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INFLUENCE OF GROWTH CONDITIONS ON EXCITON PROPERTIES IN THIN QUANTUM WELLS OF GaAs/AlGaAs

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Exciton properties in growth interrupted quantum wells of GaAs/AlGaAs are compared with those observed for structures grown without growth interruption during the molecular beam epitaxy process. We report observation of quasi-localized excitons in quantum well structures grown without growth interruptions. Quasi-localized excitons drift towards the states of a lower potential energy in the quantum well. For growth interrupted MBE structures islands with a constant quantum well thickness become large compared to the exciton radius. Free or lightly localized excitons are observed in that case.

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1. Introduction

Exciton dynamics in GaAs/AlGaAs quantum wells (QWs) has been widely studied (e.g. [1–4]). It was demonstrated that existence of disorder due to interface roughness strongly affects the localization and dephasing properties of excitons in QWs and that the interface quality can be probed by photoluminescence (PL) methods. In this paper we apply optical spectroscopy for evaluation of interface quality of two types of GaAs/AlGaAs MBE structures grown with and without growth interruption at interfaces.

2. Experimental

The GaAs/AlGaAs structures were grown by MBE using Riber 32P machine at the Institute of Electron Technology. The nominally undoped samples were grown at 630°C with 60 s growth interrupts on each interface, on semi-insulating [100]-oriented GaAs substrates (Sumitomo). The samples consisted of 6 QWs of nominal thickness 6 ML, 8 ML, 12 ML, 15 ML, 20 ML and 30 ML (1 monolayer (ML) = 2.83 Å) and were covered with a 0.1 μm GaAs cap layer. QWs were separated by 250 Å thick $Al_xGa_{1-x}As$ ($x = 0.3$) barriers. The structures without growth interrupts consisted of 4 QWs (25 Å, 50 Å, 100 Å, 200 Å) separated by 0.1 μm thick $Al_xGa_{1-x}As$ ($x = 0.3$) barriers.

Photoluminescence (PL) and PL excitation (PLE) spectra were measured at 2 K on conventional setups. Dynamics of exciton recombination was studied at the temperature range of 2–140 K with a Hamamatsu synchroscan camera with a temporal resolution of about 20 ps. Pulsed excitation was provided by a dye laser synchronously pumped with a mode-locked argon laser to give pulse lengths of about 5 ps duration.

3. Results

A rich PL spectrum was observed for the growth interrupted MBE structures. The PL consisted of several distinct emission lines due to monolayer splitting caused by QW width fluctuations by ±1 ML with a spatial extension larger than exciton radius. The PL width varied from 1.5 meV for the 30 ML thick QW to 3.5 meV for the 10 ML QW indicating high quality of the MBE structures. Zero or nearly zero (1 meV or less) Stokes shifts were observed in the PLE experiment. Structured PL was observed for each QW. In addition to free (FE) or lightly localized excitons (LE) neutral donor bound exciton (DBE) PL was resolved. For the 30 ML QW neutral acceptor bound exciton and free-to-bound (acceptor) PLs were also observed. In Fig. 1 we show 2D contour plot of the PL intensity versus energy and PL decay time for the 15 ML QW. No spectral shift of the PL is observed during exciton decay time and similar result was observed for other QWs. This result, together with the PLE data, indicates that excitons are either free or

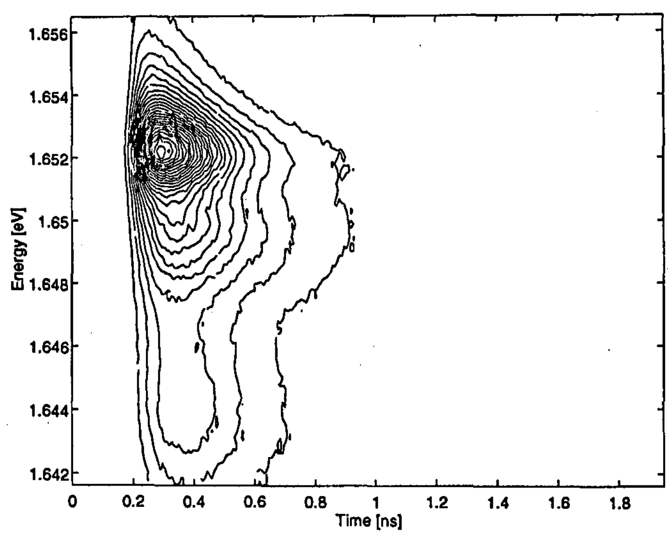

Fig. 1. The 2D contour plot of the PL intensity versus PL energy and decay time for the 15 ML (about 42 Å) QW for MBE structure grown with interrupts at interfaces. PL decay was measured at 2 K.

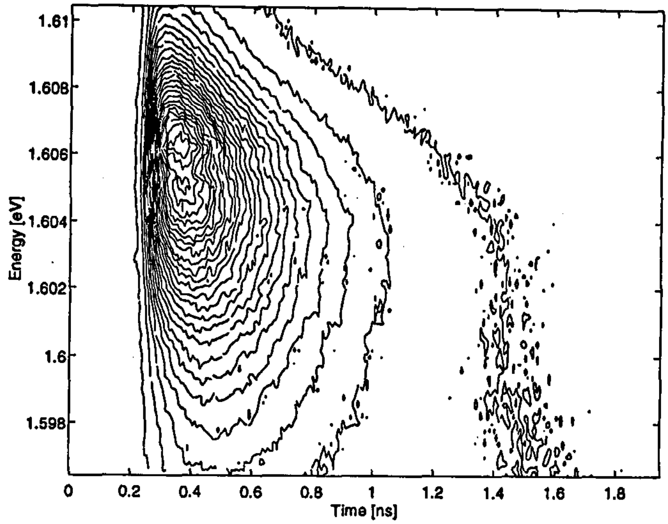

Fig. 2. The 2D contour plot of the PL intensity versus PL energy and decay time for the 50 Å QW grown without growth interrupts at interfaces. PL decay was measured at 2 K.

are only lightly localized. PL decay times depended on the QW width and were e.g. 140 ps (LE) and 240 ps (DBE) for the 15 ML QW, and 125 ps (LE) and 195 ps (DBE) for the 30 ML QW. PL rise times were in the range of 15 ps.

For the structures grown without growth interrupts the PL lines are inhomogeneously broadened. Thickness fluctuations of QWs occur at the length scale small comparing to the exciton diameter. The width of PL lines varied from 2.5 meV for the 100 Å thick QW to 10 meV for the 25 Å QW and no monolayer splitting was observed. A two-band character of the PL lines was also observed but the LE and DBE PLs strongly overlapped. In Fig. 2 we show 2D contour plot of the PL intensity versus energy and decay time for the 50 Å QW. A very distinct shift (by about 2 meV) of the spectral position of the PL is observed during the exciton decay time. This indicates that excitons are quasi-localized and that they drift between localized states during their decay time. The process is mediated by absorption or emission of acoustic phonons. The decay of the PL does not show a single exponential behavior. It depends on energy increasing as one goes from low to high energy tail of the PL line. This proves that excitons below certain energy in the low energy tail of the line are localized by potential fluctuations resulting from the well thickness variations, while those at higher energies move more or less freely in the well plane. PL decay times are longer than those found for the interrupted-growth structures and are about e.g. 175 ps (LE) and 200 ps (DBE) for the 50 Å QW, and 220 ps (LE) and 240 ps (DBE) for the 100 Å QW.

4. Discussion

Excitons lifetimes observed are considerably longer than calculated radiative lifetime of the thermalized free excitons. This lifetime we estimate, using the theory of Andreani et al. [5], to be about 20–25 ps. Such short times were recently observed by Sermage et al. [6] for 58 Å GaAs QW in GaAs/AlAs structure. The observed PL decay times are usually much longer, which can be related to more localized character of excitons in QWs [7]. For LEs, localized by potential fluctuations in QWs, the PL decay times are longer due to finite scattering (dephasing) lifetimes and finite spatial coherence. The coherence area of the LE is smaller than that of the FE and is determined by the spatial extent of a localized state. The decay of LEs can be separated to several steps [3]. First, "high energy" free (delocalized) excitons are formed by initial photo-excitation, which lose their excess kinetic energy by inelastic scattering and relax into $k = 0$ state. $k = 0$ LEs, trapped by potential fluctuations present in QWs, can decay radiatively or can lose their excess potential energy by acoustic phonon assisted drift between different localized states.

Such complicated decay scenarios were also observed in our case for the MBE structures grown with and without growth interruption. PL kinetics and PLE investigations indicate that excitons are localized by potential fluctuation present in the QWs. Assuming the fluctuation of the well width to be the half of lattice constant of GaAs and noting that the level energy in a quantum well scales approximately to the inverse square of the well thickness one can calculate the fluctuation of 1s exciton energy. For 50 Å QW one gets 9.8 meV for the fluctuation of exciton energy, which is of the order of observed width of PL line. For the 100 Å thick QW the similar estimation gives 1.4 meV and at about 150 Å the inhomogeneous contribution to the broadening of exciton line width becomes negligible.

For an increased temperature PL decay time of excitons in growth interrupted MBE structures increases rapidly with increasing temperature and becomes of about 500 ps at 60 K. This result confirms light localization of excitons in our MBE structures. For LEs decay time is first temperature independent and starts to increase with increasing temperature when excitons delocalize from potential fluctuations.

Concluding, we show that exciton dynamics in GaAs/AlGaAs QWs strongly depends on the growth procedure and interface quality of the structures. Distinct differences between PL of two types of the MBE structures are reported.

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