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Photoluminescence studies of confined states in AlGaAs/GaAs asymmetric quantum well

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Abstract

In the recombination spectra of AlGaAs/GaAs heterostructures, a peculiar and asymmetric photoluminescence (PL) band F has previously been reported [Aloulou et al., Mater. Sci. Eng. B 96 (2002) 14] to be due to recombinations of confined electrons from the two-dimensional electron gas (2DEG) formed at AlGaAs/GaAs interface in asymmetric quantum well (AQW). Detailed experiments are reported here on $GaAs/Al_{0.31}Ga_{0.69}As/GaAs{:}\delta Si/Al_{0.31}Ga_{0.69}As/GaAs$ samples with different spacer layer thicknesses. We show that the band F is the superposition of two PL bands F′ and F″ associated, respectively, to AQW and a symmetric quantum well (SQW). In the low excitation regime, the F′ band present a blue shift (4.4 meV) followed by important red shift (16.5 meV) when increasing optical excitation intensity. The blue shift in energy is interpreted in terms of optical control of the 2DEG density in the AQW while the red shift is due to the narrowing of the band gaps caused by the local heating of the sample and band bending modification for relatively high-optical excitation intensity. Calculation performed using self-consistent resolution of the coupled Schrödinger–Poisson equations are included to support the interpretation of the experimental data.

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1. Introduction

Modulation-doped quantum wells (MDQW) have been extensively investigated in the last two decades experimentally [1–6] as well as theoretically [7–11]. This kind of structures offer a typical system of a low-temperature two-dimensional one-type carrier plasma where the electron and hole mobilities are improved due to the spatial separation between the 2DEG and the donor impurities. The density of the 2DEG depends on the doping density (N_d), the distance of the doping layer from the heterointerface (spacer) and the conduction band offset (ΔE_c) [12]. In fact, the decrease of the spacer width improves the density of electrons in the AQW in the channel [13]. Among the different experimental techniques, the photoluminescence (PL) spectroscopy has been used widely to study the optical properties of the MDQW [14–16] and the influence of the 2DEG density on the PL spectrum was demonstrated [17,18]. In particular, it has been shown that one can control the density of the 2DEG by controlling the optical excitation intensity [19]. The signature of the optical control of the 2DEG is a blue shift as the optical excitation intensity increases [20–22]. On the other hand, MDQW have been used as ideal systems to investigate different aspects related to many-body effects in 2DEG. Several authors [23–26] have explained the experimental results in terms of band gap renormalization (BGR), where the effect of exchange and correlation processes is regarded as a rigid shift of the electron and hole bands in the region of band edges towards each other. In PL spectra, the signature of the BGR is a reduction of the band gap energy and a shift

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of the bound states for electrons inside the AQW as a result of band bending.

In this paper, we present a systematic PL study of $GaAs/Al_{0.31}Ga_{0.69}As/GaAs{:}\delta Si/Al_{0.31}Ga_{0.69}As/GaAs$-modulated-doped heterostructures presenting an asymmetric quantum well (AQW) in the GaAs channel close to the $Al_{0.31}Ga_{0.69}As$ /GaAs interface and a symmetric GaAs quantum well (SQW) in the barrier. Two samples (S30 and S40), with different spacer widths, and containing both a Si-dopant plane in the SQW were studied. For sample S30, which present the thinner spacer width, the PL spectra are dominated by an intense recombination band originated from the 2DEG and which is firstly blue shifted (4.4 meV) for low excitation intensities and then red shifted (16.5 meV) as the excitation intensity increases. In order to support the interpretation of the experimental data, the electron subbands in AQW and SQW are calculated by numerical resolution of Schrödinger and Poisson equations [27]. The first low subband energies and Fermi level are obtained with a significantly improved accuracy and are compared to experimental results.

2. Experimental system and samples parameters

The $GaAs{:}Si/Al_{0.31}Ga_{0.69}As/GaAs{:}\delta Si/Al_{0.31}Ga_{0.69}As/$ GaAs heterostructures samples were elaborated according to the model proposed by Schubert and al [28]. They were grown by Molecular Beam Epitaxy (MBE) on (0 0 1) oriented semi-insulating GaAs substrate and are δ doped ($2.5 \times 10^{12}\,cm^{-2}$) in a GaAs quantum well (QW) to avoids persistent photoconductivity effects associated with the deep donors [28]. It has been shown that the use of a δ-doped GaAs QW improves the 2DEG density in the AQW [29]. Finally, the samples are covered with a GaAs:Si ($1 \times 10^{18}\,cm^{-3}$) cap layer in order to avoid alloy oxidation. For our study, we have used two samples called S30 and S40 presenting different spacer thicknesses, 82 and 265 Å, respectively (Fig. 1). The reducing of the spacer will induce an increase of the 2DEG density in the AQW [30]. PL spectra were obtained by exciting the samples with a continuous (cw) ionized Argon (Ar^+) laser. The detection setup consists in a Dilor triple-monochromator and a photomultiplier tube with GaAs cathode. The samples were cooled using a closed-cycle helium cryostat.

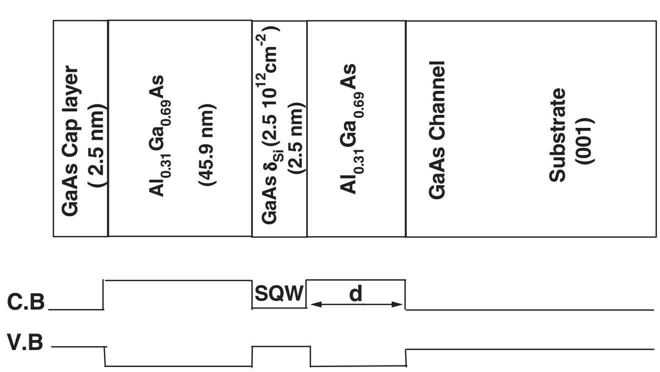

Fig. 1. Schematic representation of the sample structure and conduction band energy diagram.

3. Results and discussion

We present in Fig. 2 the PL spectra of the two samples S30 and S40 at $T = 8.5\,K$ using the excitation energy $E_{exc} = 2.41\,eV$ and excitation density $P = 15P_0$ ($P_0 = 0.12\,W/cm^2$). These spectra show the well-known GaAs PL bands associated to free exciton (FE) at 1.519 eV and radiative recombinations involving donors and acceptors in the energy range (1.437–1.49 eV). In the high-energy side of the FE line, the two samples present two additional PL bands labelled F′ and F″ located at 1.658 and 1.729 eV, respectively. These bands are attributed to radiative recombination of confined electrons, respectively, in the AQW and the SQW with free holes. A similar PL band centred at 1.72 eV in the PL spectra of a 25 Å-width $Al_{0.3}Ga_{0.7}As/GaAs/Al_{0.3}Ga_{0.7}As$ QW has been observed by P-Acosta-Dias and all [31] and is attributed to emission from confined states in the QW.

The PL intensity difference in the two samples is due to the difference between the thickness "*d*" of the spacer layer: (i) The increase of the thickness "*d*" reduces considerably the tunnelling of electrons from the SQW to the AQW and than the density of the 2DEG in the AQW; thus, the

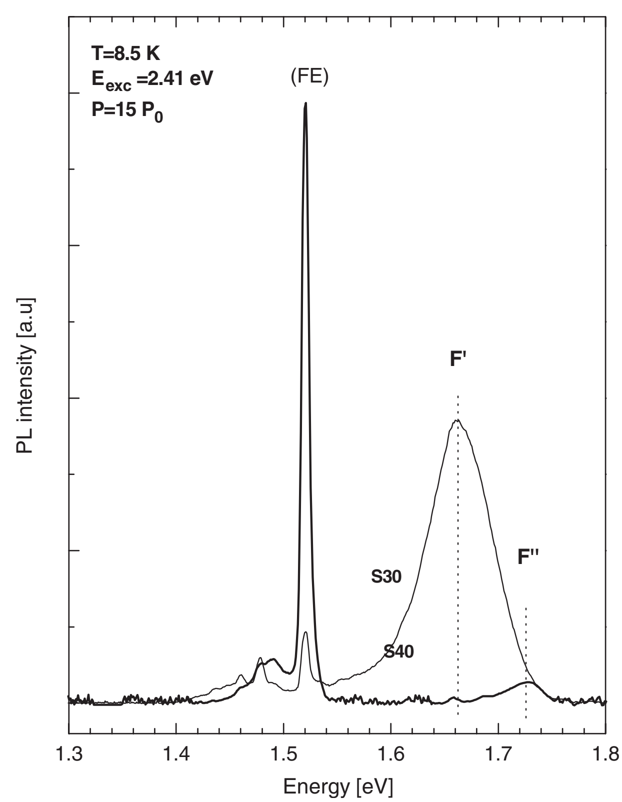

Fig. 2. Photoluminescence (PL) spectra of the studied samples obtained at $T = 8.5\,K$ with excitation intensity $P = 15P_0$ ($P_0 = 0.12\,W/cm^2$).