Polarization dependent optical absorption properties of quantum dot superlattices

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INTRODUCTION

Recently, the closely stacked periodic quantum dots (QDs), which is often called quantum dot superlattices (QDSLs), have been attracting much interest due to their unique properties[1]. For the optical device application, understanding the absorption spectrum as well as the optical polarization is very important. In this study, we theoretically investigate the polarization dependence of the optical absorption properties of InAs/GaAs QDSLs.

CALCULATION METHOD

We consider z- ([001]-) stacked InAs/GaAs QDs with a truncated pyramidal shape having (101), $(\bar{1}01)$, (011) and $(0\bar{1}1)$ as side facets. The dot height is 3 nm, the base length is 15 nm and the wetting layer width is 0.5 nm. The plane-wave expanded 8-band k·p Hamiltonian [2], [3] with periodic boundary condition is solved to obtain the electronic structures. Strain and piezoelectric effect are also included. The optical absorption spectrum $\alpha(\omega)$ is calculated by

$$\alpha = \frac{e^2}{2n_r c_0 \epsilon_0 m_0^2 \omega L_x L_y} \int \mathrm{d}K_z \sum_{a,b} |M|^2 (f_a - f_b) G \tag{1}$$

, where $|M|$ is the optical matrix element, a and b are the miniband index, n_r is the refractive index, c_0 is the light speed, ϵ_0 is the dielectric constant of vacuum, m_0 is the free electron mass, $L_x(L_y)$ is the unit cell length in x-(y-) dimension, K_z is the superlattice vector, $f_i (i = a, b)$ is the distribution function, G is the Gaussian broadening (5 meV) due to the size or compositional fluctuation.

RESULT AND DISCUSSION

Figures 1 (a) – (d) show the absorption spectra of electron-hole transition in InAs/GaAs QDSLs. We assume the valence subbands are completely filled by electron and the conduction subbands are empty. The optical polarization of the main peak near the absorption edge strongly depends on the inter-dot spacing (L_z). For L_z = 1 nm, transverse magnetic- (TM-:E_{001}) polarization is dominant and the spectrum is similar to the quantum wires. For L_z = 3 nm, TM- and transverse electric- (TE-:E_{100}) polarization are almost the same. For $L_z \geq$ 5 nm, TE-polarization is dominant. The spectrum is similar to the single QD for L_z = 10 nm. We find this polarization properties are attributed to the strain-modified valence band structures. As L_z decreases, the biaxial tensile strain in the barrier increases. The biaxial tensile strain pulls up LH and then the mixing rate of LH in the lower state of valence subband increases. This results in the strong TM-polarized absorption for small L_z.

CONCLUSION

We have theoretically investigated optical properties of InAs/GaAs QDSLs. We find that the optical absorption spectrum strongly depends on L_z and the optical polarization switches at L_z = 3 nm. These findings provide an additional degree of freedom for the design of optical devices.

REFERENCES

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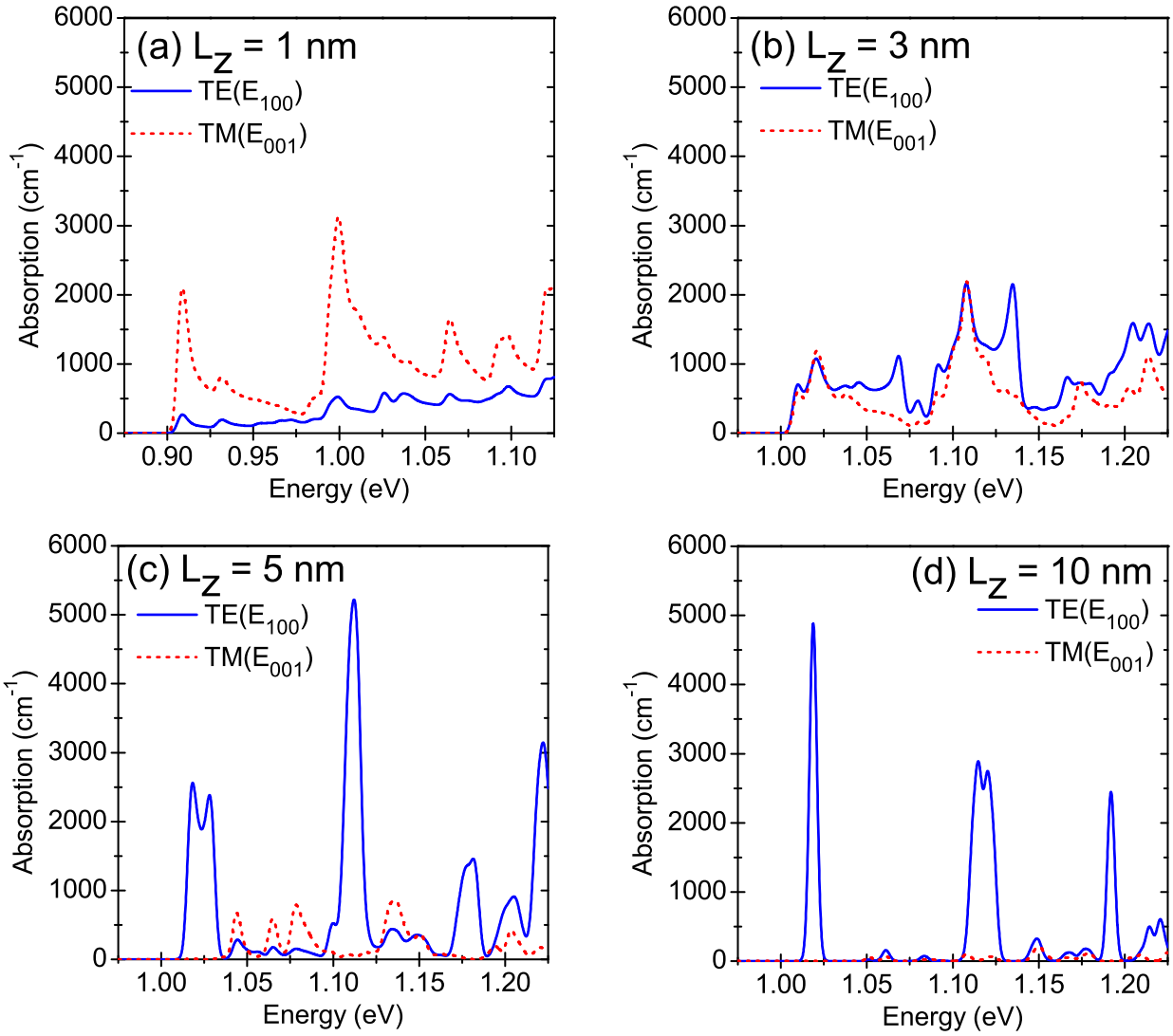

Fig. 1. TE (solid line) and TM (dashed line) polarized absorption spectra of InAs/GaAs QDSLs with inter-dot spacing of (a) L_z = 1 nm, (b) L_z = 3 nm, (c) L_z = 5 nm and (d) L_z = 10 nm.