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Optical properties of remotely doped parabolic quantum wells

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Abstract

This work is intended to report on optical measurements in a parabolic quantum well with a two dimensional–three dimensional electron gas. Photoluminescence results show broad spectra which are related to emission involving several subbands on conduction band with the fundamental level of the valence band. This assumption is based on the behavior of the PL peak position and the full width at half maximum in the function of the incident power intensity.

Keywords: Photoluminescence; Parabolic quantum wells remotely doped

Band gap engineering in semiconductor heterostructure is, nowadays, a fundamental tool for tailoring the electro-optical properties of semiconductor nanostructures and Parabolic quantum well (PQW) is a very suitable device for this purpose. Studies on optical properties in undoped PQW have already been done [1], but there are very few works concerning the doped one. In this system, a high mobility quasi-three dimensional (D) electron gas can be formed and many body effects on the optical and magnetic measurement are expected to be observed [2,3].

Our parabolic quantum well samples were grown by molecular beam epitaxy on a GaAs (0 0 1) substrate. The samples were a 1000, 1500, 2000 and 3000 Å wide parabolic quantum wells where the aluminum mole fraction x in the $Ga_xAl_{1-x}As$ alloy is graded from $x = 0$ in the center up to $x = 0.31$ at the edge of the well. To achieve the population of electron gas in the well we put Si (5×10^{11} cm^{-2}) delta doping on each side of the well, with a space layer of 150 Å. PL measurements were performed at low temperature (8.4 K). Optical excitation was provided by the blue line (4880 Å) of an Argon laser. The emission light was dispersed by a triple monocromator and detected by a cooled GaAs photomultiplier tube connected to a photon counter system. The maximum power intensity was 200 mW, with spot size of about 300 μm.

Fig. 1 shows the low temperature (8.4 K) PL measurements for one of our samples, with well thickness of 1500 Å. We present a spectrum with incident power intensity (P) of 200 and 20 mW. At high incident power intensity the spectrum is very large with shoulders at low and high energy sides. The large spectrum is a consequence of the recombination involving several occupied subbands of the conduction band and the fundamental hole level. The shoulder at low energy side (1.49 eV) is a result of the carbon acceptor, as can be clearly observed at the spectrum at $P = 20$ mW. The maximum intensity of the PL emission is located at energy of 1.515 eV in all spectra, with the exception

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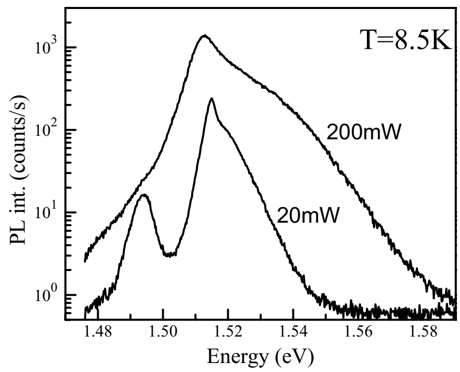

Fig. 1. Low temperature PL results of the sample 2263 at two different incident power intensity. The well width is 1500 Å and the carrier concentration after be illumined is 5.6×10^{11} cm^{-2}.

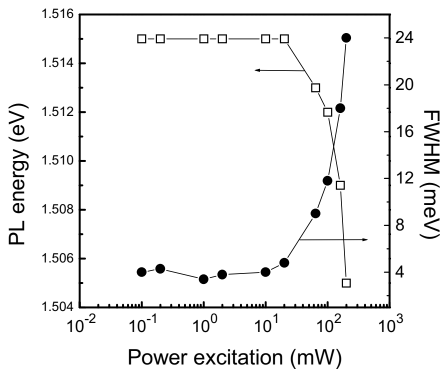

Fig. 2. PL peak position (open square) and FWHM (filled circle) as a function of the incident power intensity.

of a thicker sample. For this sample, the maximum energy is located at lower energy (1.504 eV). This sample will be discussed in more detail later. Due to the wide well thickness, for all samples, no confinement effect appeared. We detected recombinations involving electrons from the bottom of the conduction band up to the Fermi level with holes at the fundamental level of the valence band. For this reason, we can tentatively ascribe the high energy shoulder to the Fermi level inside the conduction band. Increasing the incident power excitation, the spectrum broadens to the high energy side due to the increase of the energy of the Fermi level.

Fig. 2 shows the evolution of the PL energy peak and the full width at half maximum (FWHM) as a function of the incident power excitation (P). Two regimes are clearly present, one of them, up to 10 mW where both parameters are practically constant and a second for $P > 10$ mW where an abrupt change is noticed. The energy peak position decreases in at least 10 meV while the FWHM increases its values from 3 to 24 meV. The constant behavior of these two parameters, at low power intensity, is a characteristic of one level emission (one electron subband at the conduction band and one hole subband at the valence band) where the increase of the P just increases the population of the electron–hole pairs.

As the life time of this hot carriers is higher than the recombination time, no significant changes on the spectrum are observed. However, when several subbands are involved in the radiative recombination process, these photocreated electrons can find non-occupied states increasing their life-time. The life-time increasing allows the recombination of the electrons with holes on the valence band expanding the PL emission. The increasing on the energy peak is most probably related to the moving of the Fermi level inside the conduction band as a consequence of electron population increase.

In summary, we have performed low temperature photoluminescence experiments in a set of parabolic quantum wells with different well thicknesses and doping levels. Due to the large values of the well thickness no significant quantum confinement was observed. We noticed radiative emission involving just the electron fundamental level as well as transitions involving several occupied subbands on the conduction band with holes on the fundamental level of the valence band. Radiative transitions with several occupied subbands were also confirmed by PL measurements as a function of the power incident excitation.

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