Dispersive optical bistability in ZnCdSe–ZnSe/GaAs strained-layer superlattices on reflection at room temperature

Z.P. Guan, Z.H. Zheng, Y.M. Lu, B.J. Yang, X.W. Fan

Changchun Institute of Physics, Academia Sinica Changchun 130021, People's Republic of China

Abstract

The excitonic optical bistability with nanosecond switching time in ZnCdSe–ZnSe/GaAs strained-layer superlattices has been studied on reflection at room temperature. On the basis of the shape of the measured hysteresis loops, photoluminescence and absorption spectra, the origin of the optical bistability is attributed to the effect of excitonic saturating absorption.

With constant development of III–V semiconductor superlattices and quantum-well (QW) structures, the investigation of excitonic luminescence and optical non-linearity of the II–VI super thin-layer structure has attracted much attention. In recent years important developments in the p-type doping of ZnSe by atomic nitrogen in an r.f. plasma during molecular beam epitaxy [1], have dramatically improved prospects for device quality p–n heterojunctions. ZnCdSe QW structures were studied as a laser medium [2, 3], and the blue-green injection laser diodes in ZnCdSe–ZnSe QWs [4] have been observed up to 394 K. At the same time the absorption properties of these QW systems have been found to display a strong excitonic nature [5, 6]. Wang and coworkers investigated the quantum-confined Start effect and fabricated a ZnSe–ZnCdSe self-electro-optic effect device [7, 8] at room temperature. In this paper, the saturating absorption and optical bistability with nanosecond (ns) switching time in ZnCdSe–ZnSe/GaAs strained-layer superlattices (SLSs) on reflection have been studied at room temperature (RT). On the basis of the shape of the measured hysteresis loops, photoluminescence (PL) and absorption spectra, the optical bistability in ZnCdSe–ZnSe SLS observed here is attributed to the dispersive non-linearity owing to the effect of excitonic saturating absorption.

The $Zn_{0.78}Cd_{0.22}Se$–ZnSe SLS sample used in these experiments consisted of alternating undoped thin layers of 7.5 nm $Zn_{0.78}Cd_{0.22}Se$ and 8.0 nm ZnSe with 100 periods grown on a GaAs substrate by metal–organic chemical vapour deposition. The excitation source was a dye laser pumped by the 337.1 nm line of a N_2 pulse laser. The dye-laser pulse was 3 ns in duration and 15 nm in spectral half-width with a central wavelength of 515 nm.

Fig. 1 shows a typical X-ray diffraction pattern from a $Zn_{0.78}Cd_{0.22}Se$–ZnSe SLS on a (100) GaAs substrate with a ZnSe buffer layer where some satellite peaks were observed, indicating the superlattice structure. Fig. 2(a) shows the PL spectra at 77 K and RT in a ZnCdSe (7.5 nm)–ZnSe (8.0 nm)/GaAs SLS excited by the 337.1 nm line of a N_2 laser with a pulse width of
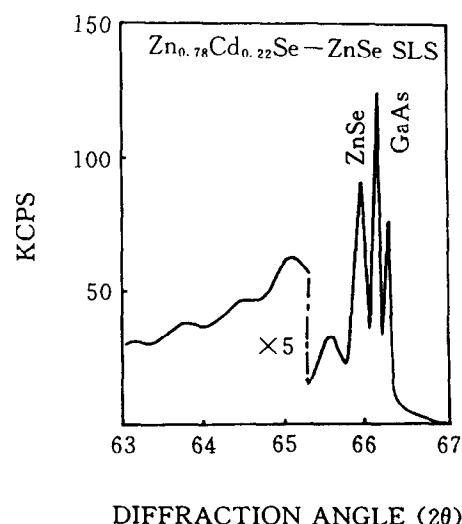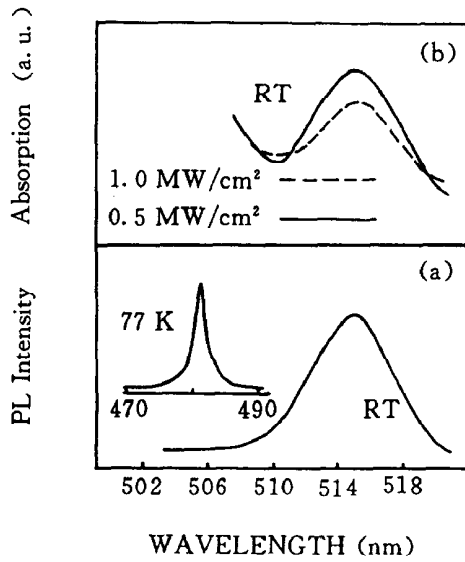

Fig. 1. X-ray diffraction pattern of a $Zn_{0.78}Cd_{0.22}Se$–ZnSe SLS.

Fig. 2. PL spectra (a) and absorption spectra under a different excitation power (b) of a $Zn_{0.78}Cd_{0.22}Se$–ZnSe SLS.

10 ns and a frequency of 20 Hz. The absorption spectrum on reflection for the same sample is measured at RT by using a broad-band dye laser under different excitation as shown in Fig. 2(b). The excitonic absorption peak is at 515.2 nm, therefore the excitonic absorption light is just at the excitonic absorption region. With increasing incident intensity the absorption band tends to saturate.

Figs. 3(a) and 3(b) are the normalized temporal shapes of incident I_0 and reflection I_r pulses in the same sample at two wavelengths. Figs. 4(a) and 4(b)
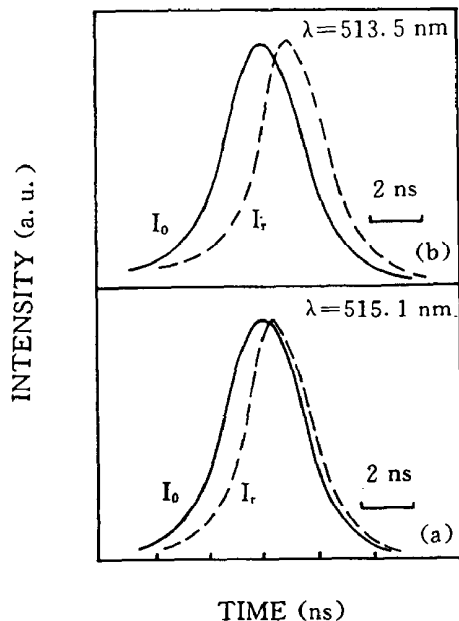

Fig. 3. Time dependence of averaged normalized incident (solid line) I_0 and reflection (broken line) I_r for different wavelengths in $Zn_{0.78}Cd_{0.22}Se$–ZnSe/GaAs at room temperature.
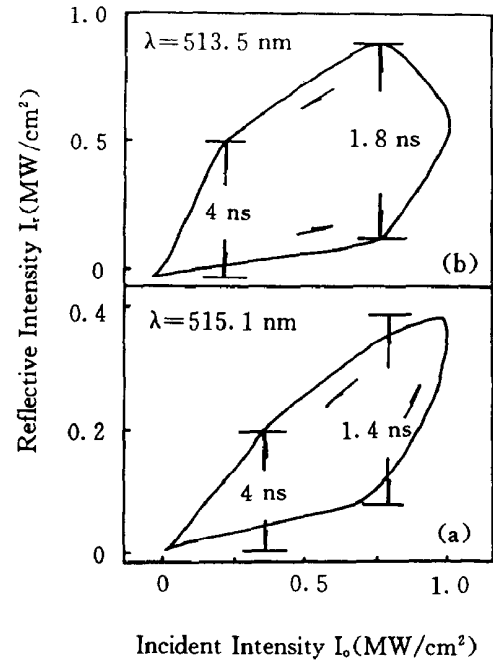

Fig. 4. The optical bistability of a $Zn_{0.78}Cd_{0.22}Se$–ZnSe/GaAs SLS on reflection at room temperature: (a) $\lambda = 515.1$ nm; (b) $\lambda = 513.5$ nm.

give the corresponding hysteresis loops by showing the reflection intensities as a function of incident intensities. It is noticed that for the incident wavelengths 513.5 nm and 515.1 nm, the temporal shape of hysteresis loops is different shape. The above two wavelengths are both situated in the excitonic absorption region, and the further from the excitonic absorption peak, the clearer the bistability is. In our experiment, the reflectivities of both natural faces in the ZnCdSe–ZnSe SLS are about 0.4. Therefore, the two natural faces of the above sample can form a simple F–P cavity, and, in the presence of loss, the reflection is [9]

$$R_{FP} = \frac{E + F \sin^2\Phi}{1 + F \sin^2\Phi} \tag{1}$$

where

$$E = \frac{(R_F - R_e)^2}{4R_e R_F} F \tag{1a}$$

$$F = \frac{4R_e}{(1 - R_e)^2} \tag{1b}$$

$$R_e = \sqrt{R_F R_B}\, e^{-\alpha L} \tag{1c}$$

$$\Phi = \frac{2\pi}{\lambda} nL = \frac{2\pi}{\lambda} (n_0 + \Delta n)L \tag{1d}$$

Here R_F and R_B are the front and rear reflectivities, the thickness is L, n and α are the refractive index and the absorption coefficient, the effective reflectivity

is R_e and the finesse is F. In our cases, α is about $1 \times 10^3 \, \text{cm}^{-1}$, $L = 1.0 \, \mu\text{m}$ and $R_F = R_B = 0.4$. From the above parameters, αL is about equal to 0.1, $F \sim 3.5$ and $E = 0.01$, we obtain

$$R_{FP} = \frac{0.01 + 3.5 \sin^2 \Phi}{1 + 3.5 \sin^2 \Phi} \qquad (2)$$

Eq. (2) shows that the major contribution to the optical bistabilities originates from the change in refractive index (Δn). This result obtained in the ZnCdSe–ZnSe SLS with an F–P cavity is reasonable and should be attributed to dispersive optical bistabilities. In Fig. 2(b), as the incident intensity increases the absorption band does not shift to the low energy side, so the optical bistability does not originate from the thermal effect.

From Figs. 4(a) and 4(b) the switching thresholds from low to high state are $0.6 \, \text{MW cm}^{-2}$ and $0.8 \, \text{MW cm}^{-2}$ for 515.1 nm and 513.5 nm of incidence, and the contrast ratio for the optical bistabilities obtained in our experiment are about 4.6:1 and 6:1, respectively. In Figs. 4(a) and 4(b) is also given the open and close times for bistability.

In conclusion, excitonic dispersive optical bistability in ZnCdSe–ZnSe SLSs on reflection at room temperature have been observed and the major non-linear mechanism is due to the change of refractive index caused by the excitonic saturation of absorption.

Acknowledgements

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