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INFLUENCE OF ELECTRON IRRADIATION ON CARRIER RECOMBINATION AND INTRADOT RELAXATION IN InGaAs/GaAs QUANTUM DOT STRUCTURES

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The influence of high-energy electron irradiation on the time-resolved photoluminescence (PL) of quantum dot (QD) and quantum well (QW) InGaAs/GaAs structures are investigated. Both rise and decay kinetics is changed due to radiation-induced defects. The decay kinetics of as-grown QWs and QDs can be described by a single time constant. The irradiated QWs still exhibit the single exponential decay but with the less time constant, whereas the second faster component appears in the PL decay of QDs along with the component present prior to irradiation. Thus, we observed interaction of confined carriers with radiation-induced defects inside or near the QDs.

1 Introduction

In the past few years, quantum dot structures have attracted increasing interest due to their outstanding performance (for a review see, e.g., [1] and references therein). One of the most important promises of QD nanotechnology is the increased tolerance for defects [2]. Higher quantum efficiency becomes possible with the basic argument that localized carriers will exhibit reduced migration to non-radiative centers. Such property is advantageous for active layers in matrix

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[*)] Present address: Universität Leipzig, Institut für Experimentelle Physik II, Linnéstr. 5, D-04103 Leipzig, Germany materials with a high number of structural defects. The tolerance to radiation-induced defects is of crucial importance in atomic energy and space applications.

Despite this, only little research has been performed with respect to radiation defects in quantum dots. The radiation resistance against damage due to 50 keV manganese ion implantation [3] and defects created by a 300 eV argon ions [4] was found to be greater for QDs than for QWs. Recently, studies of 1.5 MeV proton and 2 MeV electron irradiation of InGaAs/GaAs QD structures were undertaken, and an enhanced radiation tolerance of QDs as compared to analogous quantum wells (QWs) were reported [5,6]. The effect of irradiation with 8.56 MeV phosphorous ions and 2.4 MeV protons on the properties of QD and QW lasers has been investigated [7,8]. A higher stability of the QD devices was found.

On the other hand, possible tunneling of captured charge carriers off the high-lying states in the dots to neighboring defects in the barrier material has been used to explain the absence of the phonon bottleneck in the carrier intradot relaxation [9]. However, the existence of this mechanism has never been proved experimentally. The most obvious way to check it is to vary the defect concentration in a sample and to investigate resulting changes in the time-resolved photoluminescence (TRPL).

We report the study of the influence of electron irradiation on TRPL of InGaAs/GaAs QD and QW structures. The TRPL measurements reveal a shortening of the rise and decay times in both QWs and QDs, but the behavior of both the types of samples is qualitatively different.

2 Methods

For TRPL studies two types of samples were grown using metal-organic chemical vapor deposition (MOCVD) under identical conditions and subjected simultaneously to electron irradiation. The samples differed only with respect to the active region. In the sample QD1, the latter consisted of one layer of self-assembled InGaAs/GaAs QDs with density $\sim 5\text{x}10^{10}$ cm^{-2} on a thin wetting layer (WL). Sample CQW contained two coupled InAs/GaAs quantum wells separated by 1 nm. The active layer together with GaAs cladding layers was placed between two $Al_{0.3}Ga_{0.7}As$ barriers. The irradiation by 2MeV electrons with fluences in the range of $2\text{x}10^{15}$ to $2\text{x}10^{17}$ cm^{-2} was performed at room temperature using a Van de Graaff accelerator. The TRPL measurements were carried out at 2K using a single photon counting technique. The exciting Ti^{+}-sapphire laser operated at 790 nm with a pulse width of 2ps. The time resolution of the detecting system was 30 ps. The averaged excitation density within the pulse was 250 W/cm^{2}.

3 Results and discussion

Strong emission bands of QDs (centered at 1.238 eV) and CQW (1.346 eV) were seen in the low temperature cw PL spectra at low excitation densities due to ground state exciton recombination. At the higher excitation densities and/or the higher temperatures contributions from higher-lying QD states and the WL were observed.

With increasing irradiation fluence, all samples exhibited a decrease of the PL intensity. However, whereas in sample QD1 the QD-related PL peak could be observed up to the fluence $1x10^{17}$ cm^{-2}, the QW-related PL in sample CQW was quenched already between $2x10^{16}$ and $5x10^{16}$ cm^{-2} [7]. This behavior was essentially the same at 10, 77 and 300 K.

The results of the TRPL measurements on QD1 and CQW samples are shown in Fig. 1. The rise and decay times obtained from the exponential fitting are given in Table 1.

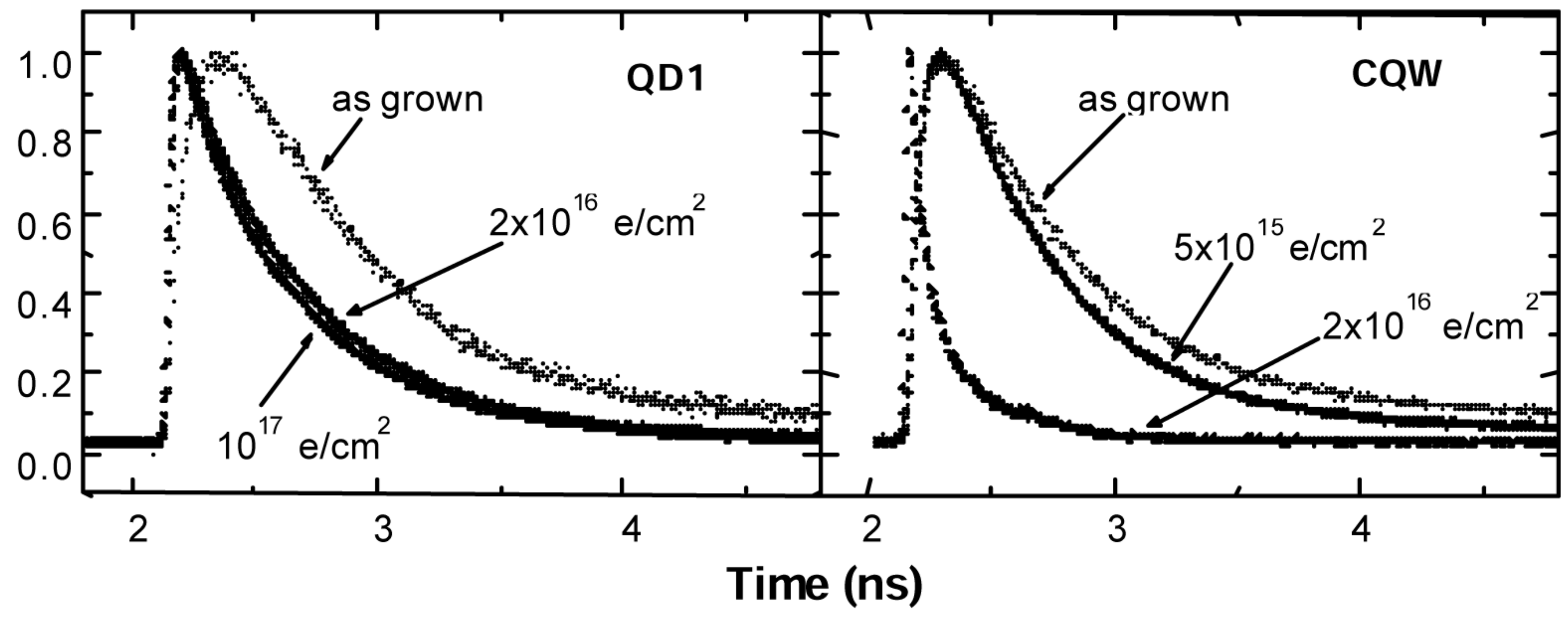

Figure 1. PL transients taken at 2 K of as-grown and electron-irradiated CQW and QD1 samples. Excitation energy is 1.569 eV. Detection energy is 1.230 eV and 1.340 eV for QD1 and CQW, respectively.

Table 1. TRPL rise and decay times.

Sample, fluence (e/cm^2)	$\hat{o}_r$, ps	$\hat{o}_{d1}$, ps	$\hat{o}_{d2}$, ps
CQW, as grown	65	485	-
CQW, $5x10^{15}$	50	440	-
CQW, $2x10^{16}$	< 20	220	-
QD1, as grown	105	565	-
QD1, $2x10^{16}$	< 20	615	295
QD1, $1x10^{17}$	< 20	600	230

The transients prior to irradiation can be fitted with single values of the rise ($\hat{o}_r$) and decay ($\hat{o}_d$) times. There is a clear impact of the introduced radiation defects on the rise as well as on the decay times in both CQW and QD samples (Fig. 1). However, there is a striking difference in changes of these times with irradiation. In

CQW sample the PL kinetics still can be fitted with single values of $\hat{o}_\mathrm{r}$ and $\hat{o}_\mathrm{d}$. Both values are reduced obviously due to the shortening of the carrier diffusion length in the barrier and increasing non-radiative recombination in the QW, respectively, caused by the radiation-induced defects. However, in QD1sample the PL decay can only be described by at least two different $\hat{o}_\mathrm{d}$ values: one $\hat{o}_\mathrm{d}$ characterizes the as-grown sample and another (shorter) one does not change with irradiation dose. We tentatively ascribe this shorter PL decay time constant to the capture of carriers confined in the QDs by defects inside or immediately adjacent to the QDs. Since not all QDs in a sample are disturbed by defects, the slow decay component is still observed even after irradiation. Qualitatively the same behavior has been observed upon resonant (below-bandgap) excitation. However, a poor signal-to-noise ratio and a strong substrate PL impeded a reliable quantitative evaluation. Experiments with other samples are in progress.

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