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Up-Converted Photoluminescence
in Partially Ordered GaInP₂/GaAs
Up to 23 T**

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**Magnetic Field Dependence of Up-Converted Photoluminescence in
Partially Ordered GaInP₂/GaAs Up to 23 T**

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MAGNETIC FIELD DEPENDENCE OF UP-CONVERTED
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GaInP₂/GaAs UP TO 23 T

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The influence of a strong magnetic field on the up-converted photoluminescence (PL) spectra of partially ordered layers of GaInP₂ grown on GaAs substrate have been investigated. The up-converted PL spectra exhibit 2 peaks. The position of the low energy peak is close to that of the peak observed in PL spectra excited by above GaInP₂ bandgap light while the other peak occurs at about 30 meV higher in energy. Both peaks show a linear dependence on B between 0 and 23 T suggesting that free carriers with effective masses of 0.084m₀ and 0.24m₀ (m₀ is the free electron mass) are involved in these transitions. We interpret the low energy peak as originating from the recombination of localized holes with free electrons while the high energy peak is related to the recombination of localized electrons with free holes.

1 Introduction

Ga_{0.5}In_{0.5}P grown under certain conditions on [100] oriented GaAs substrate forms a partially ordered alloy with a bandgap up to 100 meV smaller than that of the disordered alloy¹. The upconversion of PL from GaAs bandgap photons to GaInP₂ bandgap photons has been reported recently in quantum well structures fabricated from GaAs and partially ordered GaInP₂². The up-conversion process is efficient when the energy of incident photons is higher than the gap of the GaAs substrate² although a weak signal is visible already for energies about 30 meV smaller³. Two different mechanisms have been proposed to explain the process - 1) an Auger process which transfers both electrons and holes from GaAs to the GaInP layer (type I alignment is assumed), where they are then trapped by localized states in the GaInP layer and recombine radiatively², 2) a two-step two-photon absorption model, where an electron-hole pair in GaAs excited by the absorption of first photon is spatially separated by a type II band alignment with the electron trapped in the

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GaInP₂ layer. Then a second photon excites the hole to higher energy states from which it relaxes and diffuses to the GaInP layer and is captured again by some localized states³. In this paper we use high magnetic field to identify the nature of the recombination states in the GaInP₂ layer responsible for the up-converted emission.

2 Experimental

Three samples used in this study are all epitaxial layers of GaInP₂ about 1 μm thick grown by MOCVD on a GaAs buffer layer deposited on [100] oriented GaAs substrate. The samples differ in the temperature of their epitaxial growth – samples T650, T700 and T750 were grown at 650°C, 700°C and 750°C, respectively. The up-converted PL was excited by the 775 nm (1.60 eV) light generated by a Ti-sapphire laser. The power density was about 10mW/mm². The measurements were done in a helium bath cryostat at 4.2 K in magnetic fields up to 23 T. The spectra were analyzed using a triple DILOR XY spectrograph equipped with an optical multichannel detector.

3 Results and discussion

The normal PL spectra of our three samples, excited by above GaInP₂ bandgap light from an Ar⁺ ion laser, exhibit a single asymmetrical peak at 1.93 eV (T750), 1.89 eV (T700) and 1.88 eV (T650), respectively. The different exciton peak positions indicate their different degrees of ordering. Fig. 1 displays the normal and up-converted spectra measured on the T700 sample. When excited

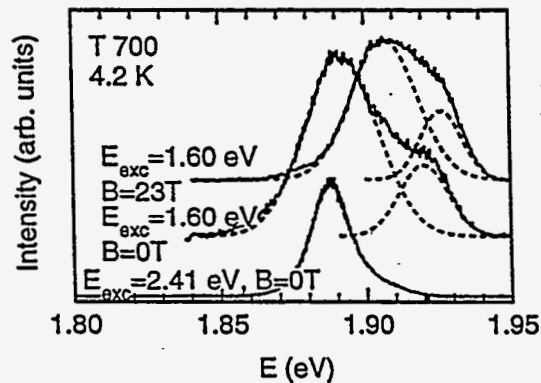


Figure 1: The PL spectra of sample T700. The dotted peaks show the deconvolution of up-converted spectra using 2 Gaussian curves.

by Ti:sapphire laser the up-converted PL consists clearly of two overlapping peaks. The position of the lower energy peak is close to the peak maximum in the normal PL spectrum. The second peak in the up-converted spectrum

is about 30 meV higher in energy. Qualitatively similar spectra are found in the other two samples. The existence of multiple peaks in up-converted PL spectra of GaInP₂/GaAs has been reported previously; however, the nature of these peaks remains unclear³.

Magnetic field B shifts both peaks towards higher energy but at different rates. The magnetic field dependence of the peak positions in the up-converted PL spectra after deconvolution is shown in Fig. 2a, again for the T700 sample. We note that both peaks shift *linearly* with B. This indicates that free carriers

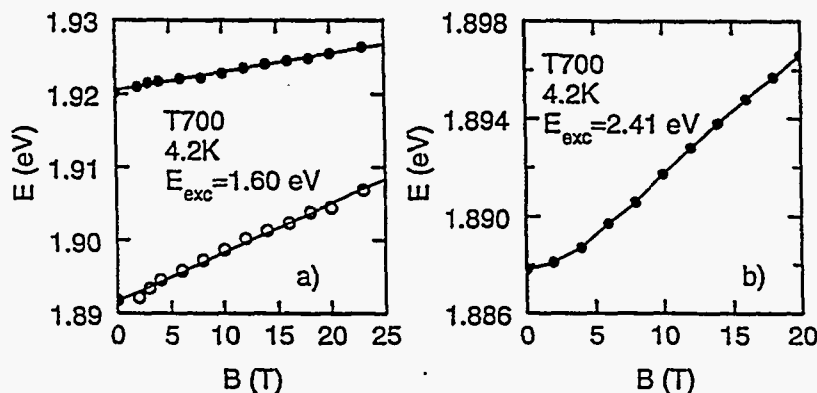


Figure 2: Magnetic field dependence of the peak positions for up-converted (a) and normal (b) PL spectra measured on T700 sample at 4.2 K.

are involved in these transitions. From the slopes of a least-square fit we deduce effective masses of $0.084m_0$ and $0.24m_0$ (where m_0 is the free electron mass) for the low energy and high energy peaks, respectively. Previous experiments^{4,5} have reported values of the electron and hole effective masses in GaInP₂ to be around $0.09m_0$ and $0.25m_0$, respectively. These results suggest that the low energy peak originates from the recombination of *localized* holes and free electrons ($0.084m_0$ being the electron mass in GaInP₂ determined by us) while the high energy peak corresponds to the recombination of *localized* electrons with free holes ($0.24m_0$ being the hole effective mass in GaInP₂). Similar linear B dependence is found in the other two samples with the deviations in electron and hole masses less than 5% from the values for sample T700. These results confirm the presence of localized states in the conduction and valence bands of partially ordered GaInP₂ and point to their important role in the up-conversion process of PL in these samples.

Fig. 2b shows the magnetic field dependence of the peak position in the normal PL excited the by 514.5 nm (2.41 eV) line of Ar⁺ laser. The dependence is clearly quadratic up to 6 T and then linear up to 23 T. This behavior is consistent with the excitonic nature of the emission from GaInP₂ reported

previously by other groups⁵. The different magnetic field dependence for normal and for up-converted PL can be explained by these two effects: 1) it has been shown that at moderately high laser excitation all traps are saturated so that the normal PL of partially ordered GaInP₂ is excitonic⁵. The up-conversion process is not as efficient so that even at rather high excitation power (~ 10 mW at 1.60 eV) the holes and electrons excited into the GaInP₂ epilayer are not sufficient to saturate all the traps. 2) The normal PL is excited from the front surface side of the sample by light which is strongly absorbed in the epilayer so that one observes mainly the signal coming from a thin layer near the sample surface. On the other hand, the up-converted signal comes from a region near the GaAs/GaInP interface and there the concentration of localized states is presumably higher than that near the sample surface.

4 Conclusion

The magnetic field dependence of up-converted PL from partially ordered GaInP₂/GaAs samples has revealed two new recombination processes – recombination of free holes with localized electrons and of free electrons with localized holes. Accurate values of the effective masses of electrons ($0.084m_0$) and holes ($0.24m_0$) in partially ordered GaInP₂ have been obtained. Our results confirm the importance of traps for electrons and holes in the PL up-conversion process at the GaInP₂/GaAs interface.

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References

1. see, for example, K. Uchida et al., *Phil. Mag.* B 70, 453, (1994)
2. F. A. J. M. Driessen, *Appl. Phys. Lett.* 67, 2813, (1995)
3. Z. P. Su et al., *Sol. St. Commun.* (in press); see also K. L. Teo et al. in this issue
4. P. Emanuelsson, M. Drechsler, D. M. Hofman, K. K. Meyer, M. Moser, F. Scholtz, *Appl. Phys. Lett.* 64, 2849, (1994)
5. E. D. Jones et al., *Proc. of the 22nd Int. Conf. on Phys. of Semicond.* (World Scientific, Singapore, 1995), p. 293