*Journal of Metals, Materials and Minerals. Vol. 13 No. 1 pp. 1-5, 2003.*

# Photoluminescence of extremely thin InGaAs/InP Single Quantum Wells grown by Organometallic Vapor Phase Epitaxy

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## ABSTRACT

The optical properties of extremely thin $In_{0.53}Ga_{0.47}As$/InP single quantum wells (SQWs) grown by Organometallic Vapor Phase Epitaxy (OMVPE) were extensively investigated by photoluminescence spectroscopy (PL). The PL spectra of 3 samples with different well widths of 2 monolayers (ML), 3 ML, and 4ML were carried out. The spectra exhibit a single luminescence peak, corresponding to the recombination between the first electron subband and the first heavy-hole subband (e1-hh1).

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## INTRODUCTION

Semiconductor compound materials from group III and V in the periodic table have recently attracted considerable interest according to their promising properties for the use in novel optoelectronic devices such as lasers and light emitting diodes. Most of these devices are fabricated in the form of a quantum structure. $In_{0.53}Ga_{0.47}As$ lattice-matched to InP has shown promise for the use in ultrahigh speed devices, utilizing the high electron mobility and a high peak velocity. A band gap of 0.75 eV is appropriate for use in photodetectors in optical communication systems. Moreover, semiconductor injection lasers using InGaAs/InP quantum well structures can be shifted into the 1.30-1.55 μm region by changing the well thickness. Room –temperature measurements of the quantum confined Stark effect in single InGaAs/InP quantum wells grown by low-pressure MOVPE were studied (Moseley, *et al.* 1989). The well thickness ranges from 45 to 110 Å. Photocurrent measurements on p-i-n diodes containing single quantum wells have been used to demonstrate strong excitonic absorption features which exhibit substantial spectral shift in an applied electric field. The optical properties of excitons in InGaAs/ InP quantum wells for the use in tunable resonant cavity enhanced photodetectors were analyzed by photoluminescence and photocurrent spectroscopy (Borgulova, *et al.* 1999). The results imply the formation of InAs or InAsP monolayers at the interface between the InGaAs QW and the InP barrier. However, little few research on the low-temperature optical characterization of very thin wells of this structure was reported.

During the last four decades, Photoluminescence spectroscopy has been extensively used as characterized tools for fundamental research. However, because of the importance of high quality materials and material structure, especially in the case of semiconductors, such as quantum wells (QWs), quantum wires (QWRs) and quantum dots (QDs), fundamental research and material characterization are not separable. Low – temperature photoluminescence of InGaAs/InP quantum wells with a well thickness ranging from 1 to 16 nm was performed in order to investigate the source supply interruption (SSI) at the interface (Hosomi, *et al.* 1995). The observed PL peak energy shifts toward a higher energy as the SSI becomes longer. PL is measured to study the optical features of GaAs/AlGaAs multiple quantum wells. The results suggest that As pressure influence on densities of the defects that can be tailored by As pressure during the MBE growth (Han, *et al*. 2002).

In this paper we employed photoluminescence spectroscopy to investigate the quality of formation of extremely thin InGaAs/InP single quantum wells grown by OMVPE. The PL peak of each sample exhibits the recombination between e1-hh1 in InGaAs QWs.

## EXPERIMENTS

Few monolayer $InP/In_{0.53}Ga_{0.47}As/InP$ SQWs were grown by Organometallic Vapor Phase Epitaxy (OMVPE) at low pressure. Trimethylgallium (TMGa), Trimethylindium (TMIn), $AsH_3$, and $PH_3$ were used as the source gases for Ga, In, As and P respectively. The flow sequence of the source gases are is shown in Figure 1. A 100 nm thick InP buffer layer was grown on a semi-insulating InP substrate. After the gas source for In an P was suspended, the InGaAs well layer was grown with varied thickness from 1-5 monolayers before the InP cap layer with a 2 nm thickness was grown. The growth temperature was 600°C. The sample structure is schematically depicted in Figure 2.

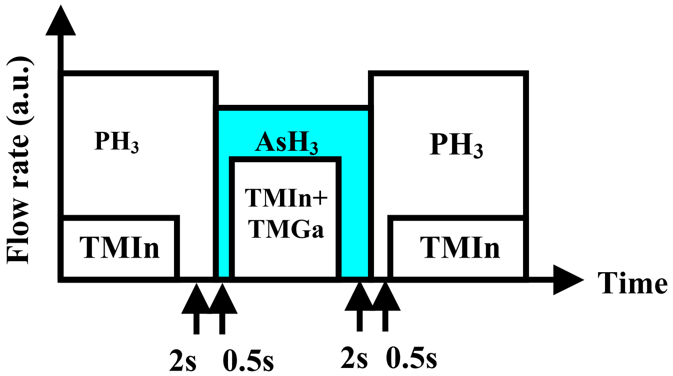


**Figure 1** Flow sequence of gas sources for InP/InGaAs SQWs.

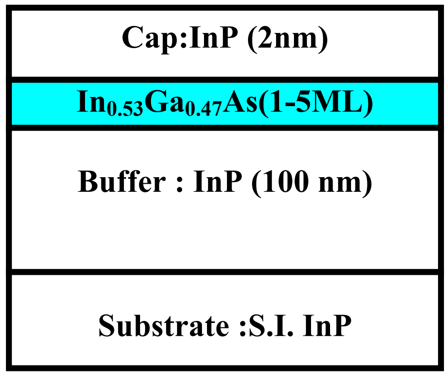


**Figure 2** Sample structure of InP/$In_{0.53}Ga_{0.47}$ As/InP SQWs.

Figure 3 shows a schematic diagram of a PL experiment set up. The PL experiment was conducted at the department of Physics, Silprakorn University. The Argon ion laser with a filtered wavelength of 488 nm was used as an optical excitation source. The sample was cooled down from room temperature (RT) to 10 K in a cryostat. The luminescence from the sample was dispersed by the monochromator and was carried out by a Ge detector. The signal was amplified by a lock-in amplifier and displayed by a PC. The stepped motor of the monochromator was controlled by a signal from a PC via a RS-232 port.

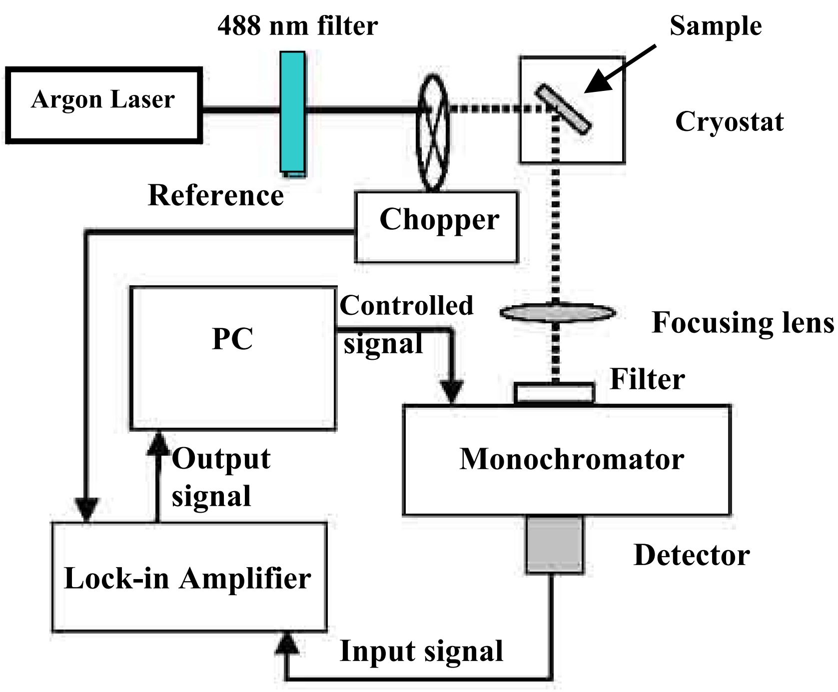


**Figure 3** Schematic diagram of Photoluminescence experiment set up.

## RESULTS AND DISCUSSION

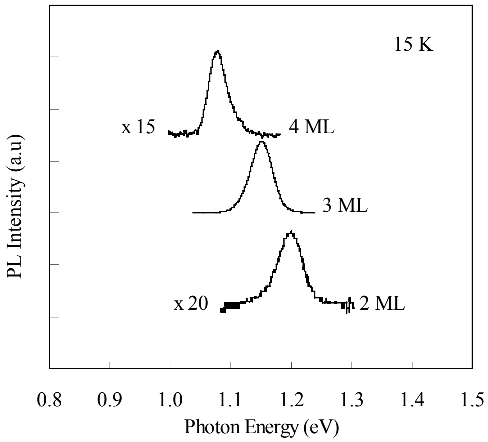


**Figure 4** PL spectra as a function of the well width at 15 K

In Figure 4, the PL spectra of all samples at 15 K exhibit clear peaks, which are attributed to the luminescence from a quantum well. The observed PL peak of the sample with the well width of 4ML, 3ML, and 2 ML is at 1.07 eV, 1.14 eV, and 1.20 eV respectively. The PL peak has a dramatic increase (about 60 meV) when the well width is decreased by only one monolayer. These features reflect the formation of the extremely thin single quantum well between lattice-matched InP and InGaAs. The sample with a 3ML-well width shows the strongest intensity, implying the optimization of good formation and uniformity of the sample. We have calculated the ground state energy level in the quantum well by solving the one-dimensional Schrӧdinger equation of a finite square well. The energy of InP and $In_{0.53}Ga_{0.47}As$ are 1.35 eV and 0.73 eV respectively (Nukeaw, *et al.* 1998). The effective mass of the electron $\left(m_e^*\right)$ and hole $\left(m_{hh}^*\right)$ for InGaAs are $0.0416m_0$ –and $0.46m_0$ respectively. The band discontinuity for conduction band, $\Delta E_c$, and valence band ,$\Delta E_V$, are 0.217 eV and 0.403 eV respectively (Nukeaw, *et al.* 1998).

In Figure 5, the calculation results of e1-hh1 transition energy are plotted by closed squares while the closed lozenges denote the transition energies obtained from the PL measurement. The calculated values are in good agreement with the experiment values. However, the calculated values show a slight difference (about 10-20 meV) from the measured values. The origin of the difference may come from the imperfection at the interface between the extremely thin layer of the InGaAs and the InP barrier (Boherer, *et al.* 1992).

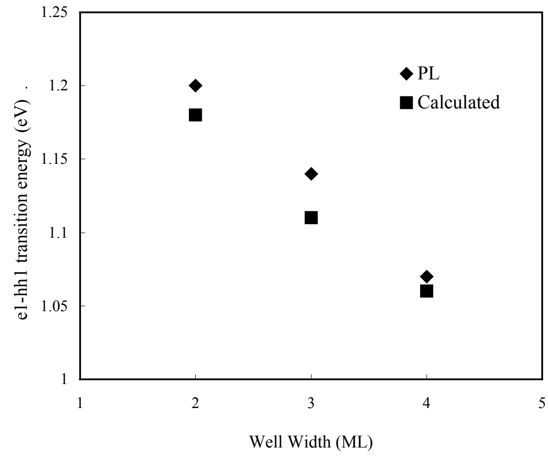


**Figure 5** Transition energy of e(1)-hh(1) in InP/InGaAs/InP SQWs as functions of well width by PL experiment.

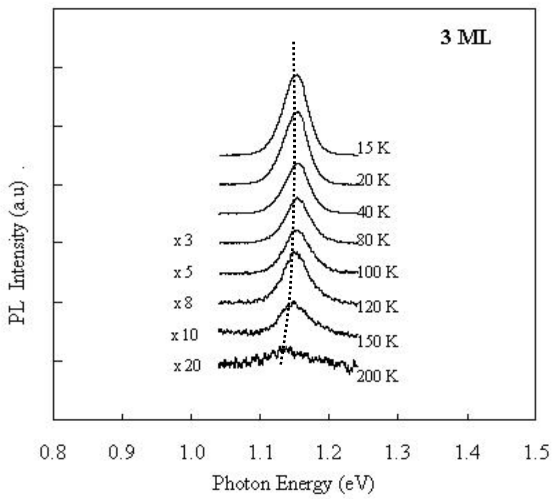


**Figure 6** PL spectra of a 3-ML sample as a function of temperature.

Figure 6 shows temperature-dependent PL of the sample with 3ML well width. As temperature is decreased from 200-15 K, PL spectra are stronger and exhibit the blue shift, moving to the higher photon energy. The tendency of the shift is illustrated by a dashed line. The peak of 1.13 eV at 200 K is slightly shifted to a higher energy of 1.15 eV at 15 K. It can be deduced that the luminescence of the extremely thin or small quantum structure is independent of the temperature (Lambert, *et al.* 1998). The PL intensity drop as the temperature increases is due to the fact that when the temperature increases, the photocarriers have a greater probability to meet various types of defects and recombine non-radiatively on them (Lambert, *et al.* 1998).

## CONCLUSION

We have conducted the photoluminescence of extremely thin $In_{0.53}Ga_{0.47}As$/InP SQWs grown by OMVPE. The PL peak reveals a luminescence from the recombination between e1-hh1 in the quantum well. The photon energy of the PL peak increases dramatically as the well width decreases by only a few monolayers and has such good agreement to calculated results. The temperature-dependent PL shows that the luminescence from this structure is almost independent to temperature due to a very small quantum structure.

## ACKNOWLEDGEMENTS

We would like to acknowledge the Department of Applied Physics, King Mongkut's Institute of Technology Ladkrabang for the research facilities. This work is supported in part by the scientific research and development No. NT-B-06-4A-22-314 from the National Electronics and Computer Technology Center (NECTEC).

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***(Revised version accepted October 3, 2003)***