Evolving Trends in Engineering and Technology *Online: 2014-10-01*
ISSN: 2349-915X, Vol. 2, pp 30-34
doi:10.18052/www.scipress.com/ETET.2.30

ELASTIC ENERGY IN INAS QUANTUM DOT-IN-A-WELL STRUCTURES

E. Velázquez-Lozada*, G. M. Camacho-González**, J. Quino-Cerdan***

* SEPI–ESIME Instituto Politécnico Nacional (IPN), Col. Lindavista, CP 07738, México DF
** ESIME-Zacatenco, IPN, Col. Lindavista, CP 07738. México DF
***UNITEC – Atizapán, Blvd. Calacoaya No.7, Edo. Méx., CP 52970, México
Corresponding Author: Erick Velázquez Lozada, Email: evlozada5@yahoo.com.mx

Keyword: Photoluminescence, Quantum dot (QD), Inhomogeneity, compressive strain

ABSTRACT

The photoluminescence (PL), its temperature dependence and X ray diffraction (XRD) have been studied in the symmetric In0.15Ga1-0.15As/GaAs quantum wells (QWs) with embedded InAs quantum dots (QDs), obtained with the variation of QD growth temperatures (470-535oC). The increase of QD growth temperatures is accompanied by the enlargement of QD lateral sizes (from 12 up to 28 nm) and by the shift non monotonically of PL peak positions. The fitting procedure has been applied on the base of Varshni analysis to the temperature dependences of PL peaks. The obtained Varshni parameters testify that in studied QD structures the process of In/Ga interdiffusion between QDs and capping/buffer layers takes place partially. However, this process cannot explain the difference in PL peak positions.

The XRD study has revealed the high intensity peaks at 2Θ= 31.6-31.8o (Kα1, Kα2) that correspond to the X ray diffraction of the Kα1 and Kα2 lines of Cu source from the (200) crystal planes of cubic GaAs. It was shown that the XRD peak is the superposition of the diffraction from the GaAs substrate and GaAs layers of quantum wells. The position of diffraction peaks related to the cubic GaAs substrate coincides with the very well know XRD data for the bulk GaAs. It means that the elastic strain in the GaAs substrate has been relaxed. At the same time the peak positions of the (200) diffraction peaks in GaAs epitaxial layers shift to the high angles in comparison with the bulk GaAs, testifying the compression strain in GaAs epitaxial layers. The minimum of elastic strain is detected in the structure with QDs grown at 510oC that manifests itself by the higher QD PL intensity and lower the PL peak energy.

RETRACTED

1. INTRODUCTION

Electronic devices based on quantum wells with InAs quantum dots (QDs) have been the subject of great interest due to the variety of their applications such as: semiconductor lasers for the optical fiber communications [1-3], infrared photo-detectors [4-6] and electronic memory devices [7,8]. For laser or photodiode applications the surface density of QDs has to be high [9-14]. It was shown earlier [3] that the InAs QD density can be increased essentially if the QDs are grown inside of GaAs/capping In0.15Ga0.85As/buffer In0.15Ga0.85As/GaAs quantum wells [3]. But even for the optimal QD growth parameters and the capping/buffer layer compositions, the InAs QD structures are characterized by photoluminescence (PL) inhomogeneity along the wafers [15-18]. The technology of growth of InAs QD structures has become more reliable enabling systematic studies their physical properties. In this paper we try to understand the physical reasons of emission inhomogeneity of InAs QDs coupled with symmetric In0.15Ga0.85As/GaAs quantum wells (QWs) at the variation of the density and the size of InAs QDs grown at different temperatures.

2. EXPERIMENTAL CONDITIONS

A set of samples was prepared using molecular beam epitaxy on (100) oriented 2"diameter semi-insulating GaAs substrates (Fig.1). InAs quantum dots (QDs) were grown inside of the symmetric In0.15Ga0.85As/GaAs quantum wells (the same In concentrations in buffer and capping

In0.15Ga0.85As layers) at five QD growth temperatures 470 (#1), 490 (#2), 510(#3) 525 (#4) and 535 (#5)oC during the deposition of InAs active regions and InGaAs wells [12,14]. The QD size increases from 12 to 28 nm and the QD density decreases from 1.1 1011 down to 1.3 1010 cm-2 versus QD growth temperatures [19]. Photoluminescence spectra were measured in the temperature range of 10-300 K using the excitation by the 536 nm line of a solid state laser model V-5 COHERENT Verdi at an excitation power density from the range of 300 W/cm2. PL spectra were dispersed by a SPEX 500 M spectrometer with a Ge detector. The X-ray diffraction (XRD) experiments were made using the XRD equipment model of D-8 advanced (Bruker Co) with Kα1 line from the Cu source (λ=1.5406 A).

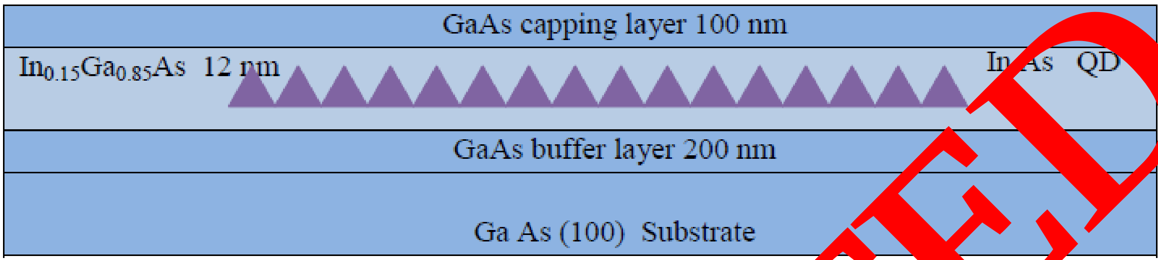

Fig.1 The design of QD structures

3. EXPERIMENTAL RESULTS AND DISCUSSION

I Typical PL spectra of the structure #3 measured at different temperatures at the excitation light density of 300 W/cm2 are shown in Fig.2.

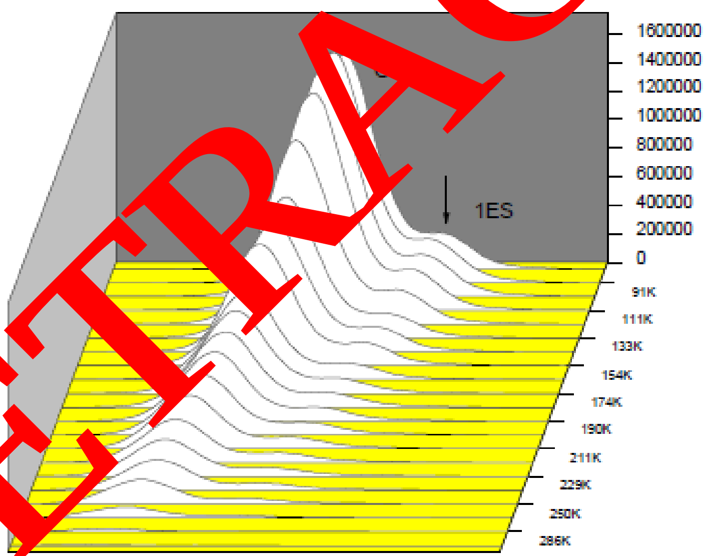

Fig. 2. Typical PL spectra measured at different temperatures for the DWELL structure #3 at the excitation density of 300 W/cm2.

Two PL bands appear due to the recombination of excitons localized at a ground state (GS) and at an excited state (1ES) in QDs (Fig.2). The excitations light density of 300 W/cm2 is chosen for prevent the influence of ES emission on the GS PL intensity (Fig.2). The QD diameters in studied structures increase monotonically from 12 up to 28 nm with the rise of QD growth temperatures from 470 up to 535 oC. Thus it is possible to expect that the PL peak position in QDs has to shift monotonically to low energy. Fig.3 presents the PL peak positions in the structures (#1- #5) measured at 10-160 K for GS PL bands. As it is clear the variation of PL peak positions with enlargement of QD growth temperatures and QD diameters is none monotonical.

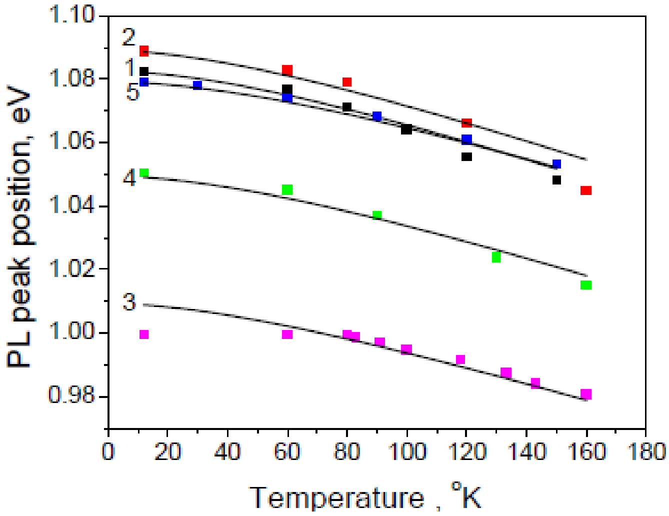

Fig. 3. The variation of PL peak positions versus temperatures. The lines present the Varshni fitting results: 1- #1, 2- #2, 3- #3, 4-#4 and 5 - #5.

Note that lower PL peak energy corresponds to higher PL intensity (Fig. 4). Two reasons can explain the variation non monotonically of PL peak positions and the PL intensity in studied QD structures: (i) the change of QD composition due to the Ga/In inter diffusion between InAs QDs and capping/buffer In0.15 Ga0.85As QW layers or (ii) the different levels of elastic strain in QD structures due to the difference in QD densities and sizes. To distinguish these two reasons PL spectra at different temperatures in the range 10-160 K have been studied. The variation of PL peak positions of ground state PL bands in all studied QD structures is presented in Fig. 3. PL peaks shift to low energy with increasing temperature due to the optical gap shrinkage. The lines in Fig.3 present the fitting results analyzed on the base of Varshni relation that presents the energy gap variation with temperature as [20]:

$$E(T) = E_o - \frac{aT^2}{T+b} \quad (1)$$

The comparison of fitting parameters with the variation of energy band gap versus temperature in the bulk InAs crystal (Table 1) has revealed that in studied QD structures the fitting parameter "a" and „b" in the temperature range 10-160 K are very close to their values for the bulk InAs crystal (Table 1) in the QD structure #3. But in other QD structures the fitting parameter "a" and „b" are different a little bit from the values in the bulk InAs crystal (Table 1). The last fact testifies that the process of Ga/In inter diffusion takes place in these QD structures. Note that the process of Ga/In inter diffusion in studied structures passes non monotonically versus QD growth temperature. It means that not only temperature but some other factors are essential as well.

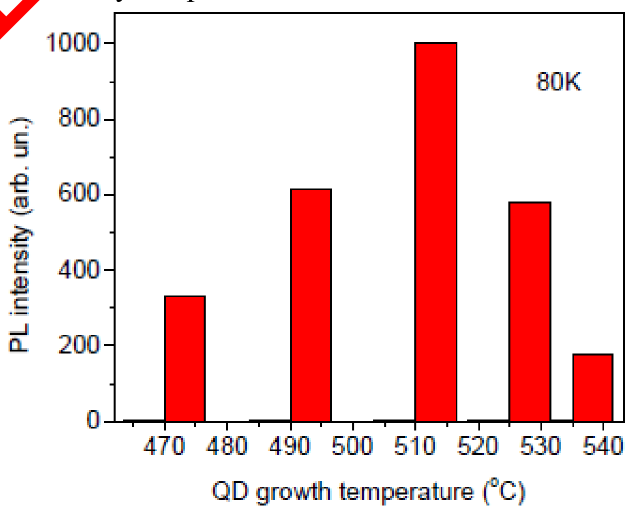

Fig. 4. Histogram of average PL peak intensities in studied structures

Figures 5 presents the superposition of XRD peaks related to the diffraction of $K_{\alpha1}$ and $K_{\alpha2}$ lines of the X-ray Cu source from the (200) crystal planes of cubic GaAs substrate and GaAs layers in studied $In_{0.15}Ga_{0.85}As$ /GaAs QWs. As one can see in figure 5 the peaks (31.69-31.70° and 31.77-31.78°) related to the diffraction of $K_{\alpha1}$ and $K_{\alpha2}$ lines from the (200) crystal planes in GaAs QW layers with QDs grown at 490-525 °C locate more close to the corresponding XRD peaks (31.63° and 31.71° [22]) of the bulk cubic GaAs (Fig.5).

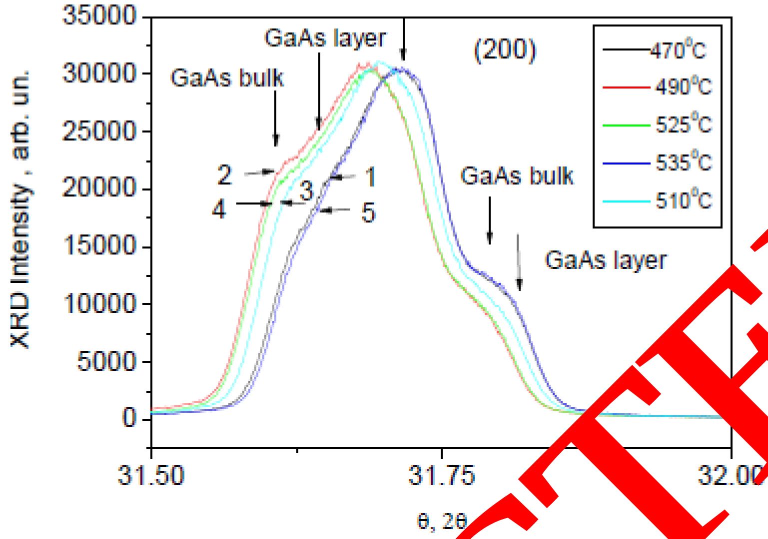

Fig. 5. XRD peaks related to the diffraction of $K_{\alpha1}$ and $K_{\alpha2}$ lines of the X-ray Cu source from the (200) crystal planes of the GaAs substrate and GaAs QW layers in studied structures: 1- #1, 2- #2, 3- #3, 4-#4 and 5- #5.

4. CONCLUSION

The last fact indicates that the level of elastic strain in $In_{0.15}Ga_{0.85}As$/GaAs QWs of #2, #3, #4 is smaller than in the structures #1 and #5. In QD structures with QDs grown at 470 and 535 °C the corresponding XRD peaks shift to higher angles (31.72° for $K_{\alpha1}$ and 31.80° for $K_{\alpha2}$) testifying the higher levels of compressive strain in the QWs of structures #1 and #5 (Fig.5). The lowest integrated PL intensities have been detected in the QD structures #1 and #5, apparently, due to the high concentration of nonradiative (NR) defects. The high level of elastic strain enhances, apparently, partial stress relaxation in the QD structures #1 and #5 that accompanies by the appearance of NR defects.

REFERENCES

[1]. D. Bimberg, M. Grundman, N. N. Ledentsov, Quantum Dot Heterostructures, Ed. Wiley & Sons (2001) 328.

[2] D. Bimberg, M. Grundmann, F. Heinrichsdorff, N.N. Ledentsov V.M. Ustinov, A.E. Zhukov, A.R. Kovsh, M.V. Maximov, Y.M. Shernyakov, B.V. Volovik, A.F. Tsatsul'nikov, P.S. Kop'ev, Zh.I. Alferov, Thin Solid Films **367**, 235 (2000).

[3]. G. T. Liu, A. Stintz, H. Li, K. J. Malloy and L. F. Lester, Electron Lett. **35**, 1163 (1999).

[4] A. Amtout, S. Raghavan, P. Rotella, G. von Winckel, A. Stinz, S. Krishna, J. Appl. Phys. **96**, 3782 (2004).

[5] R.S. Attaluri, J. Shao, K.T. Posani, S.J. Lee, J.S. Brown, A. Stintz, S. Krishna, J. Vac. Sci. Technol. B **25**, 1186 (2007).

[6] T.V. Torchinskaya, Opto-Electronics Review **6** (2), 121 (1998).

[7] D. Haft, R. J. Warburton, K. Karrai, S. Huant, G. Medeiros-Ribeiro, J. M. Garsia, W. Schoenfeld, P. M. Petroff, Appl. Phys. Lett. **78,** 2946 (2001).

[8] M. Geller, A. Marent, T. Nowozin, D. Feise, K. Potschke, N. Akcay, N. Oncana, D. Bimberg, Physica E **40**, 1811 (2008).

[9] I. Kamiya, I. Tanaka, K. Tanaka, F. Yamada, Y. Shinozuka, and H. Sakaki: Physica E **13,** 131 (2002).
[10] K. Karrai, R. J. Warburton, C. Schulhauser, A. Hogele, B. Urbaszek, E. J. McGhee, A. O. Govorov, J. M. Garcia, B. D. Gerardot, and P. M. Petroff: Nature **427,** 135 (2004).
[11] R. M. Thompson, R. M. Stevenson, A. J. Shields, I. Farrer, C. J. Lovo, D. A. Ritchie, M. L. Leadbeater, and M. Pepper: Phys. Rev. B **64,** 201302 (2001).
[12] A. Stintz, G. T. Liu, L. Gray, R. Spillers, S. M. Delgado, K. J. Malloy, J. Vac. Sci. Tech. B **18** (3), 1496 (2000).
[13] S.P. Ryu, N.K. Cho, J.Y. Lim, H.J. Lee, W.J. Choi, J.D. Song, J.I. Lee and Y.T. Lee Japan. J. Appl. Phys. **48**, 095506 (2009).
[14] T. V. Torchynska, J. Appl. Phys. **104** (7), 074315 (2008).
[15] T. V. Torchynska, J. L. Casas Espinola, L. V. Borkovska, S. Ostapenko, M. Dybiec, O. Polupan, N. O. Korsunska, A. Stintz, P. G. Eliseev, K. J. Malloy, J. Appl. Phys. **101**, 024323 (2007).
[16] M. Dybiec, S. Ostapenko, T. V. Torchynska, E.Velazquez Lozada, Appl. Phys. Lett. **84**, 5165 (2004).
[17] M. Dybiec, S. Ostapenko, T. V. Torchynska, E.Velazquez Lozada, P. G. Eliseev, A. Stintz, K. J. Malloy, Phys. Stat. Sol. (c) **2**, 2951 (2005).
[18] M. Dybiec, L. Borkovska, S. Ostapenko, T. V. Torchynska, J. L. Casas Espinola, A. Stintz and K. J. Malloy, Applied Surface Science **252,** 5542 (2006).
[19] T.V. Torchynska, A. Stintz, J. Applied Physics **108,** 2, 024316 (2010).
[20] Y. P. Varshni, Physica **34,** 149 (1967).
[21] A. Landolt-Boernstein, Numerical Data and Functional Relationship, in: Science and Technology, **22** (Springer, Berlin, (1987) p. 118.
[22] C.Y. Yeh, Z.W. Lu, S. Froyen and A. Zunger, Phys. Rev. B **46,** 10086 (1992).