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GaInAs/InP Multi-Quantum Wells and Strained Super-Lattices Grown by Chemical Beam Epitaxy

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$Ga_{0.47}In_{0.53}As$/InP multi-quantum wells were grown by chemical beam epitaxy at relatively high growth rates. Emission wavelength of these MQWs shifted from 1.58μm to 1.24μm at room temperature. Well widths associated to these wavelengths ranged from 150Å to 26Å. These results are in good agreement with theoretical calculations using the conduction offset of 0.36eV. Spectrum linewidths were measured at 300K and 77K with the narrowest linewidths of 24meV and 8meV for each temperature. These minimum values were obtained at emission wavelength of around 1.45μm.

1. Introduction

The $Ga_{0.47}In_{0.53}As$/InP system is one of the most important compound semiconductors used for optical communications and high speed electron devices. It's room temperature emission wavelength can be adjusted from about 1.6 to 1.1μm by designing proper quantum well structures. It also has excellent electron transport properties.

Although the GaInAs/InP system has been grown by many epitaxial techniques such as molecular beam epitaxy (MBE) and metal-organic chemical vapor deposition (MOCVD), the growth is usually performed at relatively low growth rates. For some important device applications, however, one needs high growth rates for total growth through-put without hindering controllability and crystal quality. Surface emitting (SE) lasers, for example, must have a relatively thick double-heterostructure of about 7μm[1] for a device with 95% reflection mirrors to obtain high external quantum efficiency. To achieve high reflectivity, vertical integration, and enhancement in spectrum linewidth reduction[2], the use of semiconductor distributed Bragg reflectors (DBRs) must be considered for SE lasers. A total thickness of such devices may even be more than 10μm. However, GaInAs can also be used for high reflective DBRs[3]. By considering all these possibilities of sophisticated surface operating devices, extremely good quality crystals must be realized since light travels through many epitaxial layers and surfaces. Chemical beam epitaxy (CBE) can satisfy these requirements. Hence, we examined optical quality of GaInAs/InP MQW structures grown at high growth rates. Also, GaInAs/InP multilayer DBR was grown by CBE and characterized for future application to SE lasers.

2. Experimental

More than 50 samples of GaInAs/InP MQW structures were grown on a n-type InP substrate by the CBE system manufactured by RIBER. An originally designed cracking cell made of Ta and pyrolytic boron nitride (PBN) was used at 900°C. Trimethylindium (TMI) and triethylgallium (TEG) were introduced into the chamber with the H_2 carrier gas. Growth temperature was kept at 540°C and flow rates of PH_3 and AsH_3 were fixed at 15 and 10sccm. Background impurity levels at 300K were $1\times10^{16}cm^{-3}$ (n) for InP and $5\times10^{15}cm^{-3}$ (n) for GaInAs. Throughout the experiment, gas valves were used instead of mechanical shatters and a growth sequence is shown in Fig. 1.

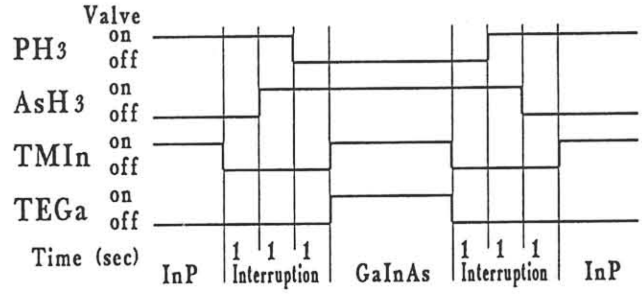

Fig.1 An example of a growth sequence is shown. Valves were used instead of shutters.

Using growth rates of 2.2Å/sec for InP and 14Å/sec for $Ga_{0.47}In_{0.53}As$, quantum wells were grown by changing growth time from 2 to 10 seconds. In Fig. 2, estimated quantum well widths are plotted against each growth time. Each sample had ten wells and

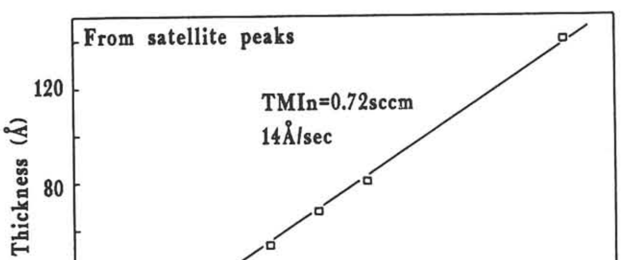

Fig.2 GaInAs well thickness is plotted as a function of growth time. Slope gives growth rate of 14Å/sec A linear behavior was observed.

was sandwiched between 190Å InP barriers. Widths were estimated from satellite peaks found in the double-crystal X-ray diffraction spectra. As seen in the figure, well thickness can be well controlled with growth time down to 2 seconds. The thinnest well obtained up to date was 26Å. Room temperature photoluminescence spectra of these samples were taken using Nd:YAG laser (λ=1.064µm) as shown in Fig. 3. The emission wavelength shift of 1.58µm to 1.24µm can be

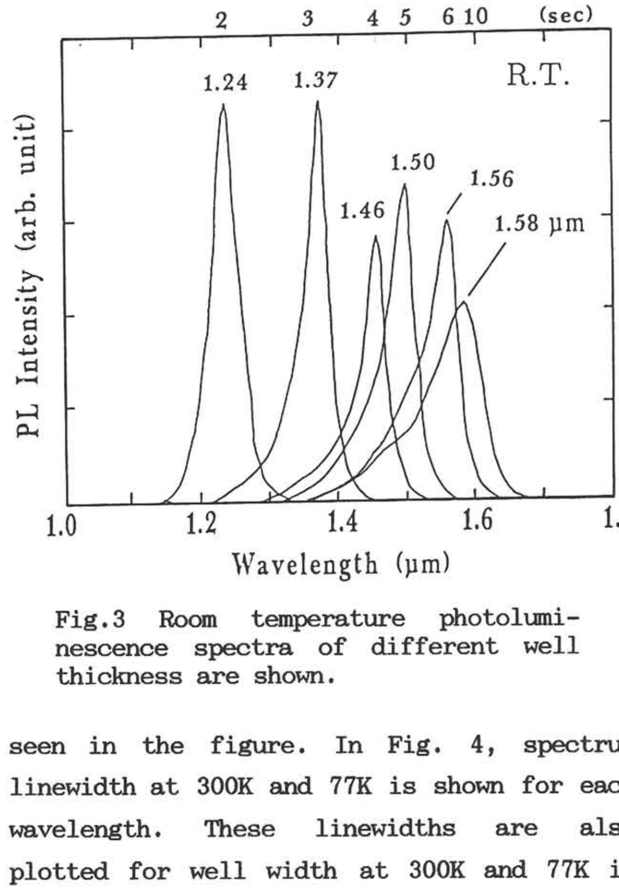

Fig.3 Room temperature photoluminescence spectra of different well thickness are shown.

seen in the figure. In Fig. 4, spectrum linewidth at 300K and 77K is shown for each wavelength. These linewidths are also plotted for well width at 300K and 77K in Fig. 5. The narrowest linewidth obtained was 24meV at 1.46µm for 300K, and 8meV at 1.45µm for 77K. Minimum linewidth seems to depend on emission wavelength and may be independent of well width at this temperature range. This linewidth obtained at 77K is far better than previously published linewidth of quantum wells grown by CBE[4]. A linewidth increase found for thinner wells is probably due to the geometrical well-width fluctuations amounted about one to two monolayers.

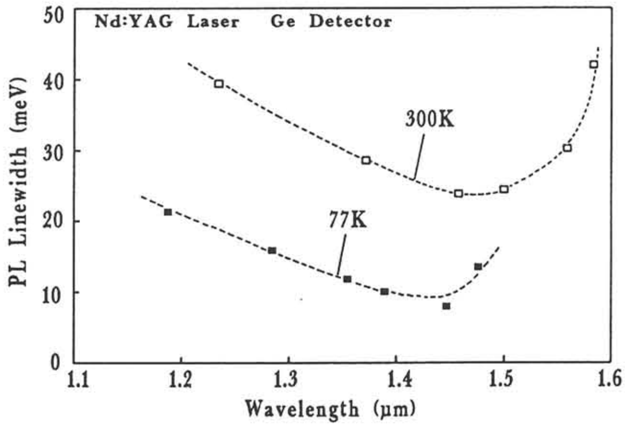

Fig.4 Photoluminescence spectrum linewidth vs wavelength is shown. White box indicates 300K data and black box indicates 77K data. Minimum linewidth seems to exist at around 1.45μm.

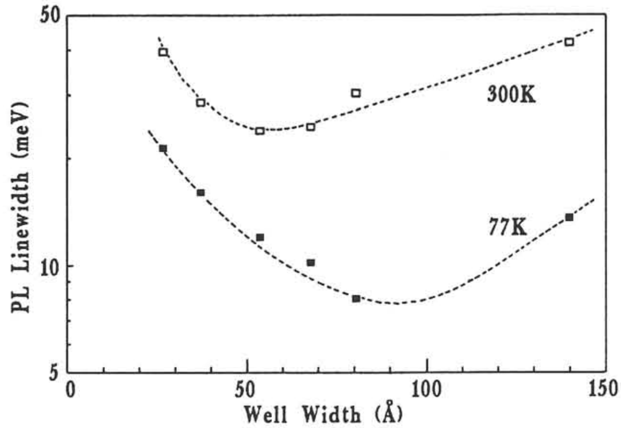

Fig.5 Photoluminescence spectrum linewidth vs well width is shown. White box indicates 300K data and black box indicates 77K data.

In Fig. 6, MQW emission wavelengths at 300K and 77K are plotted for nominal well thickness. The solid curves represent theoretically calculated values for 300K and 77K. The conduction band offset for CBE grown GaInAs/InP samples is found to be 0.36eV or 60% of the bandgap offset by curve fitting data to theoretical values. It is important for laser fabrication to reproduce the designed wavelength. From these results, one can easily choose a well width and then take the appropriate growth time to obtain a desired wavelength even with high growth rates. Photoluminescence measurements indicate that CBE materials are in good optical quality and can be used to optical devices.

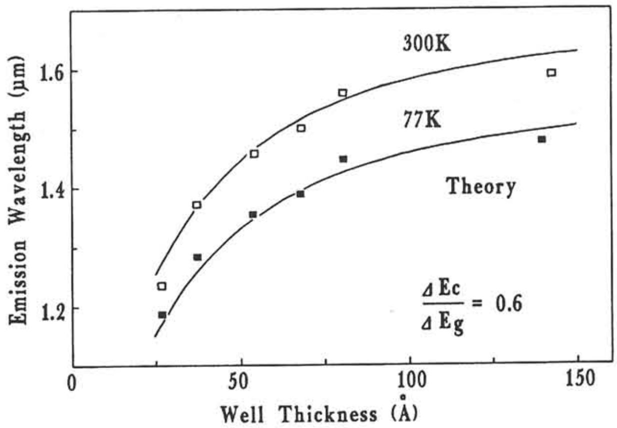

Fig.6 Emission wavelength is plotted for its corresponding wavelength. The solid curves represent theoretical calculations for 300K and 77K. The conduction band offset ΔEc of 0.36eV is used for calculations (other parameters, see Ref. 5).

Using growth rates of 2.3μm/h for InP and 4.7μm/h for $Ga_{0.47}In_{0.53}As$, a multilayer DBR was grown as a preliminary study for application to surface emitting lasers having a $Ga_xIn_{1-x}As$/InP MQW active layer. It has been investigated that band-edge absorption can be shifted toward shorter wavelengths with sufficiently high n-type doping[3,6]. We used solid silicon as a n-type dopant for a GaInAs/InP quarter-wavelength DBR for an emission wavelength of 1.6μm. The reflectivity profile of a DBR mirror consisting of 18 pairs of GaInAs/InP is shown in Fig. 7. GaInAs was doped to

$1x10^{19} cm^{-3}$ and InP was doped $7x10^{18} cm^{-3}$. As can be seen, relatively high reflectivity of 85% at 1.6μm was obtained. One reason for the difference between experimental and theoretical values was in the estimation of absorption. Absorptions for GaInAs and InP were estimated to be $100cm^{-1}$ and $30cm^{-1}$, respectively. Uniformity of this structure was excellent and layer thickness was well

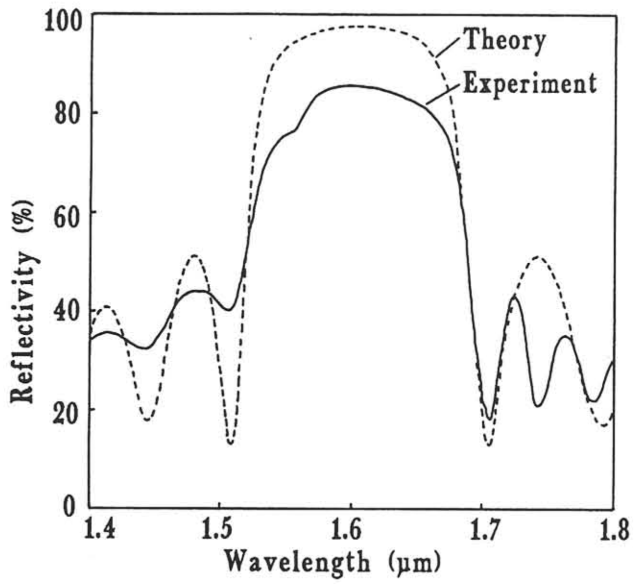

Fig.7 Reflectivity vs wavelength for a n-doped DBR mirror with 18 pairs of GaInAs/InP is shown. The dotted line represents a theoretically calculated reflectivity of the same structure.

controlled as can be seen from the band width of the profile. In order to obtain higher reflectivity, a number of GaInAs/InP layers needs to be increased and doping levels must be optimized.

3. Conclusion

We have demonstrated GaInAs MQW growth with a rate of 14Å/sec maintaining excellent thickness controllability and quality. Quantum wells as thin as 26Å were grown and linewidths as narrow as 8meV at 77K were obtained, repeatedly. The relationship between wavelength and well width was in good agreement with theoretical values by taking the 60% conduction band offset. Our results suggest that good selectivity of wavelength by the growth time. These results suggest extremely high productivity in epitaxial growth for some device application such as surface emitting lasers.

$Ga_xIn_{1-x}As$/InP strained layer superlattices have been grown to characterize their physical properties and application possibility to high performance long wavelength SE lasers. A DBR growth is also in progress and experimental SE lasers with combined structures of DBRs and a MQW active layer is currently being conducted.

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