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NONRADIATIVE RECOMBINATION PROCESSES IN (CdTe,CdCrTe)/CdMgTe QUANTUM WELL STRUCTURES

M. Godlewski, V.Yu. Ivanov, A.J. Zakrzewski, T. Wojtowicz, G. Karczewski, J. Kossut

Institute of Physics, Polish Academy of Sciences
Al. Lotników 32/46, 02-668 Warsaw, Poland

J.P. Bergman and B. Monemar

Department of Physics and Measurement Technology, Linköping University
581 83 Linköping, Sweden

Photoluminescence transitions in (CdTe,CdCrTe)/CdMgTe structure grown by molecular beam epitaxy are studied. Photoluminescence investigations show a very strong reduction of the photoluminescence intensity from chromium doped quantum wells. We explain this fact by a very efficient nonradiative recombination in the chromium-doped quantum wells. The present results indicate that the Auger-type energy transfer from excitons to chromium ions is responsible for the photoluminescence deactivation. The efficiency of this process is evaluated.

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1. Introduction

Transition metal (TM) ions are inadvertent dopants of bulk semiconductor materials. Some of them, e.g. iron, cobalt and nickel [1], are efficient centers of nonradiative recombination in bulk semiconductors. Recent studies of the present authors cleared out mechanisms of nonradiative recombination at TM sites in wide band gap II–VI semiconductors — ZnSe and ZnS [2]. In the most efficient mechanism (called the bypassing process) free carriers (electrons (e) and holes (h)) are trapped by TM ions and not by donor (D) and acceptor (A) centers active in D–A pair (DAP) radiative recombination transitions. In consequence, visible photoluminescence (PL) of ZnS or ZnSe, which is related to DAP transitions, is deactivated. The second efficient TM-related nonradiative recombination mechanism is an Auger-type three-center energy transfer process [2]. In this process e–h trapped at D–A centers recombine nonradiatively. The recombination energy is transferred to nearby TM ions, which are ionized in the consequence of the

transfer. For bulk ZnS samples and iron impurity an exchange mechanism of the transfer dominates over a dipole–dipole mechanism [2]. Estimations of the present authors (for typical contamination level with Fe) indicate that the Auger process is responsible for at most 10% of the deactivation of the visible PL of ZnS, i.e., in bulk samples this process is less efficient than the bypassing process. In this work we present the results of PL and time-resolved PL investigations of recombination transitions in quantum well (QW) structures containing chromium. Nonradiative recombination processes of excitons in QWs, related to the presence of chromium, are discussed.

2. Samples

The multiple QW structure studied was grown by molecular beam epitaxy. It consisted of two CdTe QWs (30 monolayers (ML) and 6 ML wide) and two chromium containing CdCrTe QWs (20 ML wide, grown with 1050°C temperature of the chromium cell, and 12 ML wide, grown with 1100°C temperature of the chromium cell) separated by CdMgTe barriers. The resulting Cr fraction in CdCrTe QWs remains unknown, but it was increasing with an increase in the cell temperature.

3. Experimental results

The PL of (CdTe,CdCrTe)/CdMgTe structure studied is shown in Fig. 1. A strong reduction of the PL intensity from QWs which contain chromium is observed. The excitation intensity dependence of the PL was studied. The PL intensity from all four QWs rises linearly with an increasing excitation intensity. This can be seen in the inset of Fig. 1, where the normalized PL intensity from all four QWs is shown. Then, at a relatively high light power, PL starts to saturate. This saturation is likely due to the sample heating.

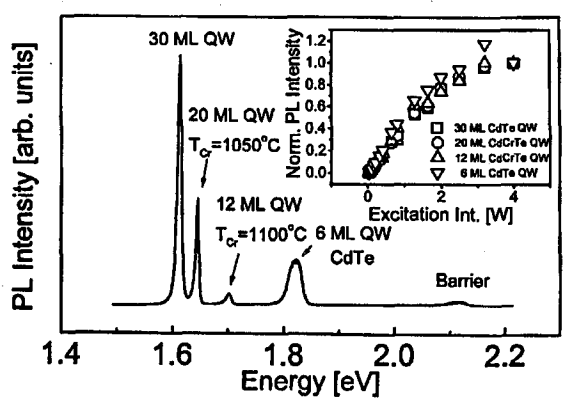

Fig. 1. The photoluminescence spectrum of the (CdTe, CdCrTe)/CdMgTe MQW structure measured at 2 K under cw excitation with Ar^+ laser. PL intensity dependence on the excitation intensity is shown in the inset.

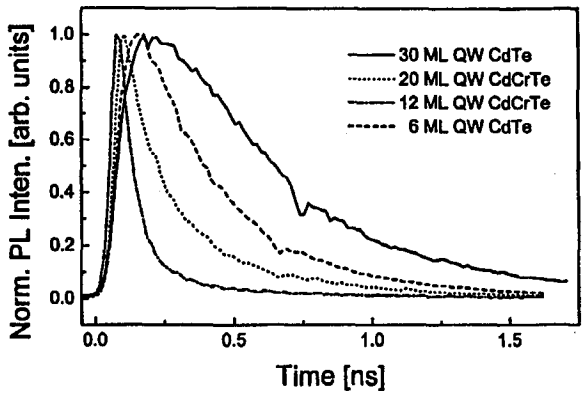

Fig. 2. PL kinetics of (CdTe, CdCrTe)/CdMgTe MQW structure measured at 2 K under pulsed nonresonant excitation conditions.

PL kinetics in picoseconds time range was measured. In general, PL decay time depends on a QW width and, often more stronger, on exciton properties [3]. For localized excitons the PL decay time is few times longer than the one predicted for free excitons in QWs with flat interfaces. It may still become longer for delocalized (mobile) excitons, which scatter on interface roughness. For II–VI heterostructures containing CdTe QWs localized excitons were typically observed at 2 K temperature [3].

In Fig. 2 we show PL kinetics observed for the (CdTe,CdCrTe)/CdMgTe MQW structure. A dramatic shortening of PL decay time is observed for both CdCrTe QWs. The PL decay time is the shortest for the 12 ML QW, which contained the highest Cr concentration. Also the PL rise time is shorter in the QWs containing chromium. A fast component of the PL decay is observed for both Cr containing QWs. The contribution of the fast component of the PL decay increases with increasing Cr concentration in the QW. However, after initial and dominant fast decay of the PL of 20 ML and 12 ML wide QWs PL decays then slower, with the PL decay time quite similar to that for the 30 ML wide QW. This slow component of the decay is observed in the time-resolved PL taken with long delays after an initial laser pulse.

4. Discussion

We have solved a set of kinetics equations describing rise and decay of PL emissions in the presence of chromium ions. The kinetics equations were solved under some simplifications. We have assumed that Cr-related processes are the only channels of nonradiative recombination and that only two processes (the bypassing and the Auger process) are efficient. We have also assumed that absorption coefficients for the ionization transitions of chromium are small as compared to coefficients of free carriers generation in QWs. Solving kinetics equations we have found that the results of the PL investigations allow to distinguish between two types of chromium-related nonradiative processes. In the case of the efficient bypassing process the PL intensity should be reduced in Cr QWs, but the PL decay

time should remain unchanged. In turn, in the case of the dominant Auger process we expect a reduction of both the PL intensity and the PL decay time, whereas the PL intensity should rise linearly with increasing excitation intensity (I) ($I^{3/2}$ dependence is expected for the bypassing process).

Shortening of the PL decay time and linear PL intensity dependence on excitation intensity are observed for Cr-doped QWs. Thus, the present experimental results clearly indicate the dominant role of the Auger-type process. This process is responsible for the appearance of the fast component of the PL decay in Cr-containing QWs. However, we cannot exclude that the bypassing process is also active in the Cr-doped QWs. We observed that after an initial and dominant fast decay PL from CdCrTe QWs decayed with nearly the same decay time as the one observed for the CdTe QWs. Such PL kinetics is expected for the bypassing process. The bypassing process, which requires carrier trapping by Cr ions, may be delayed in the time scale and likely may affect PL intensity in the time-resolved PL study taken at longer delay times.

We have fitted the PL kinetics for 12 ML QW using Inokuti and Hirayama theory [4], assuming the exchange mechanism of the transfer. We have also assumed that the excitons are at 2 K localized (this is consistent with the PL kinetics results) and that the excitons density is much smaller than the chromium concentration (PL kinetics investigations were taken at low excitation power). Inokuti and Hirayama theory describes the observed kinetics of the PL decay with two parameters — critical transfer radius and concentration of PL deactivator centers [4]. From the fit we obtained the following parameters of the exciton–Cr transfer process: critical transfer radius of about 2 nm and chromium concentration N_{Cr} — 1×10^{19} cm^{-3}. Such value of the critical transfer radius means that Cr ion must be located within the Bohr radius of the localized exciton for the efficient Auger process. The latter parameter is an effective concentration of isolated chromium ions active in the Auger-type transfer process. This concentration is likely smaller (much smaller) from the total concentration of Cr ions in the QW since Cr precipitations are expected in heavily doped QWs.

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