ELSEVIER

Journal of Crystal Growth 159 (1996) 805–808

JOURNAL OF CRYSTAL GROWTH

Picosecond optical bistability in ZnSe–CdZnSe multiple quantum wells with a Fabry–Pérot cavity

D.Z. Shen *, J.Y. Zhang, S.M. Wang, B.J. Yang, X.W. Fan

Laboratory of Excited State Processes, Changchun Institute of Physics, Academia Sinica, Changchun 130021, People's Republic of China

Abstract

Excitonic optical bistability with picosecond switching time in ZnSe–CdZnSe multiple quantum wells (MQWs) with a Fabry–Pérot (FP) cavity is investigated at room temperature. The result indicates that the threshold and switching time for the optical bistability in ZnSe–CdZnSe MQWs with a FP cavity are about 210 kW/cm^2 and 50 ps, respectively. On the basis of the excitonic nonlinear theories, excitonic absorption spectra in the ZnSe–CdZnSe MQWs under different excitation intensities obtained here, we attribute the major nonlinear mechanism for the optical bistability in ZnSe–CdZnSe MQWs with a FP cavity to the phase space filling of excitonic states and excitonic band broadening due to exciton–exciton interactions.

1. Introduction

Recently, room temperature excitonic optical nonlinearities and optical bistability in wide gap II–VI semiconductor superlattices have become an interesting research topic due to the large excitonic binding energy in comparison to III–V semiconductor superlattices [1]. Ding et al. [2] have reported the room temperature excitonic absorption in (Zn,Cd)Se–ZnSe MQWs. Wang et al. [3] have observed the optical bistability at room temperature for the first time in a ZnSe/ZnCdSe bistable self-electro-optic effect device fabricated by molecular beam epitaxy. We have investigated the room temperature excitonic optical bistabilities with nanosecond switching time in ZnSe–ZnS MQWs [4] and with picosecond switching time in ZnSe–ZnTe MQWs [5] operation in reflection. In this paper, we report the observation and study of the picosecond excitonic optical bistability in ZnSe–CdZnSe MQWs with a FP cavity at room temperature.

2. Experiment

The ZnSe–CdZnSe MQWs structure used in this study was grown on a n-GaAs substrate by metalorganic chemical vapour deposition (MOCVD) method [6] and they consisted of 5 nm CdZnSe wells and 10 nm ZnSe barriers repeated for 50 periods.

The sample studied here is ZnSe–CdZnSe MQWs within a Fabry–Pérot (FP) cavity. In order to fabricate ZnSe–CdZnSe MQWs with a FP cavity, the GaAs substrate was removed by etching to allow for making the FP cavity [7]. The FP cavity used in our research is made by vacuum deposition with a thermal source under a background pressure of 10^{-6} Torr. The reflective layer is made according to the prescription: $(HL)^p(H')(LH)^p$, where $p = 5$. The

* Corresponding author. Fax: +86 431 5955378.

0022-0248/96/$15.00 © 1996 Elsevier Science B.V. All rights reserved
SSDI 0022-0248(95)00758-X

notation $(HL)^p$ implies a quarter-wave of high-index material, H, followed by a quarter-wave of low-index material, L, p times. The region H' is the ZnSe–CdZnSe MQWs with the 1 μm thickness ZnSe buffer layer; here $H' = 1.75$ μm. The high-index material is ZnS with a refractive index n_H of 2.35. The low-index material used is cryolite (Na_3AlF_6) with a refractive index n_L of 1.35. The quarter-wave layers, having ZnS and Na_3AlF_6 alternatively, are deposited on the up-side of the MQWs layer and the down-side of the ZnSe buffer layer. Care is taken to achieve a nearly perfect match in reflectance of the two dielectric mirrors, $(HL)^5$ and $(LH)^5$, respectively. The reflectivities of the two dielectric mirrors are about 0.9, respectively.

Excitonic optical bistability in the ZnSe–CdZnSe MQWs with a FP cavity was monitored by measuring the time-dependent temporal transmitted intensities as a function of incident intensities at a wavelength of 532 nm. The excitation source is a Nd:YAG laser producing 200 ps pulses at a wavelength of 532 nm with a repetition rate of 1 Hz. The time dependence of incident I_i and transmitted I_t pulses was measured at the same time by using a M176 high speed streak camera. The experimental setup is shown in Fig. 1.

3. Experimental results and discussion

Figs. 2a and 2c show the normalized temporal shapes of the incident I_i and transmitted I_t pulses in the ZnSe–CdZnSe MQWs with a FP cavity at room temperature under the condition of low and high incident intensities, respectively, and Figs. 2b and 2d give the resulting hysteresis loops $I_t = f(I_i)$. The results show that the temporal shapes of the incident I_i and transmitted I_t pulses are quite similar under

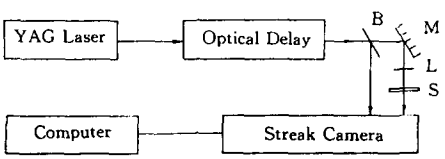

Fig. 1. Schematic diagram for measuring optical bistability in ZnSe–CdZnSe MQWs with a FP cavity: (B) beam splitter; (L) lens; (S) sample; (M) mirror.

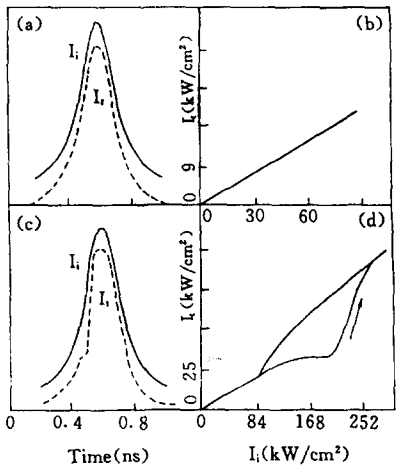

Fig. 2. Time dependence of the temporal shapes of the incident (solid curve) I_i and transmitted (dashed curve) I_t pulses in ZnSe–CdZnSe MQWs with a FP cavity at room temperature (a) under low excitation intensities and (c) under high excitation intensities. The resulting hystersis loops (b) and (d).

low incident light intensity. However, the temporal shape of transmitted I_t is obviously different from that of incident I_i under high incident light intensities. These facts indicate that the dependence of the transmitted intensity I_t on the incident intensity I_i in the case of low and high incident intensities is linear and nonlinear, respectively. An obvious optical bistability characteristic can be observed in the ZnSe–CdZnSe MQWs with a FP cavity at room temperature under high excitation intensity from Fig. 2d, in which the threshold and switching time for the optical bistability in the ZnSe–CdZnSe MQWs with a FP cavity are about 210 kW/cm^2 and 50 ps, respectively.

For a FP cavity, the optical bistability might be absorptive or dispersive. The condition for the pure absorption optical bistability is [8]

$$\frac{\alpha_0 L}{T + \alpha_b L} \geq 8, \tag{1}$$

where $\alpha_0 L$ and $\alpha_b L$ are the linear and unsaturable absorptions, respectively and T is the transmission of each face in the FP cavity. In our case, $\alpha_0 L$, $\alpha_b L$ and T are about 0.4, 0.3 and 0.1, respectively. Obviously, the critical condition for pure absorption optical bistability is not satisfied in this case. There-

fore, the optical bistability obtained here in the ZnSe–CdZnSe MQWs within a FP cavity is dispersive, that is, the major nonlinear mechanism for the optical bistability in the ZnSe–CdZnSe MQWs within a FP cavity is due to the change of refractive index in the ZnSe–CdZnSe MQWs.

In order to study the origin of the nonlinearity for the optical bistability in the ZnSe–CdZnSe MQWs with a FP cavity, the absorption spectrum of the ZnSe–CdZnSe MQWs was measured at room temperature by using broad band continuous wave light. It was found that the excitonic absorption peak of the ZnSe–CdZnSe MQWs is at 530 nm. Therefore, the wavelength of the excitation light is just in the excitonic absorption region. On the basis of the excitonic and related nonlinear theories, the major nonlinear mechanisms are as follows: the nonlinearities due to excitonic effect include phase space filling of excitonic states [9], excitonic screening of the Coulomb interaction and excitonic band broadening [9,10]; the nonlinearities due to the band gap effect include band filling and band shrinkage [11,12]. The major characteristic of the excitonic nonlinear effects is the excitonic saturation of the absorption and the characteristic of band gap effects is the shift of band edge absorption. As a general rule, the intensity in MQWs required for the excitonic nonlinear effect is smaller than that for the band gap effect. It is reasonable to consider that the excitonic nonlinear effect for the optical bistability plays a major role with increase in the incident intensity. Our interest is whether the band gap nonlinear effect for the optical bistability also plays a major role. In terms of the characteristic of the band gap effect, the band edge absorption spectra are measured by using a pump and probe technique [9] as shown in Fig. 3. The pump and probe beams are the 337.1 nm line of a N_2 laser and the tunable dye laser from 510 to 550 nm by using Coumarin-480 pumped by the 337.1 nm line of the N_2 laser. In the present pump intensity, a reduction of the excitonic absorption, a small blue shift and broadening on either side of the excitonic band in the ZnSe–CdZnSe MQWs can be observed in Fig. 3. When the pump intensity is equal to the threshold of the optical bistability in ZnSe–CdZnSe MQWs with a FP cavity, only the excitonic saturation of the absorption was observed; the shift of band edge absorption in the ZnSe–CdZnSe MQWs was

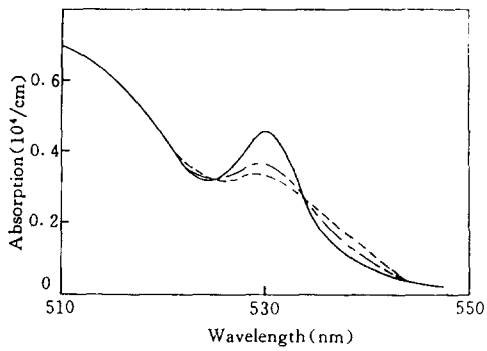

Fig. 3. The absorption spectra of ZnSe–CdZnSe MQWs at room temperature under different pump intensities, I: 0 MW/cm^2 (————); 0.1 MW/cm^2 (– – –); 0.21 MW/cm^2 (– · –).

not observed. On the other hand, the absorption coefficient of the ZnSe–CdZnSe MQWs at the 337.1 nm line is larger than that at the 532 nm line. The results indicate that the band gap effect does not play a major role in the optical bistability. Therefore, the major nonlinear mechanism for the optical bistability obtained here is due to the excitonic saturation of the absorption. According to excitonic absorption spectra in the ZnSe–CdZnSe MQWs obtained here and excitonic nonlinear theories in MQWs, the major excitonic nonlinear mechanism in the ZnSe–CdZnSe MQWs is due to the phase space filling of excitonic states and excitonic band broadening [9], and the excitonic screening of the Coulomb interaction does not play a major role [13,14]. Based on the above analysis, we attribute the major nonlinear mechanism for the optical bistability to the phase space filling of excitonic states and excitonic band broadening.

For a FP cavity operation in transmission, the transmittance of the FP cavity is

$$T_{FP} = \frac{H}{1 + F \sin^2 \varphi}, \tag{2}$$

where

$$\varphi = (2\pi/\lambda) nL, \tag{2a}$$

and

$$n = n_0 + \Delta n. \tag{2b}$$

Here λ and L are the incident wavelength and the cavity length, respectively. n_0 and Δn are the background refractive index and the change in the refractive index due to the increase of the incident inten-

sity, respectively. H and F are the maximum transmittance and finesse of a FP cavity, respectively. In our case, the transmission peak measured in the ZnSe–CdZnSe MQWs with a FP cavity is at 546 nm. It is found that the optical bistability in the ZnSe–CdZnSe MQWs with a FP cavity disappears by degrees when the value of the incident wavelength gradually departs from 532 nm. Therefore, the incident wavelength of 532 nm is just at the work point for the FP cavity [15]. The change of nonlinear refractive index in the ZnSe–CdZnSe MQWs within the FP cavity is about 0.03 at 532 nm measured by using a Z-scan technique [16] when the excitation intensity is equal to 210 kW/cm^2. The value of 0.03 is larger than that required for the optical bistability in the ZnSe–CdZnSe MQWs with a FP cavity [9]. Therefore, the positive feedback required for optical bistability can be achieved by the FP cavity with the change of refractive index due to the phase space filling of excitonic states and excitonic band broadening.

4. Conclusion

In conclusion, we have studied the excitonic optical bistability with picosecond switching time in the ZnSe–CdZnSe MQWs with a FP cavity at room temperature. The results indicate that the threshold and switching time for the optical bistability in the ZnSe–CdZnSe MQWs with a FP cavity are about 210 kW/cm^2 and 50 ps, respectively. On the basis of the experimental results measured in the excitonic absorption spectra in the ZnSe–CdZnSe MQWs and excitonic nonlinear theories, we attribute the major nonlinear mechanism in the optical bistability of ZnSe–CdZnSe MQWs with a FP cavity to phase space filling of excitonic states and excitonic band broadening caused by the exciton–exciton interactions.

Acknowledgements

The work is supported by the "863" High Technology Research Program in China, the National Fundamental and Applied Research Project and the National Natural Science Foundation of China.

References

[1] D. Lee, J.E. Zucker, A.M. Johnson, R.D. Feldman and R.F. Austin, Appl. Phys. Lett. 57 (1990) 1132.
[2] J. Ding, N. Pelekanos, A.V. Nurmikko, H. Luo, N. Samarth and J.K. Furdyna, Appl. Phys. Lett. 57 (1990) 2885.
[3] S.Y. Wang, G. Horsburgh, P. Thompson, I. Hauksson, J.T. Mullins, K.A. Prior and B.C. Cavenett, Appl. Phys. Lett. 63 (1993) 857.
[4] D.Z. Shen, X.W. Fan, B.J. Yang, L.C. Chen and J.Q. Yu, J. Lumin. 60–61 (1994) 630.
[5] D.Z. Shen, X.W. Fan, Z.S. Piao and B.J. Yang, Extended Abstracts of the 1992 Int. Conf. on Solid State Devices and Materials, Tsukuba, Japan, 26–28 August, 1992 (Business Center for Acan. Soc. Japan, Tokyo, 1992) pp. 229–231.
[6] X.W. Fan, G.H. Fan, F.Y. Jiang and Z.P. Guan, presented at Int. Symp. on Spectra and Optoelectronic Properties in Semiconductors and Related Material, Shanghai, 1990.
[7] J.M. Sun, D.Z. Shen, X.W. Fan, J.Y. Zhang, Y.M. Lu and B.J. Yang, Chin. J. Lumin. 15 (1994) 172.
[8] F. Henneberger, Phys. Status Solidi (b) 137 (1986) 371.
[9] D.Z. Shen, X.W. Fan and G.H. Fan, Nonlinear Optics 1 (1991) 319.
[10] D.Z. Shen, X.W. Fan, G.H. Fan, L.C. Chen, C.F. Li and Y.D. Liu, Chin. Acta Opt. Sinica 10 (1990) 643.
[11] D.Z. Shen, X.W. Fan, Z.S. Piao and G.H. Fan, J. Crystal Growth 117 (1992) 519.
[12] H. Haug and S. Schmitt-Rink, J. Opt. Soc. Am. B 2 (1985) 1135.
[13] S. Schmitt-Rink, D.S. Chemla and D.A.B. Miller, Phys. Rev. B 32 (1985) 6601.
[14] D.Z. Shen, X.W. Fan and G.H. Fan, Chin. J. Semiconductors 12 (1991) 763.
[15] E. Garmire, IEEE J. Quantum Electron. 25 (1989) 289.
[16] J. Ma, S.M. Wang, D.Z. Shen and X.W. Fan, presented at Int. Conf. on Nonlinear Optical Physics and Application, Harbin, China, 1995.