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Near-infrared intersubband absorption in (CdS/ZnSe)/BeTe type-II super-lattices grown on GaAs substrate by MBE

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Abstract

We study the dependence of absorption wavelength on the well width in the (CdS/ZnSe)/BeTe super-lattices(SL). With well-width reduction, the wavelength decreases from 1.795 to 1.57 μm. Structural properties, strain state and interface composition are determined via XRD measurement. A (CdS/ZnSe)/$Be_xMg_{1-x}Te$ structure is prepared and XRD reveals the average lattice constant match to GaAs substrate. TEM reveals that numerous stacking faults exist in the (CdS/ZnSe)/BeTe structure, and stacking faults are completely suppressed in (CdS/ZnSe)/$Be_xMg_{1-x}Te$ SLs. Intersubband transition down to 1.535–1.55 μm have been observed in SLs.

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Keywords: II–VI compounds; ISB-T; XRD; TEM

1. Introduction

Intersubband transition (ISB-T) in super-lattices (SL) has captured considerable attention due to the potential application in ultrafast all-optical modulators and switches. The recent attempt to extend the ISB-T to near-infrared (NIR), in particular to the fib-optic communication at 1.55 μm, has been developing fast. So far, NIR wavelengths, ISB-T, and ISB carrier relaxation times from sub-ps to ps have been reported in III–V material system such as GaN/AlGaN, InGaAs/AlAsSb, InGaAs/AlAs, and GaN/AlN [1–4].

Recently, a rapid ISB carrier relaxation in sub-picosecond range in (CdS/ZnSe)/BeTe SLs have been reported at NIR wavelength region [5,6]. Here, we improve upon the previous results and optimize the structural quality. Two SLs samples, lattice matched to GaAs substrate, are designed and obtained. ISB-T down to 1.535 μm occurs in the improved structure.

2. Experimental procedure

We prepared 6 SLs samples for this study by MBE [7]. These samples consist of 40 (S1, S2, S3 and S5). 80 (S4) and 100 (S6) periods of (ZnSe/CdS/ZnSe) well-standing between two 10 ML BeTe (S1–S4) or $Be_{1-x}Mg_xTe$ (S5, S6) barrier layers, accompanied by a 25 ML ZnSe spacer layer (S1–S5). There is no spacer layer in sample S6.

Absorption and photo-inducted absorption of samples were measured using a Fourier-transform spectrometer having an internal white light source with a wire-grid polarizer and a liquid-nitrogen-cooled InSb detector. High-resolution $\omega/2\theta$ scan and two-dimensional reciprocal space mapping (RSM) were performed by using a high-resolution X-ray diffractometer (Philips, PW3050 goniometer). HRTEM was conducted on structure parameters in $\langle 1\,1\,0 \rangle$ direction via a Hitachi H-1500 high-voltage electron microscope, operated at 800 kV.

3. Results and discussion

Fig. 1 (left) is the ISB absorptions from 0° to 90° in steps of 10° for S2 sample, calculated from transmission spectra

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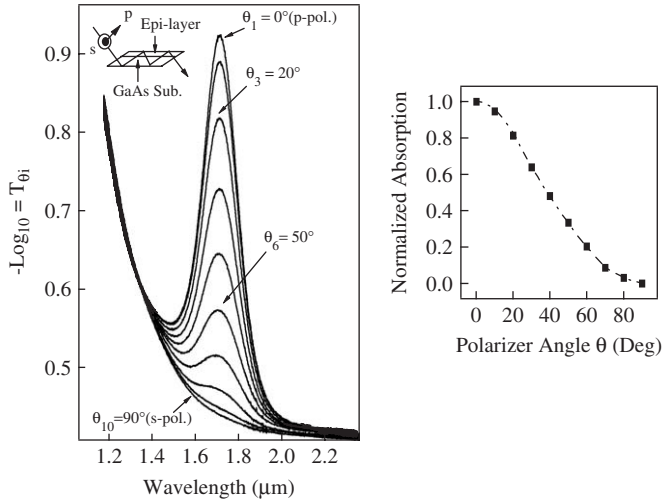

Fig. 1. (Left) ISB spectra for different polarization angles for sample S2; (right) measured ISB absorption (normalized to $\theta = 0$) vs. polarized angle. The solid line is drawn through the points as a guide to the eye.

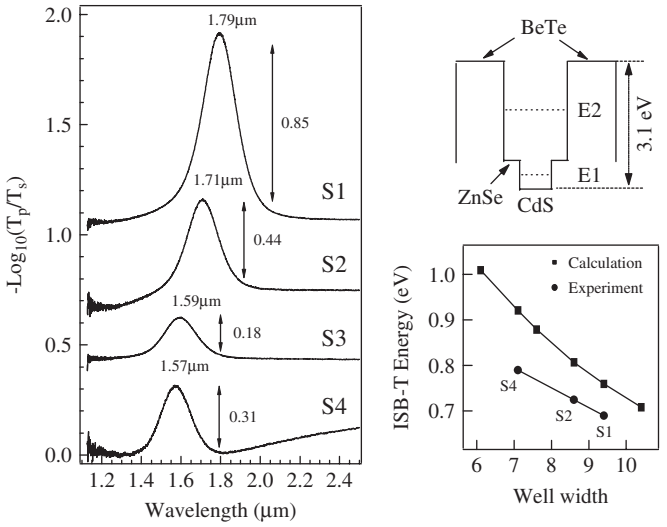

Fig. 2. (Left) absorption spectra for S1–S4; the top of right side is the well structure for numerical calculation of energy separation. The bottom is the calculated and measured ISB-T energies in (CdS/ZnSe)/BeTe SLs.

$T_{\theta i}$ (taking −log). The p-polarized direction is defined as 0°, and s-polarized as 90°, as shown in upper left inset in Fig. 1. It is shown clearly that the signal intensities gradually decrease as the polarized angle increases and vanish completely with s-polarized incident light (90°), i.e., for light polarized in the plane of the wells. ISB-T in QWs or SLs can only be induced by IR light with a component of electric field parallel to the quantum well direction (the growth direction). This polarization selection rule has been investigated in III–V material systems [8]. Following the selection rule of ISB-T in QWs or SLs, the oscillator strength, i.e., intensity of ISB absorption, approximately proportional to $\cos^2\theta$ is expected (where θ is the angle between the electric field and the growth direction). We plot the polarization dependence of ISB-T intensity on polarized angle, θ, as shown in Fig. 1(right). This kind of IR absorption in (CdS/ZnSe)/BeTe heterosturcure approximately followed the ISB-T polarization selection rule in QWs or SLs. Therefore, the present results confirm apparently that IR absorption originates from ISB-T between the ground state e1 and excited state e2 within the quantum well in (CdS/ZnSe)/BeTe heterostructure.

Shown in the left side of Fig. 2 are ISB-T spectra for samples S1–S4 with different well widths, which are deduced by taking the −log of the transmission ratio of T_p to T_s to remove the influence of background. Strong NIR ISB absorption with narrow full-width at half-maximum (FWHM) have been observed in these samples. Due to enhanced quantum confinement, the ISB-T wavelengths between the E1 and E2 subbands shorten from 1.895 to 1.57 μm with the decrease in well width. For S1–S3 samples, the intensities of ISB absorption gradually decrease with decreasing well width. This is partly due to the decreased active layer thickness. The ISB intensity in S4 increases comparing with S3 when the periods number increase. The FWHMs of S1–S4 ISB absorptions are 79, 78, 96 and 90 meV, respectively. We explain that the small fluctuation and high potential energy lead to the narrow width in spectra of ISB absorption. Based on the well structure (in top of right side in Fig. 2) the separations of energy (E1 to E2) are numerically calculated [9]. 3 ML CdS and 1.5–3.4 ML ZnSe IL are assumed for calculation. The experimental ISB-T energies in S1, S2, and S4 are also given. Their well thicknesses are 3 ML CdS and 2–3.2 ML ZnSe IL. These parameters are different from the design and modified according to the XRD and TEM. Although the nonparabolicity of the conduction band is taken into account, there is still a discrepancy between the measured and calculated results. We explain that interface diffusion and atomic exchange modify the band shape and conduction band offset in this heterostructure.

Fig. 3 displays the two-dimensional RSM (2DRSM) of S3 (top) and S4 (bottom), around the 004 symmetric (left side) and 224 asymmetric (right) reciprocal lattice points [10,11]. The iso-intensity contours are concentrated on peak of epitaxial layer in S3. However, they spread out in S4. This indicates crystal planes are precisely parallel in S3 and mosaic spread in S4. The substrate and SL's 0th peaks lie on the same straight line, as shown in the 004 symmetric 2DRSM for both samples, along the surface normal, suggesting no tilts between the substrate and the SL layer. The 224 asymmetric map of S3 shows the SL structure has coherent growth and no strain relaxation occurs. In S4 224 mapping, we can observe two peaks originated from SL layer. One almost lies in a vertical line with substrate. Another one shifts to the right, meaning a_{SL} in plane decreases in S4. A partial relaxation occurs in S4 SL due to over-the-critical thickness. This relaxation induces the stacking faults, resulting in misorientation and mosaic spread in the epilayer, correspondingly broadening the diffraction profile in 2DRSM.