NITROGEN LOCALIZED STATES IN PRESENCE OF BI-DIMENSIONAL ELECTRON GAS IN HEAVILY DOPED $GaAs_{1-x}N_x$

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Abstract. We report a low-temperature photoluminescence spectra (LTPL) of $GaAs_{1-x}N_x$ layers and 2 dimension electron gas (2DEG) $GaAs_{1-x}N_x$/AlGaAs modulation doped heterostructure grown on GaAs substrates by molecular beam epitaxy (MBE) with low nitrogen content $[N]=2\times10^{18}cm^{-3}$. At low temperature PL spectra of $GaAs_{1-x}N_x$ layers are governed by several features associate to the excitons bound to nitrogen complexes, these features disappear in (2DEG) $GaAs_{1-x}N_x$/AlGaAs modulation doped heterostructure and the PL peak energy decrease with the laser power excitation. This effect is explained by the strongly coupling of the (2DEG) fundamental state with the nitrogen localized states. An activated energy of about 55 meV is deduced by photoluminescence measurements in the 10 to 300 K range for a laser power excitation $P=6W/cm^2$.

Keywords: GaAsN; 2DEG; Molecular beam epitaxy; Photoluminescence spectroscopy; Si-doping.

1. INTRODUCTION:

The study of III–N–V semiconductors alloys, especially $GaAs_{1-x}N_x$ and $Ga_{1-y}In_yAs_{1-x}N_x$ has been increasing in the last few years due to their potential for long wavelength optoelectronics applications [1-4]. The incorporation of 1% nitrogen shifts the band gap energy of about 180 meV leading to a huge bowing (b=20 eV). A heavily nitrogen-(N) doped GaAs, often considered to as a dilute $GaAs_{1-x}N_x$ alloy, has been intensively studied to understand the giant band-structure changes in $GaAs_{1-x}N_x$. It was found that the incorporation of small amounts of nitrogen affects considerably the electronic and the optical properties.

In this work, we report low-temperature photoluminescence (LTPL) studies of a 2-dimension electron gas (2DEG) effect on nitrogen localized state in $GaAs_{1-x}N_x$ with $2\times10^{18}cm^{-3}$ nitrogen composition. We have noted that the (LTPL) spectra are strongly affected by the presence of 2-dimension electron gas (2DEG). We have measured photoluminescence spectra of $GaAs_{1-x}N_x$

alloys to examine in detail the temperature dependence of the band gap energy and the influence of localized states. It was found that the PL from $GaAs_{1-x}N_x$ does not originate from band to band transitions, but rather from localized state excitonic recombination.

2. EXPERIMENTAL

The sample 1 is formed by a 50 nm $GaAs_{0.98}N_{0.02}$ channel and two spacer layers: a 1 nm GaAs and a 3 nm AlGaAs undoped spacer. The GaAs spacer is introduced to prevent a possible interaction between Al and N, which could degrade the interface where the 2 DEG is formed. Finally, 50 nm $Al_{0.27}Ga_{0.73}As$ (Si) doped barrier and a 5 nm GaAs cap layer complete the structure. The sample 2 is formed by 50 nm $GaAs_{0.98}N_{0.02}$ and 5 nm GaAs cap layer. In this paper, we have reported detailed investigation on the PL properties of $GaAs_{1-x}N_x$ layers with nitrogen content of $2\times10^{18}cm^{-3}$ doped Silicon (Si) grown by molecular beam epitaxy (MBE).

3. RESULTS AND DISCUSSION

Figure 1 shows the photoluminescence spectra of the two samples at 10 K temperature under an excitation power of 6 W/cm^2. For the sample 2, low temperature PL spectra is essentially formed by several features visible in the range from 1.40 to 1.49 eV situated below the GaAsN and GaAs bandgap sharp lines at 1.500 eV and 1.513 eV. These features situated at 1.449, 1.462, 1.478 and 1.484 eV correspond respectively to NN_D, NN_C, NN_A, and NN_F. In sample (1), the PL spectra are formed only by a sharp line located at 1.440 eV presenting a strong asymmetric towards high energies and covering a range of energy from 1.372 to 1.600 eV. We have plot in figure 2, the PL spectra of the sample (1) performed at temperatures in the rang of 10 to 300 K and with laser power excitation P = 6 $W/\ cm^2$. The figure 3 shows the temperature dependence of the PL maximum peak energy for two laser powers excitations. We note that at low temperature range from 10 to 40 K, the PL maximum peaks keep the same energies at 1.440 eV for P = 6 $W/\ cm^2$ and 1.475 eV for P = 2 $W/\ cm^2$. At T = 45 K, the PL peaks energies increase rapidly to 1.495 eV for P = 6 $W/\ cm^2$ and to 1.50 eV for P = 2 $W/\ cm^2$. This ‘‘S-shape’’ behaviour observed by other groups in undoped III–V-N alloys [5–8] is attributed to the localized states. In addition we note that for the temperature rang superior to 60 K and for the two powers excitations, the PL maximum peaks energies decrease linearly. To describe the temperature dependence of PL peak, we suppose that at low temperature T< 45 K the carriers are bound to a band state resulting from the strong coupling between the nitrogen localized state and the (2DEG) fundamental state. The (2DEG) are confined in a triangular well and their fundamental state energy depends on the laser power excitation. For a strong power, the photoelectrons created in the conduction band induce an electric field causing a widening of the triangular well and then a redshift of the fundamental state energy.

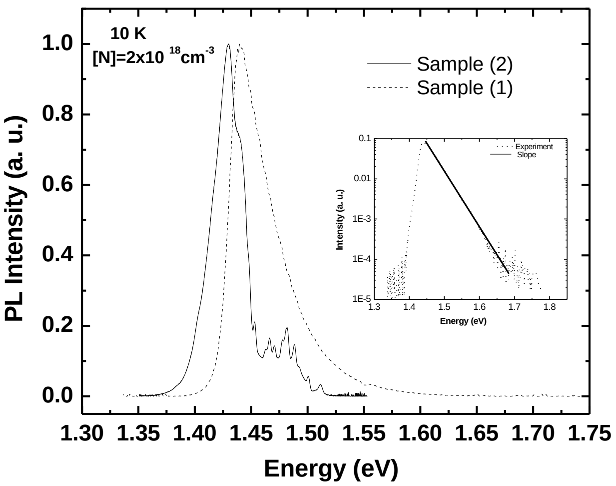


Figure 1: Peak normalized 10 K PL spectra of sample (1): and sample (2): (discontinue line) semilog PL spectra of sample (1), (solid line) exponential slope of the high-energy wing of the PL band.

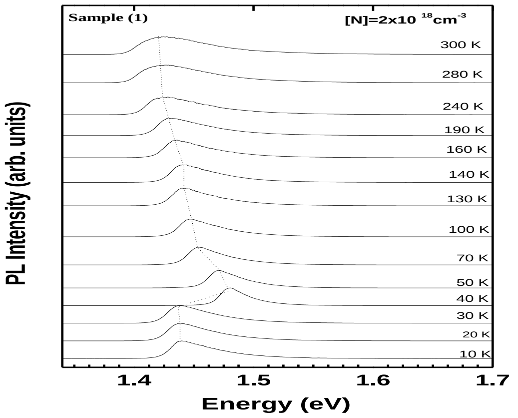
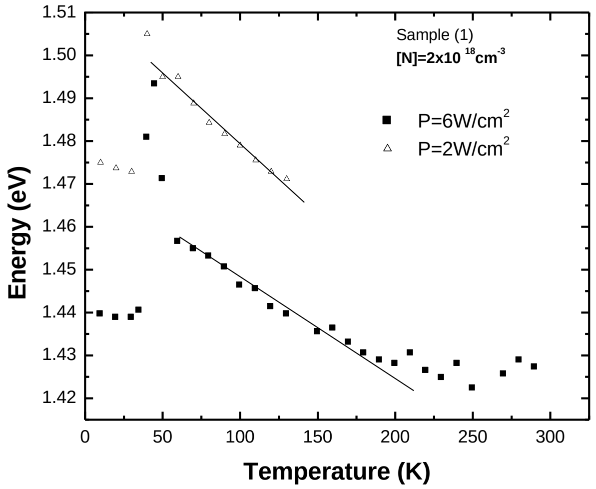


Figure 2: Peak normalized PL spectra of GaAs$_{1-x}$N$_x$ QW in presence of a 2-dimension electron gas (2DEG) sample for different temperatures (laser power P = 6w/cm^2**).**



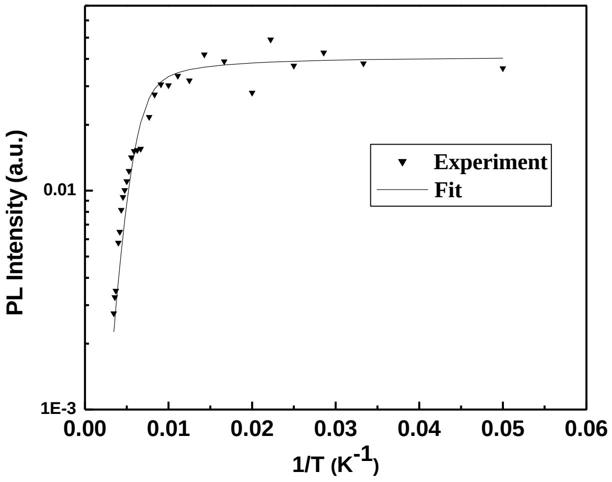


Figure 3: Temperature dependence of PL peak energy of sample (2). Empty triangle for P = 2W/cm^2, full square for P=6W/cm^2**.** The continuous lines show the linear variation of the PL peak energies for high temperature rang.

Figure 4: Temperature dependence of the integrated PL band for GaAs$_{1-x}$N$_x$ QW in presence of 2DEG sample for a laser power excitation P=6W/cm^2. Solid line is the fit using equation (1).

When the temperature increases to 45 K, the carriers are thermally activated to populate the GaAsN band state associated to a band tail. For T > 60 K, the carriers are thermally activated to depopulate the band tail. The same effect has been observed by Liang *et al.* [9] in GaInNAs/GaAs QW and attributed to the carriers bound to the localized nitrogen states with an exponential function distribution. In order to gain further insight into the mechanisms determining the thermal emission process, the integrated PL intensity, as a function of temperature was investigated and presented in Figure 4. The data can be fitted by an Arrhenius plot. Then the intensity is quenched drastically for a further increase in temperature. The activation energy at high temperatures about of 55 meV is determined from the slope of the temperature dependence of the PL intensity.

4. CONCLUSION

In summary, we have compared the nitrogen effect in the doped regime between undoped $GaAs_{1-x}N_x$ layer and $GaAs_{1-x}N_x$ QW in presence of a 2-dimension electron gas (2DEG). We have found that the low temperature photoluminescence spectra of $GaAs_{1-x}N_x$ is essentially governed by sharp lines attributed to the nitrogen localized states. In $GaAs_{1-x}N_x$ QW with (2DEG) the (LTPL) spectra shift to the high energy and the sharp lines disappear. The evolution of band gap as function of the temperature shows an ‘‘S-shape’’ behaviour attributed to the strong coupling between the nitrogen localized state and (2DEG) fundamental state at the same energy.

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