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Spectroscopic characterization of 1.3 μm GaInNAs quantum-well structures grown by metal-organic vapor phase epitaxy

H. D. Sun, a A. H. Clark, S. Calvez, and M. D. Dawson
Institute of Photonics, University of Strathclyde, 106 Rottenrow, Glasgow, G4 0NW, United Kingdom

Y. N. Qiu and J. M. Rorison
Centre for Communications Research, University of Bristol, Bristol, BS8 1TR, United Kingdom

K. S. Kim, T. Kim, and Y. J. Park
Samsung Advanced Institute of Technology, San 14-1, Nongseo-ri, Giheung-eup, Yongin-si, Gyeonggi-do, Republic of Korea

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We report optical studies of high-quality 1.3 μm strain-compensated GaInNAs/GaAs single-quantum-well structures grown by metalorganic vapor phase epitaxy. Photoluminescence excitation (PLE) spectroscopy shows clearly the electronic structure of the two-dimensional quantum well. The transition energies between quantized states of the electrons and holes are in agreement with theoretical calculations based on the band anti-crossing model in which the localized N states interact with the extended states in the conduction band. We also investigated the polarization properties of the luminescence by polarized edge-emission measurements. Luminescence bands with different polarization characters arising from the electron to heavy-hole and light-hole transitions, respectively, have been identified and verify the transition assignment observed in the PLE spectrum. © 2005 American Institute of Physics. [DOI: 10.1063/1.1868866]
The PL properties have been investigated in detail by measurements under conditions of varying excitation intensity and temperature. Figure 2(a) shows the normalized PL spectra of the sample under the excitation power of $I_0 = 84 \text{ mW}$ at various temperatures. The PL peak energy as a function of temperature is plotted in Fig. 3, in which Varshni empirical equation $E(T)=E(0) - aT^2/(T+\beta)$ which describes the temperature dependence of band gaps in semiconductors is also plotted. At high temperatures, the experimental PL energies agree very well with the Varshni equation. Least-squares fitting gives the fitting parameters $a$ and $\beta$ as $4.6 \times 10^{-4} \text{ eV/K}$ and $254.2$, respectively. The energy of the $e_1$-$hh_1$ transition observed in the PLE spectrum is denoted as $0.95 \text{ eV}$. With the assumption of the coupling strength to be $1.2\%$. With the assumption of the coupling strength to be $1.2\%$. With the assumption of the coupling strength to be $1.2\%$. With the assumption of the coupling strength to be $1.2\%$. With the assumption of the coupling strength to be $1.2\%$. With the assumption of the coupling strength to be $1.2\%$. With the assumption of the coupling strength to be $1.2\%$. With the assumption of the coupling strength to be $1.2\%$. With the assumption of the coupling strength to be $1.2\%$.

Figure 2(b) shows the PL spectra of the same sample measured at $14.8 \text{ K}$ with differing excitation intensity. It is noted that the main PL peak shifts to higher energy as the excitation intensity increases. A similar phenomenon has also been observed in MBE-grown GaInNAs/GaAs multiple quantum wells (MQWs), and can be attributed to the saturation effect of localized states.

A striking feature in Fig. 2(b) is that with the increase of the excitation intensity there appears another emission band on the higher energy side denoted by a solid circle. It is also noted in Fig. 3 that the relative intensity of this new band increases with temperature. Based on these features, this new emission band may be attributed to the $e_1$-$hh_1$ recombination. Although an earlier such observation was made by Kim et al. in GaInNAs/GaAs MQWs, no further supportive evidence for such an assignment has been given. Here we provide direct evidence by a polarized PL measurement.

As is well known, in a compressively strained QW the luminescence from the electron to heavy-hole transitions is
linearly polarized in the plane of layers, whereas the luminescence from electron to light-hole transitions is unpolarized. This polarization nature cannot be distinguished by traditional PL measurements in backscattering geometry because the polarization of the as-observed PL is always in the layer plane. However, this can be achieved by observing the linear polarization of luminescence from a cleaved edge of a QW sample. We have used the geometry shown in the inset of Fig. 4 to determine the origin of the QW luminescence. Figure 4 shows the PL spectra of the sample detected without polarization selection, and detected with polarization parallel or perpendicular to the layer plane. The spectra have been normalized with respect to the low-energy emission band. It is interesting to note the change of relative weight of the two emission bands with the polarization direction. Without the polarization (curve 2), there are obviously two emission bands. When the polarization direction is in the vertical, that is, layer plane direction (curve 3), the high-energy band has been largely suppressed and the PL spectrum is dominated by the lower-energy band. This result implies that the low-energy band is polarized in the layer plane, while the high-energy band has a component that is polarized perpendicular to the layer plane. This is further confirmed by the PL spectrum when the polarization is in the horizontal direction. In this case, the relative weight of the high-energy band to the low-energy band is even higher. It should be pointed out that, in principle, the e₁-h₁ transition should vanish in this case. In our experiment, we only observe the suppression of the PL band of e₁-h₁ transition rather than it vanishing. This can be attributed to two reasons: (1) the extinction coefficient of polarization is not 100%, and (2) the response of the monochromator is anisotropic about polarization, with the vertical direction higher than horizontal direction. Nevertheless, it is apparent that the high-energy band has a component perpendicular to the layer plane. This component can be obtained by subtracting curve 2 by curve 3, as has been shown as curve 4. The energy difference of the two emission bands is ~120 meV, which is in close consistency with the energy splitting between e₁-h₁ and e₁-h₁ transitions (123 meV) deduced by the PLE spectrum in Fig. 1. Therefore, the high-energy emission band can be safely assigned to e₁-h₁ transition.

In summary, high-quality 1.3 μm strain-compensated GaInNAs/GaAs QW samples grown by MOVPE have been studied in detail by optical measurements. The electronic structure has been investigated by PLE. The observed transition energies are consistent with theoretical calculations based on the BAC model. The polarization dependence of the PL observed in the direction of a cleaved edge has been used to identify the character of the optical transitions.

FIG. 4. Edge-emitted PL spectra of GaInNAs/GaAs SQW at 300 K. The experimental geometry is depicted in the inset. Curves 1 and 3 are measured with polarization perpendicular and in the layer plane. Curve 2 is the non-polarized PL. Curve 4 is the difference between curves 2 and 3, which represents the PL component polarized perpendicular to the layer plane (transition e₁-h₁).

$e_1 \rightarrow h_1$ transition.