INTRINSIC VERSUS EXTRINSIC EFFECTS IN EXCITATION DYNAMICS IN GaAs/GaAlAs SUPERLATTICES

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JOURNAL DE PHYSIQUE
Colloque C7, supplément au n°12, Tome 48, décembre 1987

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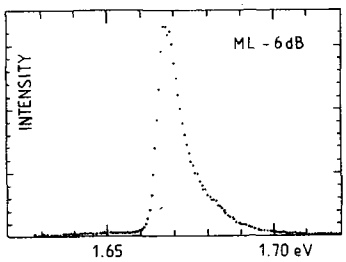
Abstract: We report studies of photoexcited carrier dynamics in GaAlAs/GaAs superlattices as a function of excitation power using optical technique. At low power, we observe a quadratic behavior of luminescence intensity, due to competition between electron-hole radiative recombination and trapping by defects. At higher power, a departure from this behavior is interpreted by a fast spatial expansion of the plasma. However, over the whole range, the measured decay time is mainly related to the trapping process.

Although it is a rather old topic, carrier transport in semiconductors is still a matter of controversy. For instance, a few years ago there was much of a debate about the possibility of a fast plasma expansion at relatively high density as suggested by M. Combescot /1/. The appearance of the new microstructures (quantum wells, superlattices) has given a boost to the study of semiconductors. Indeed, physicists have now new degrees of freedom in the design of samples. For instance, superlattices (SL) are strongly anisotropic materials. In SL, much of the research has been devoted to the study of transport parallel to the interfaces, but more recently a growing interest has appeared for the transport perpendicular to the interfaces (vertical transport) /2/. Here, we present a study of the effects of the carrier density on the properties of a GaAs/GaAlAs SL. The Al composition in the alloy is 30% and the GaAs and GaAlAs successive layers are both 30 Å thick.

The sample held at 77 K in a cryostat is photoexcited by a frequency-doubled mode-locked Nd-YAG laser. The laser can be used in two different configurations: without or with Q-switching; in the following these two configurations are respectively noted ML and QS. In the first one, a continuous train of pulses separated by 10 ns is produced (pulsewidth ≈ 100 ps). In the second one, bursts of such pulses are created: the width of the burst is about 1 µs and the repetition rate is 8 kHz; this gives larger peak power than in the ML configuration and therefore increases the available dynamic range. The laser beam is focussed on the sample to 100 µm. The luminescence emitted is collected and dispersed by a double monochromator. Luminescence spectra are obtained with conventional photon counting techniques. Single-photon counting, using a constant fraction discriminator and a time to amplitude converter, gives access to the time evolution of the intensity at a given wavelength.

The SL we have studied has a sufficiently short period to insure a large overlap between the wavefunctions of neighbouring wells and an increased 3D behavior of the carriers. Therefore, the exciton has a sufficiently low binding energy to be ionized at 77 K. This is evidenced by the two luminescence spectra shown figure 1. They have been obtained in two different experimental conditions: ML (average power incident on the sample: P=3 mW) and QS (P=11 mW); therefore the QS spectrum corresponds to a much higher peak power. Both spectra have a characteristic Boltzmann high energy tail as it can be expected for the recombination of free carriers. The effective temperatures are 90 K (ML) or 140 K (QS).



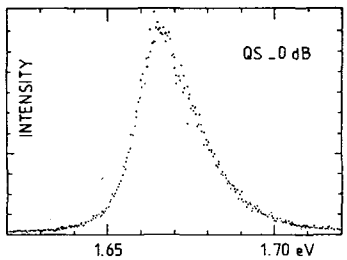


Figure 1: Luminescence Spectra. Average Power: 3 mW (ML -6 dB), 11 mW (QS 0 dB)

Figure 2,3: Luminescence intensity versus excitation power

Figure 2: ML configuration

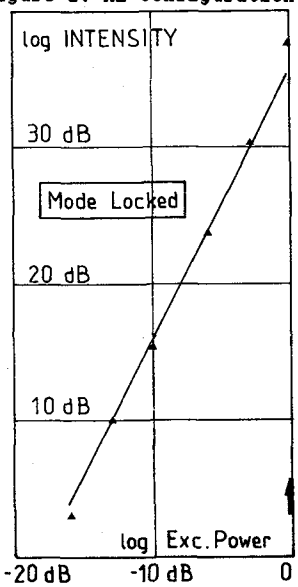


Figure 3: QS configuration

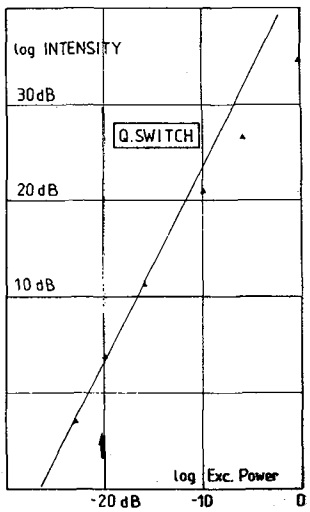


Figure 2 displays on a log-log scale the total intensity emitted by the SL as a function of the incident average power P in the ML configuration (P=13 mW for 0 dB). The straight line represents a quadratic behavior. For free carriers, this result is not surprising as shown by the following model. If we neglect the effect of the residual doping of the sample, we can write the time evolution of n and p which are respectively the electron and the hole density:

$$dn/dt = -w_1 n - Bnp + G(t)$$
$$dp/dt = -w_2 n - Bnp + G(t)$$

where w_i (i=1,2) is a trapping rate by defects, Bnp is the usual bimolecular radiative recombination and G(t) is the generation rate by the laser. The behavior of the emitted intensity is the result of the competition between the recombination and the trapping. At sufficiently low excitation density and therefore low carrier density, the bimolecular term is very small and n and p have a linear behavior with the excitation power. Then the emitted intensity given by the bimolecular term is quadratic with the power. Of course, at sufficiently high excitation density, the intensity should tend to become linear.

For the lowest powers in the QS configuration, the total emitted intensity is still quadratic with the excitation power as shown by the straight line drawn on figure 3 (now the average power P is 11 mW for 0 dB). At higher power, we can notice a strong departure from a quadratic behavior. Before discussing this last point in detail, it should be emphasized that in the QS configuration the burst is made of

pulses of different amplitudes. Nevertheless, it is obvious that the highest pulses play a dominant role. The arrow drawn on figure 3 indicates the power for which the highest pulse of the burst has approximatively the same energy as a pulse in the ML configuration at 0 dB.

But this departure from a quadratic behavior observed at high peak power is not due to the growing importance of the bimolecular term in its competition with the trapping term. If it were the case, we should have a non exponential decay of the luminescence and a faster dynamics at higher power. The time evolution of the integrated intensity obtained in the QS configuration at 0 dB is in fact exponential (figure 4). The time evolution at the maximum of the luminescence spectrum is also slower when the power is increased by more than two order of magnitude in the QS mode (figure 5): indeed, the time constant increases from 380 ps to 830 ps. It is reasonable /3/ to link this variation to a saturation of the traps either by filling by the photogenerated carriers or by direct absorption of the light. We have evidence neither for their precise nature (deep or shallow) and their saturation properties nor for their location (surface, interface, bulk). On the other hand, this saturation effect does not explain the slower than quadratic dependence of the intensity with the power. Indeed it should give a faster than quadratic dependence.

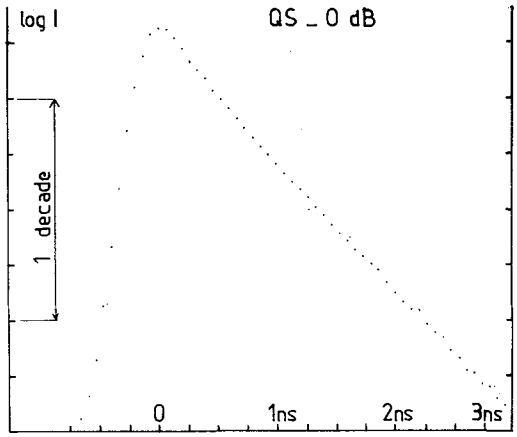


Figure 4: Time evolution /of integrated intensity

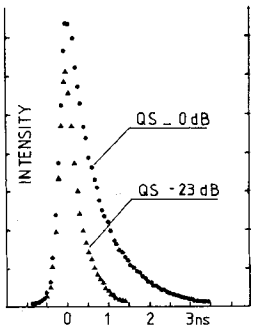


Figure 5: /at 1.668 eV

We interpret the non-quadratic evolution of the intensity as a result of a sufficiently fast plasma expansion which decreases the local density of carriers. This expansion which is density dependent prevents the bimolecular recombination from becoming comparable to the trapping. As the absorption depth (≈ 1500 A) is much smaller than the focused laser spot, we expect that this expansion takes place mainly in a direction perpendicular to the interfaces. From the incident power, we could deduce a density of 3 10^{17} cm^{-3} in the transition region but a large uncertainty due to the surface quality can reduce it by a large amount.

In summary, these results show the interplay of intrinsic (bimolecular recombination, plasma expansion) and extrinsic (trapping, trap saturation) effects in the properties of semiconductors. They also illustrate the power of combining intensity and decay measurements to study a given phenomena.

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