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Low Threshold and High Characteristic Temperature 1.3 μm range GaInNAs Lasers Grown by MOCVD

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1. Introduction

Lasers emitting at 1.3 μm have been widely used for optical access systems and optical interconnection systems. For such applications, the lasers should meet the requirements of low threshold current and operation without the need for any cooling method in order to achieve low-cost systems. These lasers consist mostly of GaInPAs alloys grown on InP substrates. However, InP-based lasers have a poor characteristic temperature (T_0) of 50 ~ 70 K due to poor electron confinement resulting from a small conduction band offset [1]. To provide a strong electron confinement, AlGaInAs lasers on InP substrates [2], InAsP lasers on InP substrates [3] and GaInAs lasers on GaInAs ternary substrates [4] have been demonstrated. So far, a high T_0 of 143 K in 1.3 μm InAsP/AlGaInAs ridge lasers on InP substrates with facet coating in the temperature range of 25 - 85°C [5] and a high T_0 of 140 K in 1.22 μm GaInAs mesa stripe lasers on GaInAs ternary substrates with facet coating in the temperature range of 20 - 50°C were reported [4].

A GaInNAs alloy semiconductor grown on a GaAs substrate is a very attractive material for long-wavelength lasers [6]. The addition of nitrogen to GaInAs decreases the band-gap energy and the lattice constant. Therefore, the GaInNAs layer can be grown on a GaAs substrate and with band-gap energy suitable for long-wavelength-range lasers [7]. Moreover, a high T_0 of over 150 K is expected due to strong electron confinement resulting from the large conduction band offset [6]. Recently, Kondow et al. realized 1.3 μm continuous wave (CW) operation of a strained GaInNAs (In: 30%, N: 1%) single quantum-well (SQW) ridge laser grown by gas-source molecular beam epitaxy (MBE) [8]. The threshold current density (J_{th}) was 6.3 kA/cm^2. T_0 value under pulsed condition was 88 K in the temperature range of 20 - 80°C [9]. We realized room-temperature CW operation with a low J_{th} of 660 A/cm^2 and T_0 of 113 K in a 1.245 μm broad area strained GaInNAs (In: 33%, N: 0.6%) double quantum-well (DQW) laser grown by metalorganic chemical vapor deposition (MOCVD) using AsH_3 and dimethylhydrazine (DMHy) [10]. Very recently, Höhnsdorf et al. realized 1.28 μm pulsed operation with a low threshold current density of 0.8 kA/cm^2 in a broad stripe GaInNAs SQW laser grown by MOCVD using tertiarybutylalsine (TBA) and DMHy [11]. T_0 value under pulsed condition was ~100 K in the temperature range of 25 - 40°C. However, these T_0 values of GaInNAs lasers are lower than the theoretical prediction of over 150 K. While, the threshold current density of GaInNAs lasers increases with increasing nitrogen content and same In content [12]. To achieve the required lasing wavelength, the incorporation of a large amount of In is needed instead of increasing nitrogen incorporation, although this induces a strain. We recently achieved a low threshold current density of 200 A/cm^2 in a wavelength range up to 1.2 μm in a highly strained nitrogen-free GaInAs/GaAs DQW laser on a GaAs substrate by increasing the In content to 39% [10]. Therefore, the nitrogen content can be reduced to 0.5% for 1.3 μm emission.

In this paper, we present high characteristic temperature as high as 160 K in the temperature range of 20 - 80°C in a highly strained GaInNAs/GaAs DQW broad area laser at 1.29 μm at room temperature grown by MOCVD. The threshold current density was 1.03 kA/cm^2 at 20°C.

2. Fabrication

Figure 1 shows a schematic of a highly strained GaInNAs/GaAs DQW broad area laser. It was grown on a (100) GaAs substrate by MOCVD using AsH_3 and DMHy. The DQW structures consisted of two 7.7-nm-thick GaInNAs 2.48 % compressively strained wells separated by a 14.7-nm -thick GaAs barrier layer. The In and nitrogen contents of GaInNAs were estimated by X-ray diffraction measurement as 37 % and 0.5 %, respectively. $Ga_{0.5}In_{0.5}P$ and GaAs were used for the cladding layer and the waveguide layer, respectively. Details of the crystal growth of the strained GaInNAs/GaAs DQW laser structure have been described in a previous paper [13]. SiO_2 was selectively removed everywhere except for the stripe region of 50 μm. Then ohmic contacts were formed.

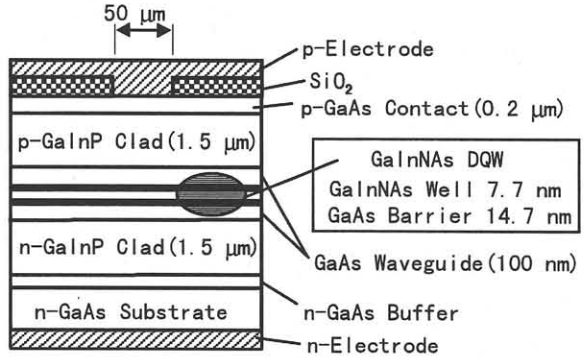

Fig. 1. Schematic of a strained GaInNAs/GaAs DQW broad area laser.

3. Laser characteristics

The lasers without a facet coating were tested under pulsed operation (1 μsec, 1 kHz). While the lasers were tested, no degradation in lasing characteristics was observed. Figure 2 shows the temperature dependence of the light output versus current characteristics in the temperature range 20 - 80°C of a 1.1 mm long laser. The threshold current and the threshold current density were 565 mA and 1.03 kA/cm^2 at 20°C, respectively. The peak emission wavelength was 1.29 μm at room-temperature. Figure 3 shows the temperature dependence of the threshold current density in the temperature range of 20 - 80°C for the laser. The T_0 value was 185 K and 160 K in the temperature range of 20 - 50°C and 20 - 80°C, respectively.

Both of a low threshold current density and a high T_0 were observed. This J_{th} is comparable to the best value of 0.8 kA/cm^2 in a 1.28 μm broad stripe MOCVD grown GaInNAs SQW laser [14]. However, T_0 value of the DQW laser was higher than that of the SQW laser. The threshold current density per well of the DQW laser is about 0.5 kA/cm^2. The DQW laser will operates at smaller J_{th} per well than that of the SQW laser. Therefore, the T_0 of the DQW laser may be higher than ~100 K of the SQW laser due to the decreased carrier overflow. We believe that the good temperature characteristics of the DQW GaInNAs/GaAs laser is mainly due to the improved electron confinement.

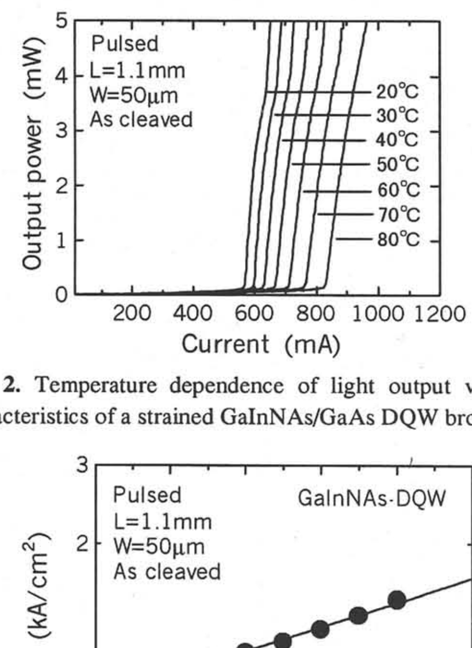

Fig. 2. Temperature dependence of light output versus current characteristics of a strained GaInNAs/GaAs DQW broad area laser.

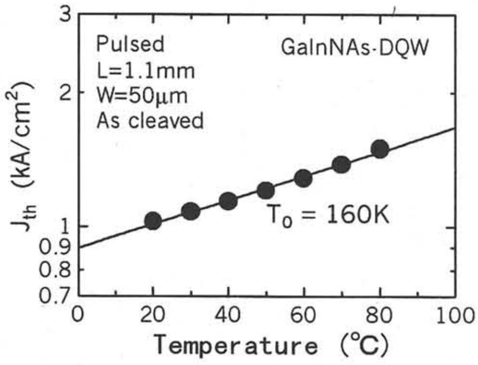

Fig. 3. Temperature dependence of a threshold current density of a strained GaInNAs/GaAs DQW broad area laser

We have also realized CW operation of a GaInNAs/GaAs DQW ridge-stripe laser with a 1.0 mm long cavity and a 7.5 μm wide ridge. The threshold current and the threshold current density at room-temperature were 87 mA and 1.16 kA/cm^2, respectively. The lasing wavelength was 1.302 μm (I = 100 mA) at room-temperature. This J_{th} is the lowest value ever reported for 1.3 μm GaInNAs/GaAs lasers under CW operation.

4. Summary

We have demonstrated 1.3 μm-range highly strained GaInNAs/GaAs DQW broad area lasers grown by MOCVD. high characteristic temperature as high as 160 K was obtained in the temperature range of 20 - 80 °C. The threshold current densities were 1.03 kA/cm^2 at 20 °C and 1.50 kA/cm^2 at 80 °C. Both of a low J_{th} and a high T_0 were obtained. The GaInNAs/GaAs material system is very promising for next generation long-wavelength lasers.

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