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Valence Band Structure and Photoluminescence Spectra in Strained-Layer GaInAs/GaInAs(P) MQW

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[Abstract] Photoluminescence (PL) spectra of strained-layer MQW's were measured. PL peak energy corresponding to electron- heavy-hole (e-hh) recombination has almost the same coefficient dE_{Peak}/dT as bulk semiconductors of GaAs and InAs. Furthermore, the dE_{Peak}/dT for electron- light-hole (e-lh) was obtained for the first time using tensile-strained MQW structures. The PL peak energy of the e-lh has less dependence on temperature than that of the e-hh.

[Introduction] Tensile-strained-barrier (TSB) structure, $Ga_{0.47}In_{0.53}As/Ga_xIn_{1-x}As$ has been proposed to control the mode gain difference between TE and TM modes.[1),2)] A polarization-insensitive (<0.5 dB) high-gain (27.5 dB) traveling wave optical amplifier was achieved using a TSB structure[3)]. In this report, the valence band structure and electron-light-hole (e-lh) recombination process are clarified by considering the temperature dependence of photo-luminescence in the TSB structure comparing with electron- heavy-hole recombination in strained-layer MQW's.

[Experiments and Results] Strained-layer MQW structures were epitaxially grown by low-pressure (50 Torr) MOVPE on Sn-doped InP (100) substrates in a vertical reactor. The lattice mismatch $\varepsilon=[(a-a_0)/a_0]\times100$ (%) was determined through the double crystal XD where a_0 is the lattice constant of the InP substrate and a is that of the mismatched layer. Ga content x was estimated from the value of the lattice constant a.

The TSB structure is as follows. Well layers are 5-nm-thick $Ga_{0.47}In_{0.53}As$. Strained barriers are 5-nm-thick $Ga_{0.72}In_{0.28}As$. The resulting band diagram structure is shown in Fig.1. The schematic band diagram of the TSB structure calculated following H. Asai and K. Oe[2),4)] is shown in Fig. 1. The light-hole band

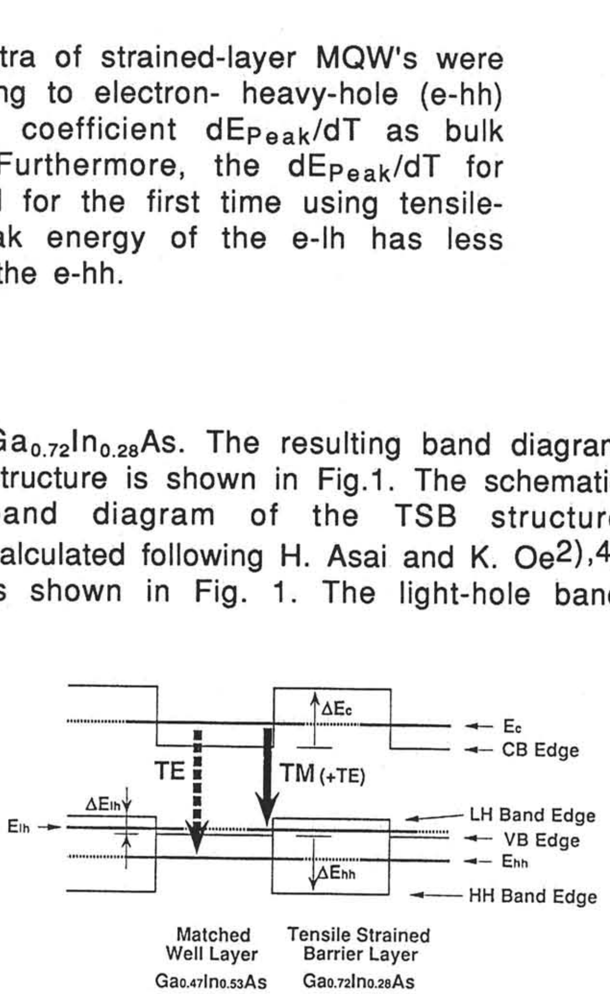

Fig.1. Band Diagram of the TSB Structure.

energy level in the barrier layers is made less than that of the heavy-hole energy in the well layers by biaxial tension in the barrier layers. This TSB structure has a "type II" band structure for light-holes and a "type I" structure for the heavy-holes as shown in Fig. 2. However, because a band discontinuity of the light hole is very small[2)], light-hole are not localized in the tensile-strained-barrier layers..

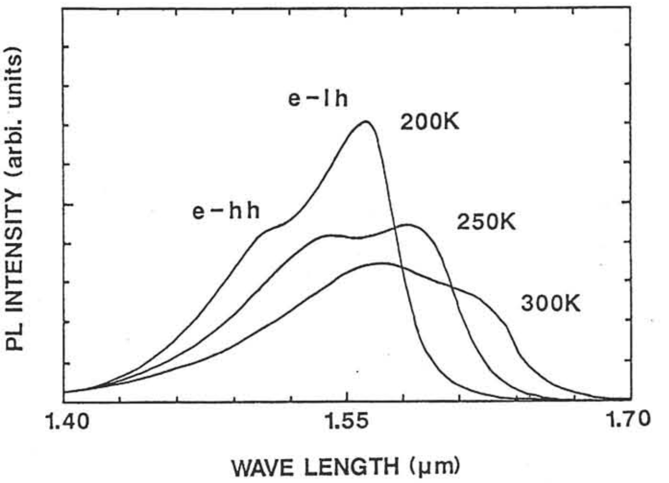

Fig.2. PL spectra of the TSB MQW at 200, 250 and 300 K.

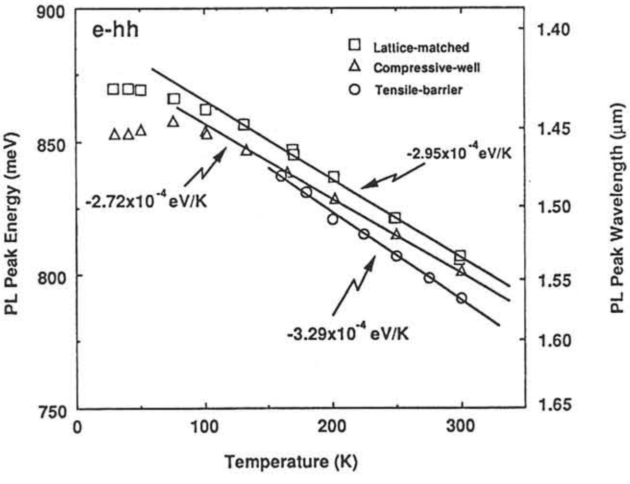

Fig.3. Temperature dependence of PL peak energies corresponding to e-hh recombination.

MQW structures which were used in this measurement are shown in Table 1. Two of the samples are a lattice-matched MQW and a compressive-well MQW which have GaInAsP (λ_g=1.3 μm) barriers of 10-nm-thick and GaInAs wells. A lattice mismatch of the latter sample was ε=+1.5 %. Another sample has tensile-strained-wells of GaInAs (ε=-1 %) with GaInAsP (λ_g=1.2 μm) barriers of 10-nm-thick. Well width were controlled to obtain a desirable PL wavelength of 1.55 μm.

PL spectra of the TSB structure at 200, 250, and 300 K are shown in Fig. 2. The two peaks observed in Fig. 2 correspond to transitions from the heavy-hole band and the light-hole band to the conduction band, respectively. As temperature is decreased, the PL intensity of e-lh photoluminescence becomes stronger. The e-hh spectrum was too weak to be distinguished below 150 K. This comes from thermal distribution of holes because the lh-level exists lower than hh-level.

Temperature dependences of the peak energies of the spectra are shown in Fig.3 corresponding to e-hh recombination in the three type samples of a lattice-matched, a compressive-well and a tensile-barrier MQW's. All of the samples shows similar dE/dT coefficient, such as -2.95×10^{-4}, -2.72×10^{-4} and -3.29×10^{-4} eV/K, respectively. This value is very close to that of bulk GaAs (-3.95×10^{-4} eV/K)[4] and bulk InAs (-3.3×10^{-4} eV/K)[5]. This means that the e-hh energy difference directly reflects the band gap energy dependence of $Ga_xIn_{1-x}As$ on temperature. Photoluminescence peak

MQW Structure	Barrier		Well		λ_{PL} (μm)
	Composition	Thickness	Composition	Thickness	
A) Lattice-matched	GaInAsP (λ_g=1.3 μm)	10 nm	$Ga_{0.47}In_{0.53}As$	5 nm x 10 layers	1.56
B) Compressive-well	GaInAsP (λ_g=1.3 μm)	10 nm	$Ga_{0.32}In_{0.68}As$ (ε=+1.0%)	3 nm x 10 layers	1.55
C) Tensile-well	GaInAsP (λ_g=1.2 μm)	10 nm	$Ga_{0.54}In_{0.46}As$ (ε=-0.5%)	8 nm x 6 layers	1.50
D) Tensile-barrier	$Ga_{0.72}In_{0.28}As$ (ε=-1.7%)	5 nm	$Ga_{0.47}In_{0.53}As$	5 nm x 10 layers	1.59

Table 1. Structures of MQW Samples

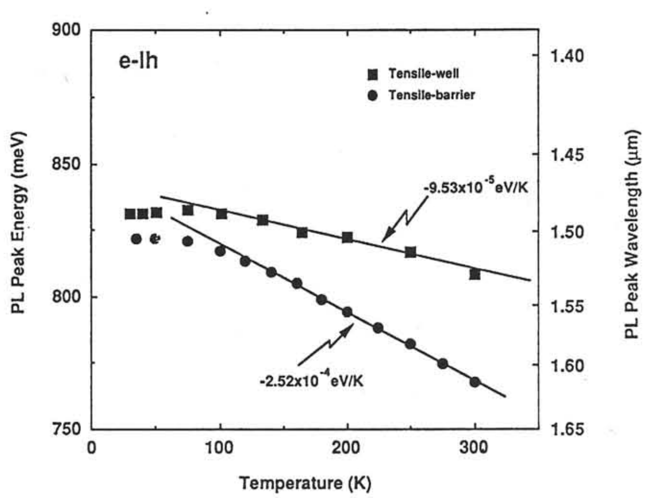

Fig.4. Temperature dependence of PL peak energies corresponding to e-lh recombination.

energy dependence on temperature are shown in Fig.4 corresponding to e-lh recombination in the two samples, such as a tensile-well and tensile-barrier MQW. They have a less dependence on temperature than the e-hh recombination at values of $(dE/dT)_{e\text{-}lh}=-9.53\times10^{-5}$, -2.5×10^{-4} eV/K, respectively. In the lower temperature region, the same peak-energy shift saturation was observed as un-strained bulk semiconductors. dE/dT coefficients are assembled in Table 2. In the TSB structure, PL spectra from both e-hh and e-lh recombination can be observed.

MQW structure	dE_{peak}/dT (meV/K)	
	e-hh	e-lh
A) Lattice-matched	-2.95×10^{-4}	——
B) Compressive-well	-2.72×10^{-4}	——
C) Tensile-well	——	-9.53×10^{-5}
D) Tensile-barrier	-3.29×10^{-4}	-2.52×10^{-4}
bulk GaAs ref.4)	-3.95×10^{-4}	
bulk InAs ref.5)	-3.3×10^{-4}	

Table.2. PL peak energy dependence on temperature in strained-layer MQW structures

[Summary] Photoluminescence dependence on temperature of strained-layer MQW structures were measured. The e-hh shows a similar behavior to bulk semiconductors, however, the e-lh represents less dependence on temperature.

[References]

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