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Polarized Photoluminescence From Nonpolar (11-20) (Ga,In)N Multi-Quantum-Wells

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Abstract. Nonpolar (11-20) (Ga,In)N multi-quantum wells have been studied by polarized, temperature dependent photoluminescence (PL). A non monotonic temperature dependence of the difference in PL peak energies recorded for E|| *c* or E⊥*c*, and of the polarization ratio is observed. We interpret these effects by first an orthorhombic distortion of the crystal and an increased electron-hole exchange energy relative to GaN. This increase is in agreement with calculations on the effect of confinement on the exciton exchange splitting.

Keywords: nonpolar, (11-20), (Ga,In)N, quantum wells, excitonic exchange energy
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INTRODUCTION

Nonpolar (11-20) GaN based emitters have attracted attention since they are expected to show improved quantum efficiencies. The active region of such devices is typically formed by (Ga,In)N quantum-wells. Hetero-epitaxially grown (11-20) GaN on r-sapphire shows strong polarization anisotropy of the photoluminescence (PL) due to the anisotropic in-plane strain that deforms the crystal to an orthorhombic structure and reduces its symmetry to C_{2v} [1]. The same kind of deformation can be expected for (Ga,In)N quantum wells for instance grown on bulk GaN [2]. We have investigated the optical properties of nonpolar (Ga,In)N/GaN quantum wells (MQW) grown by metal organic vapor phase epitaxy on a nonpolar GaN template, and compared the results to those obtained on nonpolar (11-20) GaN [1].

RESULTS AND DISCUSSION

The emission wavelength of the MQW is in the blue (2.76 eV). Polarized photoluminescence allows to access details in the temperature behavior of the QWs that cannot be seen in that clarity when standard ***c***-plane wells are studied. The PL measurements were carried out using the 244 nm line of an argon laser (I_{max}=20W/cm²). Two polarization orientations were chosen for the experiments: y (E⊥*c*) and z (E|| *c*).

Fig. 1 shows the peak energy of the MQW emission for the two polarizations as function of the temperature. First note that for light polarized perpendicular to *c*, a slight blue-shift is observed in the range of 10 to 40K, which is not observed for the counterpart polarization. This S-shape behavior is caused by localization. For this polarization (E⊥*c*) a Varshni fit of the peak energy leads to a low temperature (T=10K) delocalized exciton peak PL energy of 2.766±0.002 eV (E_{loc}=7-10 meV). An interpretation of this blue-shift can be the progressive transfer from $D^0X(\Gamma_2)$ to $A(\Gamma_2)$ levels. The observation of this blue-shift only for the y polarization can be interpreted as follows: the exciton bound to a neutral donor contains two electrons with antiparallel spins in

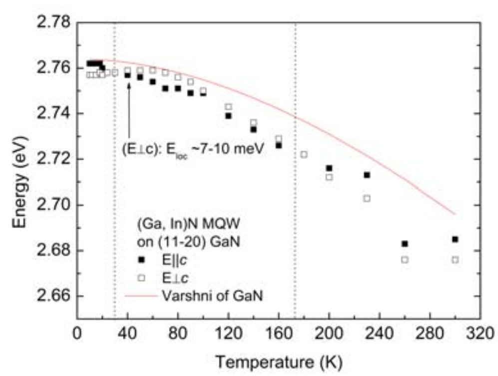

FIGURE 1. (Ga,In)N MQW peak energies as a function of temperature for both polarizations. The solid line corresponds to the variation with T of the GaN gap.

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the ground state. Then the D^0X symmetry is that of the top valence band (Γ_2) and therefore not allowed in polarization parallel to *c* (z).

In the case of the parallel polarization, the emission of the MQW peaks at an energy of 3.762±0.002 eV (10K), about 5 meV lower than the delocalized exciton energy for the counterpart polarization. This energetic separation is clearly resolved between 30 and 150 K.

We interpret these two peaks as PL emission originating from A(Γ_2) and A(Γ_1) excitons for polarization along the y and the z-direction respectively. In GaN it was shown that such splitting is due to an excitonic exchange energy of 0.6 meV [3]. Surprisingly we observe a splitting of 5 meV in the studied QWs.

Finally the evolution at higher temperatures (>180K) can be understood as population of higher energy levels, principally polarized along the *c*-direction (||*c*). This explains the crossing of the temperature dependence of the peak energies for polarizations ||*c* and ⊥*c*.

Fig. 2 shows the Arrhenius plot of the degree of polarization (ρ) determined from the integrated PL intensities from the nonpolar (Ga,In)N MQW, compared to that of the band-edge PL of nonpolar GaN [1]. At low temperature, ρ is much higher in GaN than in the MQW sample. Moreover, in the GaN case is observed a monotonic decrease of ρ with increasing T, whereas an increase-decrease of ρ occurs in the MQW case. Solid lines represent fits of these temperature dependences. In the case of nonpolar GaN, we find an activation energy of 35 meV for the decrease of ρ that corresponds to the thermal transfer of A excitons to higher energy C exciton levels [1].

The fitting of the Arrhenius plot of ρ in the (Ga,In)N MQW case is based on a 3 levels model. The first activation energy is about 5 meV. This is in agreement with the energetic separation of the PL maxima for the two polarizations. For the decrease of ρ (T>70K), the activation energy is 27 meV. This is obviously due to the population of higher exciton levels mainly polarized along the z direction (as in the GaN case) and confirms the already observed crossing of the peak energies at high temperatures.

In this 3 levels model, the energetic separation of 5 meV that manifests itself in the relative intensities and the peak energies of the PL spectra of nonpolar (Ga,In)N quantum-wells is the splitting between A(Γ_1) and A(Γ_2) exciton levels and polarized either along the z or the y axis. A third level B(Γ_1) is principally polarized along z and energetically higher than the A exciton levels by $E_2 \approx 27$ meV.

We calculated the **k=0** excitonic levels of bulk (Ga,In)N taking into account the x-ray measured strain and the excitonic exchange energy [4]. We find the

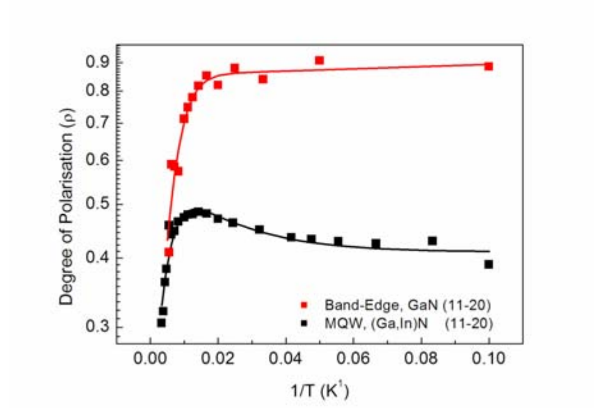

FIGURE 2. Arrhenius plots of the degree of polarization of the PL of the MQW, and of GaN for comparison.

ground state to be Γ_1(A), Γ_3(A) and Γ_4(A) (=2.8544–2.8549eV). But these excitons are either dark or with unfavorable optical selection rules. The lowest strongly allowed energy level that is visible in our geometry is of Γ_2(A) symmetry (polarized ⊥*c*). The energy of this exciton is 2.859 eV, (i.e. 5 meV higher than the ground state) with an oscillator strength of 90% in the y-direction. The calculated values are higher than the experimentally observed ones. Taking into account the energetic shift due to the confinement in the wells and the Stokes shift (≈170meV) that red-shifts the PL emission with respect to the gap of (Ga,In)N, leads to a good agreement. Calculations show that the next higher energy exciton states (B) are principally polarized along the z axis (|| *c*) and situated 26 meV higher than the ground Γ_1(A) level. We conclude that this thermal activation of ground state excitons with unfavorable optical selection rules towards strongly allowed ones, Γ_2(A) then Γ_1(B), is responsible for the increase then decrease of intensities i.e. degree of polarization.

This model is based on an excitonic exchange energy of 2.5 meV, strongly increased relative to the value known in GaN (0.6 meV) [3]. The physical origin of this large value is the quantum wells confinement, calculated following reference [5].

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