Optical transitions in GaAsN/GaAs single quantum well

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The alloys of Ga(In)NAs grown on GaAs have attracted increasing attention due to their interesting physical properties and potential applications in fabricating long wavelength optoelectronic devices. [1-4] In the optical studies, a strong dependence of the GaNAs band gap on N composition was reported and the exciton localization effect was revealed in the photoluminescence (PL) study. However, the nature of PL emission, as well as the band lineup in GaNAs/GaAs QWs, is not well established.

In this work we have investigated PL properties of a number of GaNAs/GaAs single quantum well (SQW) samples with different well widths and N compositions under various temperatures and excitation intensities. The low temperature PL was dominated by a near band exciton emission, along with the emission due to the localized states in the band tail. Fig.1 shows the 10K PL spectra of four $GaN_{0.015}As_{0.985}$/GaAs SQW samples with well-width of 3, 5, 8, and 15 nm, respectively. The dominant PL peak was attributed to the intrinsic exciton recombination involving electrons confined in GaNAs well and holes localized in the above-barrier states in the same GaNAs layer. It is a spatially-direct transition although the band lineup in GaNAs/GaAs QW could be type-II (discussed below). The intrinsic nature of PL emission was confirmed by the excitation dependence of PL. As shown in the inset of Fig.1, the integrated PL intensity can be well expressed as $I_{PL} \propto I_{exc}^{\alpha}$ with $\alpha = 1$.

The nature of the direct transition can be further revealed by the time-resolved PL measurements, using the combination of 2D streak camera and a femto-second Ti:sapphire laser. The measured decay time is around 1-2 ns, much shorter than the expected recombination process for the spatially indirect transition.

Further support to the assignment of the direct transition can be obtained from the analysis of the absorption line-shape derived from photo-voltage (PV) measurements. Under the assumption of type II band lineup, several possible absorption processes may be responsible for the absorption below the band gap of GaAs in GaNAs/GaAs SQW. Analyzing these absorption processes based on the joint density of states and the transition matrix, the near band transitions of spatially direct process within GaNAs layer have the largest absorption coefficient. While the band tail states and the spatially indirect transitions have a relatively smaller density of states and will not induce sharp absorption edges as observed in our experiment. We found that the absorption edges follow closely the PL data under temperatures above 100 K. Therefore we believe that the observed PL shares the same origin of the absorption. The observed deviation of PL peak from the expected absorption edge 100K was attributed to the exciton localization effect, as well discussed in GaAs/AlGaAs QWs..

In order to extract the information about the band offset from our PL data, we have calculated the exciton energy in GaNAs/GaAs QWs with different well width. In the calculation, the effective mass approximation was used and the influence of strain was taken into account. The band offset of ΔE_c was used as an adjustable parameter to fit the experimental results. We found that the calculation agrees well with the experimental data if a type II band lineup was assumed. The corresponding ΔE_c and ΔE_v were estimated to be 280 meV and -15 meV, respectively.

As well known that the band lineup is related to the atomic bond length at the interface. It depends on the strain of materials in the heterojunction. Therefore the band offset in the strained GaNAs/GaAs system is expected to be a function of the N composition. We have analyzed PL data obtained from another set of GaN_xAs_{1-x}/GaAs SQW samples, and studied the N composition dependence of ΔE_c, Q_c and the band-bowing coefficient (b). The results

are plotted in Fig.2. From the figure we can see that (1) N composition has less effect on Q_c, which can be expressed as $Q_c=X^{0.25}$ in the N composition range from 0.015 to 0.045. (2) ΔE_c depends strongly on N composition, but the slope is not as large as that reported in the literature[5, 6] (104 meV/N% vs 156-175 meV/N%). (3) The band bowing coefficient decreases with the increase of N composition, in agreement with the theoretical calculation of S-H.Wei.[2] It indicates that the non-linear relation between ΔE_c and N composition is more reasonable compared to the linear relation. The detailed discussion on the band-bowing coefficient and band offset will be given.

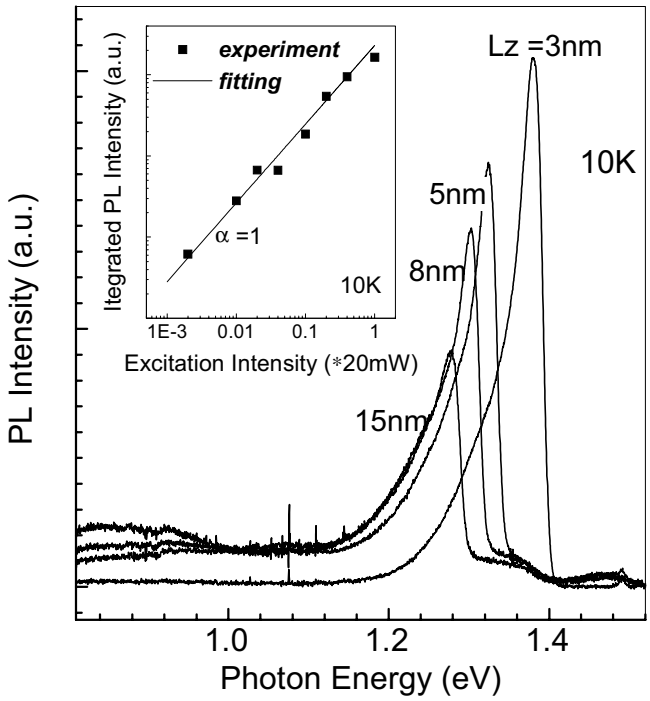

Fig.1.The LT-PL spectra of $GaN_{0.015}As_{0.985}$ /GaAs SQWs with different well width. The excitation intensity is about 30W/cm^2. The inset shows the integrated PL intensity as a function of excitation intensity.

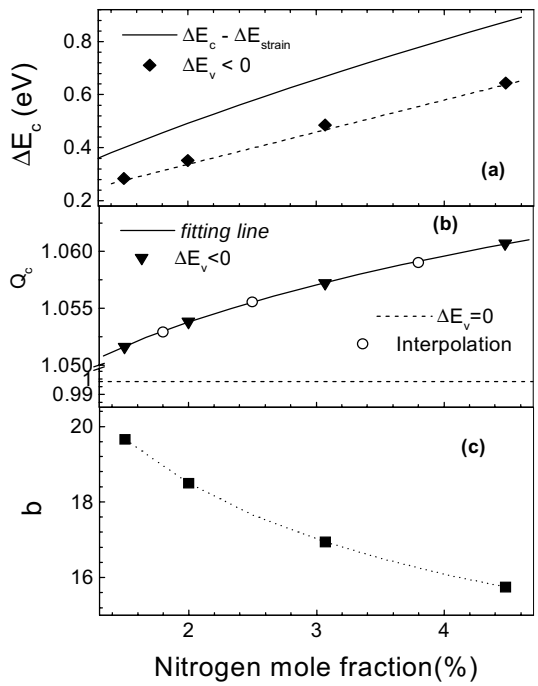

Fig.2. (a) Dependence of ΔE_c on nitrogen composition; (b) Q_c as a function of nitrogen composition; (c) The band bowing coefficient versus nitrogen composition.

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