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MBE growth of TlInGaAs/TlInP/InP SCH LD structures and their laser operation with low-temperature variation of lasing wavelength

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Abstract

TlInGaAs/TlInP/InP separate confinement heterostructures (SCHs) were grown by gas-source molecular-beam epitaxy and metal stripe laser diodes (LDs) were fabricated. Temperature variation of electroluminescence (EL) peak wavelength was as small as 0.01 nm/K. Pulsed laser operation was achieved at 77–302 K. Threshold current density for the TlInGaAs/TlInP/InP SCH LD (0.6 kA/cm^2 at 77 K) was smaller than that for the TlInGaAs/InP double heterostructure LD (0.8 kA/cm^2 at 77 K). This is due to the increased refractive index of TlInP and the improved optical confinement. Temperature variation of main peak wavelength in the lasing spectra was as small as 0.06 nm/K. This is smaller than that of InGaAsP/InP DFB LDs.

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1. Introduction

Wavelength division multiplexing (WDM) technology is very important for optical fiber communication systems for increasing transport capacity and obtaining flexible network management. However, one of the problems encountered when using InGaAsP/InP laser diodes (LDs) in WDM systems is that the lasing wavelength fluctuates with ambient temperature variation mainly due to the temperature dependence of the bandgap energy. Therefore, LDs in WDM systems must be equipped with Peltier elements to stabilize the LD temperature. To solve this problem, the use of temperature insensitive bandgap semiconductors as an active layer of LDs was proposed [1].

We proposed TlInGaAs as temperature-insensitive bandgap semiconductors as an active layer of LDs [2,3]. The observed temperature variation of photoluminescence (PL) peak energy was as small as −0.03 meV/K (0.04 nm/K), and that of the electroluminescence (EL) peak energy was −0.048 meV/K (0.064 nm/K) [4]. We obtained the pulsed current-injection laser operation at room temperature [4]. The LDs were operated under pulsed condition with 150 ns pulse width and 2.5 kHz repetition rate. The threshold current density at room temperature was about 7 kA/cm^2. The lasing wavelength was about 1.66 μm. The temperature variation of each longitudinal-mode peak wavelength was as small as 0.06 nm/K. This value is much smaller than those observed for both InGaAsP/InP Fabry–Perot (FP) LDs (0.4 nm/K) and InGaAsP/InP distributed feedback (DFB) LDs (0.1 nm/K) [5].

Laser light propagates along both TlInGaAs active layer and InP cladding layer, so the temperature variation of lasing wavelength is influenced by those of both active and cladding layer refractive indices. The use of the smaller temperature-dependent refractive-index cladding layer is effective in obtaining the small temperature-dependent wavelength LDs. We consider that the addition of Tl into InP cladding layer will result in the reduced temperature variation of refractive index of TlInP, as already confirmed for the TlInGaAs [6]. Although the exact lattice constant of TlP is not known because of the difficulty in the growth of TlP, the lattice constant of TlP is calculated to be very close to that of InP [7]. Hence, lattice matching of TlInP

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cladding layer is good and no lattice mismatch can arise, especially for small Tl composition TlInP.

It is also expected that the refractive index for the TlInP is larger than that of InP, so the TlInGaAs/TlInP/InP heterostructure will form the separate-confinement heterostructure (SCH). In this paper, we will report on the optical properties of TlInGaAs/TlInP/InP SCH LDs.

2. Experimental procedure

TlInGaAs/TlInP/InP SCH LD and TlInGaAs/InP double heterostructure (DH) samples as well as TlInP/InP layers were grown on Si-doped (1 0 0) InP substrates. Elemental Tl (5N), In (7N) and Ga (7N), and thermally cracked AsH_3 and PH_3 were used as group III and group V sources, respectively. The growth temperature was 450 °C.

TlInGaAs/TlInP/InP SCH LD samples grown in this study were composed of (i) a Si-doped n-type InP cladding layer (thickness $d = 0.2\,\mu m$, $n = 1 \times 10^{18}\,cm^{-3}$), (ii) Si-doped n-type TlInP cladding layer (thickness $d = 0.2\,\mu m$, $n = 1 \times 10^{18}\,cm^{-3}$), (iii) an undoped TlInGaAs active layer ($d = 0.2\,\mu m$), (iv) a Be-doped p-type TlInP cladding layer (thickness $d = 0.2\,\mu m$, $n = 1 \times 10^{18}\,cm^{-3}$), (v) a Be-doped p-type InP cladding layer ($d = 1\,\mu m$, $p = 1 \times 10^{18}\,cm^{-3}$) and (vi) a Be-doped p-type InGaAs contact layer ($d = 0.2\,\mu m$, $p = 1 \times 10^{18}\,cm^{-3}$). The sample structure is schematically described in Fig. 1. The layer structure for the TlInGaAs/InP DH LD samples is similar to that of Fig. 1 without the TlInP layers. Tl composition of TlInGaAs was estimated to be only several percent from the double crystal X-ray diffraction measurement data assuming Vegard's law and that the lattice constant of TlAs is equal to that of InAs.

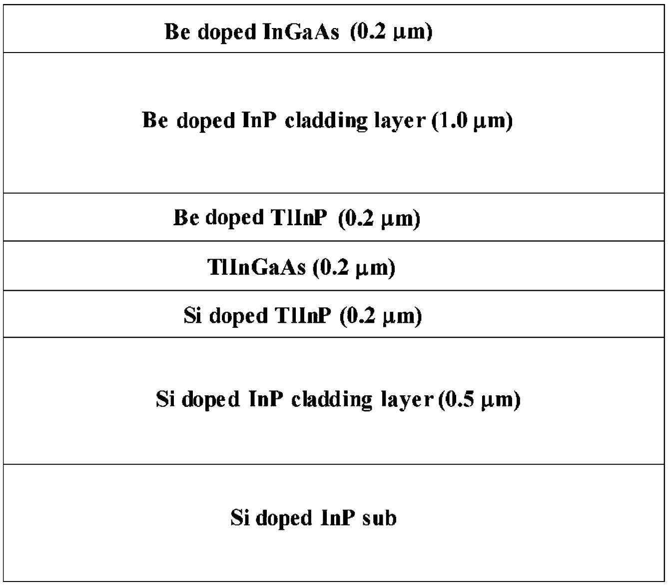

Fig. 1. Schematic drawing of the TlInGaAs/TlInP/InP SCH LD structure.

3. Results and discussion

The refractive index for TlInP was measured with the spectroscopic ellipsometer (SE) and confirmed that the refractive index of TlInP is larger than that of InP. However, the smaller temperature dependence was not clearly confirmed, probably because of the small temperature dependence of refractive index for InP as well as TlInP.

Seventy micrometers-wide and 300-μm-long metal stripe LDs were fabricated using the grown TlInGaAs/InP DH and TlInGaAs/TlInP/InP SCH wafers. The LDs were operated under pulsed condition with 150 ns pulse width and 2.5 kHz repetition rate. EL light output was detected from the cleaved-edge surface. Fig. 2 shows the temperature variation of the EL peak wavelength for the TlInGaAs/TlInP/InP SCH LED. Small temperature variation of as small as 0.01 nm/K was confirmed. This value is smaller than that of TlInGaAs/InP DH LED (0.06 nm/K). We consider that the small temperature variation of EL peak energy is due to the increase of Tl composition.

TlInGaAs/TlInP/InP SCH and TlInGaAs/InP DH LDs were operated under pulsed condition. Laser operation was achieved in the temperature range from 77 to 302 K. Fig. 3 shows the lasing spectra for the TlInGaAs/TlInP/InP and TlInGaAs/InP metal-stripe LDs at 77 K. The threshold current for the TlInGaAs/TlInP/InP SCH LD was 160 mA (threshold current density: 0.6 kA/cm^2) and it was smaller than that (200 mA (0.8 kA/cm^2)) for the TlInGaAs/InP DH LD. We consider that this smaller threshold current density for the TlInGaAs/TlInP/InP LD is due to the increased refractive index of TlInP compared with that of InP and the increased optical confinement in TlInGaAs/TlInP/InP SCH LD.

We have studied the temperature variation of lasing peak wavelength. Fig. 4 shows (a) the lasing spectra under pulsed operation as a function of temperature and (b) the temperature variation of the main peak wavelength. The temperature variation of main peak wavelength is as small

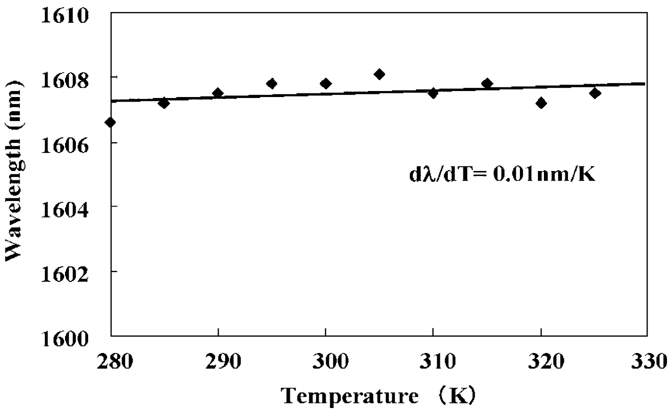

Fig. 2. Temperature dependence of EL peak wavelength for the TlInGaAs/TlInP/InP SCH and TlInGaAs/InP DH LEDs.