# PHOTOLUMINESCENCE STUDY OF INGAAS/GAAS QUANTUM DOTS

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**Abstract**

We investigate the photoluminescence properties of 10 layers InGaAs/GaAs Quantum dots embedded in the p-i-n structure. Structure is grown in MOCVD at low temperature. InGaAs/GaAs Quantum dots are potentially an important for the new generation of optoelectronic devices, especially for lasers, photo detectors and possibly for third generation solar cells. The photoluminescence (PL) spectra at variable temperature shows some special features. The measured PL results at room temperature show a prominent peak at 1176nm and very weak shoulder at near to 190 nm. This shoulder appears below the temperature 70K and become prominent at 13K. These two peaks are attributed to InGaAs QDs and to the InGaAs wetting layer respectively. Intensity of PL signal from room temperature to 250K increases very slowly and than its change very rapidly upto 100K and then look constant but in sinusoidal up and down upto 13K.

**Keywords:** Quantum Dots, InGaAs/GaAs, Photoluminescence, Electron temperature.

## 1. INTRODUCTION

Experimental effort to cross the recorded efficiency (42%) of GaAs based solar cell is an active area of research in the field of material and device sciences [1, 2]. Introduction of intermediate bands in the host material is one of the attractive extensions in fields of solar cells research. Theoretical work in this area is predicting more than 20% increase in efficiency of GaAs based intermediate band solar cells (IBSC) [3-4]. That includes quantum dot solar cell (QDSC), coupled quantum dot solar cell (CQDSC), strain compensated quantum dot solar cell (SC-QDSC), quantum well solar cell (QWSC), quantum dot-in-well solar cell (DWELL-SC) etc. Intermediate band introduced by these structures provide to perform a single high energy incident photon to convert its energy in creation of multiple electron-hole pair (excitons) or photons which have the energy less that bandgap energy can also transfer their energy to the intermediate band to create the electron-hole pairs that lead to increase in photocurrent and quantum efficiency [5].

Intermediate band of quantum dots grown by MBE in the Stranski-Krastanov mode shows very high symmetric morphology of QDs with comparison to MOCVD grown the Stranski-Krastanov mode QDs. According to industrial point of view toward mass production and cost effective, material grown by MOCVD is main focal technique towards realization [5].

### 1.1 MATERIAL SYSTEM, STRUCTURE AND GROWTH

GaAs has a direct band gap with band gap energy 1.42 eV, that is very near to the optimum energy of solar spectrum. Nearly all high efficiency solar cells are based on III-V or GaAs and its related compounds. Luque et.al. theoretically calculated and proposed the GaAs as base material for the highest efficiency intermediate band solar cell (IBSC) [3, 6]. Intermediate band in the form of quantum structuring in host material can be easily produced by metallorganic chemical vapor deposition (MOCVD) or molecular beam epitaxy (MBE). Intermediate band of quantum dots grown by MBE in the Stranski-Krastanov mode shows fine symmetric vertical alignment of QDs [7] with comparison to MOCVD grown the Stranski-Krastanov mode QDs. According to industrial point of view toward mass production and cost effective, material grown by MOCVD is main focal technique towards realization [8].

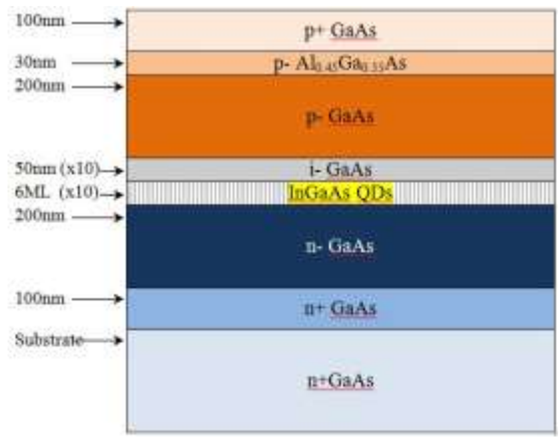
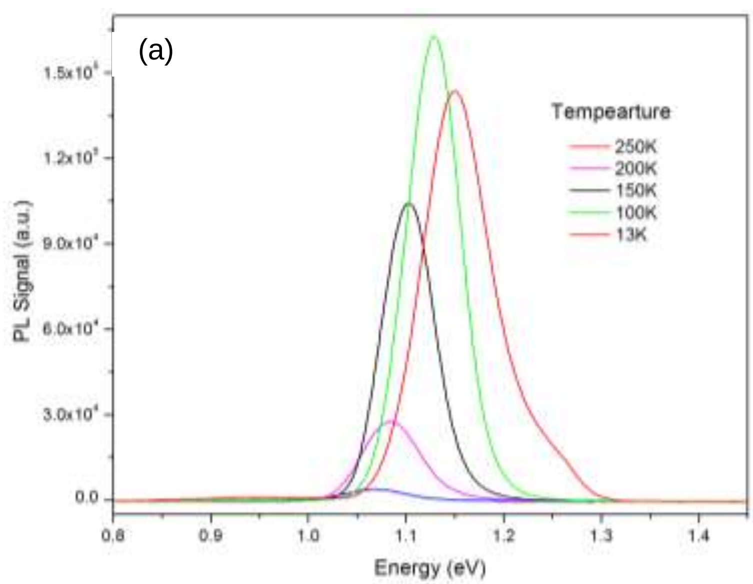



**Fig. 1** Schematic diagram of InGaAs/GaAs quantum dots sample structure.

Fig. 1 shows p-i-n structure having intermediate band solar cell of 10-layers quantum dots. Quantum Dots are grown in i-region of p-i-n diode in AIX-200 horizontal Axitron MOCVD reactor using Stranski–Kranstanov technique. All epitaxial layers were grown at low pressure 100 mbar and at temperature range of 550 to 650ºC for different layers on (001) oriented 3.5 inch n+-GaAs substrate as shown in the Fig. 1. Metalorganic gases Trimethylgallium (TMGa) and trimethylindium (TMIn) are used as gallium and indium sources and Arsine gas (AsH) for arsenic. Quantum structures of ten layers, each one is 6 monolayers (ML) for quantum dots, All of these ten layers are separated by 50 nm undoped GaAs epilayers act as barrier layer and sandwich between the 200nm n-GaAs and p-GaAs epilayers to form a p-i-n device structure.

### 1.2 PHOTOLUMINESCENCE OF InGaAs/GaAs QUANTUM DOTS

The room temperature photoluminescence (PL) spectra were taken by DWoptron Photoluminescence system with 0.32m monochromator, thermoelectric cool 2 color (Si/PbS) photo detector and Stanford 510 lock-in amplifier using 532nm excitation laser source. This PL system is controlled by DWoptron software “Monoscan”, for post-acquisition data analysis, ASCII files are used in commercially available software.



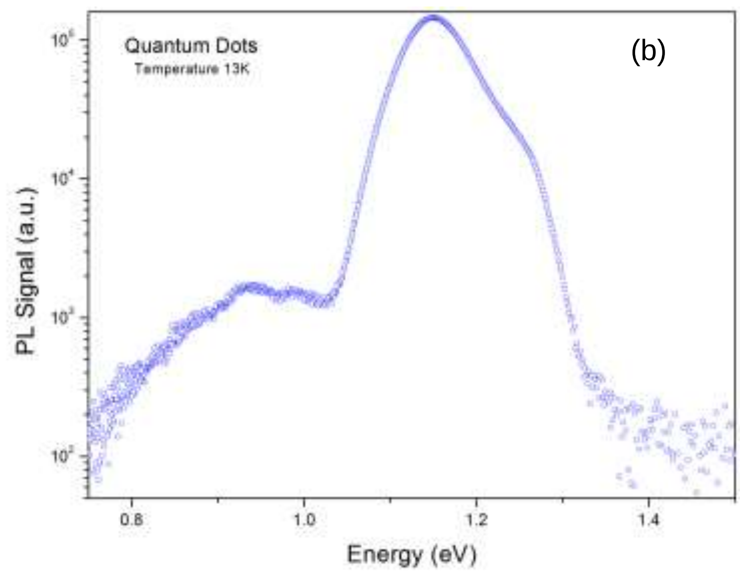



Fig. 2 (a) PL spectra of InGaAs/GaAs quantum dots at different temperatures and (b) shows single spectrum taken on temperature at 13K for analysis.

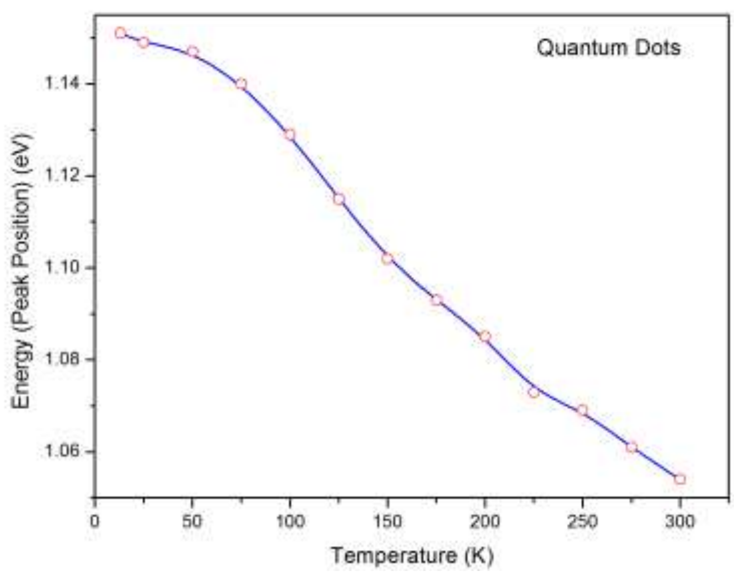



Fig. 3 Temperature dependent peak postion of luminsence from InGaAs/GaAs quantum dots.

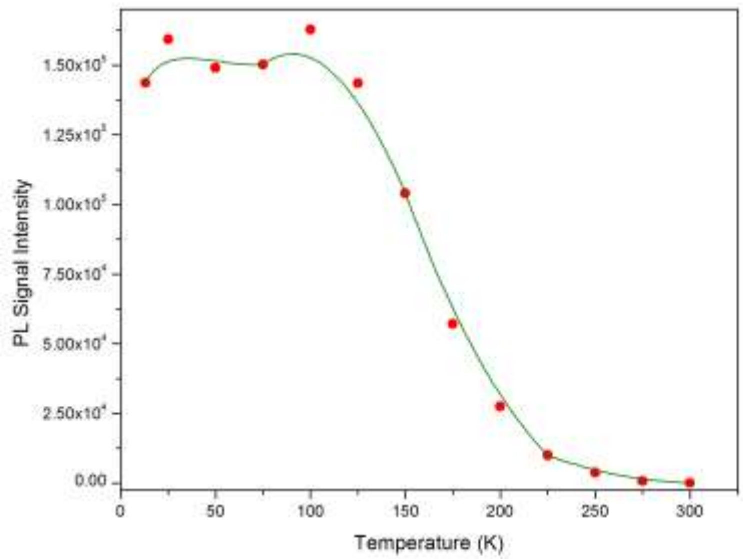



Fig. 4 Temperature dependent PL peak intensity from InGaAs/GaAs quantum dots.

## 2. RESULTS AND DISCUSSION

Fig. 1 shows the schematic layer by layer stack of different materials, in i-region of p-i-n structured material contained 10 layers of self-assembled quantum dots. Fig. 2 (a) shows temperature dependent PL spectra of the InGaAs/GaAs quantum dots sample their peaks separated from 1.06 to 1.148 eV of highest temperature 250K and 13K lowest temperature respectively. It shows that the PL peaks have blue shifts upto 88 meV in temperature range13 to 250K. It is also reveal from spectrum taken on temperature 13K that a shoulder is prominently appears on higher energy tail of the PL spectra. Fig. 2(b) is on semilog scale more clearly shows shoulder feature in the spectrum this peak ~ 1.25eV corresponds to transitions from states within the quantum dots and/or the wetting layer. These PL spectra also indicate an exponential dependence on excess photon energy on the high energy tail with a characteristic electron temperature ($T_e$). Shah *et al.* showed a following relation that closly obey the features of high energy tail of photoluminsecence spectra [9].

$$I_{PL} \propto D_j e^{-\frac{(\hbar\omega - E_g)}{k_B T_e}} \qquad (1)$$

Where $T_e$ is the electron temperature, $k_B$ is the Boltzmann constant, $E_g$ is the energy band gap, $\hbar\omega$ is the excess photon energy $D_j = \frac{1}{2\pi^2}(2\mu\hbar^2)^{3/2}\sqrt{\hbar\omega - E_g}$ is the joint density of states and $\frac{1}{\mu} = \frac{1}{m_e^*} + \frac{1}{m_h^*}$ is the reduced effective mass. Our calculation on the basis of above relation shows a very high temperature of electron ($T_e$) ~ 1065.5K in quantum dot and ~ 417.0K in the weting layer. These high temperature electrons will be responsible for the extraordinary aggitations and collissions and that will reducing the mean freepath of the electron. We thing this is the major case of experimental relaztion of intermediate band solar cells (IBSC) and especially in case of quantum dots solar cells (QDSC). So thermalization of these high temperature electrons is necessary to achieve the theoretically calculated solar energy to electricity conversion efficiency.

Fig. 3 is the veriation of PL peak energy / band gap of the quantum dots this beavior is usuall as allready reported [10]. Fig. 4 shows dependence of PL signal intensity on the sample temperature. Intensity of PL signal from room temperature to 250K increases very slowly and then its change very rapidly upto 100K and then look constant but in sinusoidal up and down fashion upto 13K. from 100K to 13K variation of intensity is looks like due to the rising of shoulder peak at higher energy end of the spectra as shown in fig.1. Because, PL intensity is proportional to the distribution of carriers (electrons and holes).

## 3. CONCLUSIONS

We have demonstrated with the help of temperature dependence photoluminescence that can be used to study of carrier behavior inside the quantum structure like quantum dots. Materials used for the fabrication of Intermediate band solar cells (IBSC) in the form of p-i-n structure showed very high electron temperature that is main hindrance for optically generated charge carries to reach the collector of device. We think to realized the 63.2% conversion efficiency there must be incorporation of some material or design of IBSC structure that thermlizied the electron temperature to some optimized level.

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## REFERENCES

[1] Mlinar, V., *Engineered nanomaterials for solar energy conversion.* Nanotechnology, 2013. **24**(4): p. 042001.

[2] Luque, A. and A. Marti, *The intermediate band solar cell: progress toward the realization of an attractive concept.* Adv Mater, 2010. **22**(2): p. 160-74.

[3] Brown, A.S. and M.A. Green, *Intermediate band solar cell with many bands: Ideal performance.* Journal of Applied Physics, 2003. **94**(9): p. 6150-6158.

[4] Luque, A. and A. Martí, *Increasing the Efficiency of Ideal Solar Cells by Photon Induced Transitions at Intermediate Levels.* Physical Review Letters, 1997. **78**(26): p. 5014-5017.

[5] Marti, A., et al., *Novel semiconductor solar cell structures: The quantum dot intermediate band solar cell.* Thin Solid Films, 2006. **511**: p. 638-644.

[6] Green, M.A., et al., *Solar cell efficiency tables (version 33).* Progress in Photovoltaics: Research and Applications, 2009. **17**(1): p. 85-94.

[7] Luque, A., et al., *FULLSPECTRUM: a new PV wave making more efficient use of the solar spectrum.* Solar Energy Materials and Solar Cells, 2005. **87**(1-4): p. 467-479.

[8] Pelzel, R., *A Comparison of MOVPE and MBE Growth Technologies for III-V Epitaxial Structures* in *CS MANTECH Conference*. 2013: New Orleans, Louisiana, USA. p. 105-108.

[9]. Shah, J., et al., *Energy-loss rates for hot electrons and holes in GaAs quantum wells.* Phys Rev Lett, 1985. **54**(18): p. 2045-2048.

[10]. Singh, S.D., et al., *Temperature dependence of the lowest excitonic transition for an InAs ultrathin quantum well.* Journal of Applied Physics, 2006. **99**(6): p. 063517