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Intrinsic Absorptive Optical Bistability in ZnS-ZnTe/BaF_2 Strained Layer Superlattices at Low Temperature

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Optical bistability (OB)of ZnS-ZnTe strained -layer superlattics (SLSs)grown on <111>oriented BaF_2substrates by metal organic chemical vapour deposition (MOCVD)at atmospheric pressure (Ap)were studied. The interband transition related to free carriers were observed at 77K. Under high excitation densities, the absorption and recombination of subband lying higher in energy becomes increasingly important. An intrinsic absorptive OB come from the high-order subband of the ZnS-ZnTe SLSs at 77K with ns switching time were reported for the first time.

1. Introduction

In recent years, OB of the superlattices in Ⅱ-Ⅳ wide-gap semiconductors have become anintersting research topic for possible applications to nonlinear signal processing and optical computing. OB about these SLSs, such as ZnSe-ZnS, ZnSe-ZnTe, ZnSe-ZnCdSe etc, have been extensively studied in our earlier works[1~4]. Jiang and Fan et al. [5]have obtained excitonic absorption related to n=2 heavy-hole and light-hole in ZnSe-ZnS SLSs at 77K. In this paper, we first observed an interband absorption come from the hight-order subband of ZnS-ZnTe SLSs under high intensity excitation. OB due to the intrinsic absorption of the hight-order subband in ZnS-ZnTe SLSs were reported at 77K with ns switching time. The bistable mechanism was investigated by theoretical calculation fitting to the experimetal results.

2. Experimental

ZnS-ZnTe SLSs were grown on <111> BaF_2 substrates by using a Ap-MOCVD apparatus. Dimethylzinc (DMZn)、diethyltellurium (DETe) and 10%H_2S together with H_2 gas were used as the source materials for zinc、tellurium and sulphur, respectively. High-purity H_2 was used as carrier gas. A ZnS buffer layer is intentionally inserted to avoid lattice mismatch between substrate and superlattice. The substrate temperatures were varied between 380℃ and 420℃ to optimize the growth conditions. The growth rate were 18-40 nm/min for ZnTe and 10-30nm/min for ZnS layers under different flow. X—ray diffraction measurements, which showed some satellites, were made on the grown superlattices. Combining the growth rates of the ZnS and ZnTe layers estimated and the separation between the satellites, the thicknesses of ZnS and ZnTe layers were determind.

In the present experiment, a typical sample with 10nm thicknesses of ZnS layers and 2. 0 nm thicknesses of ZnTe layers was chosen for detailed study. A dye laser pumped by the 337. 1nm line of a Model UV-24 N_2 pulse laser was used as excitation source. The dye laser pulse was 25nm in spectra half-width with a central wavelength of 520nm. In the bistable experiments, the dye laser pulse was 10ns in duration and the incident light wavelength was 503. 5nm. The time dependence of the incident intensities I_0 and transmitted beam intensities I_t pulses was measured by using a Model 4400 boxcar.

3. Results and discussion

Fig. 1(a) and (b)show the time trace of the incident intensites I_0(solid) and transmitted intensities I_t(broken) under different excitation densities. when excitation densities is lower or higher, it is obvious that the shapes of transmitted pulse are unchangeable or deformed compared to the shapes of incident pulse. Fig. 2(a) and (b) give the relationships between transmitted intensities I_t and incident intensities I_0 calculated from Fig. 1(a) and (b). From the Fig. 2, we found a clockwise hysteresis loop is obtained under higher excitation densities.

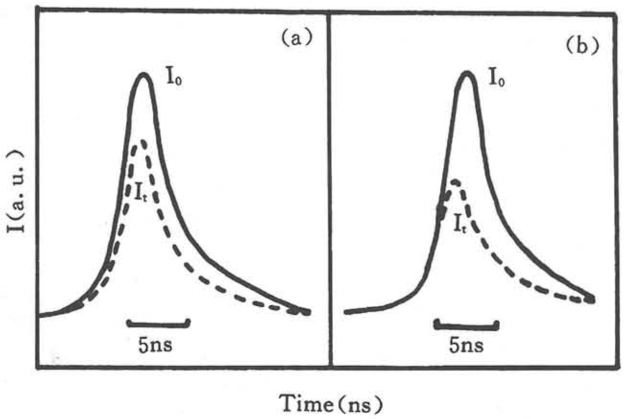

Fig. 1 Time dependence of the incident intensities I_0(solid) and transmitted intensities I_t (broken) pulses at 77K in ZnS (10nm)-ZnTe(2. 0nm) SLSs (λ= 503. 5 nm)
(a) the low density incident light
(b) the high density incident light

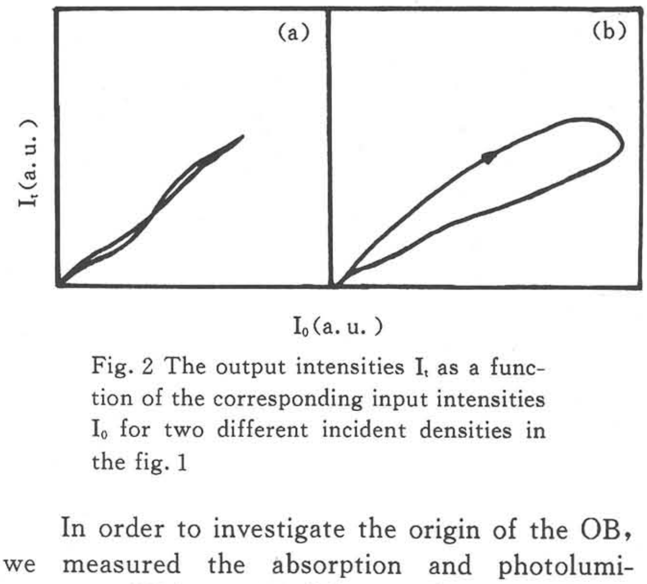

Fig. 2 The output intensities I_t as a function of the corresponding input intensities I_0 for two different incident densities in the fig. 1

In order to investigate the origin of the OB, we measured the absorption and photoluminescence (PL) spectra of the sample. Fig. 3 shows absorption spectra at 77K for two excitation intensites used in bistable experiment. We noticed that only one absorption peak is observed near 538nm when excition density is lower. Under high excitation density, the absorption spectrum has two peaks located at 505nm and 538nm, respectively. The PL spectra at 77K excited by the 337. 1nm line of a N_2 laser with different intensities, are presented in Fig. 4. A band peaked at 540nm under lower excitation density. With increasing excitation densities, the high-energy tail of this band is rapidly rised, and a new band is observed near 510nm. It is reasonable to compary the two absorption peak positions in Fig. 3 with the two emission band peak positions in Fig. 4, respectively. We measured the decay time curves of the two bands in the PL spectra. The result gives the band peaked at 510nm has fast decay rate.

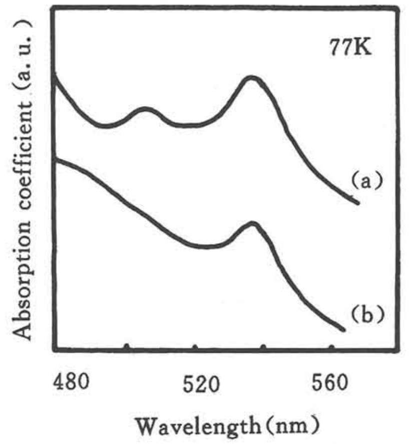

Fig. 3 Absorption spectra at 77K in ZnS (10nm)-ZnTe (2. 0nm) SLSs under two excitation densities in the fig. 1

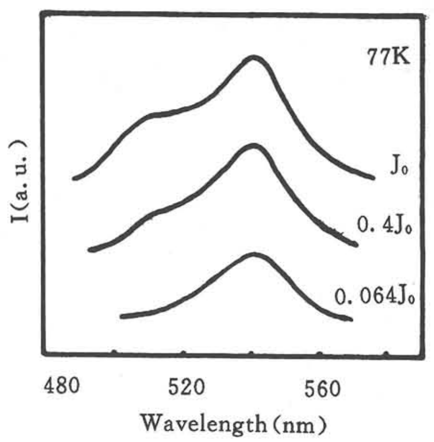

Fig. 4 Emission spectra at 77K in ZnS (10nm)-ZnTe(2. 0nm) SLSs excited by 337. 1nm line of N_2 laser with different excitation density (I_0=4MW/cm^2)

According to the tight-binding theory of Harrson[6], ZnS-ZnTe SLSs are predicted to be a type-Ⅱ superlattice system of the electron wells in the ZnS layers and hole wells in the ZnTe layers. The energy gap shifts with elastic strain are given by Ref[7]:

$$\triangle E=(-6a+\frac{\sqrt{3}}{2}d\ \frac{C_{11}+2C_{12}}{C_{44}})e_{xx}$$

where a is the hydrostatic deformetion potential, d is the shear deformation potential, th C_{ij} are the elastic constants, and e_{xx} is the stain. The kronig-Penney model[8] is used to calculate subband energy levels in the quantum wells. For the ZnS (10nm)-ZnTe (2.0nm) SLSs, calculating results show that the quantum energy levels between n=1,2 electron subbands and n=1,2 heavy-hole subbands should be around 535nm and 505nm at 77K. In contrast the experimental results, two bands observed in the Fig. 3 and Fig. 4 are considered to be free carrier transition and recombination between n = 1, 2 electron subbands and n = 1, 2 heavy-hole subbands.

By analysis and discussion, the above expermental results can be explained as follows. For type-Ⅱ superlattices, carriers have quite a long lifetime[9]. When excitation density is lower, the transition and recombination is dominantly related to the carriers lying in the basic state. The relationship of transmitted intensities I_t with incident intensities I_0 is linear. When excitation density is enough strong, the carriers in the basic state reach saturation. This leads to the absorption and recombination of high-energy carriers were observed in the Fig. 3 and Fig. 4. Because high-energy carriers have shorter lifetime, its luminescence has fast decay rate. This result demonstrates the existence of high-energy carriers under strong exciting. The photon energy of dye laser is 2.462eV (503.5nm), the energy causes resonant absorption with quantum level between n = 2 electron subband and n = 2 heavy-hole subband. Under higher excitation density, the resonant absorption becomes increasingly important. The intrinsic absorptive OB related to the mentioned above quantum level is obtained.

4. Conclusions

The ZnS-ZnTe SLSs have successfully been grown on BaF_2 substrates by Ap-MOVCD. The superlattice strueture were characterized by X-ray diffraction measurment. The intrinsic absorptive OB is observed first at 77K with ns switching time. By absorption and PL spectra measurement, we investigated the origin of the optical bistability. The OB can be attributed to intrinsic absorption come from the quantum level beween n = 2 electron subband and n=2 heavy-hole subband.

Acknowledgements

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