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THE PHOTOLUMINESCENCE SPECTRA OF N^+, Zn^+ IMPLANTED $GaAs_{1-x}P_x$ AT 1.8-4.2K

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The photoluminescent behavior of N^+ and Zn^+ implanted $GaAs_{1-x}P_x$ has been investigated at 1.8-4.2K. The experimental results show that the alloy composition x, at which the conversion of N-Zn transition N and bound excitonic recombination occurs, depends on the nitrogen and zinc doping concentrations.

1. INTRODUCTION

Previously Campbell et al.[1] studied the N,Zn photoluminescence (PL) behavior in their N^+,Zn^+ $GaAs_{1-x}P_x$ samples at 77K and observed that the conversion of the transition involving an electron bound to a nitrogen isoelectronic trap and a hole bound to a Zn acceptor (referred to as N-Zn transition) to nitrogen bound excitonic recombination at x=0.65. They presented a localized model to explain this conversion.

Motivated by the influence of different N,Zn concentrations of luminescent behavior, we found the composition x, at which the conversion of N-Zn transition to N bound excitonic recombination occurs, (denoted as X(N-Zn)-N depends on N,Zn concentration, the more the concentration of N,Zn the higher the X(N-Zn)-N. We have calculated the ratio of r of the transition probabilities between N-Zn transition and N bound excitonic recombination of three different N,Zn concentrations, the results are in fair agreement with our experimental results.

2. EXPERIMENTAL RESULTS AND ANALYSIS

The $GaAs_{1-x}P_x$ samples used in this work were grown by conventional VPE technique. Their characteristics are summarized in Table I. Figure 1 shows typical PL spectra of $GaAs_{1-x}P_x$ (x=0.43) samples at 4.2K. In Figure 1(a) the main peak (1.923eV) was identified nitrogen bound excitonic recombination (N) while in Figure 1(b,c,d) we observed N-Zn transitions[1] with energies of 1.922eV, 1.920eV and 1.898eV respectively.

Figure 2 shows the PL spectra of $GaAs_{1-x}P_x$(x=0.49) at 4.2K. The related emissions were 1.955eV, 1.953eV, 1.945eV respectively for a,b and c. From Fig.1 and Fig.2 it is clear that for the samples with same x, the more Zn^+ was implanted, the more the N-Zn peak energy decreased, and for samples with different composition but with same N^+,Zn^+ concentrations, the higher the x value was, the less the N-Zn peak energy decreased.

Figure 3 shows PL emission peak energies vs. composition x. Because of different implantation energies and annealing conditions, the Zn concentration of group III samples is estimated to be 10^{19} cm^{-3} while group II samples 10^{18} cm^{-3}. Concentrations for all cases are approximately 10^{18} cm^{-3} [2]. By comparing the emission spectra of N^+: $GaAs_{1-x}P_x$ with these of N^+, Zn^+ : $GaAs_{1-x}P_x$, we found that the Zn acceptor causes the spectra of N^+:$GaAs_{1-x}P_x$ to shift to lower energies. It is attributed to the N-Zn transition. The magnitude of this spectral shift is found to be composition x dependent, decreasing with x. We believe it is an indication of gradual conversion from N-Zn transition to N transition. We also notice that with the increase of Zn concentration the spectral shift tends to be less x dependent, that is the complete conversion from N-Zn transition to N transition will occur at high x value. Our experimental results can be well understood using localized model presented by J.C. Campbell et al.[1]. In the direct gap region, the wavefunction of Zn-bound hole is sufficiently delocalized so that its overlap with the wavefunction of the trapped electron exceeds that of bound excitonic hole. The N-Zn transition becomes dominant. With the increase of x, the Bohr radius of Zn bound hole becomes smaller, the overlap of the wavefunction of Zn bound hole and that of the N trapped electron decreases. On the other hand, with the increase of x, the Bohr radius of N-bound exciton gets smaller, the N bound hole becomes more localized in the vicinity of the nitrogen trap and N bound excitonic hole increases. As a result of these two effects the N-Zn transition is gradually converted to the N recombination and finally dominate the spectrum of N,Zn: $GaAs_{1-x}P_x$.

Numerically we have calculated the probability ratio r between Zn bound hole appearing at N center and N bound hole appearing at N center at three different N,Zn concentrations (Fig.4). It is clear that with the increase of x, r becomes smaller very quickly, implying the conversion of N-Zn transition to N transition. With the increase of N,Zn concentration the decrease of r tends to slow down, suggesting the dependence of the conversion on N,Zn concentrations.

We have simultaneously observed the N-Zn transition and N bound excitonic emission in N^+,Zn^+ $GaAs_{1-x}P_x$(x=0.57) at 1.8K and 4.2K (Fig.5). It is the first observation of the competitive process between these two transitions.

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TABLE I : The characteristics of samples used in experiments

	implanted element	ion energy (KeV)	ion influence (Cm^{-2})	annealing temp. (C°)	annealing duration
group I	N^+	170	$3\text{-}4\times10^{14}$	900	1 hr.
group II	N^+	170	$3\text{-}4\times10^{14}$	900	1 hr.
	Zn^+	170	5×10^{13} 5×10^{14} 5×10^{15}		
group III	N^+	160	1×10^{14}	850	35 min.
	Zn^+	80	4×10^{15}		

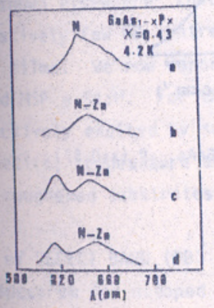

Fig. 1: The PL spectra of GaAsP(x=0.43) at 4.2K: (a) spectrum from a sample of group I, with N implantation only; (b),(c) and (d) spectra from samples of group II, with N influence of $3\text{-}4\times10^{14}cm^{-2}$ and Zn influences of 5×10^{13}, 5×10^{14} and $5\times10^{15}cm^{-2}$, respectively.

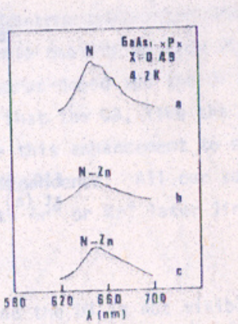

FIG. 2: The spectra of GaAsP(x=0.49)at 4.2K: (a) spectrum from a sample of group I, with N implantation only; (b) and (c) spectra from samples of group II with N influence of $3\text{-}4\times10^{14}$ and $5\times10^{15}cm^{-2}$, respectively.

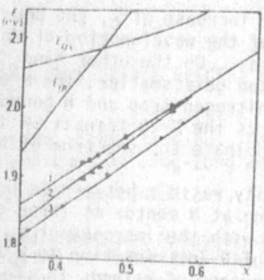

FIG. 3: Composition dependence of PL spectral peak energy of Zn^+N^+ ion implanted $GaAs_{1-x}P_x$ at 4.2K: curve 1 for group I samples, curve 2 for group II and curve 3 for group III.

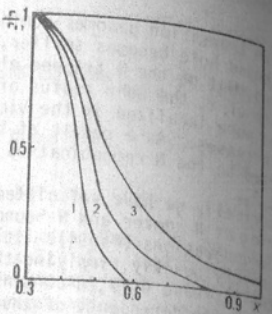

FIG. 4: The probability ratio r vs. composition x. 1. $n_N+n_{Zn}=1\times10^{17}cm^{-3}$ 2. $n_N+n_{Zn}=1\times10^{18}cm^{-3}$ 3. $n_N+n_{Zn}=1\times10^{19}cm^{-3}$. The ratio was normalized to the ratio at x=0.3.

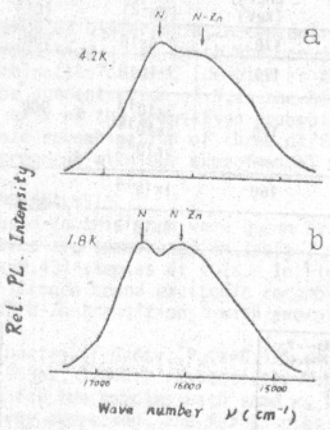

FIG. 5: PL spectra of N^+,Zn^+: $GaAs_{1-x}P_x$(x=0.57) at (a) 4.2K and (b) 1.8K.

REFERENCES

1. J.C. Campbell, N. Holonyak, Jr., and M.H. Lee, Phys. Rev. B10 (1974) 1755.
2. K.H. Lee, W.H. Zhuang, Z.G. Lee, D.M. Zhou, Jnl. of Beijing Normal Univ., 1 (1980) 47.