The Exciton Tunneling in ZnCdSe/ZnSe Asymmetric Double Quantum Well

GUANGYOU YU, XIWU FAN, JIYING ZHANG, BAOJUN YANG, DEZHEN SHEN, and XIAOWEI ZHAO
Changchun Institute of Physics, Chinese Academy of Sciences, Changchun, 130021, China, e-mail: shen@public.cc.jl.cn

Photoluminescence spectra of asymmetric double-quantum-well structure are studied in this paper. We show the excitation power dependence of exciton tunneling. Due to the different tunneling time of electrons and holes, space-charge effect is observed.

**Key words:** Asymmetric double quantum well (ADQW), exciton, tunneling

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**INTRODUCTION**

The dynamics of carrier tunneling through a thin barrier in semiconductor heterostructures was a topic of research interest in the last years, since this process was not only of basic physical interest but also of fundamental importance for application. In an asymmetric double quantum well (ADQW) structure, which consists of two different width wells coupled with a thin barrier, the subbands in each well have different energies under flat band condition, therefore, the carrier tunneling from the narrow quantum well (QWn) to the wide quantum well (QWw) becomes easy and notable. In III-V compound semiconductors ADQW, the carriers tunneling process has been investigated widely.\(^1\,^2\) Due to weak Coulomb interaction between electrons and holes in III-V ADQW, the electrons and holes tunnel independently rather than as excitons. But in II-VI compound semiconductors ADQW, exciton binding energy is large, which make the Coulomb interaction between electrons and holes not be neglected in tunneling process.\(^3\) In this paper, we report excitation power dependence of the exciton tunneling in the ADQW by photoluminescence (PL) spectra and using optical measurements, and demonstrate photoinduced space-charge buildup in the ADQW caused by the tunneling process.

**EXPERIMENT**

The ADQW samples studied were grown on Si-doped (100) GaAs substrates by low pressure (LP) metalorganic chemical vapor deposition (MOCVD) at 350°C with reactor pressure at 38 Torr. The structure consists of a 1 µm ZnSe buffer layer followed by a five-period Zn\(_{0.72}\)Cd\(_{0.28}\)Se/ZnSe ADQW, and then a 100 nm ZnSe cap layer. Each period of the ZnCdSe/ZnSe ADQW includes one narrow ZnCdSe quantum well (QWn), one thin ZnSe barrier and one wide ZnCdSe quantum well (QWw), which will be denoted later as Ln/Lb/Lw, where Ln, Lb, and Lw are the widths of the narrow well, barrier and wide well, respectively. PL spectra were excited by the 337.1 nm line of a N\(_2\) laser worked at 10 Hz and the signal was measured at 77K using a 44W grating monochromator with a RCA-C31034 cooled photomultiplier.

**RESULTS AND DISCUSSION**

Figure 1 shows the photoluminescence of the sample 3nm/4nm/7nm ADQW structure under different excitation. At low excitation (<0.2KW/cm\(^2\)), there is only one luminescence peak due to n = 1 heavy hold (HH1) excitonic transition from the wide well (not present in the figure), and with the excitation increasing, HH1 excitonic emission from narrow well is observed and shows redshift. Figure 2 shows the excitation intensity dependence of the luminescence intensity of the wide well and narrow well. The changing of the emission intensity from the narrow well is smooth with excitation, but the emission intensity from the wide well has a strong change process in low excitation range, and then trends to smooth.

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In ADQW, the transition process should include following steps: a. Electron-hole pairs are excited, and excitons are formed (for II-VI compounds, because of the larger exciton binding energy, the electron-hole pair exists as exciton). b. Electrons in excitons tunnel from narrow well to wide well, which means direct excitons (electrons, holes in the same well) transfer to indirect excitons (electrons, holes not in the same well). c. Holes in the excitons tunnel from narrow well to wide well (from indirect excitons transferring to direct excitons). d. Excitons recombine in wide well.

This process can be described by the rate equations

\[
\frac{dn}{dt} = G_n \frac{n_n}{T_{te}} - \frac{n_n}{T_r} \tag{1}
\]

\[
\frac{dp}{dt} = G_p \frac{p_n}{T_{th}} - \frac{p_n}{T_r} \tag{2}
\]

\[
\frac{dn}{dt} = G_w \frac{n_n}{T_{te}} - \frac{n_n}{T_r} \tag{3}
\]

\[
\frac{dp}{dt} = G_w + \frac{p_n}{T_{th}} - \frac{p_n}{T_r} \tag{4}
\]

where \(n_n, p_n, p_w\) are the densities of the electrons and holes in the narrow well and wide well, respectively, \(G_n, G_w\) are the generation rates of the electron-hole pairs in narrow well and wide well, \(T_{te}, T_{th}, T_r\) are the tunneling times of the electrons, holes and excitons recombination time, respectively. Here, we assume that all carriers exist as excitons due to the larger Coulomb interaction between electrons and holes and then the carriers densities used in rate equations are the densities of electrons or holes in excitons.

According to our calculation, for the sample 3nm/4nm/7nm \(\text{Zn}_{0.72}\text{Cd}_{0.28}\text{Se}/\text{ZnSe} \text{ ADQW} \) structure, the difference of \(n = 1\) electron subbands between the wide well and narrow well \(\Delta E_{1e}\) is about 60 meV, and the difference of \(n = 1\) heavy hole subbands \(\Delta E_{1h}\) is about 9 meV (see Fig. 3a), therefore \(\Delta E_{1e} > E_{\text{LO}}\) \(\Delta E_{1h} < E_{\text{LO}}\), and then the electrons in the narrow well could tunnel to the wide well by phonon-assistant but the holes could not. Additionally, because of the binary barrier, the alloy-tunneling is neglected. So that the relationship \(T_{te} < T_{th} < T_r\) is obtained. At low excitation, \(n_n\) is so small that \(\frac{n_n}{T_r}\) could be neglected in Eq. (1), and almost all of the electrons in the narrow well tunnel to the wide well before recombination with holes, as a result, no emission from narrow well is observed. With higher excitation, \(n_n, p_n\) become larger, and \(\frac{n_n}{T_r}, \frac{p_n}{T_r}\) could not be neglected, which leads to part of electrons would recombine with holes in the narrow well, and consequently results in the emission from the narrow well. Because of \(T_{te} < T_{th}\), tunneling of electrons is faster than that of holes, so electron is the minority, which decides the emission intensity in the narrow well. Therefore, \(I_n \propto \frac{n_n}{T_r}\) is obtained, where \(I_n\) is the emission intensity of narrow well. At our excitation range, the changing of the electrons density excited with excitation intensity is nearly linearly, which is the same as the experiment results shown in Fig. 2.

The minority which decides emission intensity in the wide well is hole which come from two sources, one is excited by photo in the wide well, the other one is that tunneling from the narrow well [see the Eq. (4)]. As discussion above, the densities of both kinds of the holes would change linearly with excitation intensity,