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OPTICAL INVESTIGATION OF InGaAs-InP QUANTUM WELLS

D. MORONI, J.N. PATILLON, E.P. MENU, P. GENTRIC and J.P. ANDRÉ

LEP, 3, Avenue Descartes, F-94450 Limeil-Brévannes, France

ABSTRACT

The optical properties of In$_{0.53}$Ga$_{0.47}$As/InP quantum wells have been investigated using photoluminescence and photoluminescence excitation techniques. The materials were grown by atmospheric pressure metalorganic vapor phase epitaxy. The nature of the luminescence has been determined by studying the PL dependence on temperature and excitation power. It is found to be mainly due to exciton recombination at 2 K and above 100 K to free carrier recombination. The capture efficiency is almost independent of well thickness whereas the radiative efficiency, which is very good, increases when well width decreases.

INTRODUCTION

New high speed telecommunication systems require higher and higher performances for optoelectronic devices. The use of quantum size effect allows to obtain new devices such as superlattice avalanche photodiode or superlattice effective mass filter. Consequently, InGaAs-InP quantum wells (QW) and materials, suitable for 1.3 - 1.55 µm optical fiber telecommunication, have been grown by several growth techniques. Among them, atmospheric pressure MetalOrganic Vapor Phase Epitaxy (AP-MOVPE) has been used for the growth of ultra thin layers on large wafers. We present here some recent results concerning i) the origin of the luminescence, as investigated by photoluminescence (PL) and photoluminescence excitation (PLE) measurements and ii) the efficiency of the capture process and radiative recombinations observed in InGaAs/InP QW structure.

I - GROWTH PROCEDURE

The samples were grown at 580°C in a horizontal atmospheric pressure MOVPE reactor. The details of the growth technique have been described elsewhere. We have studied both multiple QW samples with a stack of QW's of different thicknesses (Frijlink's structure) and a series of single QW. InP and InGaAs bulk materials have been studied elsewhere. Their electrical characteristics are reported in Table I. The luminescence spectrum of the In$_{0.53}$Ga$_{0.47}$As alloy exhibits only one sharp line which has been attributed like Goetz to bound exciton recombinations (fig. 1). P.L.E. measurements show a Stokes shift of 4 meV.


Table I

<table>
<thead>
<tr>
<th></th>
<th>T = 77 K</th>
<th>T = 300 K</th>
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<tbody>
<tr>
<td></td>
<td>μ (cm/Vs)</td>
<td>μ (cm/Vs)</td>
</tr>
<tr>
<td>In0.53Ga0.47As</td>
<td>93 000</td>
<td>10 500</td>
</tr>
<tr>
<td>InP</td>
<td>137 000</td>
<td>5 200</td>
</tr>
</tbody>
</table>

II - PHOTOLUMINESCEENCE AND PHOTOLUMINESCEENCE EXCITATION

The description of the PL experimental set up is given elsewhere(6). For the PLE measurements, the luminescence was excited by light from a tungsten lamp dispersed by a 32 cm monochromator. Typical 4 K PL spectra for QW of different thicknesses are displayed figure 2. The nominal thicknesses (LW) have been estimated from the growth rate of thick layer to be 15-25-80-160 Å. In addition to the carrier confinement effect in the well, a luminescence broadening is observed as LW decreases: for thick wells (LW > 100 Å) the full width at half maximum (FWHM) (≈ 4.5 meV) is close to the bulk value (2 meV). As already reported by Razeghi et al(9), the fluctuations observed in the PL energies of QW's Frijlink series, while scanning the laser spot along a wafer, indicate alloy compositional fluctuations (0.45 < Ga < 0.47).

In figure 3, the 2 K PL and the 2 K PLE spectra of a 150 Å thick QW are shown. The luminescence line is narrow and a low energy tail is observed. The PLE spectrum displays a step-like shape due to the quasi 2 D joined states density with an excitonic peak at the beginning of each step. These peaks are fitted with a good accuracy with the theoretical QW transitions. The different QW transitions have been calculated using Bastard's model with the already determined (11,12) conduction band offset (220 meV), an In0.53Ga0.47As bandgap energy of 810 meV and the estimated nominal well thickness. These transitions have been reported (arrows) on fig. 3.

The Stokes shift has been seen to increase (5, 10 and 30 meV) as the well thickness decreases (200, 150 and 14 Å respectively). This might indicate that the excitons or carriers are bound to impurities or defects with a binding energy depending on well thickness. The 2 K PL behaviour has been studied as a function of
the excitation power. Below 10 W/cm², the luminescence peak remains at the same wavelength and its linewidth remains unchanged. This strongly indicates an excitonic nature of the luminescence. For higher excitation levels (> 10 W/cm²), the initial narrow luminescence line broadens and some shoulders appear on its high energy side. These shoulders correspond to the excited transitions (i.e. EILH1, E1H3, E2HH2...). Thus, with a high excitation level (resulting in a high carrier temperature), band to band luminescence can also be observed at 2 K.

PL measurement of nominally undoped single QW have been performed between 2 K and 300 K. In figure 4, the PL peak energy (a) and FWHM (b) of a 80 Å QW are plotted versus temperature. The shift to higher energy of the luminescence between 2 and 100 K has been explained by an ionization of the excitonic complex. Above 100 K, the PL peak energy follows the InGaAs bandgap thermal variation. Between 50 and 100 K, the FWHM is linear in temperature with a slope = 0.8 x kT (thermal energy) which is consistent with E1HH1 subband to subband radiative emission (G. Bastard's private communication). Finally at 300 K, the luminescence spectrum exhibits a main peak and some shoulders on its high energy side. Assuming that the main peak is due to E1HH1 recombination, the shoulders can be fitted with transitions involving excited levels. This overall behaviour clearly indicates that band to band transition is involved above 100 K.

III - CAPTURE PROCESS AND RADIATIVE EFFICIENCY

In figure 5, the integrated intensities of the PL spectra (IPL) for a set of single QW structures have been reported. The InP cap layer is 500 Å thick. The results, plotted versus the energy of the PL peak position, have been corrected according to the monochromator and the Ge detector response. For the 4880 Å excitation wavelength (excitation of the QW and essentially of the InP barrier) IPL from the narrowest well (15 Å) is found to be four times higher than from InGaAs thick well (160 Å) and ten times higher than IPL from bulk material. IPL involves a capture process by the well of photo-excited carriers from the cladding layers and the radiative efficiency. Theoretically, the capture decreases with decreasing well thickness.

In order to study radiative efficiency, we have performed excitation at 9100 Å (direct excitation of the QW without any absorption in the InP barrier). The luminescence intensity is much less intense than for indirect excitation owing to the weak absorption in the QW. For a QW, the absorption spectrum without excitonic effects, is a reproduction of the joined density of states : i.e. a series of steps arising at each allowed inter-subband transition. The intensity for a transition involving a heavy hole is three times more intense than a transition involving a light hole (13). Neglecting the exciton effect, the absorption coefficient at a given wavelength is hence proportional to N = (NH + 1/3 NL) where NH (NL) is the number of transition, En HHH (ENLHm) within the laser line and involving a heavy (light) hole level. In fig. 5, we have reported the luminescence intensity corrected according to the QW absorption IPL/N. The variation in IPL intensity versus PL energy is similar for both excitation wavelengths : capture seems to be independent of well thickness.
whereas the luminescence efficiency increases when well thickness decreases. In addition, the high efficiency of the process of capture by the QW of carriers from the adjacent InP layers is also proved by the fact that InP luminescence is completely quenched by the presence of the InGaAs QW in the InP layer by comparison with the same structure without the QW. The change in IPL is probably due to the decrease of radiative lifetime (with respect to non-radiative lifetime) with decreasing thickness. When well thickness decreases, the electron and hole wavefunctions overlap more and the radiative matrix element increases (14).

CONCLUSION

The optical properties of high quality InGaAs/InP single QW's grown by AP-MOVPE have been reported. Below 100 K, the luminescences behaviour versus excitation power and the Stokes shift indicates an excitonic luminescence nature. When the temperature increases, band to band luminescence is observed. The high efficiency of the process of capture by the quantum well of carriers from the adjacent InP layers does not seem to be a function of well thickness. The QW luminescence efficiency, higher than that of bulk, increases when well width decreases.

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