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A Novel Structure for TM Mode Gain Enhancement in Long Wavelength Strained Layer Superlattice Laser Diodes with the Tensile Stress on the Barrier Layers

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A novel "tensed barrier" structure is proposed to control TE/TM mode gain. Strain induced band engineering has been expected to improve opto-electronic device characteristics. $Ga_{0.47}In_{0.53}As/Ga_{0.61}In_{0.39}As$ strained layer superlattice structure was adopted for an active region of Fabry-Perot lasers. TM mode stimulated emission was obtained at 1.58μm and TM mode enhancement was confirmed.

[Introduction] Strained-layer superlattice (SLS) structure growth techniques coupled with strain induced band engineering are expected to improve the opto-electronic device characteristics. Change in the valence band structure results in the suppression of non-radiative recombination, such as Auger and Inter-valence band absorption processes. Furthermore, in $Ga_xIn_{1-x}As/Ga_yIn_{1-y}As$ SLS structures, TE or TM mode gain enhancement is expected through splitting the valence band into light hole and heavy hole bands caused by biaxial tension or compression. In this report, a novel "tensed barrier" structure is proposed as an active region to enhance the TM mode gain in long wavelength laser diodes. This structure provides stimulated emission in TM mode at 1.5-1.6μm wavelength.

[Background] The recombination between conduction electron and light hole makes TM and TE mode radiation, and TM mode gain is approximately four times larger than TE mode. In multi-quantum well system without stress or under compressive stress, TE mode gain is larger than TM mode because optical transition from conduction band to heavy hole band is dominant. Under a biaxial tensile stress, valence band splits into two bands, heavy and light hole band. The

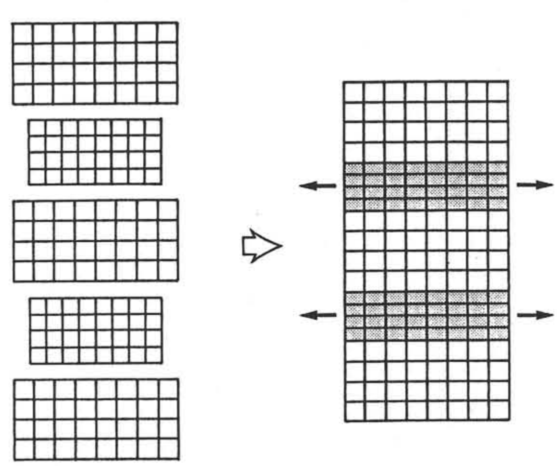

Fig.1. Schematic illustration of lattice mismatched layers and tensile strained layers in an SLS structure grown epitaxially.

Shaded area shows tensed layers and 4 black arrows indicate a direction of stress.

energy level of the light hole band becomes lower than heavy hole, then recombination rate between conduction electron and light hole becomes larger. As a result, the TM mode gain enhancement can be obtained.

In order to enhance TM mode gain, "tensed well" structure was considered first. But, it was difficult to construct the "tensed well" structure suitable for long wave length opto-electronic devices. The reason is as follows. $Ga_xIn_{1-x}As$ (x>0.47) was available for the "tensed well" layers because of its smaller lattice constant than InP substrate. This composition, however, had a larger band gap than lattice-matched composition (x=0.47). So, it was necessary to make use of larger band gap barrier than compressed or unstrained case for the purpose of quantizing electronic states in the well. And moreover, because of the large band gap in a bulk state, it was hardly to adjust a quantized band gap energy for 1.5 μm region.

A novel "tensed barrier" structure is proposed in order to control TE/TM mode gain in a long wave length region. Lattice-matched $Ga_{0.47}In_{0.53}As$ was used for the well layers. $Ga_xIn_{1-x}As$ (x>0.47) was adopted for the barrier layer whose lattice constant a_s was smaller than that of InP substrate. These layers were epitaxialy grown by turns and then constituted the SLS structure. The in-plane lattice constant of the SLS structure was just matched to InP substrate, so tensile stress was given to the barrier layers along in-plane direction. Figure 1 represents schematic illustrations of lattice mismatched layers and tensile strained layers in an SLS structure.

[Experiments and Results] SLS structures were epitaxialy grown by low-pressure (50 Torr) MOVPE on Sn-doped InP(100) substrates. Ten layers of 30 A thick $Ga_{0.47}In_{0.53}As$ were used for the well layers, and 50 A thick $Ga_xIn_{1-x}As$ (x=0.61) were adopted for the strained barrier layers in order to get "tensed barrier" layers. The lattice mismatch is defined as $\varepsilon=(a_s-a_0)/a_0$, where the a_s is the lattice constant of the strained layers when the strain is released, and the a_0 is that of the InP substrate. Strain value ε was estimated from (400), (511) and/or other diffraction peaks including satellite peaks obtained in double crystal X-ray diffraction measurements. A value of $\varepsilon=-0.009$ is obtained for this composition (x=0.61) and an in-plane lattice constant difference between the SLS structure and InP was below the measurement error level (<0.01A). It is confirmed that the barrier layers were elastically transformed.

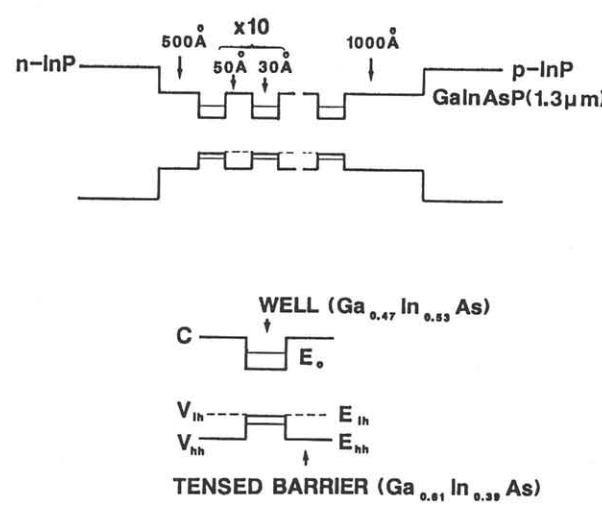

Fig.2. Schematic diagram of the "tensed barrier" SLS active layer of TM laser. The lower diagram shows a detailed band diagram of tensed barriers ($Ga_{0.61}In_{0.39}As$) and a well ($Ga_{0.47}In_{0.53}As$) schematically.

V_{lh}: light hole valence band.
V_{hh}: heavy hole valence band.
C: conduction band.

A schematic band diagram of the tensed barrier SLS structure derived from H.Asai and K.Oe[1] is shown in Figure 2. The biaxial tension in barrier makes the light hole subband energy level (E^{b}_{lh}) drop below the heavy hole (E^{b}_{hh}). The light hole energy level of the barrier layers nears the heavy hole energy of the well layers (E^{w}_{hh}). It seemed that the heavy hole band had a type-II superlattice band structure. Therefore, the recombination rate between the light holes and the conduction electrons may increase.

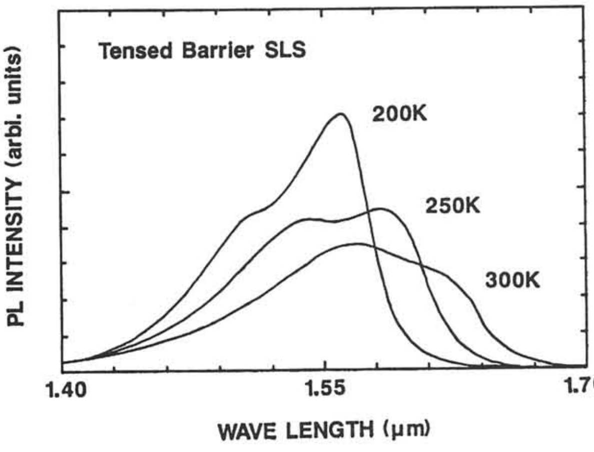

Fig.3. Temperature dependence of photoluminescence spectrum from a $Ga_{0.47}In_{0.53}As/Ga_{0.61}In_{0.39}As$ SLS structure excited by a He-Ne laser.

Figure 3 shows the photoluminescence spectra of the sample excited by a He-Ne laser at 200, 250, 300K. There are two peaks corresponding to transitions from the conduction band to the heavy hole band and the light hole band, respectively. As decreasing a temperature, these peaks were shifting to a short wave length side and the longer wave length peak was becoming larger. This reflected the carrier distribution with between the two energy bands with temperature.

Figure 4 shows the TM/TE mode gain spectra of a ridge waveguide laser at 25C when the driving current was $0.9I_{th}$. The wave-guide is 9μm wide and 320μm long. A threshold current I_{th} of this laser was about 140mA and the wave length was 1.6μm. The mode gain difference $\Delta G(=G_{TM}-G_{TE})$ was as large as 38 cm^{-1}. The peak wavelength of the TM mode gain agreed with the longer wavelength peak of the PL spectrum shown in Figure 3. In the mode gain measurement, the injected holes populated in the lower energy level first, corresponding to the light hole level, and recombine with the conduction electrons successively. As a result, the TM mode gain became much larger than TE's.

DC-PBH structure Fabry-Perot lasers were constructed adopting the "tensed barrier" SLS layers mentioned above as an active region buried by LPE method. The active region was 1.5μm wide and the cavity length was 300μm. The TM mode

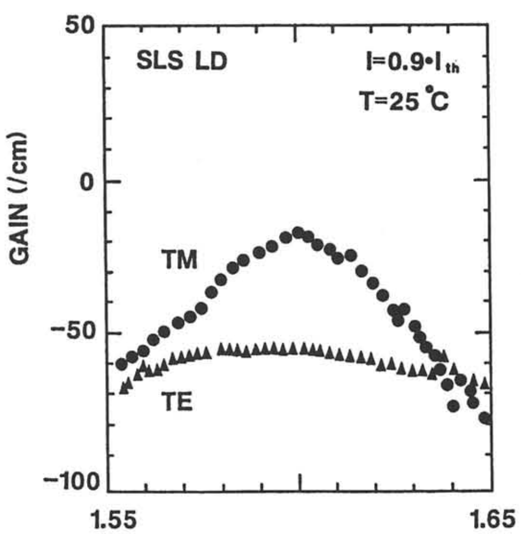

Fig.4. TM/TE mode gain spectrum of a "tensed barrier" SLS ridge waveguide Fabry-Perot LD.

continuous oscillation was obtained. Figure 5 represents a I-L characteristics of the SLS-LD at 25 C under cw condition. The threshold current I_{th} was about 16.5 mA, the wavelength was 1.58 μm, and the maximum output power was above 16mW. This property was almost the same level as ten-wells lattice-matched MQW LDs.

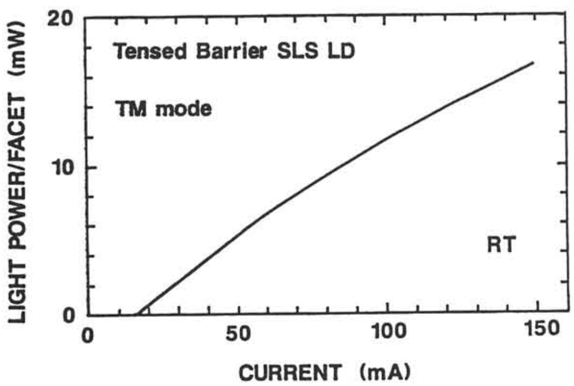

Fig.5. I-L characteristics of DC-PBH "tensed barrier" SLS laser.

[**Conclusion**] A novel "tensed barrier" SLS structure is proposed. TM mode stimulated emission was obtained and the enhancement of the TM mode gain was confirmed. Furthermore, it is expected that TE/TM mode gain difference is controllable through a strength of a stress, thickness of the wells and/or barriers. As a fact, polarization insensitive traveling wave type amplifier was obtained[2] using the "tensed barrier" structure mentioned in this report with different composition barriers.

1)H.Asai and K.Oe, J.Appl.Phys.**54**,2052('83)

2)K.Magari, M.Okamoto, H.Yasaka, K.Sato, Y.Noguchi and O.Mikami,IEEE Photon.Technol. Lett.,to be published.