Temperature Characteristics of λ=1.3 μm GaInNAs/GaAs Quantum Well Lasers Grown by Chemical Beam Epitaxy

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1. Introduction

Long-wavelength vertical-cavity surface-emitting lasers (VCSELs) have attracted great interest for use not only in high-speed local area networks (LAN) but also in wide area networks (WAN). However, the conventional InP-based long-wavelength VCSELs have some problems, such as insufficient temperature characteristics and difficulty in fabrication of VCSEL structures. Recently, a GaInNAs alloy, which can be grown on a GaAs substrate, was proposed to solve the difficulties in InP-based long-wavelength lasers [1]. The GaInNAs alloy is expected to have excellent temperature characteristics due to its large conduction band offset. In addition, GaInNAs VCSELs can use the same structural layout as GaInAs/GaAs VCSELs, such as an AlGaAs/GaAs distributed Bragg reflector (DBR) and a selectively oxidized AlAs current confinement structure [2]. Recently, excellent high temperature characteristics of GaInNAs/GaAs edge emitting lasers were reported by many groups. In addition, room temperature continuous-wave operations of 1.2 - 1.3 μm VCSEL have been reported [3-6]. These results are advantageous for low cost optical module without temperature controller. However, details of temperature characteristics are still unclear. In this paper, high temperature lasing characteristics of GaInNAs/GaAs laser emitting at 1.3 μm range grown by chemical beam epitaxy (CBE) are investigated.

2. Growth and Fabrication of GaInNAs/GaAs Quantum Well Lasers

Laser wafers were grown by combination of low-pressure metal-organic chemical vapor deposition (LP-MOCVD) and CBE. At first, a 1.5 μm-thick n-$Al_{0.42}Ga_{0.68}As$ layer was grown by LP-MOCVD at 690°C. In succession, a $Ga_{0.655}In_{0.345}N_yAs_{1-y}$/GaAs ($y$ = 0.080 or 0.095) double quantum well (DQW) active layer with the well width of 7.5 nm and the barrier width of 25 nm was grown by CBE at 475°C. Triethylgallium (TEGa) and trimethylindium (TMIn) were used for group-III precursors, and AsH_3 and radical nitrogen discharged at radio frequency (rf) radical beam cell from pure nitrogen gas (N_2) were used for group-V precursors. The 120 nm-thick GaAs separate confinement heterostructure (SCH) layer grown at 540°C. An *In-situ* thermal annealing was performed at 600°C for 45 minute under As_2 ambient after the active layer growth [7]. Then a 1.5 μm-thick p-$Ga_{0.52}In_{0.48}P$ cladding layer and 0.1 μm-thick p^+-GaAs capping layer were grown monolithically by CBE at 540°C. Broad area contact laser with the stripe width of 50 μm was fabricated. Both facets were cleaved without any reflection coating.

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3. Measurement and Discussion of High Temperature Lasing Characteristics

The temperature characteristics of GaInNAs laser at λ = 1.27 μm and λ = 1.30 μm were investigated in detail. Figure 1 shows the cavity length dependence of the characteristic temperature T_0 of GaInNAs-LD emitting at λ = 1.27 μm (y = 0.008) and λ = 1.30 μm (y = 0.0095) with the temperature range from 10 to 80°C. The characteristic temperature decreased with decreasing cavity length for shorter cavity (< 400 μm in this experiment) devices. On the other hand, longer cavity (> 400 μm) devices show that the cavity length does not affect so much to T_0. Thus, we have to treat the data separately from shorter (< 400 μm) and longer (> 400 μm) cavity.

Temperature dependence on the inverse differential quantum efficiency for various cavity lengths was measured from the slope efficiency at each temperature, as shown in Fig. 2. Linear relation was observed for longer (> 400 μm) cavity lengths, while large deviation from the linear relation was observed for shorter cavity length. Internal quantum efficiency η_i and internal loss α_i were estimated for longer (> 400 μm) cavities from the next equation, as shown in Fig. 3 and Fig. 4, respectively.

$$\frac{1}{\eta_d} = \frac{1}{\eta_i}\left(1 + \frac{\alpha_i L}{\ln(1/R)}\right) \quad (1)$$

A differential quantum efficiency η_d can be determined as $\eta_d = 2\eta_s / h\nu$, where η_s is slope efficiency and hν is photon energy. A facet mirror reflectivity of R = 0.32 was assumed. The internal losses did not

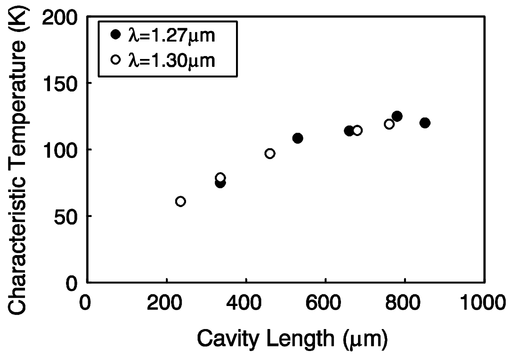
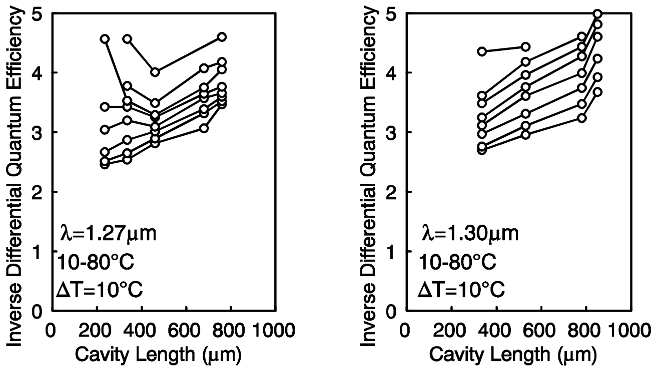


Fig. 1 Cavity length dependence on the characteristic temperature T_0 ranging from 10 to 80°C.



(a) λ = 1.27 μm (b) λ = 1.30 μm

Fig. 2 Cavity length dependence on the inverse external quantum with the temperature ranging from 10 to 80°C.

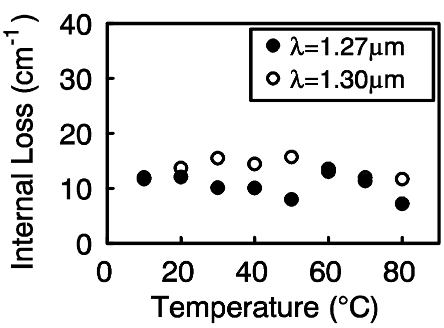


Fig. 3 Temperature dependence on the internal loss of GaInNAs/GaAs laser.

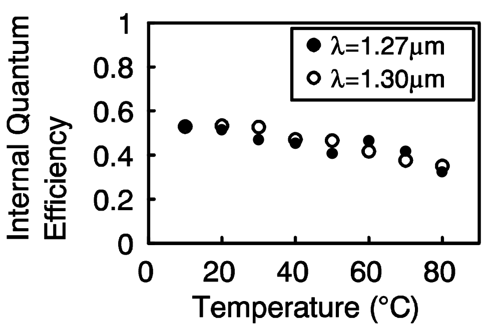
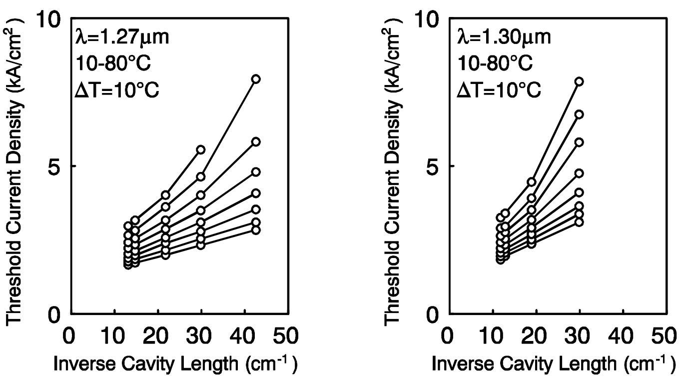


Fig. 4 Temperature dependence on the internal quantum efficiency of GaInNAs/GaAs laser.

increase with increasing temperature (even fluctuation was observed) for longer cavity devices (with lower loss). On the other hand, internal quantum efficiency decreased with increasing temperature. It is considered that non-radiative recombination center with large temperature dependence may influence the decreasing of the internal quantum efficiency due to the insufficient crystal quality of GaInNAs layer. Auger recombination may not influence because it is reported that Auger recombination does not affect the threshold current of GaInNAs/GaAs laser from hydrostatic pressure dependence of the laser threshold current [8].

Temperature dependence on the inverse cavity length dependence of the threshold current density was measured as shown in Fig. 5. Threshold current density J_{th} is expressed as Eq. (2), where J_{tr}, α_{total} and G_0 show the transparency current density, total loss and gain constant, respectively. An optical confinement factor $\Gamma = 0.0398$ was used. Gain constant and transparency current density were estimated from Fig. 5 using Eq. (2), where the internal loss and the internal quantum efficiency for each temperature were derived from Eq. (1). Temperature dependence on transparency current density and gain constant were shown in Fig. 6 and Fig. 7, respectively. The transparency current density was unchanged for all temperature range, however, gain constant decreased with increasing temperature. This tendency is the same as 0.98μm range InGaAs/GaAs laser [9].



(a) λ = 1.27 μm (b) λ = 1.30 μm

Fig. 5 Temperature dependence on the cavity length dependence of the threshold current density.

$$J_{th} = \frac{J_{tr}}{\eta_i} \exp\left(\frac{\alpha_{total}}{G_0 \cdot \Gamma} \right) \qquad (2)$$

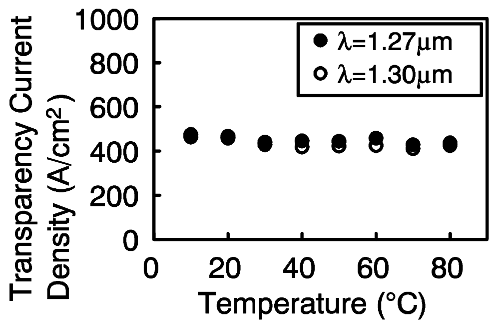


Fig. 6 Temperature dependence of the transparency current density of GaInNAs/GaAs laser emitted at λ = 1.27 μm and λ = 1.30 μm.

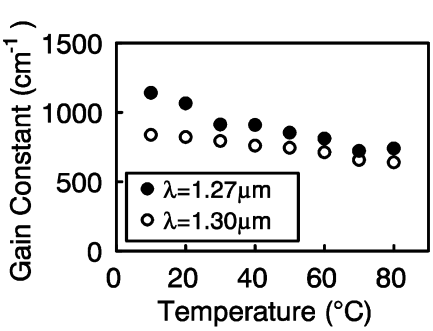


Fig. 7 Temperature dependence of the gain constant of GaInNAs/GaAs laser emitted at λ = 1.27 μm and λ = 1.30 μm.

Thus, the decrease of the gain constant is considered to be due to decreasing of gain. Unchanged transparency current density and internal loss may also express that these results were not induced by carrier overflow but be done by decreasing of gain. The smaller gain constant of λ = 1.30 μm is considered due to the poor crystal quality.

From these results, it is considered that the temperature dependence of the gain originated from the Fermi-Dirac distribution of carriers was dominant for the temperature characteristics of GaInNAs/GaAs laser in this experiment. Due to the temperature dependence on the gain, the T_0 decreases with increasing mirror loss because larger current density is required to obtain threshold gain.

4. Conclusion

In conclusion, we have evaluated the temperature characteristics of 1.3 μm-range GaInNAs/GaAs laser grown by CBE. The T_0 (20-80°C) of GaInNAs/GaAs laser varied from 60 to 130K with the cavity length. The internal loss and the transparency current density unchanged whereas gain constant changed with increasing temperature. It is considered that the temperature dependence on the gain induced these results.

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