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Low Power Consumption Operation of a 1.06-μm-Wavelength Single-Mode Laser for Efficient Second-Harmonic-Generation Green Laser Modules

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1. Introduction

Semiconductor laser diodes have been used in various fields such as the communication, spectroscopy, and sensing fields. In recent years, 1.06-μm semiconductor lasers have been expected as light sources of green lasers that use second harmonic generation (SHG) for mobile electronics applications. High-brightness 530-nm green laser light can be obtained from 1.06-μm laser light via a periodically polled lithium niobate (PPLN) waveguide by using the SHG effect. Since it is important to match the laser wavelength with the quasi-phase matching (QPM) wavelength of PPLN waveguide, which is as narrow as 0.2 nm, single-mode lasers such as the distributed Bragg reflector (DBR) laser [1] or distributed feedback (DFB) laser [2] are required. In particular, a DFB laser integrated with a semiconductor optical amplifier (SOA) is preferable because it suppresses mode hopping and wavelength fluctuation under direct modulation [3]. However, due to the difference of temperature dependence between the lasing and QPM wavelengths, a thermo-electric cooler (TEC) is usually used to keep the temperature constant. For mobile electronics applications, the total power consumption should be reduced to less than 1 W and hence the wavelength adjustment scheme without a TEC is desired, because the power consumption in a TEC is very large (up to several watts).

In this paper, we present a micro-heater-loaded 1.06-μm-wavelength DFB laser integrated with a SOA for TEC-free operation. The micro heater is considered to be effective for the low-power consumption adjustment of the difference between the lasing and QPM wavelengths, which varies with environmental temperature change. We report wavelength adjusted operation with a high output power, single-mode and very low power consumption in the temperature range from 10 to 60°C.

2. Device structure

The developed device consists of a 500-μm-long DFB laser section and a 1500-μm-long SOA section. These sections are integrated in the longitudinal direction with a separation of 400 μm in order to be isolated electrically and thermally from each other. Antireflection and high reflection coatings are applied to the facets of the SOA and DFB laser sections, respectively. The waveguide in the SOA section is slightly bended to decrease reflectivity further. To suppress the wavelength fluctuation, the DFB laser is driven by a constant current, and the optical power is controlled by the current injected into the SOA.

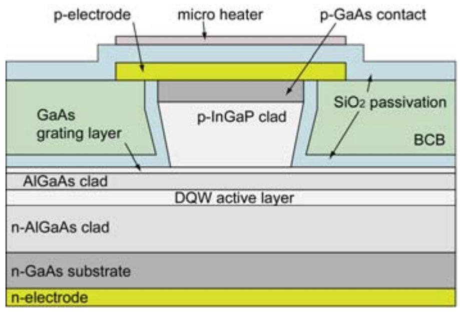

Fig. 1 Schematic cross-sectional view of the DFB laser section

Figure 1 shows a schematic cross-sectional view of the DFB laser section. An InGaAs/GaAs double quantum well (DQW) structure was applied to the active layer in all sections. A uniform Bragg grating with a period of about 160 nm was formed on the surface of the GaAs grating layer. A 2.5-μm-wide ridge waveguide was formed by wet etching and planarized by Benzocyclobutene (BCB). To compensate for the environmental temperature change, a micro heater, which can precisely control the lasing wavelength, was formed above the electrode of the DFB laser. The heater and electrode are isolated electrically from each other by inserting SiO_2, as shown in Fig. 1.

3. Device characteristics

First, we measured the temperature dependence of the lasing wavelength for the developed device. The DFB laser current and the SOA current were set to 100 and 400 mA, respectively. In Fig. 2, the black rectangles indicate the lasing wavelength without the heater adjustment at each temperature. From these plots, the temperature coefficient of the lasing wavelength shift was derived to be 0.083 nm/K. The red circles indicate the lasing wavelength with the heater adjustment by current injection into the micro heater at each temperature. Therefore the coefficient was successfully controlled with the micro heater to 0.058 nm/K, the value of the QPM wavelength shift of PPLN waveguide shown in [4]. Regarding the heater characteristics, a high tuning efficiency of 20 pm/mW and wide tuning range of 3

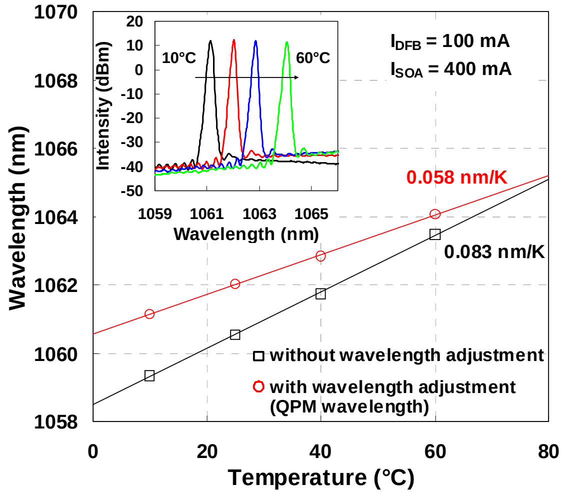

Fig. 2 Lasing wavelength with and without heater adjustment as a function of temperature. Inset: Optical spectra with the heater adjustment.

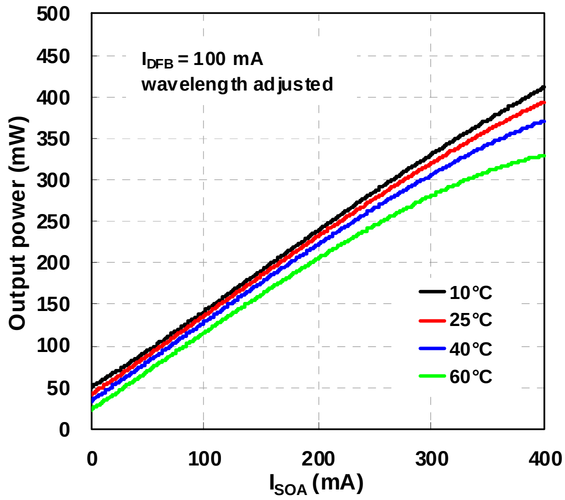

Fig. 3 Continuous wave L-I characteristics under wavelength adjusted operation at various temperatures

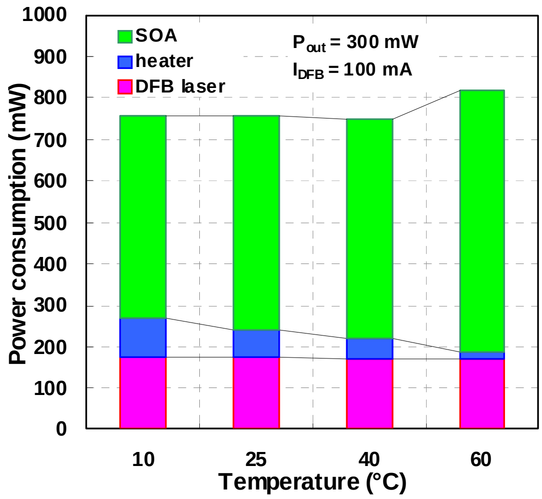

Fig. 4 Total power consumption at various temperatures

nm were achieved. As a result, the heater consumption power was less than only 100 mW for the above adjustment. Optical spectra under wavelength adjusted operation are also shown in the inset of Fig. 2. The spectra remained single-mode with a side mode suppression ratio (SMSR) of larger than 40 dB in each temperature condition.

Continuous wave light-current (L-I) characteristics under wavelength adjusted operation are shown in Fig. 3 at temperatures of 10, 25, 40, and 60°C. The DFB laser current was set to 100 mA. The output power increased with a maximal slope efficiency of 1.0 W/A, and more than 400 mW of kink-free output power was achieved at 10°C. Moreover, more than 300 mW of output power was achieved even at high temperatures of 60°C. This high output power and high slope efficiency originated from a high internal quantum efficiency of 0.95 and low internal loss of less than 2 cm^{-1}, which were estimated from L-I characteristics of simulataneously fabricated Fabry-Perot lasers with several cavity lengths.

Figure 4 shows the total power consumption of wavelength adjusted operation in different temperature conditions. The total power consumption consisted of the power consumption of the DFB laser, micro heater, and SOA. Operation with a high output power of 300 mW was achieved at a power consumption of less than 820 mW even at a high temperature of 60°C. This power consumption was much less than the temperature stabilizing operation with a TEC, which is apparently due to the local temperature control with a micro heater. From this output power and power consumption, 100 mW of output power of green light and more than 10% of wall-plug efficiency (WPE) can be expected by properly designing the PPLN waveguide.

4. Summary

A micro-heater-loaded 1.06-μm-wavelength DFB laser integrated with a SOA was developed. By using a micro heater, the temperature coefficient of the lasing wavelength shift was successfully controlled to be the same as that of PPLN waveguide in the temperature range from 10 to 60°C. More than 300 mW of kink-free output power and single-mode spectra with a SMSR larger than 40 dB were achieved under wavelength adjusted operation at each temperature. This operation was achieved with a power consumption of less than 820 mW, which is much less than the power consumption of temperature stabilizing operation by using a TEC. These results show that our developed single-mode laser is promising as the light source of low-power-consumption green lasers that use SHG.

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