Extended Abstracts of the 1997 International Conference on Solid State Devices and Materials, Hamamatsu, 1997, pp. 46-47

Invited

1.3 μm Semiconductor Lasers on InGaAs Ternary Substrates Toward Low-Threshold and Temperature Insensitive Operation

H. Shoji, K. Otsubo, T. Kusunoki, T. Suzuki, T. Uchida, T. Fujii,
Y. Nishijima, K. Nakajima, and H. Ishikawa
Fujitsu Laboratories Ltd., 10-1 Morinosato-Wakamiya, Atsugi 243-01, Japan
Phone: +81-462-50-8250, Fax: +81-462-48-5193, E-mail: hshoji@flab.fujitsu.co.jp

1. Introduction

Recently, temperature insensitive operation of semiconductor lasers emitting at 1.3 μm is strongly desired for applications in future optical access networks and optical interconnection systems. Temperature dependence of threshold current and slope efficiency should be much smaller than that of conventional lasers over a wide temperature range. However, lasers on InP substrates are much inferior to those on GaAs substrates in their temperature characteristics.

One of the key technologies to improve the temperature characteristics is to realize a deep potential well for 1.3 μm strained quantum well (QW). A theoretical study predicts that the deep potential well suppresses the carrier overflow to barrier layers and enlarges the subband separation, resulting in larger optical gain [1]. Lower threshold current and better temperature characteristics are expected in lasers with the deep potential well. From this point of view, so far, wide bandgap structures such as AlGaInAs [2] and InAsP QWs [3] on InP substrates have been investigated. New structures such as GaInNAs QW on GaAs substrates [4] and InGaAs QW on GaAs substrates with InGaAs graded buffer [5] have been also reported.

To obtain the deep potential well, we proposed the use of InGaAs ternary substrate whose lattice constant is in-between GaAs and InP [6]. The InGaAs substrate with indium content of 0.25-0.3 enables a formation of QWs emitting at 1.3 μm. In this paper, we review our approach toward 1.3 μm lasers on the InGaAs ternary substrate with low threshold current and excellent temperature characteristics.

2. Theoretical Calculation

We theoretically estimated the gain properties of strained QW on InGaAs ternary substrate [1, 7]. First, the band lineup of the strained QW with separate confinement heterostructure (SCH) layers was calculated, then the band structure was determined. Based on the band calculation, we calculated the optical gain as a function of the sheet carrier density which includes the carriers in the SCH layer. Figure 1 shows a comparison of the calculated peak gain between an InGaAs/InAlGaAs strained QW on an $In_{0.26}Ga_{0.74}As$ substrate and an InGaAs/InGaAsP strained QW on an InP substrate as a function of sheet carrier density and temperature. It is shown that larger optical gain and smaller temperature dependence could be obtained in the ternary substrate case. This difference is mainly due to the deep potential well. A deeper potential well leads to larger subband separation which reduces the distribution of carriers to upper subbands, and it also results in the reduction of electron overflow to the barrier layer. In addition to the enhanced optical gain, larger optical confinement to the active layer is also expected because of the larger refractive index contrast in the wide bandgap structure. These results predict that low threshold current and excellent temperature characteristics could be obtained in lasers on the ternary substrate. High characteristic temperature (T_0) over 150 K and low threshold current less than one third of that of laser on InP substrate are expected.

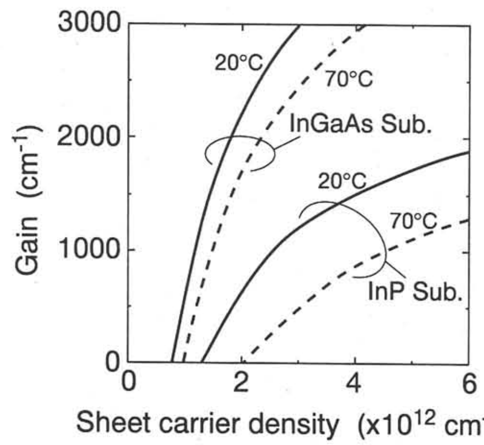

Fig. 1 Calculated optical gain as a function of sheet carrier density and temperature. InGaAs/InAlGaAs strained QW on $In_{0.26}Ga_{0.74}As$ substrate and InGaAs/InGaAsP strained QW on InP substrate are compared.

3. Fabrication of InGaAs Substrates

To realize a strained QW emitting at 1.3 μm, InGaAs substrates with indium content of 0.25-0.3 are required. We have been trying to grow the InGaAs crystal by ourselves [8-10]. At first, we employed a double crucible liquid encapsulated Czochralski (LEC) growth technique with a supply of GaAs source material at a constant temperature, and we obtained uniform InGaAs single crystals with indium content of 0.05-0.15 [8]. However, in this method, the growth of InGaAs bulk crystal with indium content over 0.2 was difficult because of large segregation of gallium in the InGaAs material system. To overcome this problem, we developed a new growth technique called as multi-component zone growth method [9, 10]. By this method, we obtained InGaAs substrates with indium content over 0.2. Recently, an InGaAs substrate with indium content of 0.26 has been achieved, and a photoluminescence peak at 1.3 μm has been observed in the QW grown on it [11].

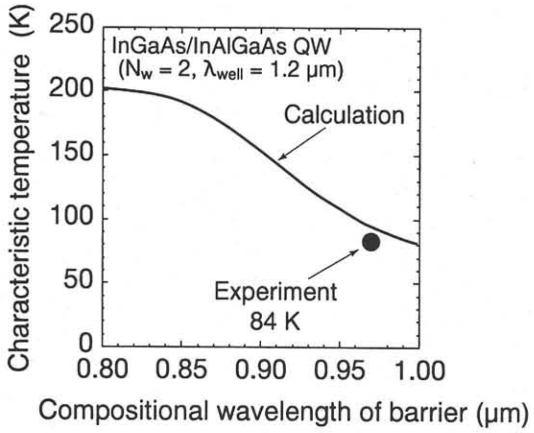

Fig. 2 Calculated characteristic temperature (T_0) as a function of compositional wavelength of barrier layer. InGaAs/InAlGaAs QW on $In_{0.21}Ga_{0.79}As$ substrate is assumed. Closed circle denotes an experimental result.

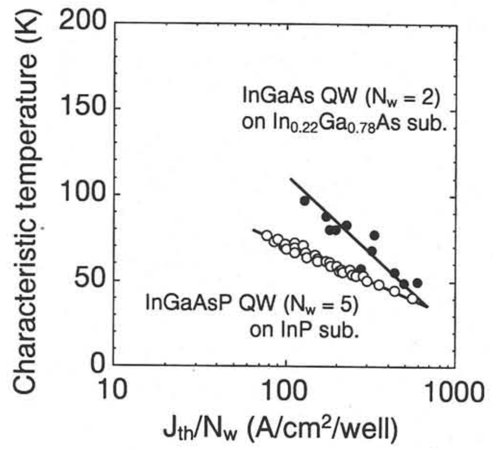

Fig. 3 Dependence of characteristic temperature (T_0) on threshold current density per well for lasers on InGaAs substrate and InP substrate.

4. Fabrication of Lasers

The first strained QW lasers on the ternary substrate was demonstrated on an $In_{0.05}Ga_{0.95}As$ substrate grown by the LEC technique [12]. Although the lasing wavelength was 1.03 μm because of the low indium content of 0.05, we obtained excellent characteristics in the fabricated devices. This result evidenced that the ternary substrate has a sufficient quality for laser fabrication. After that, we succeeded in the fabrication of InGaAs/InAlGaAs/InGaP lasers on an $In_{0.21}Ga_{0.79}As$ substrate grown by the newly developed multicomponent zone growth method [13]. Due to the increased indium content up to 0.21, we achieved a lasing wavelength of 1.22 μm, reaching close to lasing at 1.3 μm. The threshold current density was as low as 355 A/cm^2. Because the compositional wavelength of InAlGaAs barrier was as long as 0.97 μm, the T_0 was 84 K, which agreed well with our theoretical prediction as shown in Fig. 2. Higher T_0 over 150 K is expected by realizing wider bandgap barriers whose compositional wavelength is shorter than 0.9 μm.

5. Toward Improved Performance

For realizing a higher T_0 value, reduction of threshold current density is important. Recently, we have found that the T_0 values of lasers on ternary substrate have a strong dependence on the threshold current density compared with those on InP lasers. Figure 3 shows a dependence of T_0 on threshold current density for InGaAs/InAlGaAs/InGaP lasers (2 wells, λ_{well} = 1.2 μm, λ_{SCH} = 0.9 μm) fabricated on an $In_{0.22}Ga_{0.78}As$ substrate [14]. It is clearly shown that lower threshold current density leads to higher T_0 on the ternary substrate. As shown in this figure, a high T_0 around 100 K has been achieved in a laser with threshold current density of 128 A/cm^2/well. In addition to the improvement of substrate quality, further reduction of threshold current density by increased number of QWs and by the use of wider bandgap InAlAs cladding layer in stead of InGaP will make it possible to realize a T_0 over 150 K.

6. Conclusions

We have described our attempts to realize 1.3 μm semiconductor lasers on InGaAs substrate. Our growth technique of the InGaAs substrate is now reaching to the realization of high-indium-content substrate which enables a formation of 1.3 μm QWs. Lasing characteristics of lasers fabricated on the ternary substrates also suggest that the ternary substrate has a potential for low-threshold and temperature insensitive operation. By improving the crystal quality of the InGaAs substrates, 1.3 μm semiconductor lasers with excellent performance will be realized.

References

1) H. Ishikawa and I. Suemune: IEEE Photon. Technol. Lett. **6** (1994) 344.
2) Z. Wang, D. B. Darby, R. Panock, P. Whitney, and D. C. Flanders: 14th Intl. Semicond. Laser Conf. PD10 (1994).
3) H. Oohashi, S. Seki, T. Hirono, H. Sugiura, T. Amano, M. Ueki, J. Nakano, M. Yamamoto, Y. Tohmori, M. Fukuda, and K. Yokoyama: Electron. Lett. **31** (1995) 556.
4) M. Kondow, S. Nakatsuka, T. Kitatani, Y. Yazawa, and M. Okai: Electron. Lett. **32** (1996) 2244.
5) H. Kurakake, T. Uchida, T. Higashi, S. Ogita, and M. Kobayashi: 15th Intl. Semicond. Laser Conf. Tu3.4 (1996).
6) H. Ishikawa: Appl. Phys. Lett. **63** (1993) 712.
7) H. Shoji, K. Otsubo, T. Fujii, and H. Ishikawa: IEEE J. Quantum Electron. **33** (1997) 238.
8) K. Nakajima and T. Kusunoki: J. Cryst. Growth **169** (1996) 217.
9) T. Suzuki, T. Kusunoki, T. Katoh, and K. Nakajima: Abstr. Int. Conf. InP & Related Materials, WB1.4 (1995).
10) T. Kusunoki, K. Nakajima, H. Shoji, and T. Suzuki: Abstr. Material Research Society, Fall Meeting, E6.1 (1995).
11) K. Otsubo, H. Shoji, T. Kusunoki, T. Suzuki, T. Uchida, Y. Nishijima, K. Nakajima, and H. Ishikawa: 16th Electron. Materials Sympo. C-3 (1997).
12) H. Shoji, T. Uchida, T. Kusunoki, M. Matsuda, H. Kurakake, S. Yamazaki, K. Nakajima, and H. Ishikawa: IEEE Photon. Technol. Lett. **6** (1994) 1170.
13) H. Shoji, K. Otsubo, T. Kusunoki, T. Suzuki, T. Uchida, and H. Ishikawa: Jpn. J. Appl. Phys. **35** (1996) L778.
14) K. Nakajima, T. Kusunoki, and K. Otsubo: J. Cryst. Growth **173** (1997) 42.