Excellent temperature characteristics of GaIn(N)As lasers on GaAs

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We present excellent temperature characteristics of long wavelength GaIn(N)As lasers on GaAs substrates operating at 1.2-1.3µm wavelength range. Highly strained GaInAs QWs have been grown successfully by suppression of growth mode change from 2D to 3D by MOCVD. High quality GaInNAs materials are also grown by MOCVD and CBE by optimizing the growth condition. We demonstrate that highly strained GaInAs and GaInNAs QW lasers show small temperature dependence on the threshold current ($T_0>200$K) and the slope efficiency due to their large conduction band offset. High temperature operation beyond 180°C was also observed. These characteristics will be advantageous in next era optical datalinks.

1. Introduction

For the next era LANs and interconnect systems, low cost and parallel operation of optical systems are strongly demanded. From the point of compatibility to the single mode fiber network, the 1.2-1.3μm wavelength band is most suitable for a high-end optical datalink system. A vertical cavity surface emitting laser (VCSEL) is one of candidates of light sources due to its potential of 2D array, easy coupling to an optical fiber, low power consumption, and so on.

For the low cost optical datalink system, a small temperature sensitivity of laser performance is a critical issue because of removal of temperature controller and tolerance for various circumstances. However, the GaInAsP/InP system emitting at 1.2-1.3μm wavelength band has a problem on the temperature characteristic. In addition, a high reflectivity mirror is difficult for the InP-based system, resulting poor performance of long wavelength VCSELs. GaAs based materials emitting at over 1.2μm are expected for long wavelength VCSELs.

In this study, we demonstrate excellent temperature characteristics of 1.2-1.3μm wavelength lasers based on GaAs systems. The active materials of highly-strained (>2%) GaInAs and GaInNAs have been carefully optimized about the growth condition and quantum well (QW) structures. The observed lasing characteristics are comparable or better than conventional long wavelength lasers.

2. Highly-strained GaInAs Lasers

2.1 Growth of highly-strained QWs

The GaInAs QW is matured in 0.98μm lasers. The wavelength is increased by increasing indium composition and/or well thickness, however, the maximum wavelength of GaInAs QW is considered to be limited by the critical thickness. In our previous study, we found that the QW structure beyond the critical thickness was grown successfully by optimizing the growth condition [1]. Figure 1 shows photoluminescence (PL) properties for various indium compositions. Lines show theoretical critical thickness.

QWs were grown by MOCVD using TBAs which can be decomposed at lower temperature than AsH3. A low growth temperature of 550°C, high growth rate (1.5μm/h) and high V/III ratio were optimized for the growth of highly strained GaInAs QWs. These growth conditions are key issue for suppression of the growth mode change from 2D to 3D which is the main cause of the quality degradation of a high strained material. A GaInAs strained buffer layer (SBL) was inserted below the QW. The SBL improves the epitaxial surface and suppresses the clustering of indium. PL result indicates that high...
quality QWs are grown successfully even above the critical thickness and the maximum wavelength was reached beyond 1.2\textmu m.

2.2 Lasing characteristics of highly-strained QWs

A laser wafer was grown using highly strained QWs with a SBL and fabricated to 50\textmu m-wide broad stripe laser [2]. Figure 2 shows the threshold current density for various cavity lengths of Ga\textsubscript{0.62}In\textsubscript{0.38}As double QW lasers. The lasing wavelength was 1.18\textmu m. The lowest threshold current density was 170A/cm\textsuperscript{2} and a 150\textmu m long cavity device showed 500A/cm\textsuperscript{2} without facet coating.

Temperature characteristics were measured under pulsed condition as shown in Fig. 3. The temperature range was from 30\degree C to 180\degree C which was the maximum of the measurement system. Figure 4 represents a threshold current dependence on the temperature. The characteristic temperature \( T_0 \) of highly strained GaInAs laser was over 200K which is enough for suppression of the carrier leakage even at high temperature. A 1.2\textmu m GaInAs laser operated up to 180\degree C with a small-degradation of the slope efficiency. For the application of optical datalinks, a temperature dependence of threshold current and slope efficiency requires complicated control of both bias and modulation current. Thus, small change on slope efficiency of highly strained QW laser is advantageous for simple optical modules.

The lifetime measurement under constant current condition was performed for 300 hours as shown in Fig. 5. Initial aging was observed, however, the output power was almost stabilized after 100 hours. This result indicates the highly strained GaInAs laser may be enough tough in spite of the wide well thickness above the critical thickness.

On the other hand, GaInAs/GaAs system has over 200meV of \( \Delta E_c \) which is enough for suppression of the carrier leakage even at high temperature. A 1.2\textmu m GaInAs laser operated up to 180\degree C with a small-degradation of the slope efficiency. For the application of optical datalinks, a temperature dependence of threshold current and slope efficiency requires complicated control of both bias and modulation current. Thus, small change on slope efficiency of highly strained QW laser is advantageous for simple optical modules.

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The VCSEL structure of highly strained GaInAs laser is under growing. The structure may be almost the same as already commercialized VCSELs in a short wavelength range. A single mode operation of a 1.2\textmu m VCSEL can be applicable in long distance high capacity optical datalinks [3].
3. GaInNAs Lasers

Some optical communication applications require a standard wavelength of 1.3\,\mu m. To elongate the emission wavelength on the GaAs substrate, GaInNAs is expected as the most promising material. The GaInNAs is proposed by Kondow in 1995 [4] and 1.3\,\mu m edge emitting lasers and VCSELs have been already demonstrated [5, 6]. The problem of GaInNAs is poor optical quality and large threshold current of lasers due to difficulty of epitaxial growth of N-As systems. We have grown the GaInNAs by chemical beam epitaxy (CBE) [7] and metalorganic chemical vapor deposition (MOCVD) [8] for improving the crystal quality.

3.1 MOCVD Growth of GaInNAs

The growth condition for a high quality GaInNAs QW has been examined for MOCVD using DMHy as nitrogen precursor which has a lower decomposition temperature than NH_3. Figure 6 shows the PL intensity dependence on the emission wavelength for the various growth rate from 0.2\,\mu m/h to 1.0\,\mu m/h. The growth temperature was 520\,^\circ\,C. The indium composition was 31\% and 33\% and the well width was 50\,A. The emission wavelength was elongated by increasing nitrogen composition. The PL intensity of GaInAs was almost the same for each growth rate. For the case of the growth rate of 1.0\,\mu m, GaInNAs QW showed a large intensity dependence on the wavelength. By decreasing the growth rate, the wavelength dependence of the PL intensity improved and we found that the low growth rate of 0.2\,\mu m/h is the optimum for improving PL characteristics. The GaInAs QW grown at 0.15\,\mu m showed poor luminescence characteristic.

The GaInNAs is considered to be in miscibility gap and the thermal non-equilibrium condition may be important to realize homogeneous alloy. From the point of non-equilibrium growth condition, high growth rate may be required, however, low growth rate was key condition for improving the quality. The growth mechanism and further optimized condition are under investigation.

3.2 MOCVD grown GaInNAs Laser

A GaInNAs laser was grown using 0.2\,\mu m/h of growth rate for QWs. The n-side and p-side cladding layers were grown by different MOCVD system which was optimized to grow the AlGaAs cladding layers. At the both side of GaAs SCH layers, the wafer was taken out from the reactor to change the reactor. The active layer consisted of GaInNAs double QWs and GaInAs SBL which was inserted beneath the QW. The indium and nitrogen composition was 0.33 and 0.7\%, respectively. The well width was 84\,A and the emission wavelength was 1.25\,\mu m. The wafer was fabricated to a broad stripe laser.

Figure 7 shows the threshold current density versus cavity length. The lowest threshold current density was 340\,A/cm² which was the lowest for MOCVD grown GaInNAs lasers emitting at over 1.2\,\mu m [9]. The threshold current density per well is estimated to be 170\,A/cm²/well which is the lowest for GaInNAs lasers ever reported. All the reported GaInNAs lasers were plotted in Fig. 8 as the relation between threshold current density and the lasing wavelength. Our result is comparable with the conventional 1.3\,\mu m lasers.
In Fig. 9, L-I curves for the temperature range from 10°C to 180°C are drawn. Kinks in the light output curve may be due to lateral mode change. The excellent temperature characteristics were also observed for GaInNAs lasers and these are comparable with highly strained GaInAs lasers. The characteristic temperature was 210K for the temperature range between 10°C and 80°C. The change of external quantum efficiency for the temperature was almost negligible below 120°C. In this study, we demonstrated the good temperature characteristics of GaInNAs lasers with a low threshold current, for the first time.

3.3 CBE growth of GaInNAs Lasers

We have been also investigated the GaInNAs growth by chemical beam epitaxy (CBE). The GaInNAs has been grown by CBE using radical nitrogen. We have demonstrated the importance of the ion trapping for removing non-radiative centers and advantageous of the post thermal annealing [10, 11].

Figure 10 shows the temperature dependence of threshold current for different wavelength lasers grown by CBE. This is the first lasing by CBE grown GaInNAs [12]. A characteristic temperature ($T_0$) of 270K was demonstrated at around room temperature for 1.2µm sample and the laser was operated up to 170°C with a slope efficiency change ($d\eta/dT$) below 0.004dB/K. The threshold current density of a laser emitting at 1.27µm showed a worse temperature characteristic, however, $T_0$ of over 190K and up to 90°C operation was still observed. The CBE grown GaInNAs laser showed poor threshold current density compared with MOCVD grown lasers, however, optimization of growth conditions will improve the lasing performance. We believe that the crystal quality of GaInNAs is not depends on the growth technique.

5. Summary

In this study, we demonstrated 1.2µm highly strained GaInAs and 1.2-1.3µm GaInNAs lasers with excellent temperature characteristics. These lasers are grown on GaAs substrate and easily applicable to VCSELs. These lasers are promising for use in high performance optical datalink systems.

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References