Composite Quantum Wells on InP for blue Stark shift

A. Yu. Silov, B.Aneeshkumar, M.R.Leys, H. Vonk and J. H. Wolter
COBRA Inter-University Research Institute, Eindhoven University of Technology
P.O. Box 513, 5600MB Eindhoven, The Netherlands
e-mail: a.yu.silov@phys.tue.nl

Abstract: Structures with real space separate confinement of electrons and holes can cause both blue- and redshifting of the absorption edge. Such a separate confinemnt can be achieved in a composite well structure, with materials with reverse band offset ratio with respect to the barrier. We made use of $InAs_yP_{1-y}$ and $Ga_xIn_{1-x}As$ squantum wells surrounded by InP barriers. Both wells are about 4 nm thick and are separated by 1 nm InP. The structures were grown by Chemical Beam Epitaxy in a p-i-n structure. It was found that an electric field of about 30kV/cm produces a blue shift of 25 meV.

1. Introduction

In recent years there has been a great deal of interest in structures with separate confinement of electrons and holes in real space. They are especially used to realize a two dimensional exciton condensate [1] and for exploring the blue shifting nature of the absorption edge [2]. Here we demonstrate a large blue shift by using composite quantum well structures with separate confinement of electrons and holes. This has been accomplished by growing the composite well region out of materials with reverse band offset ratio with respect to the barrier material [3].

2 Samples

To realize the separate confinement we made use the two ternary materials $InAs_yP_{1-y}$ and $Ga_xIn_{1-x}As$ surrounded by InP barriers. The $InAs_yP_{1-y}$ layers with y = 0.35 or y = 0.42 are always in compression with respect to the InP substrate while the $Ga_xIn_{1-x}As$ layers were grown either lattice matched (x= 0.47) or in tension (x= 0.67). In this latter case, the sample is so-called "strain-balanced". At the $Ga_xIn_{1-x}As$ / InP interface the conduction band to valence band offset ratio is assumed to be 40:60 and at the $InAs_yP_{1-y}$ / InP interface it is taken to be 70:30. The photocreated electrons are thus confined within the $InAs_yP_{1-y}$ while the holes are confined within the $Ga_xIn_{1-x}As$. Both quantum wells are approximately 40 Å thick and are separated by a 10 Å thick InP barrier. All the structures were grown by Chemical Beam Epitaxy on n-doped (100) InP, misorientated 0.5^o towards the (111)B [4]. The quantum well region was grown in the intrinsic region of a n-i-p structure. We have grown pairs of "normal" ($Ga_xIn_{1-x}As$ layer at substrate side) and "inverted" structures ($InAs_yP_{1-y}$ at the substrate side).

3 Results and Discussion

A cross-sectional image made by means of Transmission Electron Microscopy (TEM) is shown in figure 1. At the bottom interface, one can one can observe an arsenic rich layer, formed during the gas switching procedure. One can clearly observe thin (10 Å) layer of InP separating the $Ga_{0.47}In_{0.53}As$ layer from the $InAs_{0.35}P_{0.65}$ layer.

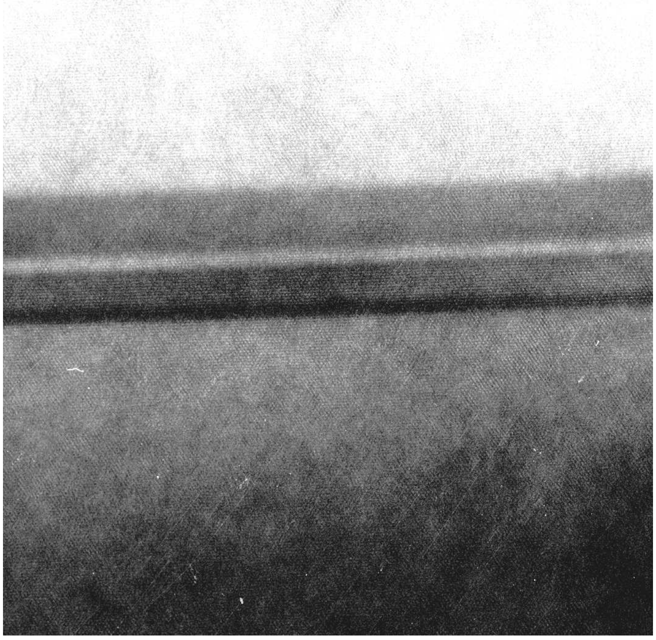

Fig 1 Cross sectional TEM image of a composite quantum well structure

Figure 2 shows the results of photocurrent measurements. They were performed at 100 K under reverse bias varying up to 13.5 V. Tunable infrared laser light was used as an excitation source. The photocurrent measurements on samples with a 1.3% compression on the $InAs_{0.42}P_{0.58}$ side of the composite quantum well and containing the lattice matched $In_{0.53}Ga_{0.47}As$ show linear Stark shift in an electric field up to 15 kV/cm. The red shift is due to the fact that the applied electric field pulls the photocreated electrons and holes further apart. Figure 2 shows the Stark shift of the lowest energy transition as a function of the applied field. Here the line is the theoretical fit to the experimental data. The initial linear Stark shift is a clear indication of the separated confinement for electrons and holes in real space. The photocurrent measurements on sample with 1.1% compression on the $InAs_{0.35}P_{0.65}$ show that the slope of the linear red shift of the absorption edge is smaller. From this slope we can calculate the electron-hole separation in real space. For the $InAs_{0.42}P_{0.58}$ sample, the electron-hole separation is 40 Å, whereas for the sample with 1.1% compression it is approximately 34 Å.

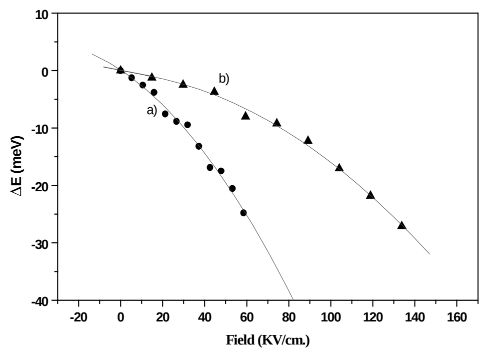

Fig.2 Stark shift of the lowest energy transition with respect to applied field
a) $InAs_{0.42}P_{0.58}$ well under 1.3 % compression,
b) $InAs_{0.35}P_{0.65}$ well under 1.1% compression

Using photoluminescence at 5 K we have investigated the strain balanced samples. The wavelength of 532 nm from a Nd:YAG laser was used as the excitation source. An unfocused beam was used and the power density was about 400 mW/cm^2. The photoluminescence spectra at 5 K are shown in Fig. 4.

Two pairs of samples were investigated: one with lattice matched $Ga_{0.47}In_{0.53}As$ and the other with $Ga_{0.67}In_{0.33}As$ under tension. In each pair one is the inverted structure of the other, so that the built-in field is reversed. The $InAs_yP_{1-y}$ has the same composition in all structures with y=0.42. For the pair with $Ga_{0.47}In_{0.53}As$ composition, the shift between the photoluminescence peaks is 15 meV, while for the pair with the $Ga_{0.67}In_{0.33}As$ well the shift between the photoluminescence peaks is 50 meV. In $Ga_{0.67}In_{0.33}As$ well the ground state for the valence band becomes light hole in character. The strain increases the spatial separation between the electrons and holes, and the calculated separation is 45 Å. There is no coupling between the electronic states in the valence band for the attice matched $Ga_{0.47}In_{0.53}As$, but there exists a residual coupling in the conduction band.

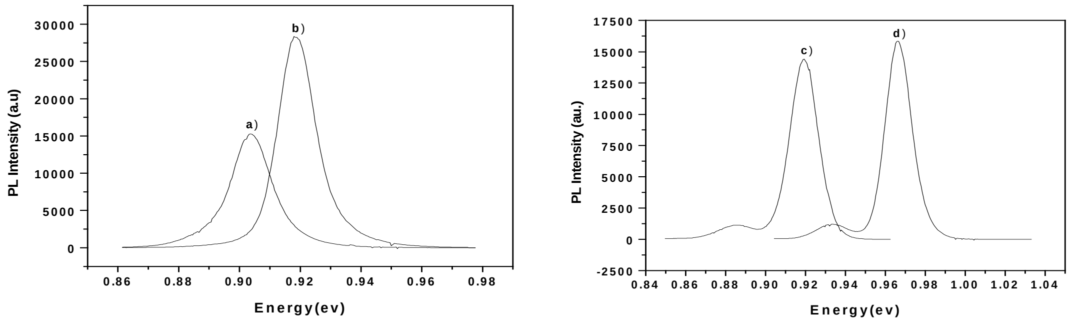

Fig.2 Low temperature photoluminescence spectra:
a) $InAs_{0.42}P_{0.58}/InP/Ga_{0.47}In_{0.53}As$; **b)** $Ga_{0.47}In_{0.53}As/InP/InAs_{0.42}P_{0.58}$; the shift between the two peaks is 15meV;
c) $InAs_{0.42}P_{0.58}/InP/Ga_{0.67}In_{0.33}As$; **d)** $Ga_{0.67}In_{0.33}As/InP/InAs_{0.42}P_{0.58}$; the shift between the two peaks is 50meV.

By putting more tension on the $Ga_xIn_{1-x}As$ side of the composite well, this residual coupling can be greatly reduced. Thus the corresponding photoluminescence peak shifts towards the high-energy side, compared to the lattice matched case. Additionally, it is found that an electric field of about 30 kV/cm can produce a large blue shift of 25 meV. All our measurements agree with the calculations in the framework of Bir-Pikus strain Hamiltonian.
In conclusion, we achieved large blue Stark shift in the composite quantum well structures using separate confinement of electrons and holes in real space. Due to the high asymmetry in the confinement, these structures can be used to achieve both red and blue shift of absorption edge.
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