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Optical Bistability in ZnSe-ZnS Superlattices Optical Waveguide

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The excitonic optical nonlinearities and optical bistability are observed in ZnSe-ZnS superlattices optical waveguide at room temperature for the first time. The excitonic absorption band is broadened and tends to saturating absorption, and has a blue shift towards short wavelength side with increasing incident intensities. At higher incident intensity, the switching response time of the optical bistability is 500 ps. The results suggest that the optical nonlinearities are due to the phase space filling of excitonic states, excitonic saturating absorption and excitonic band broadening, while the major contribution to the optical bistability is due to increasing absorption effect caused by phase space filling of excitonic states and excitonic band broadening.

KEYWORDS: ZnSe-ZnS superlattices, optical nonlinearities, optical bistability

1. Introduction

With the development of the semiconductor laser and light emitting diode in blue and green light wavelength region,[1-3] the investigating and exploring of the optical switch and optical bistability devices matched to the short wavelength of visible light region have attracted much attention. Because the Ⅱ-Ⅵ wide band gap semiconductor superlattices (SLs) and multiple quantum wells (MQWs) have characteristics of big binding enery of exciton, short lifetime of exciton and large room temperature excitonic optical nonlinearities. Therefore, they have attracted much interest for practice application of optical switch devices in optical computing field. Since Shen et al.[4] firstly observed the transient optical bistability with ns response time in ZnSe-ZnS MQWs at 77K, the optical bistability in ZnSe-ZnS and ZnSe-ZnTe superlattices has been further investigated.[5,6] The switching power has been still too high to use in practical application. In order to reduce the switching power, we have adopted the waveguide structure to reduce the switching power of optical bistability device of ZnSe/ZnS planar waveguide.[7] In this paper we report for the first time, the observation of optical bistability with 500 ps response time and low threshold switching power in ZnSe-ZnS SLs planar waveguide.

2. Experimental

The ZnSe-ZnS SLs sample used in this experiment consisted of 2 μm cladding layer of ZnS and guiding layer with 120 periods of 1.5 nm ZnSe wells and 7.8 nm ZnS barriers grown on GaAs substrate by atmospheric pressure metal organic chemical vapor deposition (AP-MOCVD). Electronic grade dimethylzinc, H_2Se and H_2S were used as source materials for Zn, Se and S, respectively. High purity H_2 was used as the carrier gas. The growth process was automatically controlled. The planar waveguide cleaved along the natural cleavage plane of ZnSe-ZnS SLs waveguide sample was length of 2 mm and width of 0.5 mm. The excitation source for absorption spectra was a tunable pulsed dye laser with a Coumarin-440 pumped by the 337.1 nm line of a model UV-24 pulsed nitrogen laser with 10 ns full width at half-maximum (FWHM) and repetition rate of 30 Hz. The dye laser pulse was 5～6 ns in duration (FWHM). The tunable laser beam was focused onto the ZnSe-ZnS SLs guiding layer by a 50x microscope object. The spot diameter of the incident light beam on the ZnSe-ZnS SLs waveguide was about 50 μm. The incident light intensities were changed by a neutral density filter. The transmitted light from ZnSe-ZnS SLs waveguide under different incident intensities was monitored by a photodiode. Signal recovery was performed with the aid of a 4400 Boxcar averaging system. The experimental set-up is shown in Fig. 1.

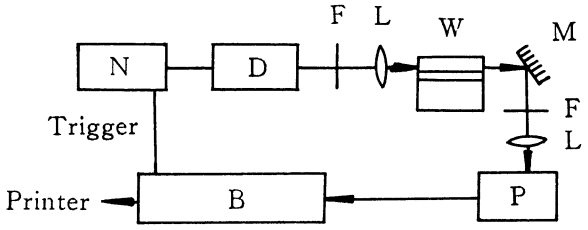

Fig. 1. The experimental set-up for optical nonlinear absorption and optical bistability. N, nitrogen laser; D, Dye laser; F's, neutral density filters; W, waveguide; M, mirror; L's, microscope lenses; P, photodiode; B, Boxcar averaging system.

3. Results and Discussion

Figure 2 shows the absorption spectra of ZnSe-ZnS SLs planar waveguide under different incident intensities at room temperature. As can be seen from the figure, the peak position of absorption

band is located at 435 nm under the lowest incident intensity of 0. 01 I_0. The absorption band shifts to short wavelength side, and tends to saturating and broadening with increasing incident intensities from 0. 01 I_0 to I_0. The result can be considered as the reason of phase space filling of excitonic states and excitonic band broadening[8,9] because exciton concentrations in ZnSe-ZnS SLs layer increase and occupy the exciton states with higher energy with increasing incident intensities. Figure 3 shows the photoluminescence (PL) of the ZnSe-ZnS SLs planar waveguide excited by the 337. 1 nm line of a N_2 laser at room temperature. The peak position of PL spectrum is located at 435. 5 nm. It is in agreement with that of the absorption spectrum at the lowest incident intensity. The fact indicates that they have the same origin. This feature is similar to our recent work[5] in which it is attributed to the exciton absorption and exciton luminescence. Hence, it is reasonable to think that the absorption band peaked at 435 nm should be attributed to the exciton absorption. Owing to the excitonic optical nonlinear effects, the transmitted I_t pulse is compressed obviously at the short wavelength side of excitonic absorption band with increasing incident intensities. Figures 4(a) and 4(b) show the averaged and normalized temporal shapes of the transmitted I_t and incident I_i pulses at 430. 8 nm, above the exciton absorption peak position. Correspondingly, figures 4(c) and 4(d) show the resulting hysteresis loops, $I_t = f(I_i)$ of the optical bistability under different incident intensities. From figure 4(c), in the case of the lower incident intensity, the change of transmitted I_t depending on the incident I_i is approximate to the linearity, and figure 4(d) displays clear characteristic of optical bistability at the higher incident intensity. Based on the fact that the transmitted light rapidly descend to low state from high state, it is obviouly increasing absorption optical bistability which results from phase space filling of excitonic states and excitonic band broadening.[8,9] As the compressed transmitted I_t pulse in figure 4(b) nearly vertically falls from the position of the maximum intensity, it results in that the transmitted light in figure 4(d) more rapidly falls into the off state from

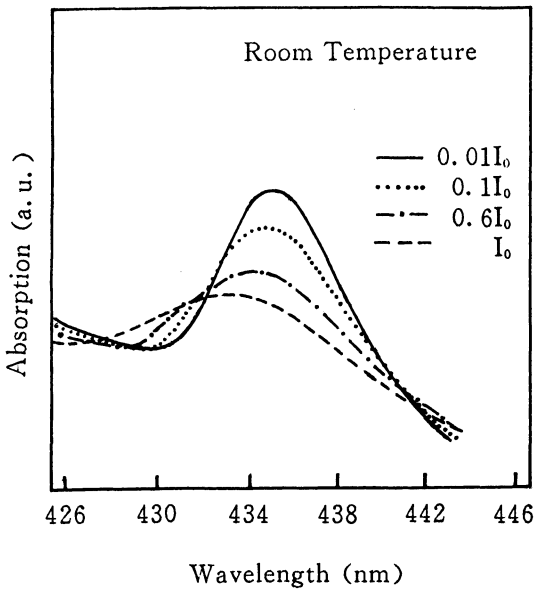

Fig. 2. absorption spectra from the ZnSe-ZnS SLs planar waveguide at room temperature under different incident intensities ($I_0 = 40$ mW/μm^2).

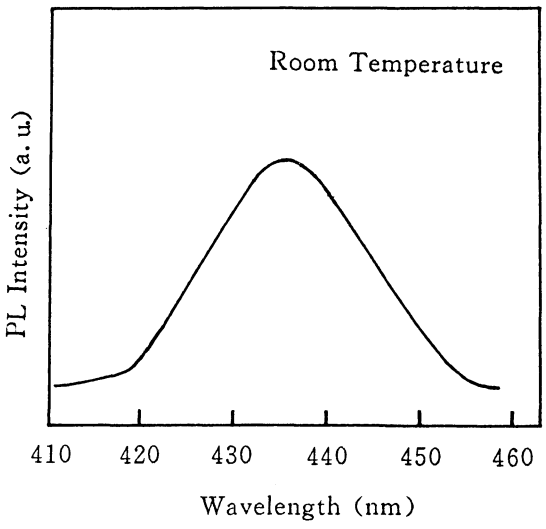

Fig. 3. PL spectrum from ZnSe-ZnS SLs waveguide sample at room temperature.

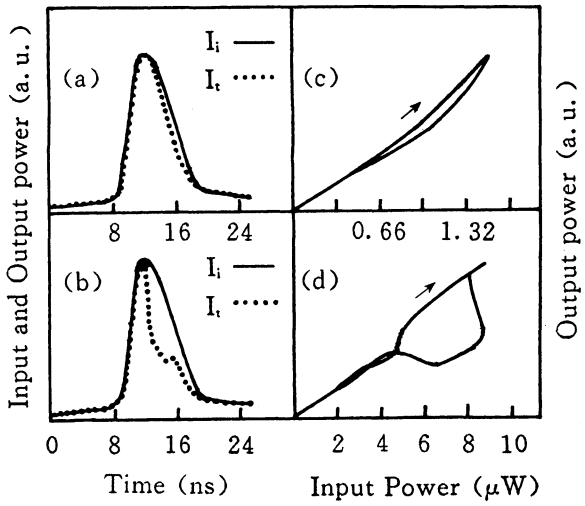

Fig. 4. Time dependence of averaged normalized incident (solid) I_i and transmitted (broken) I_t pulses at 430. 8 nm (a) and (b) under different incident intensities of 0. 1 I_0 and 0. 6 I_0 and the resulting hysteresis loops (c) and (d).

the on state in 500 ps. The switching response time is 500 ps under the incident intensity of 24 $mW/\mu m^2$ (corresponding to averaging power of about 9 μW). The threshold switching power into the waveguide is ~ 1 μW after correcting for reflection and coupling losses. The result is much lower than that of the same kind of optical bistability device having been reported so far. This is due to the action of two dimensional limitation of the optical waveguide to the incident light.

4. Conclusions

We firstly observed the optical nonlinearities of excitonic saturating absorption caused by phase space filling of excitonic states and excitonic band broadening, and increasing absorption optical bistability of exciton in ZnSe-ZnS SLs planar waveguide at room temperature. The switching response time of the optical bistability is 500 ps. The threshold switching power is much lower than that of the ZnSe-ZnS SLs optical bistability devices reported before.

Acknowledgements

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