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PL Study on Structure Dependence of $Ga_xIn_{1-x}As/InP$ Strained Multi-Quantum Wells Grown by CBE

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We have investigated optical characteristics of strained MQW with various structures grown by CBE. We grew strained MQW samples at the optimum condition and observed some characteristics depending on the structure by photoluminescence (PL) measurement. PL intensities were stronger than lattice matched MQW and peaked around at 20Å thick wells. There exists the optimum layer thickness of wells and barriers to release the accumulated strain in the MQW. It was also found that observed PL linewidths were broadened according to the stress.

1. INTRODUCTION

The use of strained multi-quantum wells (MQW) is quickly becoming a key technology for the future of opto-electronic devices. High performance GaInAs(P)/InP semiconductor lasers have been demonstrated using strained MQWs[1)2)]. However, the optimum parameters of strained MQW structures, such as composition, well thickness and barrier thickness have not been fully examined and understood. CBE (Chemical Beam Epitaxy) has good controllability when growing crystals of accurate thickness and composition, it may also provide high quality strained materials. In the present study, we have investigated the optical quality of compressive strained MQW of various structures using CBE, focusing especially on the strain release.

2. EXPERIMENT

The RIBER CBE-32 was used for growing strained samples. Trimethylindium(TMI), triethylgallium(TEG) with a H_2 carrier gas and pure PH_3 and AsH_3 were used as the gas sources. Growth temperature was kept at 520°C. Figure 1 shows a schematic structure of strained MQW. All samples consist of ten $Ga_xIn_{1-x}As$ wells and eleven InP barriers grown on an (100) oriented InP substrate. Most samples had the barrier thickness of 270Å . This value is thicker than the barrier thickness of standard MQW lasers which is about 100Å. We also grew some samples which had the barrier thickness of 150Å and 200Å with the same well conditions of some 270Å barrier samples. The well thicknesses of these strained MQW ranged from a minimum of 3Å for InAs MQW to around 60Å as the photoluminescence peak wavelength at the room temperature was shorter than near 1.7μm. The thickness of wells and barriers were estimated from satellite peaks in X-ray diffraction spectra[3)]. The growth rate was 3Å/sec for InP and 3-14Å/sec for $Ga_xIn_{1-x}As$. The layer thick-

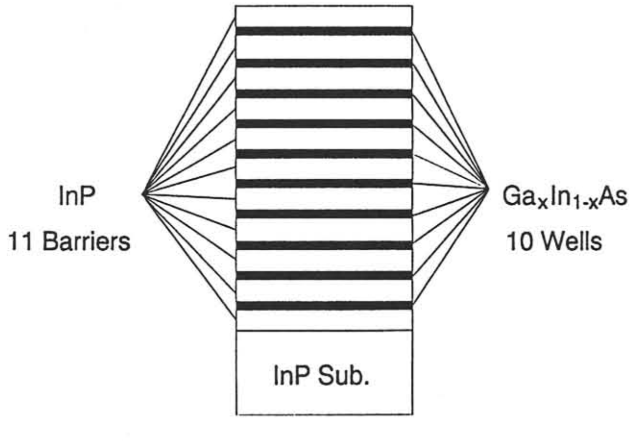

Fig. 1 A schematic presentation of strained MQW grown for the experiment. Ten $Ga_xIn_{1-x}As$ wells and eleven InP barriers were grown on InP substrate.

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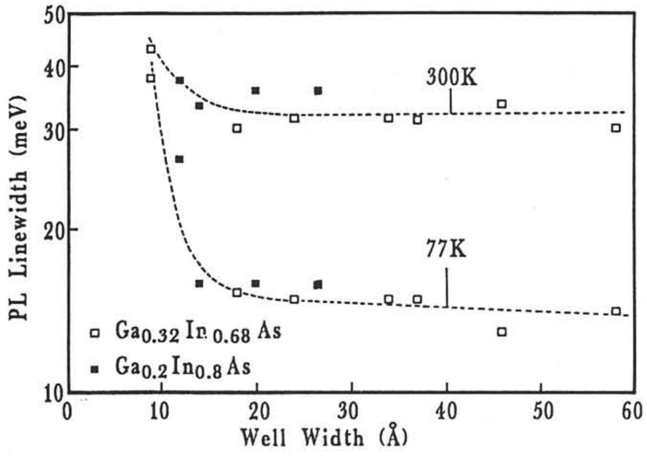

Fig. 2 PL linewidth (full width at half maximum) as a function of well width is plotted. Dotted lines are drawn to connect data. The linewidth of InAs/InP MQW was about two times broader than these data.

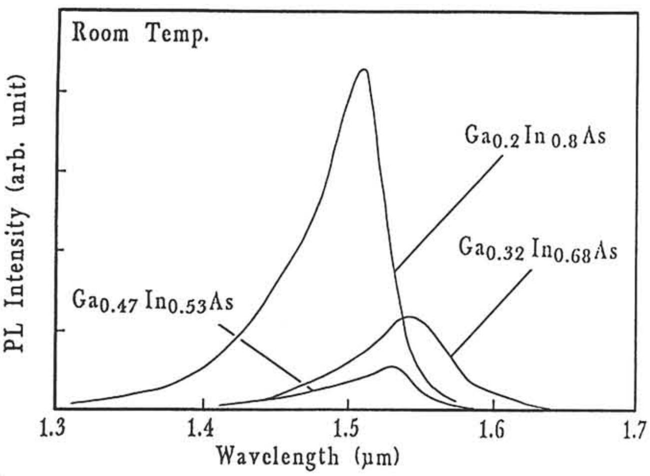

Fig. 3 A comparison of PL intensity of different MQWs is shown. Well thicknesses are adjusted so that their peak wavelength is around $1.55\mu m$. Strained materials showed stronger intensity than lattice matched MQW ($Ga_{0.47}In_{0.53}As$).

ness was controlled only by changing growth time according to composition. Since the fluctuation of the interface between wells and barriers affects the material quality, we carefully optimized the growth sequence to obtain intense single-peaked photoluminescence spectra.

Under this condition, we studied the structural dependence of strained MQW by photoluminescence (PL) measurement. In Fig. 2, the PL spectrum linewidth of $Ga_{0.32}In_{0.68}As$ and $Ga_{0.2}In_{0.8}As$ strained MQWs was plotted for well widths at 300K and 77K. Most samples with well width from 20Å to 60Å exhibited linewidths of around 30meV for 300K and 16meV for 77K. The linewidth of InAs/InP strained MQWs was about two times broader than the data shown in this figure. As for lattice matched MQW grown by CBE, the linewidths of 24meV for 300K and 8meV for 77K were obtained[4]. Though the strained MQW in Fig. 2 had similar linewidths, more thoroughly strained materials show broader spectra. Linewidth broadened very rapidly for thinner wells below 20Å. This may be caused by layer thickness and compositional fluctuation and moreover due to stress fluctuations.

PL spectra of strained MQW are shown in Fig. 3 and compared with lattice matched ($Ga_{0.47}In_{0.53}As$) MQW. These samples had peak wavelengths near $1.55\mu m$ at 300K and well widths of $Ga_{0.2}In_{0.68}As$, $Ga_{0.32}In_{0.68}As$ and $Ga_{0.47}In_{0.53}As$ were 26Å, 37Å and 75Å, respectively. As seen in this figure, strained MQW had higher intensities than lattice matched ones. The more compressive MQW in two strained samples of $Ga_{0.2}In_{0.68}As$ luminesced much higher than the others. It will be caused by the increase of the transition rate or transition probability for spontaneous emission. However, these samples had defferent well thicknesses and the same barrier thickness of 270Å.

Figure 4 shows PL intensities versus well width for $Ga_{0.32}In_{0.68}As$, $Ga_{0.2}In_{0.8}As$, and InAs MQWs sandwiched by barriers with the width of 270Å. The intensity of the InAs MQWs, was not as high as that of other compositions with the same well thickness. It means that the optimum composition exists to luminesce at the highest intensity. The PL intensities peaked around at 20Å for

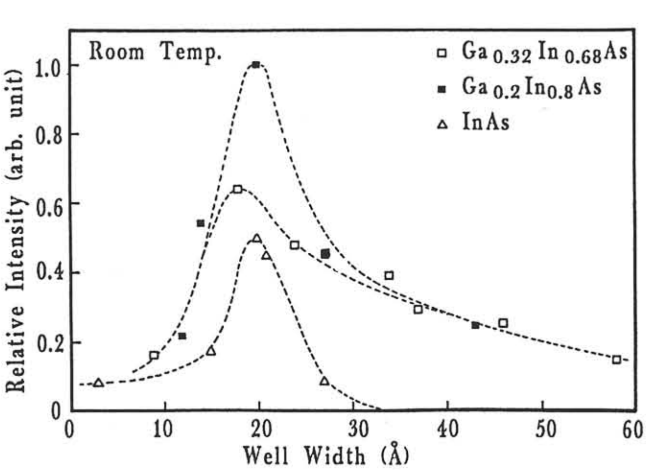

Fig. 4 PL intensities of strained MQWs are shown as a function of well thickness. These data was plotted relative to the sample of $Ga_{0.2}In_{0.8}As$ with a 20Å well thickness. Dotted lines were drawn to connect data.

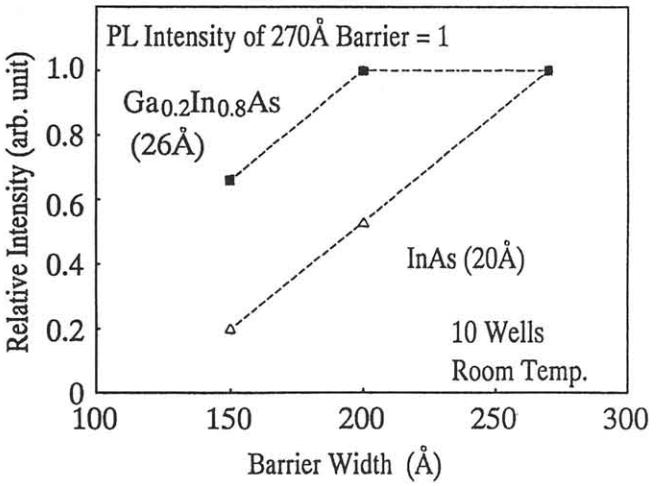

Fig. 5 PL intensities are plotted as a function of barrier thickness for different strains. The intensities were normalized by the sample of 270Å barrier thickness.

all compositions. Tabata et al also observed that the integrated PL intensity from the InAs single quantum well peaked at 15Å[5]. The intensity decrease below 20Å may be caused by thickness and compositional fluctuations as stated above or by the reduction of effective excited carriers. On the other hand, the intensity decreases above 20Å are considered to be due to the reduction of quantum effect or the accumulated stress in the MQW. The latter effect may strongly depend on barrier thickness.

The peak PL intensities for various barrier thicknesses are shown for two compositions in Fig. 5. The well thicknesses are adjusted so that their PL peak wavelength are near 1.55μm at room temperature. According to this figure, there exists a minimum barrier thickness for $Ga_{0.2}In_{0.8}As$ and over 270Å thick barrier is required for the InAs MQWs to sustain the stress. The intensities of $Ga_{0.32}In_{0.68}As$ were the same for barrier thicknesses of 150Å,but this is not shown in this figure. The different of PL linewidths of InAs MQWs and two other strained MQWs are shown in Fig. 2. Differences were caused by the amount of barrier. The minimum barrier thickness depends on the degree of stress, well width, and number of wells. By introducing tensile strain to the barrier, it is possible to keep a thin barrier due to the strain compensation[6].

3. CONCLUSION

We optimized the growth condition of strained MQW and pointed out some characteristics depending on the structure. At the same barrier thickness, the PL linewidths of two strained materials showed the same broadening. InAs, the most strained material, broadened the most. We observed an increase of PL intensity compared with lattice matched MQWs. Intensities peaked at a well width of 20Å. There exists an optimum layer thickness of wells and barriers to release the accumulated strain in the MQW. This causes characteristics of the PL intensity and linewidth. The obtained data will be utilized for future laser device design.

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REFERENCES

1) P. J. A. Thijs and T. V. Dongen, *Electron. Lett.* 25 (1989) 1735.
2) C. E. Zah, F. J. Favire, R. Bhat, S. G. Menocal, N. C. Andreadakis, D. M. Hwang, M. Koza and T. P. Lee, *IEEE Photon. Technol. Lett.* 2 (1990) 852.
3) M. Sugawara, M. Kondo, S. Yamazaki and K. Nakajima, *Appl. Phys. Lett.* 52 (1988) 742.
4) T. K. Uchida, T. Uchida, K. Mise, N. Yokouchi, F. Koyama and K. Iga, *Conf. on Solid State Devices and Materials*, Sendai, 1990, (Extended Abstract B-4-5).
5) A. Tabata, T. Benyattou, G. Guillot, Z. Sobiesierski, S. A. Clark, R. H. WIlliams, M. Gendry, G. Hollinger and P. Viktorovitch, *Conf. on Indium Phosphide and Related Materials*, UK, 1991, (WP50)
6) B. I. Miller, U. Koren, M. G. Young and M. D. Chien, *Appl. Phys. Lett.* 58(1991) 1952.