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EXCITATION AND RECOMBINATION PROCESSES IN $InAs_xP_{1-x}$:Yb ($x = 0.04$, 0.07 and 0.11)

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Excitation and recombination mechanisms of Yb^{3+} $4f$–$4f$ intra-shell emission in InP and InAsP (4, 7 and 11% of As) are analyzed.

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1. Introduction

Recent studies indicate that $4f$–$4f$ emission of Yb^{3+} in InP is excited by energy transfer from the Yb-bound exciton to the $4f$ "core" states of the ion [1–3]. At increased temperature intensity of the Yb^{3+} $4f$–$4f$ emission decreased, which was explained by the back-transfer of energy from the excited $4f$ state of Yb to either the Yb-bound exciton [1] or to band gap states of InP [4]. The above model is tested in the present work for Yb doped $InAs_xP_{1-x}$:Yb with 4, 7 and about 11% As fraction. The results of photoluminescence (PL), PL decay and optically detected cyclotron resonance (ODCR) experiments are compared with those obtained for InP:Yb.

2. Results and discussion

The PL spectra of Yb doped InP and InAsP (4, 7% of As) samples were measured. For InP:Yb the PL spectrum consists of a donor bound exciton (n-type sample was studied) recombination at 1417.5 meV, a donor–acceptor pair (DAP) recombination and its LO phonon replicas at 1387.5 meV and 1344.6 meV, respectively, and of the structured $^2F_{5/2} \rightarrow {}^2F_{7/2}$ PL emission of Yb^{3+} with sharp zero-phonon lines at 1248.6, 1242.5, 1238.1 and 1230.7 meV. For the 4 and 7% As samples the PL bands broaden and two Yb-related emissions can be resolved.

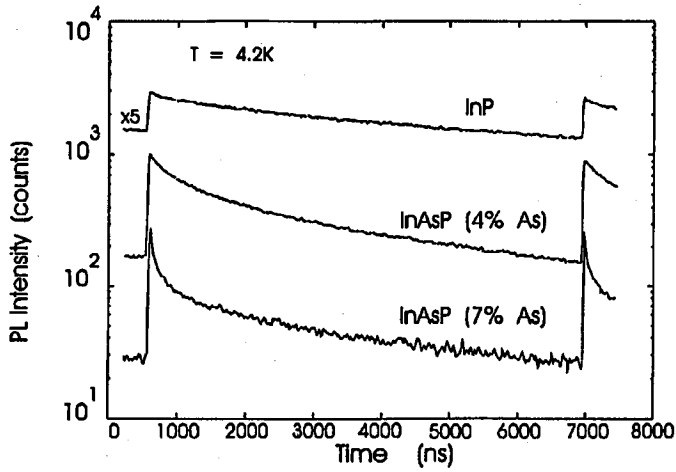

Fig. 1. PL decay of the Yb^{3+} $4f$–$4f$ emission in InP and InAsP (4% and 7% of As).

These were attributed to the two different Yb centers: a cubic and an axial one Yb–P_3As [5]. The Yb emission is not observed for the nominally 11% As sample.

In Fig. 1 we show the PL decay measurements of the Yb^{3+} $4f$–$4f$ emission in InP and in InAsP. The decay time (estimated from the exponential part of the decay) of the $4f$–$4f$ PL of Yb^{3+} depends on As fraction. It is (at 4.2 K) 10.4 μs in InP and is 4 μs for the 4% and 2.5 μs for the 7% InAsP. It was postulated previously that the decay time of the Yb^{3+} PL emission may be controlled by an Auger type nonradiative transition involving energy transfer from the excited Yb^{3+} to the externally Yb-bound carrier [1, 2, 4, 6]. The initial non-exponential part of the decay was related to the Auger mechanism. We expect, therefore, that the observed shortening of the exponential component of the decay cannot be explained by an increase in the Auger effect efficiency. The change of covalency of the Yb bond with increasing As fraction in InAsP may be an alternative explanation of the effect [7]. The PL spectra measured suggest another explanation. For the 4 and 7% InAsP samples the Yb PL is superimposed on low energy wing of the DAP band, which may result in energy transfer link between the two emissions (Yb decays nonradiatively due to energy transfer to DAP band). The above model explains the large difference in response of the Yb^{3+} PL to carrier heating observed in the ODCR experiment. It was shown previously that the PL of Yb^{3+} is only slightly enhanced in intensity when shallow donors and excitons are impact ionized by collisions with hot carriers [3]. This is in contrast to the results obtained for the 7% As sample, for which a nearly 100% change of the relative PL intensities is observed once the DAP transitions are deactivated [8].

In Fig. 2 we compare the temperature dependencies of the Yb^{3+} PL decay times for InP and InAsP. At increased temperatures the decay time of the PL shortens rapidly. The Yb PL emission was too weak for the 4% sample to evaluate the deactivation energy. For the 7% sample we could, however, trace the emission

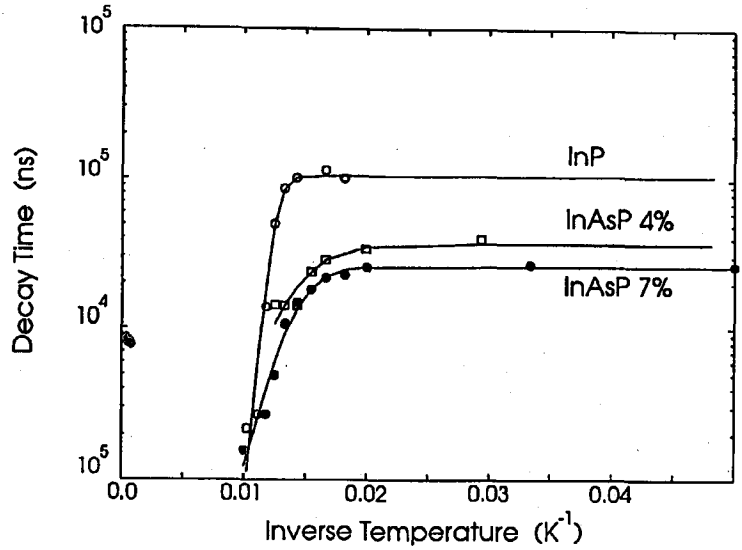

Fig. 2. Temperature dependence of the PL decay time of the $4f$–$4f$ emission of Yb^{3+} in InP and InAsP (4% and 7% of As).

down to 100 K and estimate the PL deactivation energy (63 meV, 50 meV if a $T^{3/2}$ pre-exponential factor is introduced). For InP we found the deactivation energy of about 190 meV, which, after introducing a $T^{3/2}$ correction to the pre-exponential term [1], is equal, within the experimental error, to the energy difference between InP band gap energy and the Yb^{3+} PL emission energy. Thus we conclude that in InP:Yb the back-transfer proceeds to the band states of InP rather than to the Yb-bound exciton state, as was suggested previously (deactivation energy of 145 meV was expected in that case [1]).

We expected that for InAsP samples, for which the back-transfer occurs at lower temperature Yb-bound exciton may be stable and direct radiative recombination of the exciton would be observed. Such direct radiative recombination of the rare earth bound exciton was observed in few cases only [9–11]. The PL(T) measurements showed in fact a new PL band at increased temperature, whose appearance might be correlated with the decay of the $4f$–$4f$ PL of Yb^{3+} [12]. We could not definitely confirm that this PL band is due to a direct radiative decay of the Yb-bound exciton state, as a free-to-bound transition of free electrons and holes localized at shallow acceptors appears in similar spectral region.

We also found that the Yb^{3+} decay time depends weakly on the excitation intensity and it is slightly shorter at increased excitation intensities. The aim of the above experiment was to verify if there is any correlation between the Yb^{3+} lifetime and free carrier concentration. Such correlation was expected if the Auger effect determines decay time of the Yb^{3+} PL. The observed effect is however too small to verify positively the decay mechanism of the Yb^{3+} PL emission.

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