Chapter 3

GaAs on GaAs by MBE

The main research on RIBER 32-P MBE at Semiconductor Device Research Laboratory is to grow III - V compound semiconductor, such as GaAs, AlGaAs, InGaAs. This chapter will describes some works on GaAs and AlGaAs growing onto GaAs substrates which could be examined epitaxial quality by using photoluminescence (PL) technique.

3.1 Preparation of GaAs Substrate

Most of the MBE growth of GaAs, $Al_xGa_{1-x}As$ has been performed on (100)-oriented substrate slices 200-350 μm thick. The GaAs substrates are, normally, successively rinsed in trichloroethylene, aceton, methanol, and deionized water. Finally, the substrates are blown dry with nitrogen gas before mounting them with liquid indium to a heated Mo blocks under dust-free conditions. Generally, the substrate that placed in air can be oxidized to generate surface-oxidized phases and the oxidation could be enhanced by the sample heating for indium soldering on the sample holder.

The samples were then immediately loaded into the loading chamber of the MBE system for pre-evacuation. Afterward, the sample is heated on the preparation chamber oven upto 400°C for 30 minutes to outgas moisture and some contamination from the substrate surface in the condition of $< 10^{-10}$ Torr background equivalent pressure vacuum. The substrate is then consequently passed to keep in the transfer chamber before the epitaxial growth process.

In the growth chamber, there is a manipulator that has a heater and revolving stage which can catch the Mo block. The revolving stage is used to make a homogeneous temperature while the substrate is heated by the heater. The substrate temperature is a significant parameter for the growing process, then the PID controller should be used with proportional setting to prevent or decrease the temperature fluctuation.

The surface-oxidized phases that occurred previously must be desorbed before the growth start. The substrate is heated in arsenic ambient and checked with RHEED pattern for the oxide desorp point (typically around 540°C). At this point, RHEED should be changed from spotty to streaky pattern. After carefully increasing the substrate temperature, with the proportional situation, (2x4) RHEED pattern should be observed to ensure that the substrate surface has acceptable 2D-reconstruction.

3.2 Epitaxial Growth of GaAs Bulk

The GaAs substrates were grown epitaxial layers of undoped-GaAs and also Si-doped, Be-doped epitaxy. The substrate temperature for each growth was set at 630°C. An approximately 1 μm thick GaAs layer was grown with the growth rate ~1 μm/hr. The flux intensity of As_4 was measured by an ionization gauge placed at the manipulator in the same position of the substrate holder. All of the epitaxy were grown with the same flux intensity of As_4 at $2x10^{-6}$ Torr and Ga flux intensity was $2.5x10^{-7}$ Torr. The epitaxy have mirror like surfaces after the MBE growth processes then examined by using Photoluminescence technique.

The epitaxial layers of $Al_xGa_{1-x}As$ were also grown to prove the variation of Al flux intensities effect to the fractional ratio (x) of the layers. This experiment was carried out by fixing the Ga flux intensity and varying the Al flux intensity.

3.3 Epitaxial Growth of $Al_xGa_{1-x}As$/GaAs Multi-Quantum Well

The experiment included also an attempt to grow $Al_xGa_{1-x}As$/GaAs multi-quantum well by using the $Al_xGa_{1-x}As$ that has wider energy gap as a barrier layer while the GaAs as a well layer. The fraction ratio (x) in the $Al_xGa_{1-x}As$ is controlled around 0.2 to 0.3 by using growing parameter that has been confirmed from the previous bulk growth.

All of the $Al_xGa_{1-x}As$/GaAs multi-quantum well structures were grown by computerized control MBE. Semi-insulator GaAs wafers have been used as the substrates. Each epitaxial layer was formed by appropriate shutter control of Ga, Al and As sources in the growth chamber of the MBE machine. All epitaxial layers in the samples in this experiment are undoped. MBE technique gives high quality (confirmed by RHEED pattern during the crystal growth) and provides quantum well width in oder of an atomic layer. There were four types of multi-quantum well structures in the experiment. They are different in number of quantum wells as well as different variable well widths.

The thickness of each epitaxial layer could be estimated from the time and growth rate of MBE process. Growth rate could be confirmed by in-situ RHEED pattern oscillation. It was maintained around 1 monolayer per second (~ 2.5 Å/s). The structural details of each type of the samples were described as followings :

Type I : This sample has two quantum wells, having well width of 30 and 60 Å respectively. The two wells are separated by 850 Å $Al_xGa_{1-x}As$ barrier layer as shown in figure 3.1 (a). The sample is called *2 MQW* structure.

Type II : There are 12 quantum wells in this sample. The top most well layer is the narrowest having the thickness of 14Å. The next inner wells gradually thicker by 14 Å more until the last bottom well which is 170 Å. The $Al_xGa_{1-x}As$ barrier layers are kept at 850 Å as shown in figure 3.1 (b). The sample is called *12 MQW* structure.

Type III : This sample has 6 groups of multi-quantum wells. Each group has 4 repeated quantum wells with the same thickness. The quantum wells of the top most group are 30 Å thick. The next groups of inner wells are 60, 85, 110, 140 and 170 Å respectively as shown in figure 3.1 (c). The $Al_xGa_{1-x}As$ barrier layers between these different groups are 850 Å thick. But the barrier layers between repeated wells in each group are kept rather thinner at 500 Å. The sample is called *4x6 MQW* structure.

Type IV : The sample is grown with 10 repeated quantum wells with all are same well width. The well width is 150 Å and the barriers are 750 Å thick. A shematic of this sample is shown in figure 3.1 (d). The sample is called *10 MQW* structure.

The well layers are varied to study effect of well width to the quantized energy state in the quantum well. And also proved by the photoluminescence technique. Results of these multi-quantum well preparations will be described in the next subject. Quantum well structure is one of the important research that can magnify further to the fabrication of optoelectronic devices.

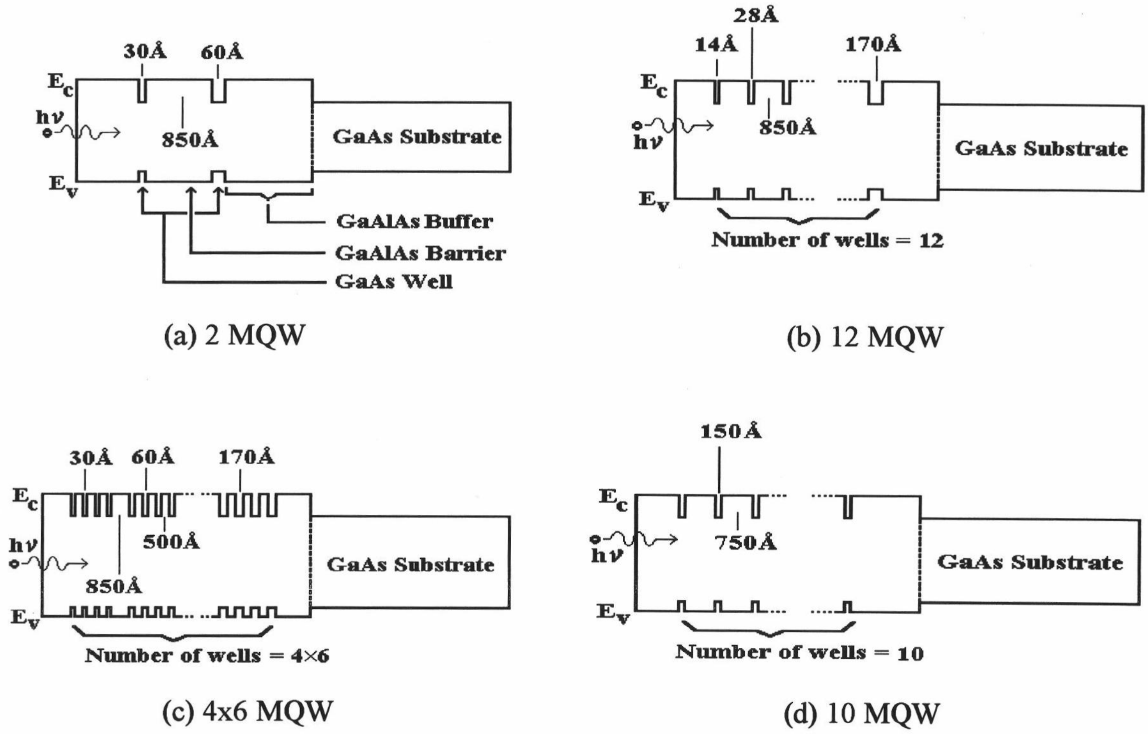

Figure 3.1 Schematic diagram of the 4 types of MQW for the experiment

3.4 Photoluminescence Technique

Luminescence is a basic optical phenomenon of a solid when it is supplied with some form of energy. Luminescence in semiconductor materials can be distinguished in various types by the method of excitation. For example :

Photoluminescence : excitation arises from the photons absorption

Cathodoluminescence : excitation is by bombardment with electron beam

Electroluminescence : excitation is from either a.c. or d.c. electric field

Whatever the form of energy pumped into the material, the final stage is an electronic transition between two energy levels, E_1 and E_2 ($E_2 > E_1$), with the emission of radiation of wavelength λ given as :

$$\frac{hc}{\lambda} = E_2 - E_1 \tag{3.1}$$

Where h is Planck's constant ($4.132 \cdot 10^{-15}$ eV•sec) and c is the light velocity ($2.998 \cdot 10^{10}$ cm/sec). Normally, E_1 and E_2 are part of two groups of energy levels, so that, instead of a single emission wavelength, a band of wavelength is usually observed.

For the photoluminescence (PL), optical excitation occurs. A photon is absorbed by the semiconductor, creating an electron-hole pair which then recombines, emitting another photon. This technique has the advantage that it can be used to excite materials in which contact or junction technology is not adequately developed, or in high-resistivity materials, such as undoped semiconductor. Optical excitation permits flexibility in the configuration of the excited region and in the choice of the location on the crystal.

Photoluminescence measurement system consists of laser source as an optically pumping, optical path to collect photon or luminescence signal, monochromator to separate photon spectral, photo multiplier to multiply a photon to several electron signal, small signal lock-in amplifier to gain up the luminescence signal enough for recording and computer system to store spectral data and to control the monochromator system.

Figure 3.2 shows a diagram of the PL measuring system. The laser used in this research was an argon ion laser which has optical wavelength of 488 nm or equal to photon energy of 2.538 eV that enough to pump electron across band gap of GaAs (E_g = 1.424 eV at 300 K). The laser beam was chopped and focused onto the sample which placed in a cryogenic system. The cryogenic system provides very low temperature environment to the sample, typically at 10 K. At low temperature, the luminescence efficiency increases due to less of phonon interaction.

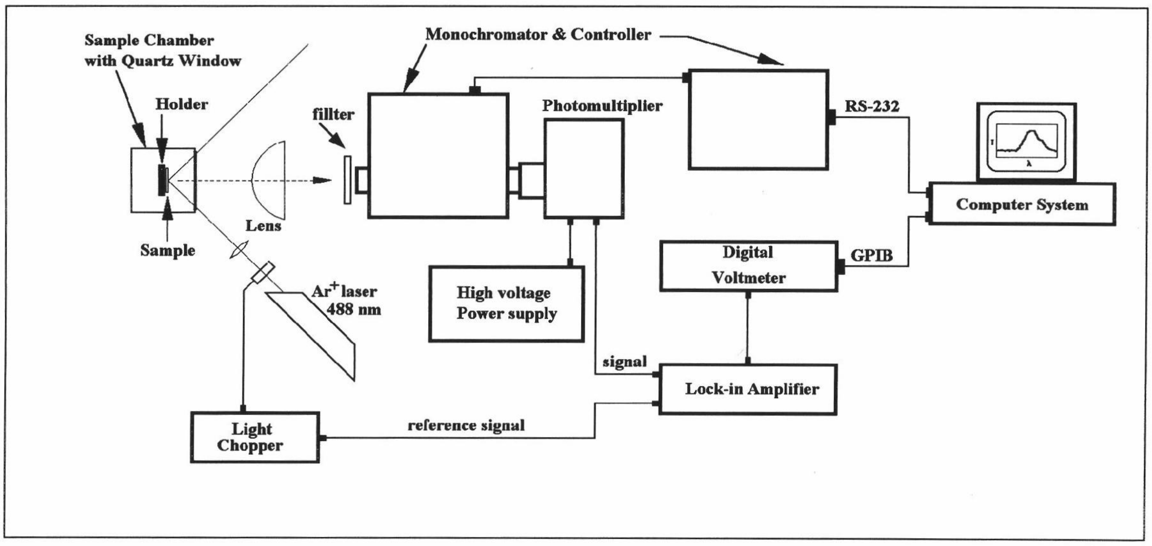

Figure 3.2 Diagram of the photoluminescence measurement system

3.5 Photoluminescence of Bulk Materials

PL spectrum is useful to determine crystallography characteristic of the epitaxial layers. By a mirror-like homogeneous epitaxy or bulk crystal, PL spectrum is like a bell-shape that has a peak corresponds to an energy gap of the crystal. Figure 3.3 is a PL spectrum of GaAs semi-insulator substrate at 77 K . The peak of the PL spectrum appears at 825 nm or 1.502 eV that due to the characteristic of GaAs.

Energy gap of GaAs at 300 K = 1.424 eV

Temperature coefficient = 0.000395 eV/K

From the calculation the energy gap of GaAs at 77 K should be 1.512 eV. The variation come from an accuracy and resolution of the monochromator.

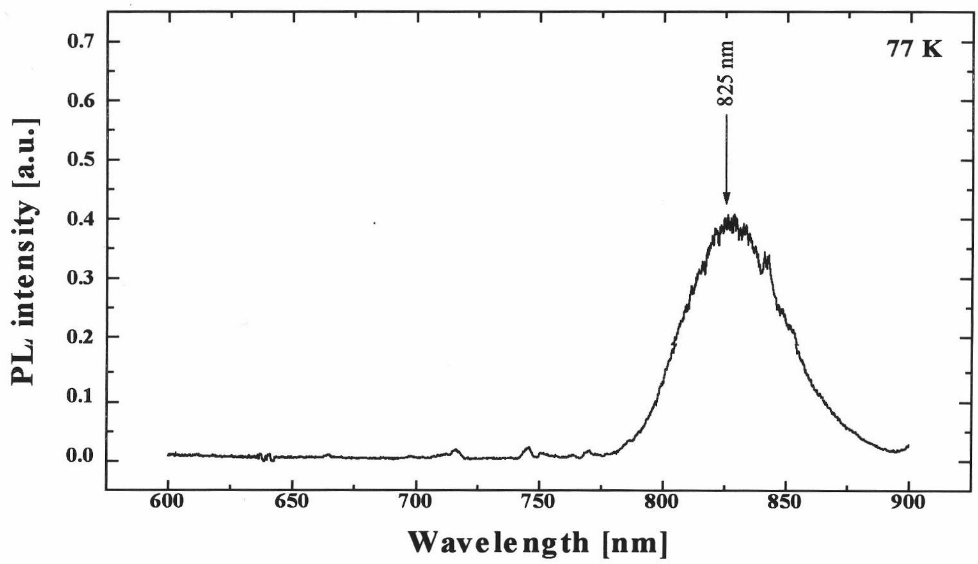

Figure 3.3 PL spectrum from GaAs substrate at 77 K

A PL spectrum of Si-doped GaAs epitaxy is shown in figure 3.4. The spectrum has 2 peaks at 822 nm and 877 nm. From the studies [9], the peak at 822 nm came from band to band transition and the peak at 877 nm came from Si-donor level transition. Silicon donor level acts as a radiative recombination center and the donor stage is lower than the conduction stage of GaAs.

In figure 3.5 the PL spectrum from Be-doped GaAs layer is shown. The PL peak is shifted to 845 nm which comes from a transition from the conduction band to the acceptor stage that higher than the valence band of GaAs. Normally, it is hard to produce highly-doped Be epitaxy using conventional effusion cell. The sharp peaks at the range 700 to 800 nm come from interference at the layer interface.

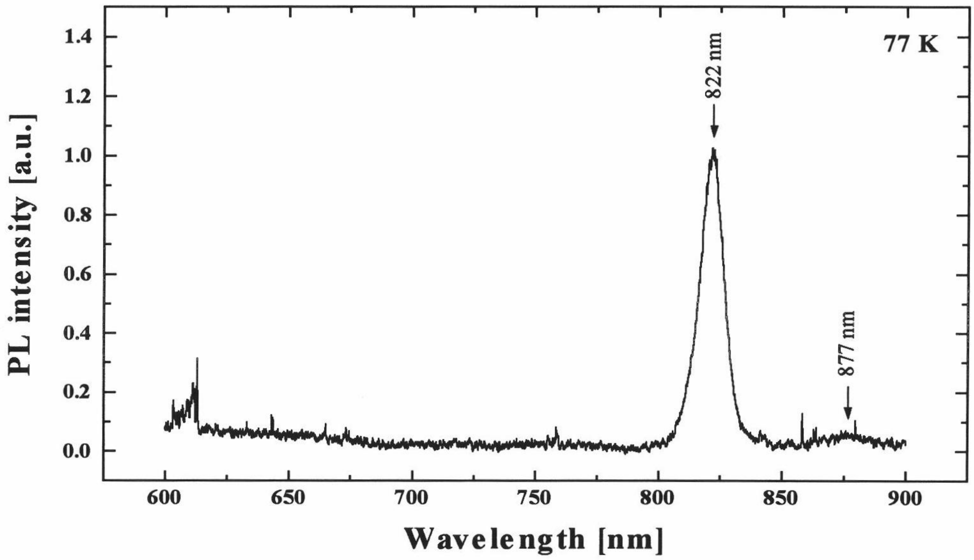

Figure 3.4 PL spectrum from Si-doped GaAs layer at 77 K

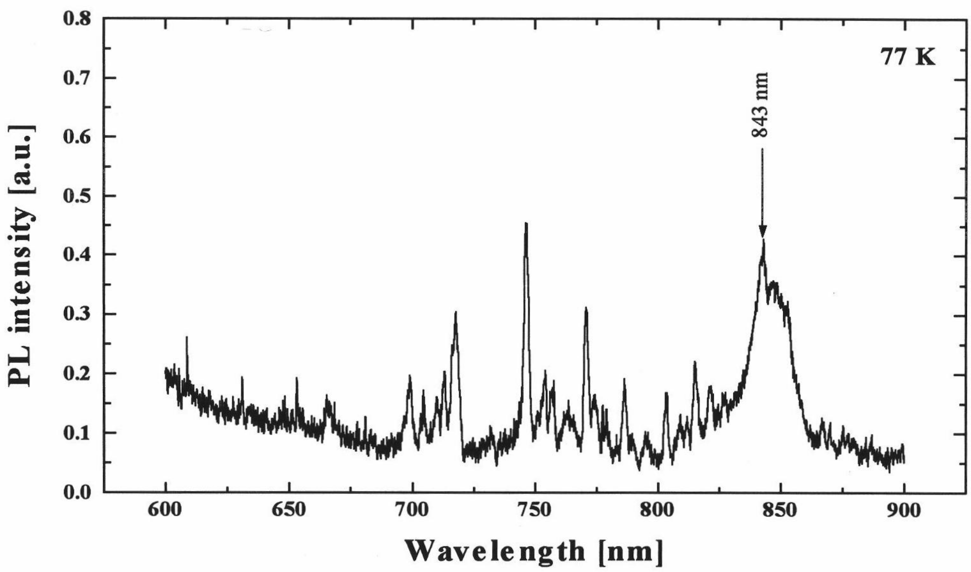

Figure 3.5 PL spectrum from Be-doped GaAs layer at 77 K

Figure 3.6 shows PL spectrum from Si-doped AlGaAs epitaxy on GaAs substrate. A fine peak appears in short wavelength separately from a bell-shape AlGaAs peak. This fine peak came from a radiation from donor level which generated from silicon dopant. A different energy that the two peaks split is 142 meV higher an energy level of AlGaAs conduction band. The peak of AlGaAs at 741 nm or 1.672 eV indicates Al content equal to 13 % that calculated from [10]:

at 300 K $$E_g = 1.424 + 1.247x \tag{3.2}$$

$$dE_g/dT = -3.95 - 1.15x \quad (\text{x}10^{-4}\ \text{eV/deg}) \tag{3.3}$$

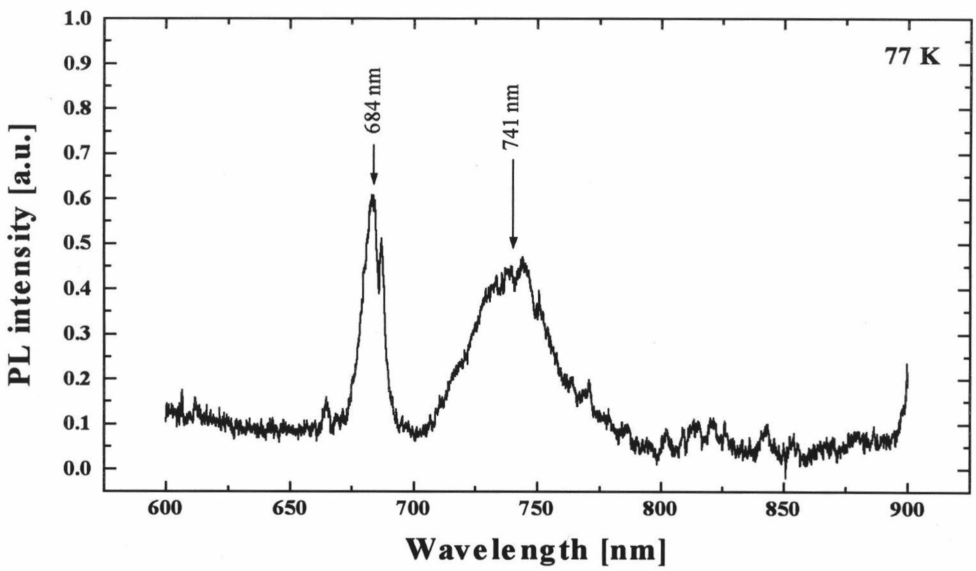

Figure 3.6 PL spectrum from Si-doped $Al_{0.13}Ga_{0.87}As$ layer at 77 K

The PL spectrum that shown in figure 3.7 comes from also Si-doped AlGaAs with higher Al content. The peak at 636 nm repesents $Al_{0.35}Ga_{0.65}As$ layer and the peak at 654 nm comes from Si doping level.

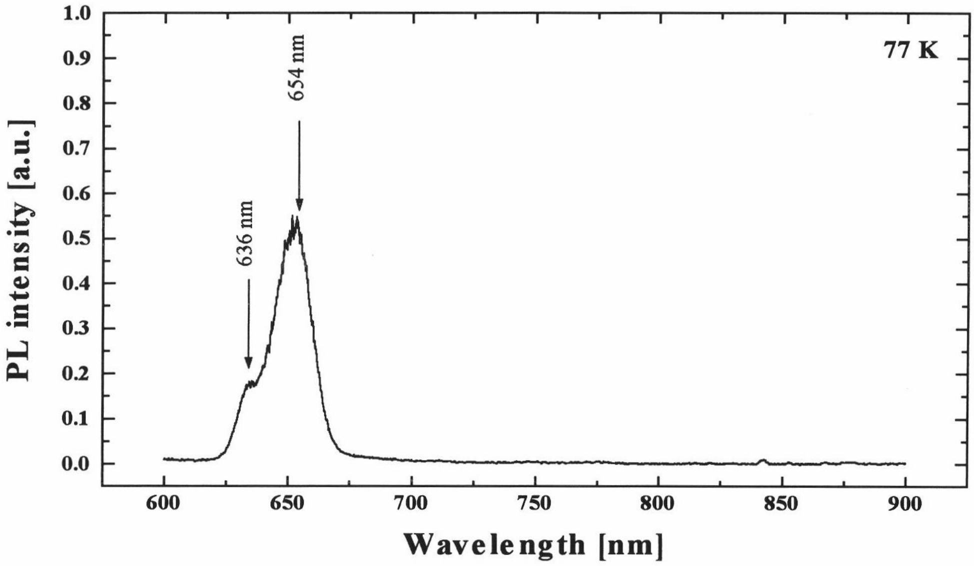

Figure 3.7 PL spectrum from Si-doped $Al_{0.35}Ga_{0.65}As$ layer at 77 K

3.6 Photoluminescence of Multi-Quantum Well Structures

The 4 types of MQW that have been prepared from the previous section are examined by PL technique at 10 K using closed-circuit helium cryogenic as a cooling system.

Figure 3.8 to 3.10 show PL spectrum at 10 K of the first 3 type samples respectively. Several PL peaks could be observed from the luminescent spectrum of each sample ranging from red to infrared wavelength of 600 to 800 nm. The PL peaks were originated from the transitions from the quantized energy states in the quantum wells, respect to their well widths [11].

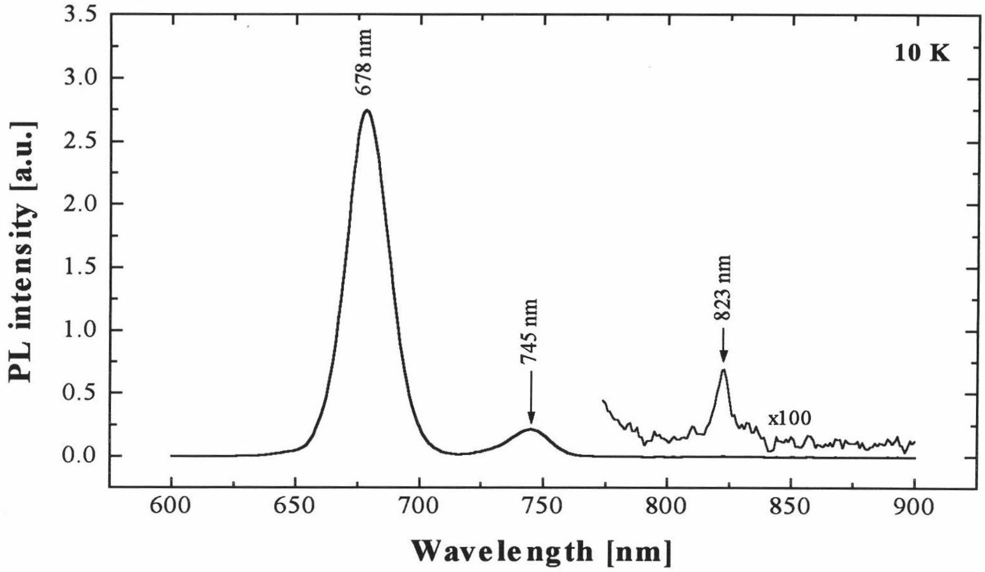

Figure 3.8 PL spectrum from the sample 2 MQW

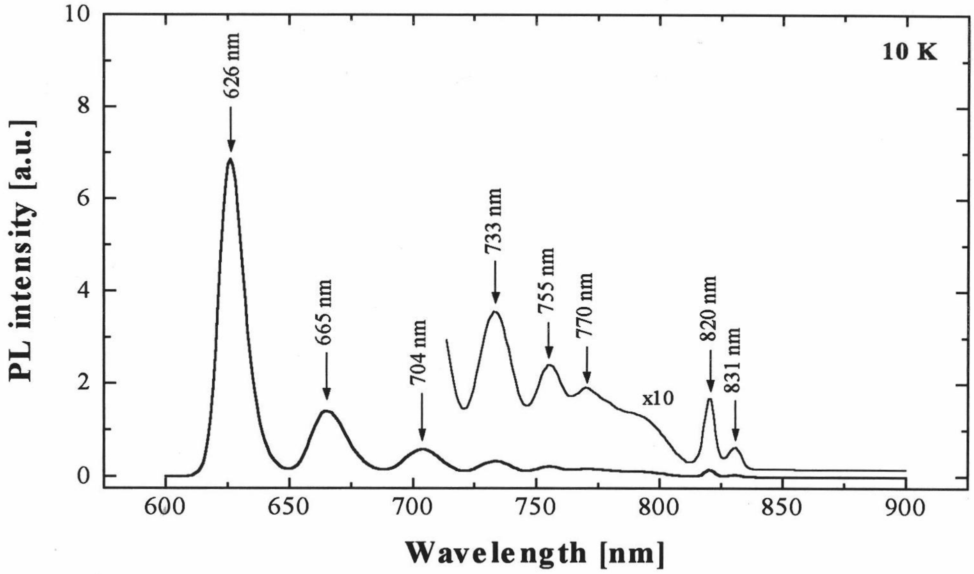

Figure 3.9 PL spectrum from the sample 12 MQW

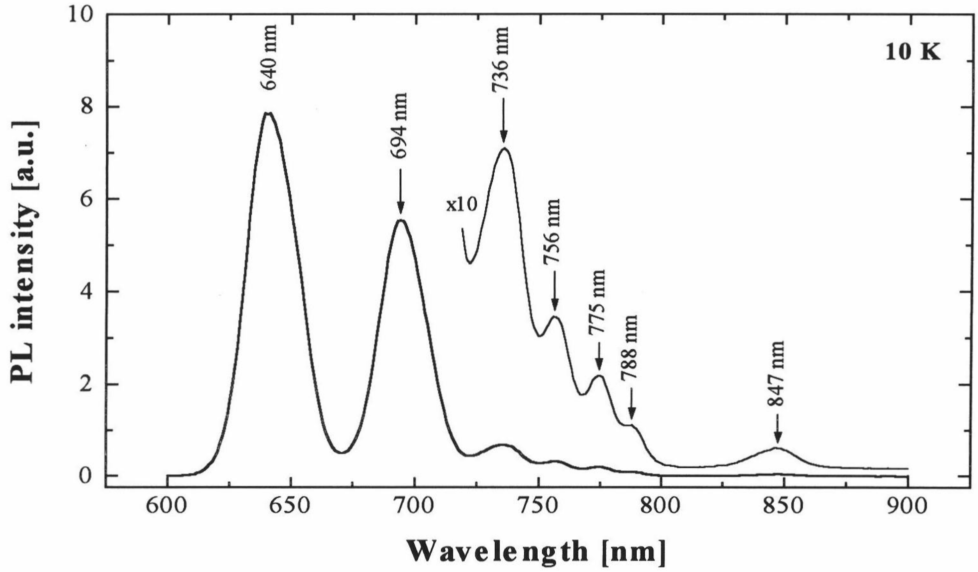

Figure 3.10 PL spectrum from the sample 4x6 MQW

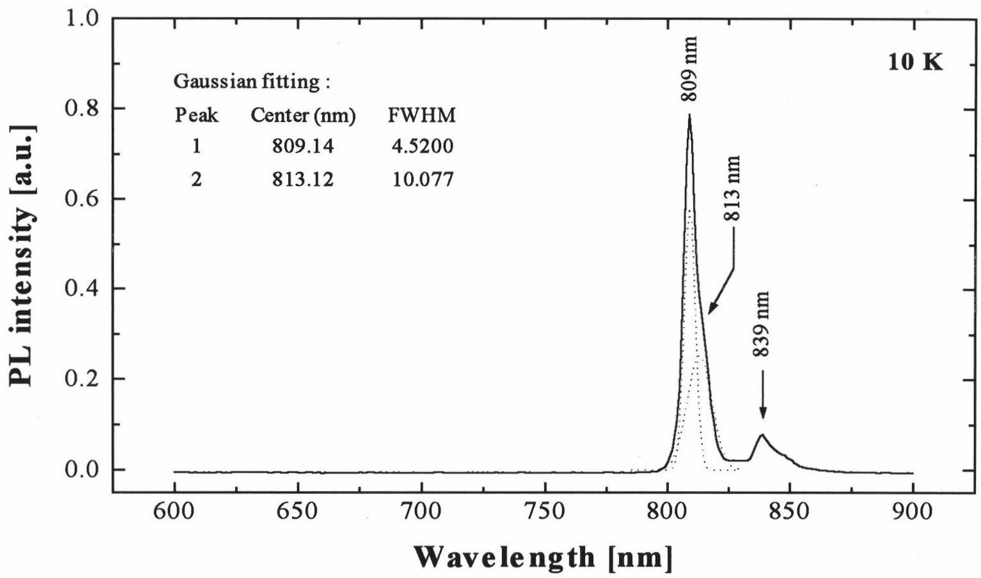

Figure 3.11 PL spectrum from the sample 10 MQW

The peak at the shortest wavelength is always the highest peak in the spectra at low temperture. The follower peaks at longer wavelengths are smaller respectively. This could be explained by the reason that when the exciting laser beam reaches the samples from the top surfaces, most of it light power would be absorbed in the top most layers. Therefore, the transmitted photons down to the lower layers then become less and less luminescence occurs. In the experiment, all the multi-quantum well structures were designed in the fashion that the top most layers were the narrowest well widths and become gradual enlarged as the wells were located deeper. The quantized energy levels in individual well were then like a staircase from higher energy from the top layer down to lower energies from the bottom layers. This is so-called *Window effect*. An application of the window effect is to develop a dynamic range of passive optoelectronic devices, i.e. the devices could response wider light spectrum such as wide spectral and high efficiency solar cells [12].

The PL spectrum from the sample 10 MQW shows a sharp peak that has the full width at half maximum (FWHM) 4.5 nm. The spectrum intensity is multiply from each quantum well. This PL spectrum confirm the growth precision of the MBE.