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Exciton Dynamics of GaAs/AlGaAs Quantum Wells

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Abstract – We present a study of exciton relaxation in GaAs/AlGaAs quantum well structures by using time-resolved photoluminescence techniques. We observed that light-hole exciton has a longer decay time than heavy-hole exciton, which results from the difference of the exciton population factor. We considered the thermal population time to explain the observed exciton dynamics.

Exciton dynamics in quantum wells have been much investigated by using the time-resolved spectroscopic methods for understanding of physical phenomena and possible device applications. The optical properties of quantum well structures are strongly influenced by the properties of the exciton state. For example, the increase of exciton binding energy [1, 2] and oscillator strength [3, 4] due to size quantization is responsible for the strong enhancement of the absorption and emission at the exciton transition energies, even at room temperature. Since the electron-phonon coupling is basically unaffected by the two-dimensional confinement the exciton scattering is unchanged. This explains why excitons continue to determine the linear and nonlinear optical properties of quantum wells. Feldmann *et al.* [5] demonstrate theoretically and experimentally the fundamental relationship between the radiative exciton lifetime and the exciton linewidth, which corresponds to the phase coherence time in the case of a homogeneous transition. However, so far only heavy-hole (hh) exciton dynamics has been of concern to many scientists [5-8]. We expected that light-hole (lh) exciton in addition to hh exciton provides important information on the exciton dynamics. We report the dynamics of lh exciton as well as hh exciton in GaAs/AlGaAs 120 Å and 150 Å multiple quantum wells (MQW).

GaAs/AlGaAs multiple quantum wells were grown by molecular beam epitaxy (MBE). A 1 μm undoped GaAs buffer layer was grown on a semi-insulating GaAs substrate followed by an undoped AlGaAs barrier layer and an undoped GaAs well layer with 10 periods, and a 10 nm-thick GaAs cap layer.

To resolve lh and hh exciton spectra in photoluminescence (PL) and time-resolved PL (TRPL), the PL signal was dispersed by 1 m monochromator (McPHERSON 2061, spectral resolution: 0.1 meV). The light source for TRPL measurements was a cavity-dumped dye laser synchronously pumped by a mode-locked Ar ion laser. The cavity-dumped dye laser has ~2 ps pulsewidth and ~5 mW average power at 3.8 MHz dumping rate. The PL signal was detected by a microchannel plate photomiltiplier tube (Hamamatsu R2809U) and then amplified by a wideband amplifier (Philip Scientific), sent to a Quad constant fraction discriminator (Tennelec), a time-to-amplitude converter (Tennelec), a photon counter (Ortec), a multi-channel analyzer (Nucleus), and stored in a computer. The instrumental response of our TCSPC system was typically 70 ps, which gives us about 10 ps time resolution employing deconvolution technique. Samples were mounted on a closed-cycle liquid-helium cryostat for low-temperature PL and TRPL measurements.

Figure 1 shows the PL signals with dependence on excitation intensities in 150 Å MQW. Two PL spectra due to lh and hh exciton are clearly resolved with low excitation intensity, and at the highest excitation the spectra due to hh exciton are splited into two peaks with 1meV splitting energy, indicating that the peak at high energy is caused by the biexciton formation.

Figure 2 shows PL decay profiles at the peak positions of hh and lh excitons as a function of excita-

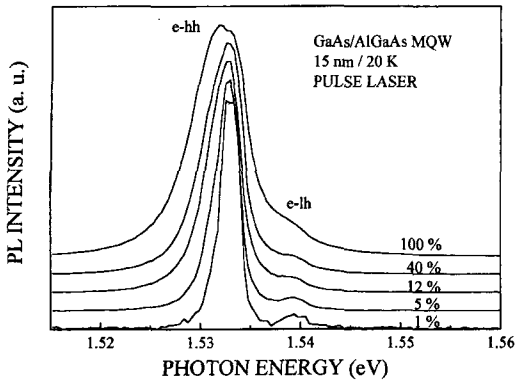

Fig. 1. TRPL signals of lh and hh excitons as a function of excitation intensity in 150 Å MQW. The inset shows the PL spectra vs excitation intensity.

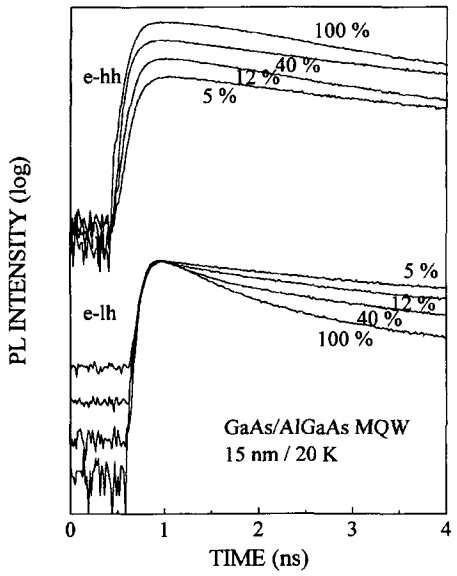

Fig. 2. PL decay times of lh and hh excitons vs excitation intensity in 120 Å and 150 Å MQW.

tion intensity at 20 K. We observed that TRPL signal of lh exciton exhibits double-exponential decay, while that of hh exciton single-exponential decay. Comparing to the PL signals in Fig. 1, we suggest the fast decay component of lh exciton could be contributed by the tail of hh exciton signal. The PL and TRPL data for 120 Å MQW were similar to those for 150 Å MQW.

The PL decay times of lh and hh excitons for 120 Å and 150 Å MQWs depending on excitation intensity are shown in Fig. 3. In contrast to the decay

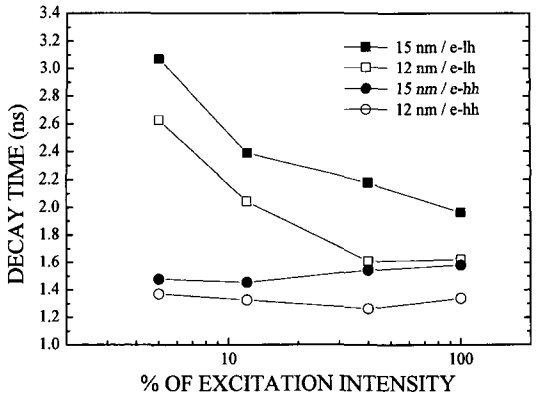

Fig. 3. Schematic energy diagram for excitonic dynamics.

time of hh exciton, that of lh exciton increases with decreasing excitation intensity. This effect is attributable to the lower binding energy of lh exciton than that of hh exciton ($E_{B,hh}/E_{B,lh} = 1.6$). This also indicates that free-carrier recombination becomes dominant in lh decay process at high excitation intensity. At the lowest excitation intensity, the decay time of lh exciton is almost twice of that of hh exciton in 120 Å and 150 Å MQWs. If this results from the inhomogeneous line broadening caused mainly by interface roughness, the decay time of lh exciton should be fast, because the penetration of lh exciton wavefunction into the barrier is more significant than that of hh exciton. Thus, the slower decay of lh exciton is considered to be caused by homogeneous line broadening. The decay time due to homogeneous line is given by [5]

$$\tau \propto E_B^{-1}(M/\mu)(\Delta(T)/r(T)) \quad (1)$$

where Δ(T) and r(T) are homogeneous linewidth and excitonic population factor, respectively. Since the decay time variation depending on EB is canceled out by the mass term (M/μ), the slow decay of lh exciton is affected by r(T), which is smaller in lh exciton. This trend is consistent with the theoretical results reported by Srinivas *et al.* [8].

The schematic energy diagram for the exciton dynamics is presented in Fig. 4. Since we observed PL decay of lh exciton and τ_{rlh} process is believed to be very fast (few tens ps), we can suppose a steady state approximation.

$$\langle n_{lh}(t)\tau_{rlh}\rangle \cong \langle n_{hh}(t)/\tau_{rhh}\rangle \quad (2)$$

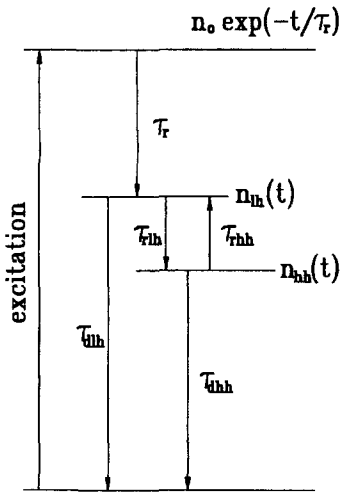

Fig. 4. Exciton Dynamics of GaAs/AlGaAs Quantum wells.

where τ_{rlh} and τ_{rhh} are relaxation and thermal population times, respectively. From the PL intensity ratio and the difference in rise times between lh and hh excitons, τ_{rlh} and τ_{rhh} were calculated to be 70 ps and 370 ps for 150 Å, and 80 ps and 780 ps for 120 Å MQWs, respectively. Eccleston *et al.* [9] have presented thermal population time from the fast decay component of TRPL signal at higher temperature than lh-hh splitting energy (2.4 meV). On the other hand, we presented thermal population time at lower temperature than lh-hh splitting energy (~6 and 9 meV) by observing TRPL signal of lh exciton.

In conclusion, we observed that the decay time of lh exciton was almost twice of that of hh exciton, which was caused by the decrease of the exciton population factor of lh exciton. We obtained the thermal population time by observing TRPL signal of lh exciton.

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