Optical Absorption in $InAs/In_{0.48}Ga_{0.52}P$ Quantum Dot Superlattices

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Introduction

Recently, semiconductor quantum dot (QD) array-based intermediate band solar cells (IBSCs) have received much attention as ultrahigh efficiency solar cells[1]. The concept of IBSCs is to increase the photocurrent by the additional two-step photon-absorption via the intermediate band (IB or QD minibands) states as illustrated in Fig. 1. Although InAs/GaAs IBSCs are widely studied, the optical properties are not suitable for solar spectra, because the wavelength of absorbed light from IB (MB_0: first miniband) to the conduction band is too long. Instead we propose solar cells based on $InAs/In_{0.48}Ga_{0.52}P$ which provides higher efficiency of sunlight absorption. $In_{0.48}Ga_{0.52}P$ is lattice-matched material to GaAs with wider bandgap than GaAs. We present theoretical calculations of the absorption spectra of $InAs/In_{0.48}Ga_{0.52}P$ IBSCs.

Calculation Method

We consider z-stacked $InAs/In_{0.48}Ga_{0.52}P$ QD superlattices (QDSLs) with a pyramidal shape. The dot height is 3 nm, and the base length is 8 nm. The inter-dot spacing in z-direction is 3 nm. We calculated the electronic and optical properties by solving the plane-wave expanded 8-band k p Hamiltonian [2], [3] with periodic boundary condition. We also took into account of strain and piezoelectric effects. The electronic and optical properties of $InAs/In_{0.48}Ga_{0.52}P$ QDSLs are also compared with those of conventional InAs/GaAs QDSLs. For the valence band (VB) to IB (MB_0) or CB transitions (VB $\rightarrow$ IB or VB $\rightarrow$ CB), we assume the VB subbands are completely filled with electrons and the IB and CB subbands are empty. For the IB $\rightarrow$ CB transitions, we assume the IB is completely filled and the CB subbands are empty.

Result and Discussion

Figs. 2 (a)–(d) show the TE (x- and y- direction) and TM (z-direction) polarized absorption spectra of InAs/GaAs QDSLs and $InAs/In_{0.48}Ga_{0.52}P$ QDSLs, where we find the absorption spectra of $InAs/In_{0.48}Ga_{0.52}P$ QDSLs are blue-shifted compared to InAs/GaAs QDSLs. In addition, the absorption band of $InAs/In_{0.48}Ga_{0.52}P$ QDSLs is narrowed compared to InAs/GaAs QDSLs. These results indicate $InAs/In_{0.48}Ga_{0.52}P$ QDSLs have the strong quantum confinement effect due to the large conduction band offset, and thus the IB width become narrower. In the IB $\rightarrow$ CB transitions for the TE polarization, the peaks due to the transition between IB (MB_0) and MB_1, MB_2 become narrower. This result is not only due to the narrower IB width but also due to the change of MB_1 and MB_2 from the continuum states to the localized states below the effective potential barrier.

Conclusion

We find that the IB $\rightarrow$ CB transition energy gap can be widened by changing a barrier material from GaAs to lattice-matched $In_{0.48}Ga_{0.52}P$. This suggests that $In_{0.48}Ga_{0.52}P$ is a good candidate for a barrier material of ultrahigh efficiency IBSCs.

References

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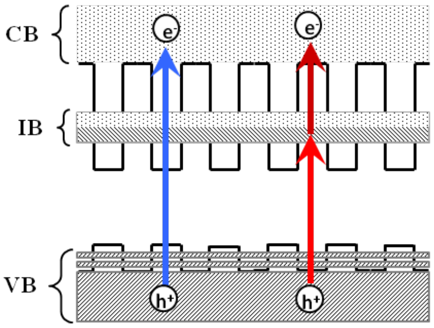

Fig. 1. Schematic view of the VB ⟶ IB (MB_0), VB ⟶ CB, and IB (MB_0) ⟶ CB transitions.

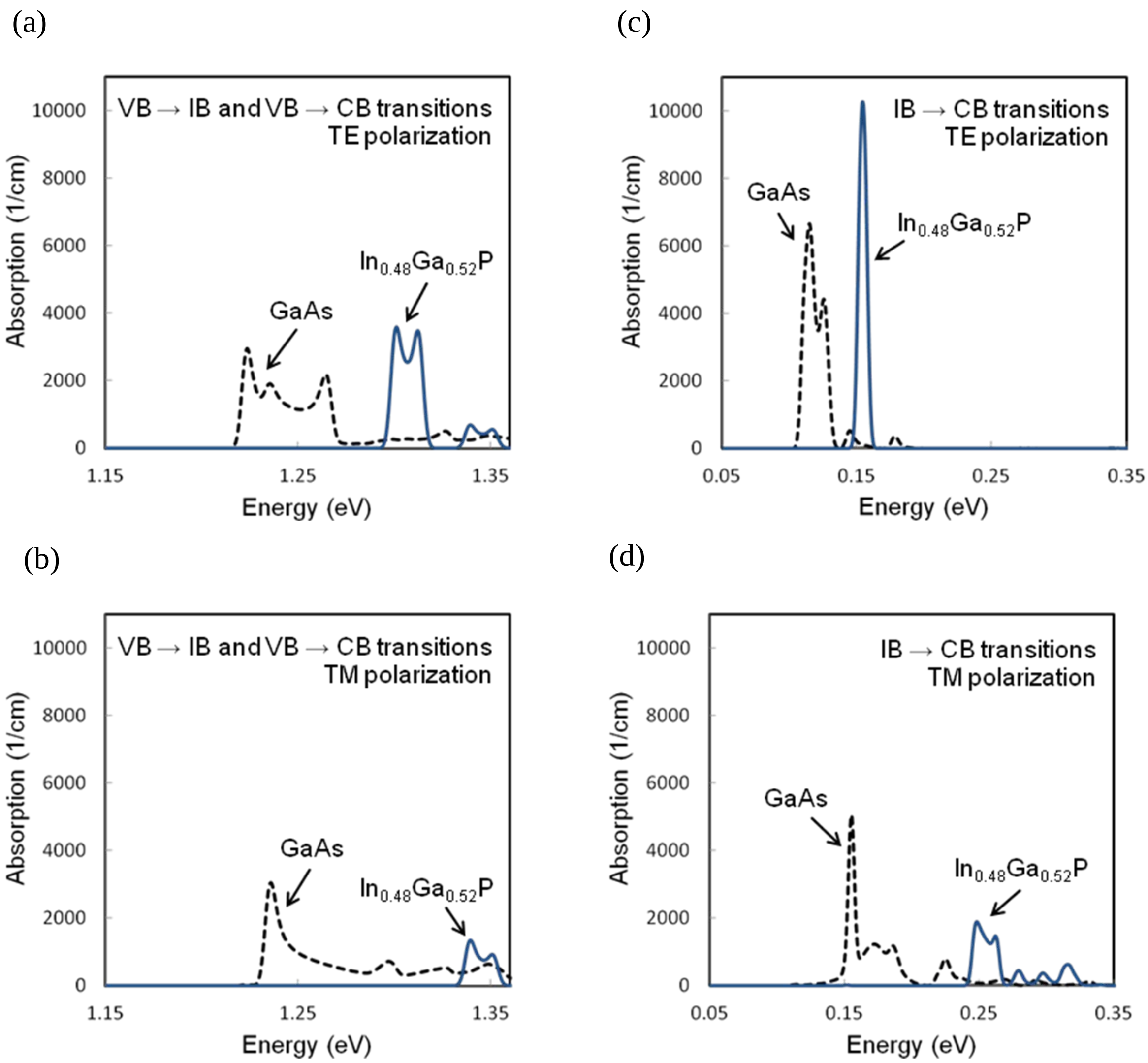

Fig. 2. The absorption spectra of InAs/GaAs QDSLs (dashed line) and InAs/$In_{0.48}Ga_{0.52}P$ QDSLs (solid line) (a) TE polarized in the VB ⟶ IB (MB_0) and VB ⟶ CB transitions, (b) TM polarized in the VB ⟶ IB (MB_0) and VB ⟶ CB transitions, (c) TE polarized in the IB (MB_0) ⟶ CB transitions, and (d) TM polarized in the IB (MB_0) ⟶ CB transitions.