New Results on Bound Excitons in Quantum Wells

J. B. B. de Oliveira[a], E. A. Meneses[b] and E. C. F. da Silva[c]

[a] *Departamento de Física - FC, Universidade Estadual Paulista, Caixa Postal 473, 17033-360 Bauru, SP, Brazil*

[b] *Instituto de Física Gleb Wataghin, Universidade Estadual de Campinas, Caixa Postal 6165, 17083-970, Campinas, SP, Brazil*

[c] *Instituto de Física, Universidade de São Paulo, Caixa Postal 66318, 05389-970, São Paulo, SP, Brazil*

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The formation of bound excitons (BE) is investigated for a GaAs/GaAlAs multiple quantum well (QW) system. The photoluminescence (PL) spectra are analysed as a function of the excitation energy. It was found that the carriers photogeneration, either in the barrier or directly in the well, do not play an important role on the BE formation. We conclude that defects localized at interfaces are ionized by of capture charges which in turn bound the free exciton (FE).

I. Introduction

Interface roughness and defects degrade the electrical and optical properties of the heterostructures which determine the devices operation.[1] For this reason, interface morphology in semiconductor heterostructures has been widely investigated due to its great importance in the performance of opto-electronic devices.[2] Excitons have been used as efficient sensors to investigate the interfaces in atomic scale due to its sensibility on the structural aspects of the sample.[4] Recently, Srinivas et al.[4] reported on the BE formation by ionized defects localized in the barriers in a GaAs/GaAlAs QW. Their conclusions are based on the fact that a BE emission is only observed when the sample is illuminated by photons with energy higher than the barrier band gap energy (i.e., when the carriers are excited in the barrier before relaxing to the well). However, when the carriers are photogenerated directly in the well (i.e., with energy bellow the band gap barrier) the BE emission was not observed anymore.

In this work we investigated a sample, grown by MBE, which consists of 20 periods of GaAs QW (80Å) confined by $Ga_{0.7}Al_{0.3}As$ barriers (300 Å). PL measurements were performed using a He-liquid cryostat and a conventional detection system. Different light sources were used: an Ar^+ laser, an Ti-Sa laser and a halogenic lamp. Our experimental results are very similar to the ones reported by Srinivas and co-workers, but we present additional investigations and a new interpretation for the data.

II. Results and discussions

In Fig. 1 are shown low temperature (T=3.2 K) PL spectra obtained with different light sources: (a) the Ar^+ laser ($h\nu_{exc}$ = 2.41 eV) and, (b) the Ti-Sa laser ($h\nu_{exc}$ = 1.689 eV). We can observe the peak associated with the fundamental FE emission (at 1.564 eV) and a low-energy peak (at 1.563 eV). PL measurements as a function of temperature and excitation power intensity, PLE measurements, and a detailed line-shape analysis indicated that the low-energy peak corresponds to a BE emission.[5] However, in the asymmetrical spectrum (b) of Fig. 1, apparently only the FE emission is observed. The basic difference in the experimental conditions utilized to obtain the spectra of Fig. 1 is the photogeneration of carriers preferentialy in the barriers

($h\nu_{exc} = 2.41$ eV) or directly in the wells ($h\nu_{exc} = 1.689$ eV), since the barrier band gap energy of our sample is at 1.951 eV (as determined by PL measurements).

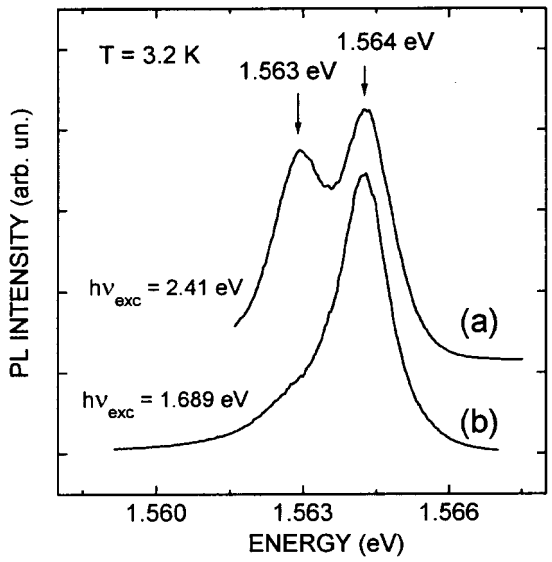

Fig. 1. PL Spectra obtained at T = 3.2 K and with excitation energy a) above (2.41 eV) and b) below (1.689 ev) the barrier band gap energy.

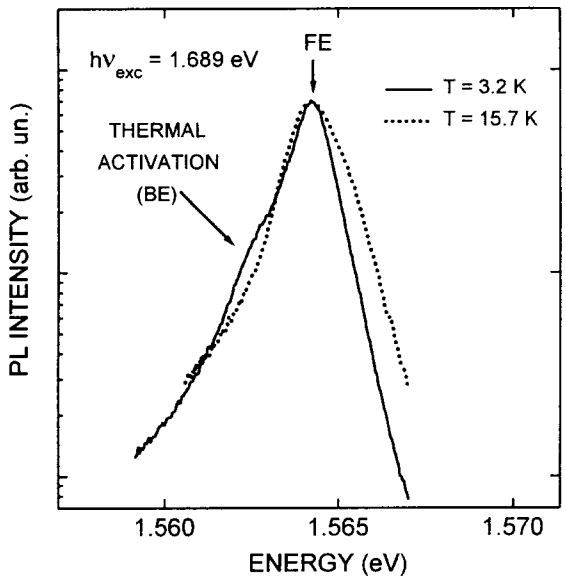

Fig. 2. PL spectra measured with excitation energy below the barrier band gap energy at 3.2 K (solid line) and at 15.7 K (dotted line).

Our experimental results, quite similar to the ones reported by Srinivas and co-workers, indicate that the excitation energy plays an important role on the BE formation. Then, in order to improve our understanding about the process of the formation of the BE, we carried out a detailed study of the PL spectra as a function of the excitation energy.

In Fig. 2 we plotted in logarithmic scale, the PL spectra obtained with an excitation energy such that the carriers have been photogenerated directly into the well ($h\nu_{exc} = 1.689$ eV), measured at different temperatures. It can be observed in this figure that the increase of the temperature yields a small, but evident, decrease of the PL intensity in the low-energy side of the spectra. This effect indicates a thermal activation process probably associated with the BE emission.

We also performed PL measurements for different excitation energies using a halogenic lamp and a 0.3 m monochromator. The excitation power intensity was maintained approximately constant. The results are depicted in the Fig. 3. The most visible aspect is the monotonic increase of the intensity of the BE emission relatively to the FE peak. For excitation energy of 2.883 eV the BE peak completely dominates the emission espectrum. In the Fig. 4a we plotted in logarithmic scale the upper spectrum of Fig. 3 (for excitation energy of 1.771 eV, below the barrier) where it can be observed the BE peak as a shoulder in the low-energy side of the spectrum. The same spectrum (1.771 eV) is perfectly fitted using a Gaussian and a Lorentzian curve for the FE and BE peaks, respectively, as can be seen in Fig. 4b. Our results clearly indicate the presence of the BE emission even when the carriers are created directly in the well. However, the most important result, showed in the Fig. 3, concerns the *non-abrupt* change in the PL spectra for excitation energies either below or above the barrier band gap.

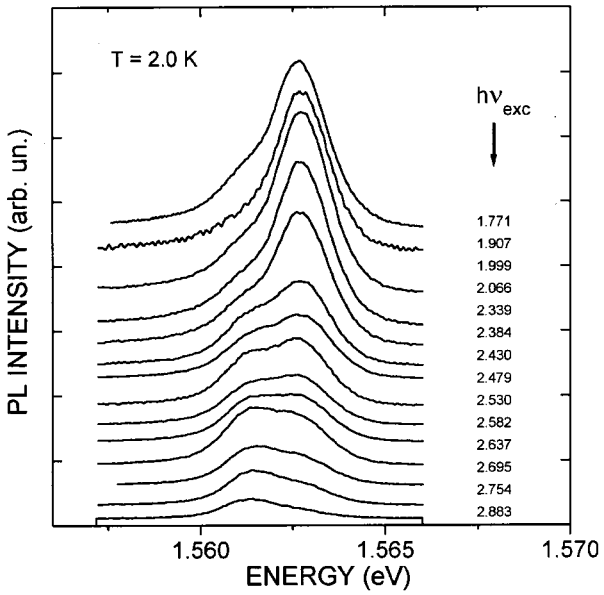

Figure 3. PL spectra performed at T = 2.0 K, for different excitation energies and using a halogenic lamp. The power excitation energy was maintained approximately constant.

The PL spectra plotted in Fig. 3 were decomposed in Gaussian (FE) and Lorentzian (BE) curves and the respective integrated intensities were calculated. In Fig. 5 we plotted the integrated intensity related to the BE and FE peaks, as well as the total integrated intensity of each spectrum as a function of excitation energy. It can be observed that all the intensities reach a maximum value when the sample is excited with energy close to the barrier gap energy (1.951 eV). This behavior is a consequence of the increase of the absorption volume when the GaAlAs alloy starts to absorve. On the other hand, for higher excitation energies all the intensities decrease, probably due to major participation of non-radiative and GaAlAs band gap recombinatipns. Furthermore, it is also important to notice that the intensity of the emissions change monotonicaly as a function of excitation energy, confirming our assumption about the simultaneous presence of the BE and FE emissions in all spectra.

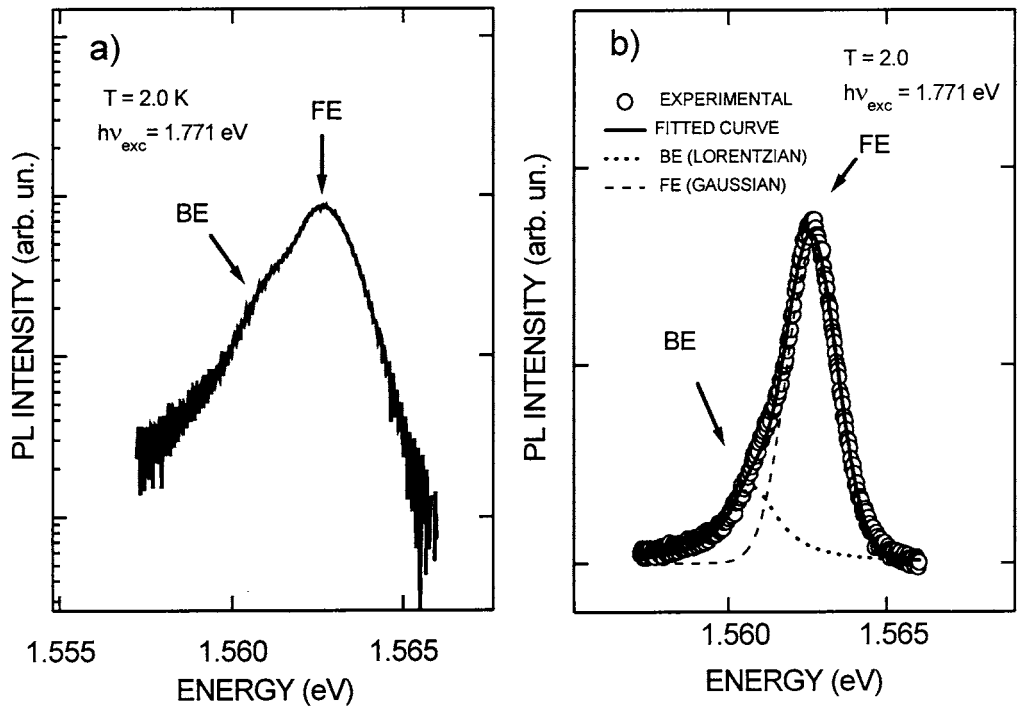

Figure 4. a) PL spectrum from the Fig. 3 measured at T = 2.0 K and with excitation energy of 1.771 eV plotted in logarithmic scale; the BE emission is observed as a shoulder in the low energy side of the spectrum and b) The same spectrum decomposed in a Lorentzian (dotted line, BE emission) and a Gaussian (dashed line, FE emission) curve; the experimental data and the fitted curve are represented by the open circles and solid line, respectively.

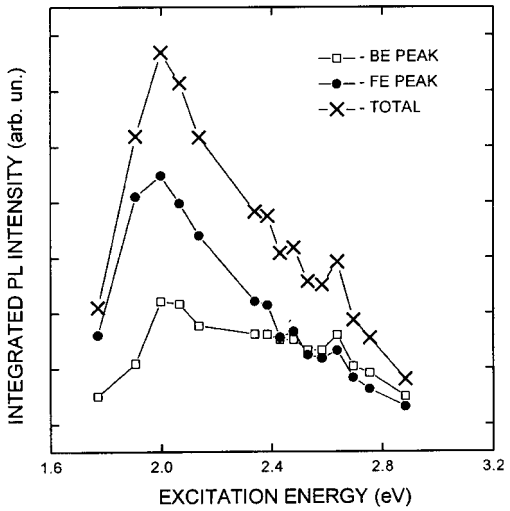

Figure 5. Integrated PL intensity plotted as a function of the excitation energy after the deconvolution of the spectra showed in Fig. 3. The open squares represent the BE peak intensity, the solid circles the FE peak intensity and the crosses the total intensity. The solid lines represent a guide to the eyes.

III. Conclusions

The influence of the excitation energy on the BE formation was studied for a GaAs/$Ga_{0.7}Al_{0.3}As$ multiple quantum well sample. Our experimental results demonstrated that in our sample the excitation energy do not play an important role in the formation process of the BE, i.e., the BE formation does not depend if the carriers are excited in the barrier or directly in the well. Similarly to Srinivas et al. we believe that the BE is formed by ionized defects which in turn bound the FE. However, contrarily to their interpretation, our results indicated that the ionized defects are not localized at the barriers but at the QW interfaces.

Acknowledgments

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