LETTER

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2-µm wavelength tunable distributed Bragg reflector laser

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Abstract: We demonstrate a tunable distributed Bragg reflector (DBR) laser diode operating in the 2-µm region. A strained InGaAs multi-quantum well is used for the active region, and InGaAs is used for the passive region in the 2-µm DBR laser. The fabricated DBR laser emits a single-mode continuous wave at 2.02 µm, and the output power exceeds 6 mW at room temperature. A wavelength tuning range of about 10 nm is achieved by controlling of injection currents to the DBR regions.

Keywords: semiconductor laser, tunable laser, gas sensing

Classification: Integrated optoelectronics

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1 Introduction

Semiconductor lasers emitting in the 2-µm wavelength region are very useful light sources for sensing trace gases such as CO_2 and N_2O in the environment. There have already been several studies related to 2-µm semiconductor lasers [1, 2, 3]. Single mode InP-based semiconductor lasers, such as distributed feedback (DFB) lasers, are particularly attractive candidates because of their advantages including their lasing characteristics, processing technologies and reliability, which have matured through the development of telecommunications lasers [4, 5, 6]. Those lasers have strained multi quantum wells (MQW) with InGaAs as the active layer. Wavelength tuning can be achieved by current-induced temperature tuning of the active region. However, the wavelength tunable range of a DFB laser is limited to around a nanometer. On the other hand, with distributed Bragg reflector (DBR) lasers we can realize wideband wavelength tuning. A DBR laser has an active region that provides optical gain and a DBR region whose refractive index can be changed by controlling the injection current. A wider wavelength tuning range of 5~10 nm can be expected by controlling the refractive index of the DBR region [7]. However, no tunable DBR lasers operating in the 2-µm region have yet been reported.

In this paper, we describe a 2-µm DBR laser. It can achieve wideband wavelength tuning in the 2-µm region at room temperature.

2 Device structure and fabrication

Fig. 1 shows the structure of the 2-µm DBR laser we fabricated. The laser consists of a semiconductor optical amplifier (SOA) region, a front DBR region, an active region, a phase control (PC) region, and a rear DBR region. Strained InGaAs MQWs are used in the active and SOA regions, and InGaAs is used as the passive

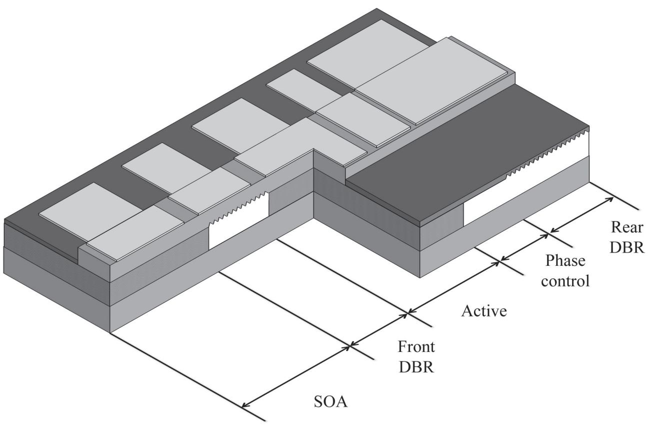

Fig. 1. Device structure of 2-µm DBR laser.

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layer for the DBR and PC region. We approximated the refractive index of InGaAs in the 2-µm wavelength region by using the numerical method described in ref. [8] when designing the passive layer (DBR and PC region), and we determined the thickness of the passive layer so as to maximize the optical coupling between the active and passive layers.

The 2-µm DBR laser was fabricated as follows. First, MQW active layers (InGaAs six-well MQW layer, $\lambda_{PL} = 2.02$ µm) for the active and SOA regions were grown on an n-InP substrate. Next, passive layers for the DBR region and the PC region (InGaAs bulk layer, $\lambda_{PL} = 1.65$ µm) were selectively grown and butt-jointed to the active and SOA regions on the same n-InP substrate. Then, grating patterns were formed on the front and rear DBR regions by using electron beam lithography. The pitch of the grating pattern was set to obtain a Bragg wavelength of 2015 nm. The coupling coefficient κ of the corrugation grating was designed to be 25 cm^{-1}, where the grating depth was carefully controlled by wet chemical etching. An over-cladding p-InP layer was regrown, and then a ridge mesa structure was formed by dry and wet chemical etching. Metal electrodes were then formed. Finally, both the front and rear facets of the 2-µm DBR laser were coated with antireflective film.

3 Experiment and results

The light output characteristics of the 2-µm DBR laser were measured at 25°C without injecting current into the passive layer. The threshold current was 20.2 mA. The output power was 6.45 mW when the injection currents input into the active layer (I_{act}) and the SOA layer (I_{soa}) were both fixed at 100 mA. The lasing spectrum is shown in Fig. 2. The lasing wavelength was 2018.8 nm, and this result agrees well with the designed value mentioned above.

Next, we measured the wavelength tuning characteristics of the 2-µm DBR laser. In this experiment, the front and rear DBR regions were connected to one electrode, and the I_{act} and I_{soa} were both fixed at 100 mA at 25°C. Fig. 3(a) shows the lasing wavelength when the DBR region current (I_d) was tuned to 50 mA, and

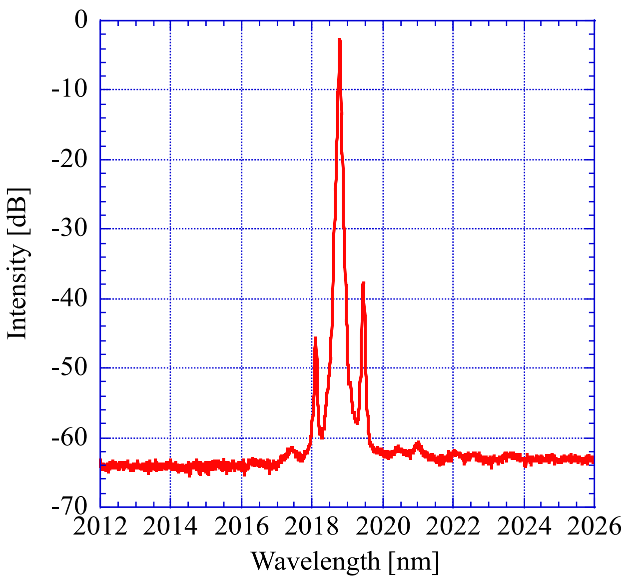

Fig. 2. Lasing spectrum.

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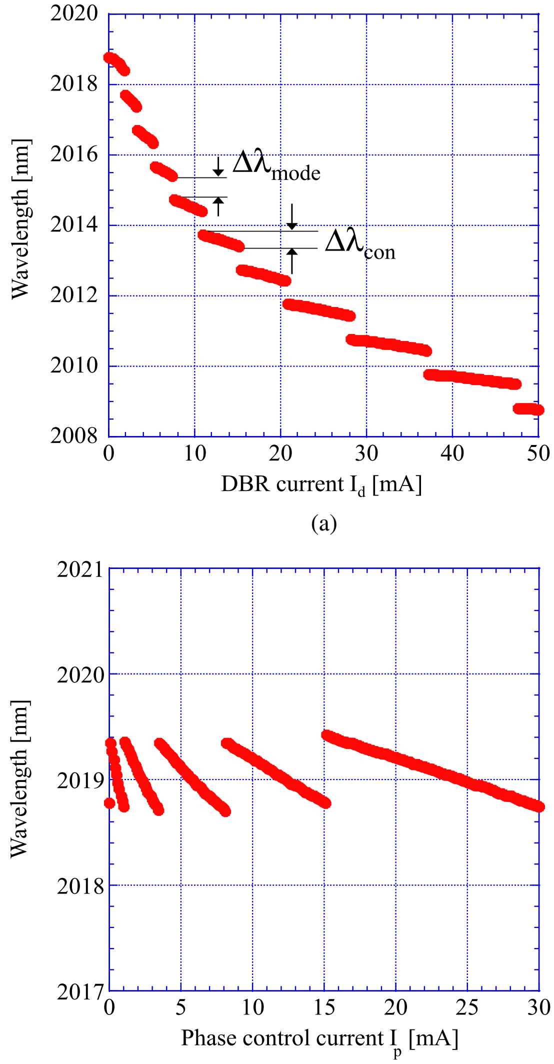
Fig. 3(b) shows the lasing wavelength as a function of the phase control region current (I_p). Consequently, the lasing wavelength was tuned from 2018.8 to 2008.8 nm, and a tuning range of 10 nm was achieved by controlling I_d and I_p. The coupling coefficient of the grating was estimated from the experimental results as follows. As shown in Fig. 3(a), the continuous wavelength change and the mode hopping are repeated as I_d increases. The relation between the continuous tuning range $\Delta\lambda_{con}$ and the cavity mode spacing $\Delta\lambda_{mode}$ is expressed as



(b)

Fig. 3. Lasing wavelength for (a) DBR current I_d and (b) Phase control current I_p.

$$\frac{\Delta\lambda_{con}}{\Delta\lambda_{mode}} = \frac{L_{eff}}{L_a + L_p} \tag{1}$$

where L_{eff} is the effective length of the DBR mirrors, L_a is the length of the active region, and L_p is the length of the phase-control region. From this equation, the effective length of the DBR mirrors is estimated to be 255 µm. In this study, L_a and L_p were 400 and 150 µm, respectively. The coupling coefficient κ can be calculated using the effective length [7, 9]. The estimated κ was 26 cm^{-1}. This result agrees well with the designed value mentioned in section 2.

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The tunable characteristics of the 2-µm DBR laser were evaluated by comparing them with those of a 1.55-µm DBR laser as shown in Fig. 4. The horizontal and vertical axes, respectively, are the injection current density for the DBR region and the refractive index variation in the InGaAs bulk layer estimated from the amount of Bragg wavelength shift. In this study, the band-gap wavelength of the DBR region was 1.4 µm for the 1.55-µm DBR laser. The variation in the refractive index of the 2-µm DBR laser is larger than that of the 1.55-µm DBR laser. With the wavelength tuning by carrier effect as a result of current injection, the coefficient of the carrier effect depends on the effective electron mass corresponding to the band-gap wavelength of the DBR region [10]. Therefore, the 2-µm DBR laser has an advantage over tunable semiconductor lasers operating in the 1.55-µm region because it can use the DBR region, which has a longer band-gap wavelength.

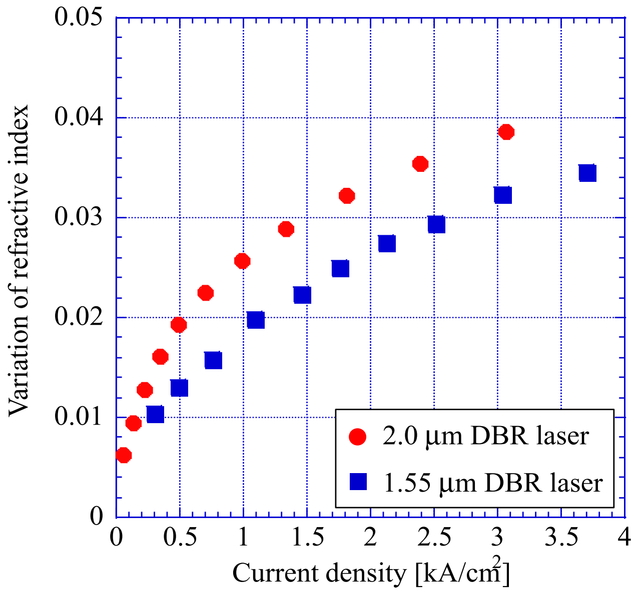

Fig. 4. Variation of refractive index in 1.55-µm DBR laser and 2.0-µm DBR laser.

4 Conclusion

We demonstrated a 2-µm DBR laser. We achieved an output power of 6.45 mW when we set both I_a and I_s at 100 mA. We achieved a wavelength tuning range of 10 nm by controlling the injection current input into the DBR and phase control regions. The 2-µm tunable DBR laser presented in this study could be used as a light source for trace gas sensing in the 2-µm region.

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