

Carrier Dynamics Investigated by Time Resolved Optical Spectroscopy

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We have investigated the transport of carriers in GaAs using time resolved optical spectroscopy with picosecond resolution. Carriers are optically created to the sample surface by an ultra-fast laser pulse. They diffuse and drift through a thick GaAs layer, until they are captured by an InGaAs quantum well, where they recombine with holes from a p-type doped layer at an inner InGaP barrier. Our study was performed with a set of samples with different GaAs layer thickness. As the GaAs thickness increases, the emission from the quantum well is delayed and its decay slows down significantly. We have investigated the effect of an applied DC field between the surface and the InGaAs quantum well. The transient of the quantum well emission is mostly independent of the applied DC voltage up to field of the order of 20 KV/cm, including both polarities. This is a clear indication that the carrier transport is dominated by ambipolar diffusion due to the Coulomb interaction that strongly couples photoinjected electrons and holes. On the other hand, the decay of the GaAs emission varies significantly when a DC gate voltage is applied such as a current appears at the structure.

I Introduction

A large amount of experimental and theoretical work has accumulated on carrier transport in semiconductors over the last decades[1]. This research remains however fundamental for the development of high-speed electronic and optoelectronic devices. An especially interesting point is the investigation of carriers transport when they are far way from equilibrium conditions. Carrier transport processes have been shown to affect greatly many of the static and dynamics properties of quantum well (QW) lasers[2]. Time resolved luminescence spectroscopy has provided important insight into the dynamical behavior of many physical systems.

II Experimental details

Our samples were grown by metal-organic chemical vapor deposition (MOCVD) epitaxy. The structure consisted of a top GaAs layer, a 50Å InGaAs quantum well (QW), a thin InGaP intrinsic layer, which acts as a space layer, followed by a p-doped InGaP layer and a p-doped GaAs buffer layer, on top of the GaAs substrate. An external electrical field may be applied to the structure through a semitransparent Au Schottky contact on the GaAs surface and an ohmic contact at the hole-gas created at the InGaAs QW. Three sam-

ples were grown with identical conditions and different thickness of the top GaAs layer: 100 Å, 1 μm and 4.5 μm. Time-resolved photoluminescence (PL) data were obtained using an up-conversion system. Carriers are generated by photoexcitation with a picosecond laser pulse (7400 Å, 70 mW). The emitted luminescence is focused at a nonlinear crystal. Optical gating with picosecond resolution is achieved by sum-frequency mixing with a reference laser pulse. The sum-frequency signal, generated at the nonlinear crystal, if luminescence and reference pulse have temporal overlap, is dispersed by a 0.5 m spectrometer and detected by single-photon counting. The temporal evolution of the luminescence is obtained by delaying the reference laser beam with respect to the excitation pulse. The samples are kept at low temperatures (~5 K) at all measurements.

III Results and discussion

Fig. 1 shows a schematic diagram of our structures and the IxV curve for the sample with the thickest GaAs top layer. The structure behaves as a normal diode. For $V > +5V$, a significant current arises due to the hole-gas conduction.

The light penetration depth on GaAs for the wavelength of excitation laser (7400 Å) is of the order of 0.5

μm [3]. For the sample with the thicker GaAs top layer ($4.5 \mu\text{m}$), direct optical absorption at the QW is therefore negligible and the number of carriers at the QW will be basically dominated by the motion of carriers through the GaAs barrier. In this case, the capture of carriers by the QW may be considered to be instantaneous for carriers close to the edge of the QW, relative to the carrier mean free path. As we decrease the GaAs top layer thickness, direct absorption at the QW increases, but the majority of carriers are still generated within the GaAs barrier, since this layer is always more than an order of magnitude larger than the QW. However, contrarily to the case of the sample with the thicker GaAs layer, most of the photocarriers is then created close to the edges of the QW. Therefore, the capture time of carriers by the QW has to be explicitly considered on the transient equations of the system and the motion of the carriers through the GaAs barrier becomes irrelevant.

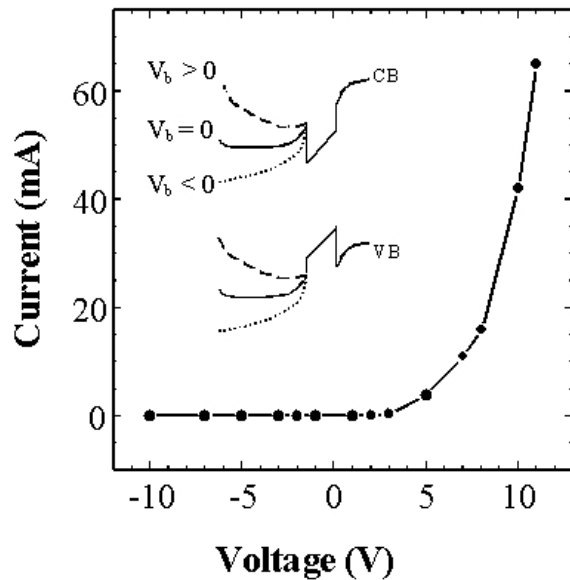


Figure 1. Schematic diagram of structures and the $I \times V$ curve.

Fig. 2(a) shows the time-resolved PL from the GaAs layer (Fig. 2a) for the samples with different GaAs layer thickness. The GaAs emission from the sample with the $4.5 \mu\text{m}$ layer, that should represent the behavior of a bulk-like structure, shows a relatively long rise time of the order of 400 ps. Similar results have been reported for bulk GaAs at lower excitation powers, when the photoluminescence is dominated by excitons and were attributed to the slow energy relaxation of the hot excitons via acoustic phonons[4]. As the GaAs top layer thickness decreases, the rising time of the GaAs emission seems to decrease, which actually reflects the very efficient trapping of carriers by the near QW, that quickly drains the carriers from the GaAs barrier. Elec-

tron capture times by quantum wells estimated from previous experimental results varies from 1-100ps[5], which qualitatively agrees with the results presented in figure 2(a) and 2(b), which shows the time-resolved PL from the QW emission for our samples. The relatively fast rising time (55 ps) for the sample with the thinner GaAs top layer agrees with the electron capture times mentioned above. The time constant obtained from the PL decay for this sample (530 ps) describes the effective carrier lifetime at the QW, including radiative and non-radiative processes. As the GaAs top layer increases, both the rising and decay of the QW emission slows down due to the effect of the carrier transport through the GaAs barrier, which results in an effective broad generation rate for the QW. The QW emission from the sample with the thicker GaAs layer remains essentially null for 30 ps which clearly demonstrates that photocarriers created close to the QW are negligible and the QW transient becomes basically determined by the diffusion-drift of carriers through the GaAs layer.

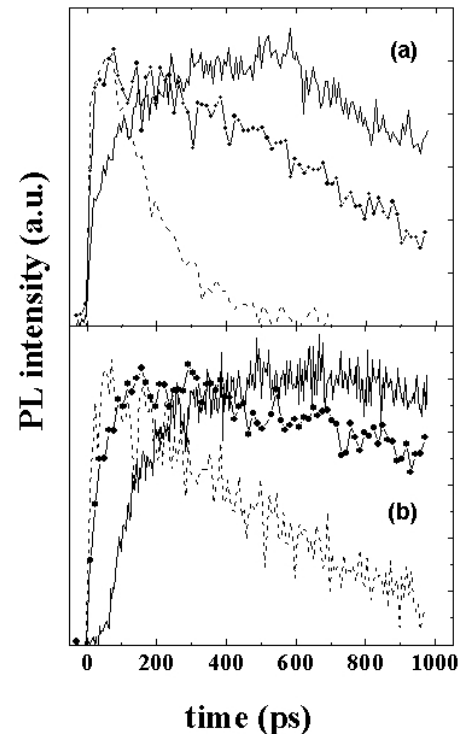


Figure 2. The time resolved PL for (a) GaAs layer and (b) QW emission.

Figs. 3 shows the time-resolved PL emission from the GaAs layer and the QW for different DC gate voltages between the surface and the QW. The transients have been normalized in order to make it easier to observe its transient shape. As observed in Fig. 3(a) the decay of the GaAs emission remains basically constant for negative bias but varies significantly for a positive gate voltage. This effect is probably related to the increase of current observed for this condition. In contrast, the transient of the QW emission is mostly

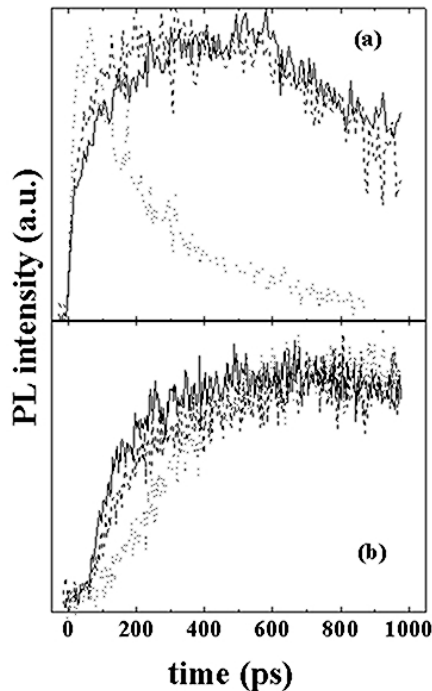


Figure 3. The time-resolved PL emission for different applied DC field (a) GaAs layer and (b) QW emission.

independent for voltages up to 10 V, which corresponds approximately to fields of the order of 20 kV/cm, including both polarities. This is a clear indication that the carrier transport is dominated by ambipolar diffusion, due to the Coulombic interaction which strongly couples photoinjected electrons and holes. The presence of the electrical field at our structure tend to separate the center of charge of those photogenerated electrons and holes, what then created a strong polariza-

tion field which opposes and cancel out the other fields. The transport of carriers through the GaAs layer can therefore be described by a single effective ambipolar diffusion coefficient defined in terms of the individual diffusion coefficients of electrons and holes. It is also interesting to note that, even then the PL decay of GaAs emission becomes relatively very fast when a + 10V gate voltage is applied at the structure, no noticeable effect is observed at the transient from the QW emission neither on its intensity. This indicates that the mechanism which extinguish the GaAs radiative recombination does not affect the number of electrons that arrives at the QW, neither alters its diffusion velocity. A more quantitatively analyze our results, can only be obtained through the numerical solution for the transient equations to describe our system. This work is now under progress.

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