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# On the Band Gaps and Band Offsets of Type I Multiple Quantum Well (MQW) System

J.S.A. Adelabu, J.O. Ajayi and A.O. Awodugba
Department of Physics, University of Abuja, FCT, Abuja, Nigeria

**Abstract:** Measurements of Optical Absorption (OA) and Photoluminescence (PL) have been carried out on type I Multiple Quantum Well (MQW) system of GaAs-AlGaAs grown by Molecular Beam Epitaxy (MBE). An attempt has been made to compare exciton peak obtained for both heavy hole and light hole at band offset of 70/30 at different temperatures (Theory and Experiment). It is revealed from the investigation that the confinement energies of the particles increase with increase in the height of the potential barrier fro electron and decrease with increase in height of the potential barrier for light hole and heavy hole. The increase is more pronounced in the case of the light hole.

**Key words:** Optical absorbtion, photoluminescence, exciton peak, confinement, potential barrier

## INTRODUCTION

The band-gap in between valence and conduction bands is of key interest for all semi-conducting properties. Infact, many of the interesting properties of Multiple Quantum Well (MQW) structures are determined quantitatively by difference in the band gap $\Delta E_g$ of the two components forming the MQW system as shown in Fig. 1 and the band offsets $\Delta E_c$ and $\Delta e_v$ (which is the fractional distribution of the band gap difference between the conduction band and the valence well established in the case of GaAs-AlGaAs, the quantities, $\Delta E_c$ and $\Delta E_v$ have witnessed a great deal of controversy with values ranging 57 and 85% for the former and 43 and 15% for the latter. Nevertheless, $\Delta E_g$ for a given aluminium composition exhibits a range of values in the literature and thus even this quantity cannot be assumed to be beyond disput. For example, Casey and Panish (1978) have reported that the energy gap of $Al_xGa_{xz}As$ is a given function of x. This will consequently lead to varying $\Delta E_g$ even for the same value of x, there will still be some uncertainties in the $\Delta e_g$ since the control of the shutter cannot be exact.

The most direct approach to the problem has been via optical techniques, notably via measurement of optical absorption (Dingle *et al*., 1974; Dingle, 1975) and luminescence (Dawson *et al*., 1985; Miller *et al*., 1980, 1981, 1984; Rogers and Nicholas, 1985; Weisbuch *et al*., 1981). The early research of Dingle *et al*. (1974) gave the value of the parameter as 85/15 while the lowest figure of 57/43 was obtained by Miller *et al*. (1984) using parabolically shaped quantum wells. Many other studies, among which are those by Adelabu and Abdullahi (1987), Dawson *et al*. (1985) and Rogers and Nicholas (1985) tend to favour a figure near the arithmetic mean of 70/30 for the $\Delta E_c/\Delta E_v$.

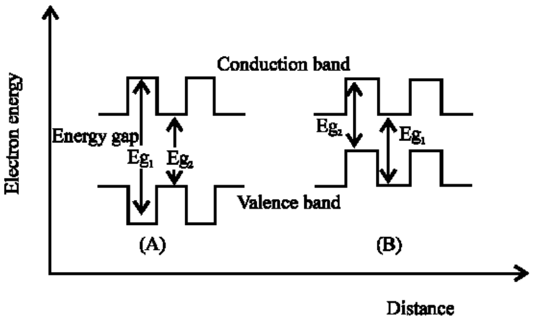

Fig. 1: Periodic Potential for (A) type 1 MQW and (B) type II MQW

Another variable is the theoretical model used to interprete the optical data (Adelabu, 1993), early interpretations (Dingle *et al*., 1974; Dingle, 1975 and a host of other literature) were based on the particle in a box model. This is now superceded by such models as the envelop function model (Bastard, 1981), the K.P. Model (Bastard, 1982; Bastard *et al*., 1984) or the fight-building model (Schulman and McGill, 1979), (Schulman and Chang, 1983, 1985) which takes into account light and heavy hole mixing. While valence band effects may be quite complex, they do not have a large effect on optical absorption and luminescence. Hence, a straight forward envelop function model applied to electrons, light hole and heavy holes may be regarded as adequate to interprete optical spectra, provided non-parabolicity is included.

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**Corresponding Author:** J.O. Ajayi, Department of Pure and Applied Physics, Ladoke Akintola University of Technology, P.M.B. 4000, Ogbomoso, Oyo State, Nigeria

It is the mission of this research to present the results of investigations of optical absorption and luminescence spectra measurements and their interpretations using the envelop function model including non-parabolicity.

## MATERIALS AND METHODS

**Experimental measurements:** Both Optical Absorption (OA) and Photolumescence (PL) spectra measurements were carried out. The specimens used in the investigations were grown by Molecular Bean Epitaxy (MBE). They consisted of GaAs/$Al_0Ga_{0.2}As$ MQW. The well-widths of the samples ranged between 50-110Å while the barrier width was fixed at 100Å, each sample had a period of 100. All the specimens for optical absorption were prepared by first mechanically polishing the substrate and then followed by chemical etching (which is the removal by chemical means of the substrate at the spot of illumination). While the luminescence spectra measurements were made with the 647 nm line of a CW-Krypton laser absorptions spectra measurements were made with a UNICAM 700C spectrophometer. Temperatures were assumed with an iron-doped gold versus Chronel thermometer (with a reading error of ±0.05k) located near the specimens at the tip of a variable temperature cryostat.

**Theoretical consideration and calculations:** The theoretical calculations adopted for the interpretations of the experimental results are similar to those by Adelabu (1993, 1999) and Adelabu *et al.* (1988, 1989). In the calculations, the Super Lattice (SL) and (MQW) wave functions are taken as linear combination of plane waves inside layers of each components materials (i.e., GaAs and AlGaAs) while the usual effective mass boundary conditions at two successive SL and MQW interfaces (Bastard, 1981; White and Sham, 1981) were applied making use of Bloch's theorem. These led to the dispersion relation:

$$\text{CosQD} = \text{Cos}k_1d_1\text{Cos}k_2d_2 - \frac{1}{2}\left(z + \frac{1}{z}\right)\text{Sin}k_1d_1\text{Sin}k_2d_2 \qquad (1)$$

Where:

$D = d_1 + d_2$ = The periodicity length

Q and $K_1$ = The wavelength components

$d_1$ and $d_2$ = The layer thicknesses of material (AlGaAs) and material 2(GaAs)

## RESULTS AND DISCUSSION

Typical absorption spectra of the specimens are shown in Fig. 1 while Fig. 2 presents typical photoluminescence spectra. As usual (Adelabu, 1993) the peak structures are translated as excitonic transitions between sub-bands (Dingle *et al.*, 1974; Dingle, 1975). Before applying the model (as contained in Eq. 1 and 2), it is necessary to take into account the excitonic bonding energy and the effect of strain resulting from the absorption measurements. The strain effect was evident from the observed discrepancies between the absorption moles, the luminescence peaks and is associated with the chemical etching of the substrate at the spot of illumination. The values of the excitonic bonding energies which were subtracted from the energy Eigen values derived numerically from Eq. 1 and 2 were taken to be those of Jiang (1984). These values took into account the necessary variation as a function of well-width and mass discontinuity. Researchers have assumed that the energy shift between the luminescence peak (which is higher) and the absorption peak observed for the lowest energy transition which was 13 meV on the average was applicable to all transition. Thus, researchers have made corrections accordingly to all the absorption data. The results of the calculations of the particle states at different bond offsets are given in Table 1.

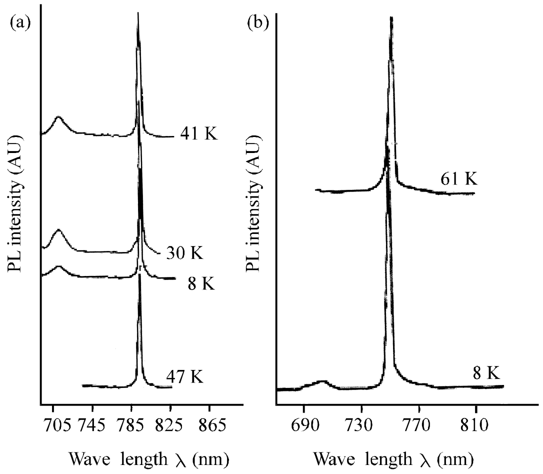

Fig. 2: Typical photoluminescence spectra of samples with well-width of a = 10 nm, b = 5 nm

Table 1 presents the variation of eigen values HH, LH, E, the transistion (IE+IHH) and the trasistion (2E+2H). The results in the table clearly revealed that for any particular band offset, the eigen value increase as the well width decreases. Also, it shows that while the electron confinement energy, transition eigen values for (IE + HH) and (2E+2HH) decrease down the table, both the confinement energies for HH and LH increase down the table with a tremendous increase in the case of LH. The observation is due to the fact that as the conduction band or the potential barrier height for the electron decreases

Table 1: Confinement energy for electrons, heavy holes and light holes in the sample with well width of 10 and 5 nm at different band edge discontinuities

| Band edge discontinuity | 5 nm (HH) | 10 nm (HH) | 5 nm (LH) | 10 nm (LH) | 5 nm (E) | 10 nm (E) | 5 nm (1E+1HH) | 10 nm (1E+1HH) | 5 nm (2E+1HH) | 10 nm (2E+1HH) |
|---|---|---|---|---|---|---|---|---|---|---|
| 85/15 | 14.1289 | 5.2506 | 29.7852 | 8.1236 | 84.3915 | 38.4583 | 98.5203 | 43.7089 | 319.2368 | 175.0836 |
| 80/20 | 15.6563 | 5.6006 | 36.6597 | 11.2314 | 81.9730 | 37.6770 | 97.6293 | 37.6770 | 310.9631 | 133.3971 |
| 75/25 | 16.7064 | 5.7279 | 42.4821 | 12.1124 | 80.1910 | 31.5036 | 96.8974 | 37.2315 | 302.1484 | 131.2650 |
| 65/35 | 18.4885 | 6.0143 | 51.4559 | 13.0344 | 75.2904 | 30.6126 | 93.7789 | 36.6269 | 282.4189 | 126.8099 |
| 60/40 | 19.0931 | 6.1098 | 55.2427 | 14.1225 | 72.5537 | 29.7852 | 91.6468 | 35.8950 | 271.5039 | 124.1051 |
| 57/43 | 19.4280 | 6.2936 | 57.1894 | 16.3624 | 70.7465 | 29.3870 | 90.7745 | 35.6806 | 265.0456 | 122.3905 |

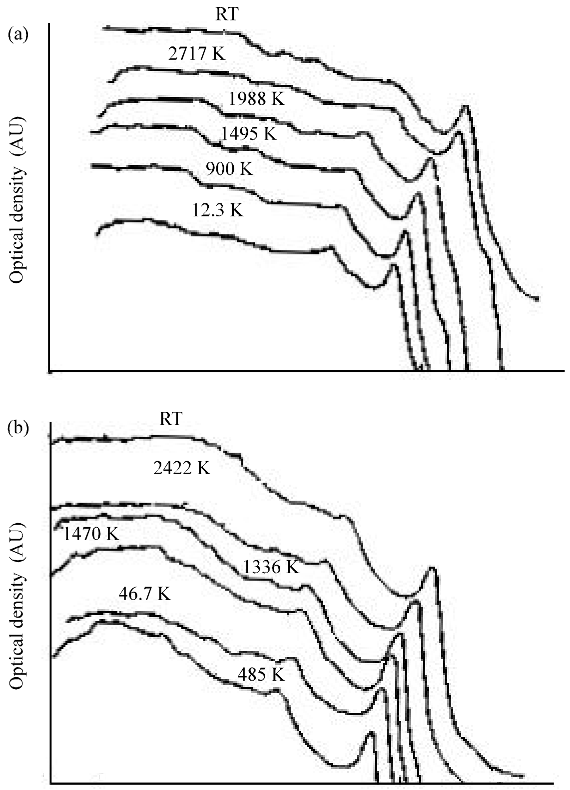

Fig. 3: Typical absorption spectra of samples with well-width of a = 10 nm, b = 5 nm

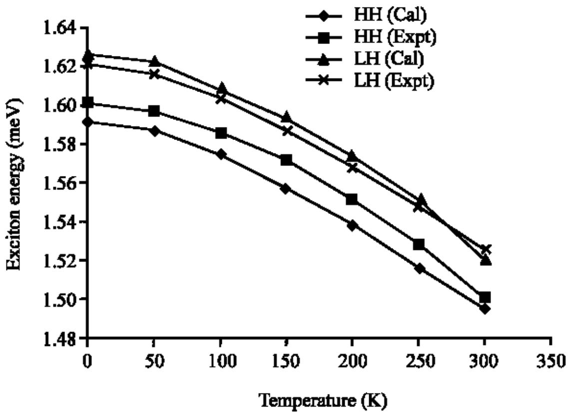

Fig. 4: Comparison of heavy hole and light hole exciton peak at ratio $\Delta E_c/\Delta E_v$ (70/30) at different temperatures for GaAs/AlGaAs heterostructure

that for the hole increases in other to keep the band gap difference for the particular MQW System constant. Thus, it is observed that the confinement energies of the particles increase with the height of the potential barrier. The increase is more pronounced in the case of light hole (Fig. 3).

Figure 4 present the energetic position of the HH and LH excitonic peak (theory and experiment) at band offsets of 70/30. A close look at the fittings of experimental data to theoretical data as presented in Fig. 4 reveals that there is very good agreement. This is confirmed with the aid of computer using one way Analysis of Variance (ANOVA) and revealed that there is no significant difference between theory and experiment.

## CONCLUSION

Researchers have carried out measurement of OA and PL on type I MQW System of GaAs/AlGaAs grown by molecular beam epitaxy. The comparison of experimental result with the calculated result shows a close agreement of the two. Calculation actually mimic experiment as evident in Fig. 2 and 3. It is revealed from the investigation that confinement energies of the particles vary as band offsets.

## REFERENCES

Adelabu, J.S.A. and G.L. Abdullahi, 1987. Measurement of band-gap difference in GaAs MQW systems. Global J. Pure and Appl. Sci., 3: 109-117.

Adelabu, J.S.A., 1993. On the interpretation of optical spectra in GaAs/AlGaAs SL and MQW systems. Physica B., 183: 264-270.

Adelabu, J.S.A., 1999. Quantum confinement in synthetic solid state semiconductors. J. Pure and Appl. Sci., 2: 47-52.

Adelabu, J.S.A., B.K. Ridley and G.J. Davies, 1989. Room temperature optical absorption and confinement effect in GaInAs/AlInAs MQW. Semicond. Sci. Technol., 4: 677-681.

Adelabu, J.S.A., B.K. Ridley, E.G. Scott and G.J. Davies, 1988. Energy levels and optical absorption associated with GaInAs/AlInAs MQW. Semicond. Sci. Technol., 3: 873-878.

Bastard, G., 1981. Superlattice band structure in the envelope function approximation. Phys. Rev., B24: 5693-5697.

Bastard, G., 1982. Theoretical investigations of superlattice band structure in the envelope function approximation. Phys. Rev., B25: 7584-7597.

Bastard, G., O.U. Ziemelis, C. Delalande, M.I. Voos, A.C. Gossard and W. Wiegmann, 1984. Bound and Virtual bound states in semiconductor quantum wells. Solid State Commun., 49: 671-674.

Casey, H.C. and M.B. Panish, 1978. Heterostructure Lasers, Part A: Fundamental Principles. Academic Press, New York, pages: 189.

Dawson, P.L., G. Duggan, H.J. Ralph, K. Woodbridge and G.W.T. Hoof,t, 1985. Positions of the sub-band minima in GaAs-AlGaAs quantum-well heterostructures. J. Superlattices and Microstructures, 1: 231-235.

Dingle, R., 1975. Confined carrier quantum states in ultra thin semiconductor heterostructures. Festkoperprobleme, Adv. Solid State Phys., 15: 21-48.

Dingle, R., W. Wiegmann and C.H. Henry, 1974. Quantum states of confined carrier in very thin AlGaAs-GaAs heterostuctures. Phys. Lett., 33: 827-830.

Jiang, T.F., 1984. An alternative approach to exciton binding energy in GaAs/AlGaAs quantum wells. Solid State Commun., 50: 589-593.

Miller, R.C., A.C. Gossard, W.T. Tsang and O. Munteanu, 1982. Extrinsic Photoluminescence from GaAs quantum wells. Phys. Rev., B25: 3871-3877.

Miller, R.C., D.A. Kleinman, W.A. Nordland and A.C. Gossard, 1980. Luminescence studies of optically pumped quantum wells in GaAs-AlGaAs multilayer structures. Phys. Rev., B22: 863-871.

Miller, R.C., D.A. Kleinman, W.T. Tsang and A.C. Gossard, 1981. Observation of excited levels of excitons in GaAs quantum well. Phys. Rev., B24: 1135-1136.

Miller, R.C., Kleinman, D.A. and A.C. Gossard, 1984. Energy gap discontinuities and effective masses for GaAs-AlGaAs quantum wells. Phys. Rev., B29: 7085-7087.

Rogers, D.C. and R.J. Nicholas, 1985. Limit on band discontinuities in GaAs heterostructures deduced from optical photoresponse. J. Phys. C. Solid State Phys., 18: 1891-1896.

Schulman, J.N. and McGill., 1979. The CdTe/HgTe superlattices: Proposal for a new infrared material. Appl. Phys. Lett., 34: 663-665.

Schulman, J.N. and Y.C. Chang, 1985. Band mixing in semiconductor superlattices. Phys. Rev., B31: 2056-2068.

Schulman, J.N. and Y.C. Chang, 1983. Reduced Hamiltonian method for solving the tight-binding model interfaces. Phys. Rev., B29: 2346-2354.

Weisbuch, C., R.C. Miller, R. Dingle and A.C. Gossard, 1981. Intrinsic radiative recombination from quantum states in GaAs/AlGaAs multi-quantum well structures. Solid State Commun., 37: 219-222.

White, S.R. and I.J. Sham, 1981. Electronics properties of flat-band semiconductor heterostuctures. Phys. Rev. Lett., 47: 879-882.