Study of the interface properties in InGaP/GaAs multi quantum wells grown by Low−Pressure MOVPE from liquid sources

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The Al−free InGaP/GaAs heterostructure is an interesting alternative to AlGaAs/GaAs system in a wide range of micro− and optoelectronic applications [1−3]. Nevertheless, the required ML−abruptness of both normal and inverse InGaP−GaAs interfaces is not obtainable, due to both the As/P intermixing and the In memory effect during the MOVPE growth process in which a standard gas switch sequence (GSS) is adopted [4]. As a consequence, unintentional InGaAsP intermediate layers are formed at the interfaces, so that the optical properties of the InGaP/GaAs quantum wells (QW's) are affected by unexpected, low−energy photoluminescence (PL) contributions [5], whereas either the hindrance of the QW emission or its line−shape width increasing, are expected.

In this work different lattice−matched InGaP/GaAs single and multi QW structures were grown on exact, S.I. (001)GaAs substrates at 600°C by low−pressure MOVPE, with the use of the TMGa, TMIn, TBAs and TBP precursors; GaAs quantum well thickness varied in the range 3−8 nm.

In order to enhance the direct interface abruptness, different GSS's were exploited for the interface growing, and few ML−thick GaAsP interlayers (IL), were inserted at the GaAs−on−InGaP interface [6]. Low−temperature photoluminescence (PL), High resolution X Ray Diffraction (HRXRD), Transmission Electron Microscopy (TEM) analysis and Photo Reflectance Spectroscopy (PR) measurements were performed on the grown heterostructures for correlating the interface properties and the width of the QW emission with the parameters of the growth method adopted. A model to predict the expected PL energy emission from the GaAs QW's, referred to an ideal square QW's with finite potential barriers, was employed to compare the theoretical and experimental results.

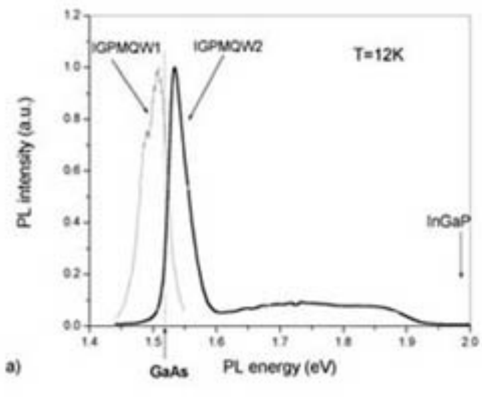

Fig. 1 a) *PL spectra of two QW structures having the same well width (8.3 nm): when the IL is absent (IGPMQW1, 20 stacked wells) the low energy emission is observed; when the IL is inserted (IGPMQW2, single well) the confinement energy is evidenced.*

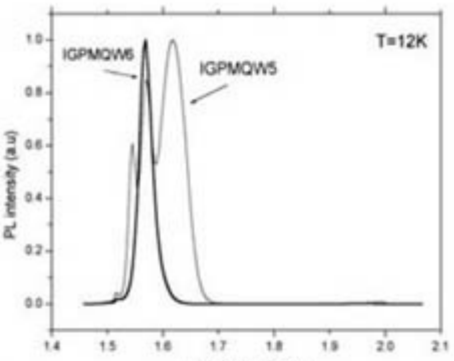

Fig 1b) *PL spectra of two QW structures where the IL's are inserted: in IGPMQW5, 3 wells with different widths (7.2, 5.5, 3.5 nm) and same GSS (GaAsP growth time = 4s) are present; in IGPMQW6, 3 wells having the same nominal width, but different IL's at the interfaces (GaAsP growth times of 1,3,5 s, respectively) are present.*

Figs. 1 show the PL spectra obtained from different MQW structures. It can be observed that when a standard GSS is employed, the low−energy emission at 1.508 eV (lower than the GaAs band gap) is present even when 20 MQW's are stacked and no trace of confinement emission can be detected, whereas, the insertion of the IL at the GaAs−on−InGaP interface evidences the emission from a single QW of the same width (Fig 1a). In all cases of Fig. 1b the GaAsP IL was inserted: three emission peaks, corresponding to the three stacked QW's with different thicknesses of sample IGPMQW5 are displayed and only one single emission peak is observed from sample IGPMQW6, in which three nominally identical QW's are stacked. Concerning this last sample, it has to be noted that, despite of the same growth time, the three QW's apparently show a slightly increasing width in the range 4.6−5.7 nm, as measured by TEM observations (not reported here). Moreover, the three QW's exhibit comparable interface morphologies, with the inverse interfaces sensibly worse than the direct ones; measurements of the structural properties (X−ray topography and cathodoluminescence analysis) did not evidence lattice defects related to dislocations. Such small width variations correspond to PL energy shifts which are within the experimental error.

Concerning the FWHM of the PL peaks, they turned out to be in the range of 20−58 meV, thus resulting still higher by a factor 3−4 with respect to similar structures grown by arsine and phosphine [7], but well comparable with others grown by TBAs and TBP [8]. We conclude that, as reported in the literature, the insertion of the IL has both the effect of evidencing the confinement effect and reducing the problems at the interfaces.

From the fitting of the experimental HRXRD curve in the case of sample IGPMQW2 it is possible to draw a few preliminary conclusions: (i) a substantial agreement between the nominal values of barrier composition and thickness and the measured ones has been found. (ii) the fitting suggested the existence of a relatively broad direct GaAs−on−InGaP interface, that is described by an effective 'interface' layer characterised by intermediate composition between that of the well and of the barrier. (iii) a significant improvement of the fitting seems to be achieved by considering a more complex situation at the well/lower−barrier interface than that expected from project data. The calculations are in progress. The comparison of the experimental results and theoretical model, concerning the transition energy of the GaAs QW's as a function of the well width, shows a good agreement.

In Fig. 2 the room temperature PR spectrum of the sample IGPMQW5 is reported; even at RT, we observed clear and well resolved spectral features we attributed to the signals obtained from wells of different width. The PR features of the GaAs band gap (buffer) dominate the low energy part of the spectrum. At higher energy the GaAs split−off structure as well as the incipit of the fundamental gap of the InGaP (lattice matched) spectral features can be observed. In the figure, solid arrows mark the energy positions of the ground state QW exciton transitions (1HH−1E) of the three QWs (QW1 = 1.46 eV; QW2 = 1.49 eV; QW3 = 1.545 eV) as obtained by simulating the optical response of the heterostructures with line shape models characteristic of exciton transitions in confined semiconductor systems [9, 10].

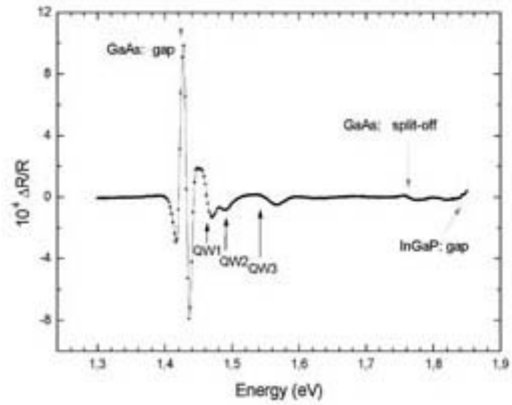

Fig. 2 *Room temperature PR spectrum of the sample IGPMQW5. Solid arrows mark the ground state exciton transitions of the three QWs (QW1 = 1.46 eV; QW2 = 1.49 eV; QW3 = 1.545 eV)*

Typical values of the broadening parameters observed for the PR features of the QW's ranged from 15 to 35 meV in the case of QW heterostructures containing GaAsP IL's. In contrast, these values were noted to roughly double in the weak and evanescent spectral features characterizing the heterostructures which have been grown without IL's.
An example of the effect of the IL on the optical properties of the InGaP/GaAs QWs is displayed in Fig. 3, where the room temperature spectrum of sample IGPMQW6 is shown: it appears that the differences observed by TEM in the width of the three nominally identical wells are real.

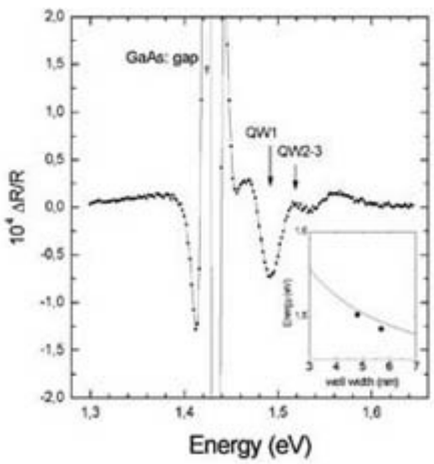

Fig. 3 *Room temperature PR spectrum of the sample IGPMQW6. Solid arrows indicate the QW related PR features. The structure at 1.485 eV (QW1) is due to the thickest well (5.7 nm). The broadened structure at an energy " 20 meV higher (QW2−3) is attributed to the two thinnest wells (4.6 and 4.9 nm). In the inset, the calculated behavior of the transition energy versus the well width (solid line) may be compared with the experimentally derived exciton transition energy (dots).*

As a matter of fact, solid arrows indicate the experimentally derived energy (at 1.485 eV) of the ground state exciton transition due to the thicker well and the energy location of a weak broadened PR feature (placed at an energy " 20 meV higher), which we assign to the optical response of the two thinner wells. Our attribution is consistent with the experimental observation that the broadening parameters of the spectral features of QWs containing GaAsP IL's of at least 4 sec are significantly smaller with respect to the ones characterizing QWs grown without interface IL's. Moreover, as shown in the inset of Fig. 5, the comparison of the calculated behavior of the

transition energy versus the well width (solid line) with the experimentally derived exciton transition energies (dots) seems to confirm the QW origin of both spectral features.
The above considerations might indicate that the different thicknesses and compositions of the GaAsP IL's inserted in sample IGPMQW6 play a crucial role in determining the effective well width; such an effect could not be evidenced by PL analysis. In addition, other preliminary analysis on our structures tend to confirm the observation that different interface terminations (As or P), along with In surface segregation and P/As mixing effects can sensibly shift the energy emission of such structures [11].
Fig. 4 reports the High−Resolution TEM image of the top GaAs well in sample IGPMQW6: it can be clearly seen that the inverse interface is of lower morphological quality and that the well width is not perfectly uniform along the growth plane.

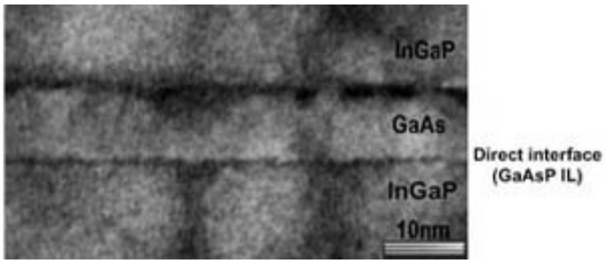

Fig. 4 *High Resolution TEM image of the top GaAs well in sample IGPMQW6 (thickness of 5.7 nm). The upper interface is clearly worse than the lower one.*

However, in order to support the hypothesis that different IL's modify the effective width of the QW's, a systematic study is on progress to investigate on the potential threshold effect of the IL thickness and its composition.
In conclusion, although it requires further analysis, the insertion of the GaAsP IL at the direct interface of our GaAs−InGaP MQW's grown by MOVPE from TBAs and TBP led to promising results, among which: a) the suppression of the anomalous PL emission at 1.508 eV, b) PL emission from the GaAs QWs, also confirmed by Photo Reflectance Spectroscopy measurements, which exhibits a good correlation with theoretical expectations, c) interface oscillations limited to ~1 nm; d) evidence of influence of the IL on the effective well width.
Future work will be therefore devoted to the optimization of the optical quality of our GaAs/InGaP MQW's, with particular attention to the improvement of the morphological quality of the inverse InGaP−on−GaAs interface, by the study of the effects of different GSS's.

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