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INTER-ISLAND ENERGY TRANSFER IN AlGaAs/GaAs QUANTUM WELLS GROWN BY MOLECULAR BEAM EPITAXY

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The results of photoluminescence, time-resolved photoluminescence, photoluminescence excitation and photoluminescence kinetics studies are presented for a $Al_{0.3}Ga_{0.7}As/GaAs$ quantum well system grown without growth interruptions at the interfaces. The time-resolved photoluminescence measurements show drift of excitons towards lower energy states induced in a quantum well by potential fluctuations. We present also a first direct evidence for migration of free excitons from the 24 to 25 ML regions of the quantum well and interpret these results within a linear rate model, deriving the transition rate of 290 ps^{-1}. Such inter-island migration processes have been observed till now only in growth interrupted structures.

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1. Introduction

Exciton migration between different islands in a quantum well (QW) of varying thickness has been observed experimentally for growth interrupted GaAs/AlGaAs QW structures (see e.g. Refs. [1–3]). Such exciton migration is a consequence of fluctuations in a QW width of a planar size larger, much larger than exciton radius. Potential fluctuations in a QW [4,5] can also give rise to exciton localization [6] and Stokes shift between the heavy hole exciton lines observed in photoluminescence (PL) and PL excitation (PLE) studies [7].

In this communication we present the results of PL, PLE and PL kinetics and time-resolved PL measurements explicitly demonstrating the complex nature of excitons in a high quality GaAs/AlGaAs QW structure grown without growth

interruptions at interfaces. By selectively exciting the PL emission (SPL spectrum) we resolve several PL components and relate them to the presence of large (compared to the exciton radius), relatively flat regions of the QW differing in width by one monolayer. This effect was observed previously only for samples grown with growth interruptions at the interfaces. The in-plane and inter-island migration of excitons is demonstrated and its time scale is determined.

2. Experimental

The PL experiments were performed on an $Al_{0.3}Ga_{0.7}As/GaAs$ QW structure grown at 630°C on the (001) oriented semi-insulating GaAs substrate covered with 1 μm thick undoped GaAs epilayer by molecular beam epitaxy using a Riber 32P system. The structure was grown without growth interruptions at the interfaces. The PL study was performed for nominally 25 monolayer thick QW confined between 400 Å thick AlGaAs barriers. The structure was capped with a 100 Å thick undoped GaAs layer. The PL, PLE and PL kinetics measurements were performed at 2 K on experimental setups described elsewhere [8].

3. Results and discussion

In Fig. 1 (*a*) we show PL spectrum observed under a nonresonant excitation, where the excitation energy falls into the continuum of electron and hole states, but still lies below the AlGaAs barrier energy. The spectrum measured for a resonant excitation condition (resonant excitation when a photon energy coincides with one of the heavy hole (HH) or light hole (LH) exciton energies) is shown in Fig. 1 (*b*). Distinct differences between the two PL spectra are visible. We decomposed the resonant excitation PL spectrum into three Gaussian components, centered at 1.5852 eV, 1.5836 eV and 1.5815 eV. Based on the results of theoretical calculations and the PLE experiments shown below, we attribute these PL components to the free exciton (FE) recombination in the 24 monolayer wide (FE 24 ML) (1.5852 eV PL) and 25 monolayer wide (FE 25 ML) (1.5815 eV PL) regions in the QW plane. The 1.5836 eV PL is assigned to the neutral donor bound exciton (DBE) recombination in the 24 ML wide region of the QW (DBE 24 ML). The full width at half maximum of these components is 2.1 meV, 1.5 meV and 2.3 meV for the FE 24 ML, DBE 24 ML and FE 25 ML emissions, respectively. The PL spectrum measured under the nonresonant excitation conditions is dominated by a single line, which we associate with the DBE 25 ML PL. The FE 24 ML, FE 25 ML and DBE 24 ML PL emissions observed under the resonant excitation contribute to a weak high energy wing of the observed PL band. We note also the presence of a partly resolved low energy component of the PL emission with a maximum at about 1.579 eV. This PL is much broader than the other four and is thus likely of different origin, as will be discussed later on.

The assignment of the FE 24 ML and FE 25 ML PL emissions is based on the PLE results presented in Fig. 2 and theoretical modeling results discussed elsewhere [8]. The PLE spectra were measured with the detection set at different photon energies within the PL spectrum. Figure 2 (*a*) shows the PLE spectrum measured for the detection set at the FE 24 ML emission (1.5854 eV PL) and in Fig. 2 (*b*) the detection was set at the DBE 25 ML emission (1.5800 eV PL). The

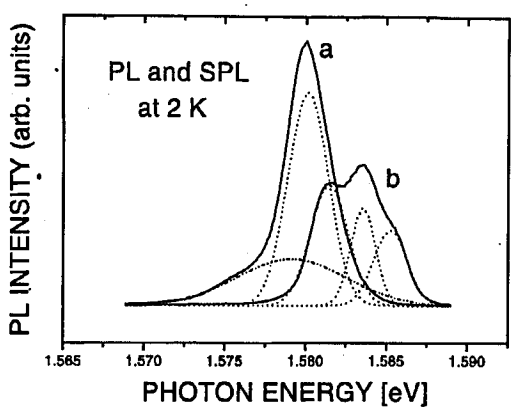

Fig. 1. *a* — the photoluminescence spectrum measured at 2 K for a nonresonant excitation at 1.6978 eV. Curve *b* shows the SPL spectrum measured for a resonant excitation into the HH exciton at 1.5869 eV (HH FE 24 ML). Similar PL was observed for the excitation into the LH FE 24 ML (1.6067 eV). The dotted lines show contributions from the recombination of FE 24 ML, DBE 24 ML, FE 25 ML and DBE 25 ML excitons and of a broad PL band, tentatively identified with a free-to-bound transition.

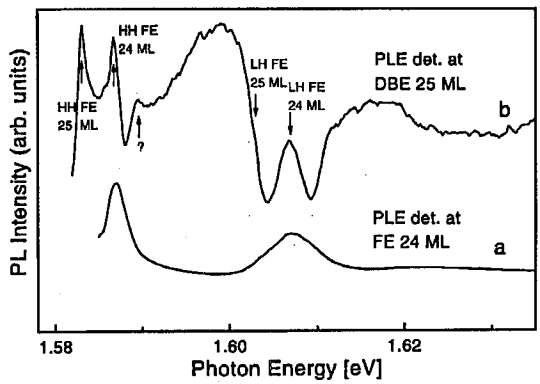

Fig. 2. Photoluminescence excitation spectrum for detection energy set at the peak of the FE 24 ML emission (1.5852 eV) (*a*) and at the peak of the DBE 25 ML emission (1.5802 eV) (*b*).

PLE spectra measured with the detection set at other photon energies contained similar information. We attribute the sharp PLE peak at 1.5869 eV (Fig. 2 (*a*)) to the heavy-hole free exciton peak of the FE 24 ML emission. The LH exciton peak is observed at the higher energy.

The PLE curve detected at the DBE 25 ML peak (Fig. 2 (*b*)) shows a number of additional features compared to the one in Fig. 2 (*a*). It contains an additional heavy hole exciton peak at 1.5831 eV (HH FE 25 ML) and two broad bands with the maxima at about 1.599 eV and 1.618 eV. The first of them overlaps with the LH

FE 25 ML peak, which thus could not be resolved in our study. We explain these two broad PLE bands, with maxima at 1.599 eV and at 1.618 eV, by transitions to continuum states of the first confined electron/heavy hole and electron/light hole pairs. By shifting the detection energy we observed that the appearance of these two broad PLE peaks correlates with the observation of a PL spectrum peaked at 1.579 eV. We tentatively assign this PL band to the free-to-bound (free electron–acceptor) optical transition.

We underline the presence of the HH and LH FE 24 ML peaks in the PLE (see Fig. 2 (*b*)) detected at DBE 25 ML PL. We explain this fact by excitation transfer from the FE 24 ML to the FE 25 ML and then DBE 25 ML. The temporal evolution of this transfer was studied in detail. To quantify the effects of PL time decay and exciton migration, we decomposed the time-resolved PL spectra into three (resonant excitation) and two (nonresonant excitation) Gaussian components and traced their time and intensity evolution for the FE 24 ML, DBE 24 ML, FE 25 ML and DBE 25 ML PL emissions. We observed that the DBE 24 ML, FE 25 ML and DBE 25 ML PLs move towards lower energies during excitons decay, with the rate of about 0.97 meV/ns (DBE 24 ML), 1.34 meV/ns (FE 25 ML) and 1.03 meV/ns for the DBE 25 ML PL. Such motion of exciton lines towards lower energies reflexes their drift-diffusion [5].

The PL decay times of individual PL subbands were determined from the deconvolution of the time-resolved PL spectra. To evaluate the rate of excitons migration rate we notice a clear difference in the PL decay times for the two FE emissions. The decay time of the FE 24 ML emission is 115 ps, while the FE 25 ML decays with the time constant of 190 ps. The 75 ps difference between the decay times of the two FE emissions is too large to be explained by a difference in the radiative decay time of two QWs differing in width by only one monolayer [6]. We relate this difference to the effect of exciton migration from QW regions 24 monolayers wide to regions 25 monolayers wide. From the linear rate equations we derive the exciton transfer rate from the 24 to the 25 ML region to be approximately 290 ps^{-1}. Similar transfer rate was given by Deveaud et al. [3] for GaAs/AlGaAs structure grown with growth interrupts at the interfaces. Finally, we point out that the measured Stokes shifts of 1.5–2.0 meV and the observed FE line width of about 2 meV correlate well with the theory reported by Fang Yang et al. [7].

Concluding, we present the direct evidence of the inter-islands (large regions of flat interfaces) exciton migration for the GaAs/AlGaAs MBE structure grown without growth interruptions at interfaces.

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