown in Figure 12. The line width is measured by the delayed self-heterodyne method at the temperature of 30℃ with the constant SOA current of 150 mA. From this result, the spectrum line widths of less than 300 kHz are obtained for more than 200 mA DFB current in all wavelength ranges. These values obtained are equivalent results compared to the characteristics of the GaInAsP-based wavelength tunable laser, and it can be confirmed that there is no negative influence on the wavelength characteristics when using the AlGaInAs-based materials.

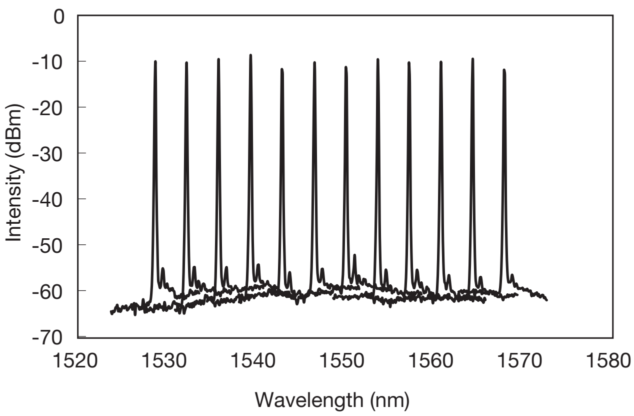

Figure 11 Laser spectrum of the wavelength tunable laser.

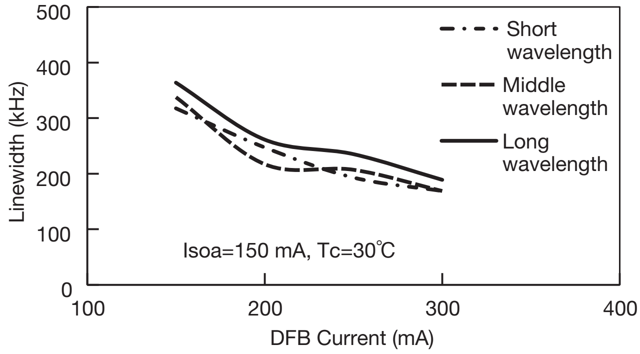

Figure 12 DFB current dependence of the spectrum line width.

3.3 Characteristics of the1550m AlGaInAs/InP BH Wavelength Tunable Laser Module

To confirm an optical output and an impact of reduction in the power consumption under the condition close to a practical use, we have fabricated butterfly-type simplified modules and have evaluated the AlGaInAs/InP BH wavelength tunable laser developed this time.

Figure 13 shows optical output characteristics of three typical wavelengths (short, middle and long wavelengths) of the wavelength tunable laser module fabricated this time. The optical output at the fiber end was measured with a constant DFB operation current of 200 mA at LD temperature of 30, 50 and 70℃. From this result, the fiber coupled power obtains 130 mW at 30℃, 100 mW at 50℃ and 80 mW at 70℃ for all wavelength with an SOA of 1000 mA. Compared to the result of the device evaluation in the previous section, the saturation current is higher, because the heat radiation of the self-heating of the device is improved by being installed in the module.

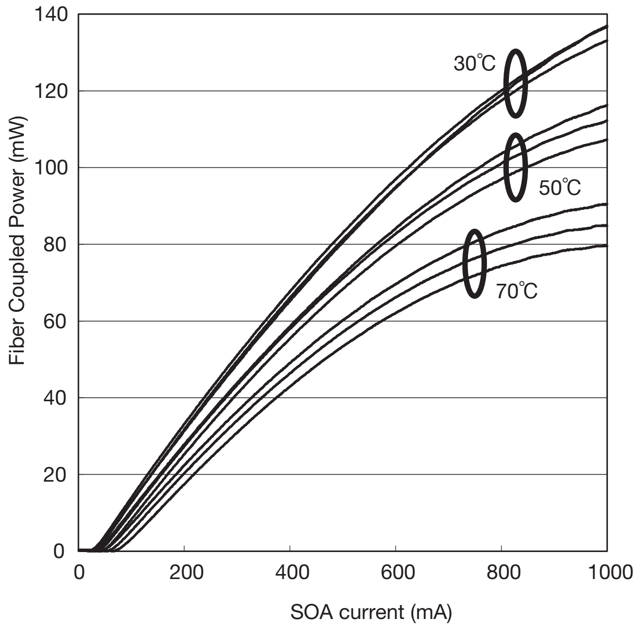

Figure 13 L-I characteristics of the butterfly-type tunable laser module.

Figure 14 shows the result of the LD operation temperature dependence of the TEC power consumption and the SOA operation current. The condition of the module operation is an optical output of 40 mW and the case temperature of 80℃. From this result, it is found that the TEC power consumption of the module is decreasing inversely proportional as LD operation temperature is increasing. That is because the SOA operation current increases to obtain a constant output with the increase of the LD operation temperature, and then the TEC output is limited by its self-heating. Also, the TEC power consumption becomes 3 W at 15℃ LD operation temperature and 1.7 W or less at more than 30℃. Therefore, it is found that shifting the LD operation temperature to the higher temperature can decrease the TEC power consumption substantially by about half. From this result, we can say that the usages of the AlGaInAs/InP-based materials are prospective technique for a low power consumption of the optical integrated devices.

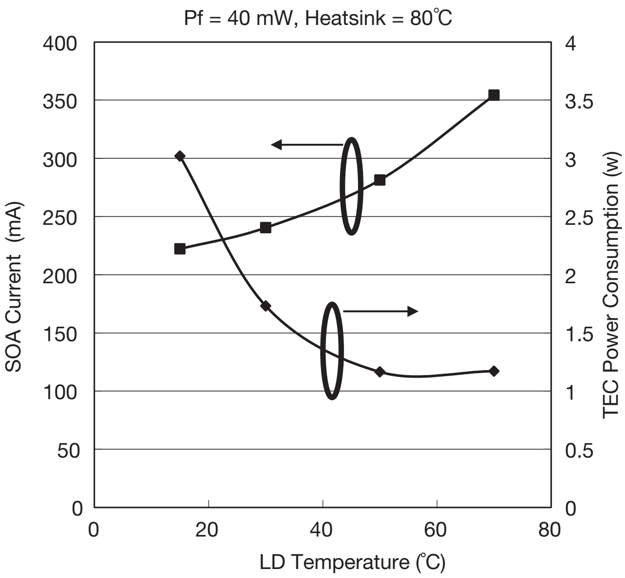

Figure 14 Operation temperature dependence of the TEC power consumption and the SOA operation current.

4. CONCLUSION

We have developed a BH laser using 1550 nm AlGaInAs/InP-based materials toward the realization of a high-performance photonic integrated circuit. First, we have confirmed that the initial characteristics and the reliability on a discrete FP laser, and then, with that result, we have confirmed that the temperature characteristics are better and the reliability is equivalent as compared to the GaInAsP/InP-based materials. Subsequently, as the application to photonic integrated circuits using these techniques, we have fabricated a 1550 nm wavelength tunable laser which is integrated with 12 channel-DFB laser array and an SOA as the first case for AlGaInAs/InP-based materials. From this result, an optical output more than 90 mW at 30℃ and 50 mW at 70℃ are obtained on the all 12 channels. Moreover, 90 mW of optical output saturation current characteristic at the 750 mA is obtained. Therefore, as the DFB array integrated wavelength tunable laser, the highest optical output in previous reports is obtained. Moreover, as fabricating a laser module and predetermining the operation temperature for 15 to more than 30℃, it is confirmed that the TEC power consumption can be reduced by approximately 50%.

From the result above, we substantiate that the BH structure using AlGaInAs/IP-based materials is superior to the BH structure using GaInAsP-based materials for the optical output characteristics at high temperature and at the time high injection current, and high temperature operation, high output performance and possibility of a significant reduction of the power consumption on the wavelength tunable laser and the wavelength tunable laser module fabricated as an example of the photonic integrated circuit. That is, we can confirm that AlGaInAs/IP-based material is a prospective technique for the realization of a high-performance photonic integrated circuit.

REFERENCES

1) T. Yamamoto, K. Takada, M. Matsuda, S. Okumura, S. Akiyama, and M.Ekawa: “1.55-μm-Wavelength AlGaInAs Multiple-Quantum-Well Semi-Insulating Buried-Heterostructure Lasers” Conf. Dig., ISLC 2006, pp. 15-16.
2) T. Mukaihara, T. Kurove, T. Kimoto, and A. Kasukawa: Proc., ECOC 2003, We. 4. P.81, pp. 718-719, Sept. 2003.
3) N. Iwai, M.Wakaba, M. Kobayakawa, K. Kiyota, T. Kurobe, G. Kobayashi, T. Kimoto, S. Tamura, T. Mukaihara, N. yokouchi, H. Ishii, and A. Kasukawa: “1550 nm AlGaInAs/InP widely Tunable BH Laser based on Arrayed DFB” Conf. Dig., ISLC 2012, TuA2.
4) M. Wakaba, N. Iwai, M. Kobayakawa, K. Kiyota, T. Kurobe, G. Kobayashi, T. Kimoto, S. Tanura, T. Mukaihara, N. Yokouchi, H. Ishii, A. Kasukawa: “DFB Array Integrated Wavelength Tunable Light Source Having a 1.55 μm AlGaInAs Buried Structure”, IEICE Society Conference 2012, C-4-17.
5) M. Wakaba, N. Iwai, K. Kiyota, H. Hasegawa, T. Kurobe, G. Gobayashi, E. Kaji, M. Kobayakawa, T. Kimoto, N. Yokouchi, and A. Kasukawa: “High Power Operation at High Temperature of AlGaInAs/InP Widely Tunable BH Laser”, Conf. Dig., OECC 2013, MK2-4.
6) K. Kiyota, M. Wakaba, N. Iwai, T. Kurobe, G. Kobayashi, E. Kaji, M. Kobayakawa, T. Kimoto, N. Yokouchi: “DFB Array Integrated Wavelength Tunable Laser Having an AlGaInAs-based BH Structure”, IEICE General Conference 2013, C-4-1.