Journal of Crystal Growth 117 (1992) 519–522
North-Holland

JOURNAL OF CRYSTAL GROWTH

Picosecond optical bistability in ZnSe–ZnTe/CaF_2 multiple quantum wells at room temperature

D.Z. Shen, X.W. Fan, Z.S. Piao and G.H. Fan

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

We present the first observation of room-temperature picosecond optical bistability in ZnSe–ZnTe multiple quantum wells (MQWs) grown by metalorganic chemical vapour deposition (MOCVD) on transparent CaF_2(111) substrates. On the basis of the direction of the hysteresis loop, the absorption and the energy band structure in ZnSe–ZnTe MQWs, we show that the nonlinear mechanism for the optical bistability of ZnSe–ZnTe MQWs is due to the effect of increasing absorption, which is ascribed to the band gap shrinkage of ZnSe–ZnTe MQWs due to the high density of electrons and holes in the MQWs. The ps switching time can be explained by the electrons excited to the conduction band of ZnTe layer in ZnSe–ZnTe MQWs relaxing quickly to the conduction band of ZnSe layer in this material system.

1. Introduction

Optical nonlinearities of II–VI wide gap semiconductor have become an interesting research topic recently [1–4]. ZnSe–ZnTe MQWs are a kind of semiconductor superlattices with a energy band structure of type II [5]. These MQWs can cover a wide spectral range from the red to the blue by changing the well and barrier widths in the ZnSe–ZnTe MQWs, and they can be expected to be used in new optoelectronic devices. Therefore, it is very important to investigate the optical properties of ZnSe–ZnTe MQWs [6]. Until now, there has been no report on the optical nonlinearities in ZnSe–ZnTe MQWs. In this paper, we report the first observation of optical bistability in ZnSe–ZnTe MQWs grown by MOCVD on transparent CaF_2(111) substrates with picosecond switching time at room temperature.

2. Experimental results and discussion

The material system studied here is ZnSe–ZnTe MQWs, grown by MOCVD [7], on transparent CaF_2(111) substrates. The electronic grade dimethyl zinc (DMZ) and diethyl tellurium (DET) sources were contained in stainless-steel bubblers placed in a temperature-controlled bath, the mode fractions of DMZ and DET were adjusted by the temperature of cooling bath and by the flow rate of the H_2 carrier gas. 10% H_2Se mixed in high purity H_2 gas was used as the source of Se. In order to avoid the pernicious gas phase premature reaction, an RF heated reactor equipped with a water cooling sheath was used. H_2Se was supplied through the central nozzle and an inner tube, and met the DMZ and DET 2.5 cm away from the substrate. The flow rates of the source gases were automatically controlled by opening or shutting the valves linked with each mass flow controller using an IBM PC-XT computer. The growth conditions for the fabrication of ZnSe–ZnTe MQWs on CaF_2(111) are as follows: the substrate temperature is 460°C, and the flow rates of DMZ, DET and H_2Se are about 5×10^{-5}, 20×10^{-5} and 20×10^{-5} mol/min, respectively. The temperatures of the cooling baths for the DMZ and DET are about −25°C and +10°C, respectively. 100 periods of the ZnSe–ZnTe superlattice with 5 nm ZnTe wells and 5 nm ZnSe barriers were grown.

All measurements reported here were taken at room temperature except the excitonic emission

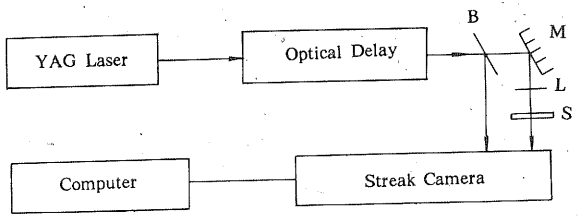

Fig. 1. Schematic diagram for measuring optical bistability in ZnSe–ZnTe MQWs on CaF_2: (B) beam splitter; (L) lens; (S) sample; (M) mirror.

of ZnSe–ZnTe MQWs. The absorption and emission spectra were made by using a broad-band continuous wave light source and the 337.1 nm line of a N_2 laser (with a pulse width of 10 ns and a frequency of 30 Hz), respectively. The signals were received using a SPEX 1404 monochromator with cooled RCA-C31034 photomultiplier, in which the electronic signals obtained by the photomultiplier were collected using a computer in conjunction with a photon counter and a 4400 Boxcar signal average system. The time dependence of incident I_0 and transmitted I_t pulses was measured by using a M176 high speed streak camera with 2 ps response time. The excitation source was a Nd : YAG laser producing 1 ns pulses at a wavelength of 532 nm with a repetition rate of 1 Hz. The experimental setup is shown in fig. 1.

Figs. 2a and 3a show the normalized temporal shapes of the incident I_0 and transmitted I_t pulses with a wavelength of 532 nm at room temperature in the condition of low and high incident

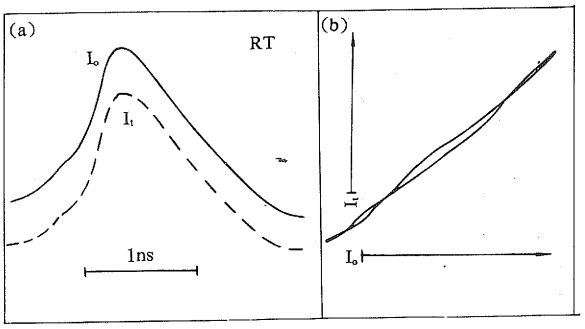

Fig. 2. Time dependence of the temporal shape of the incident (solid curve) I_0 and transmitted (dashed curve) I_t pulses (a) in ZnSe–ZnTe MQWs on CaF_2 at room temperature under low excitation densities. The resulting hysteresis (b).

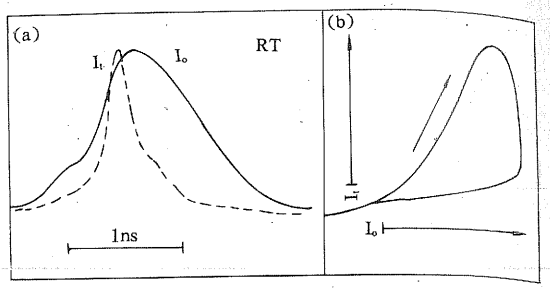

Fig. 3. Time dependence of the temporal shape of the incident (solid curve) I_0 and transmitted (dashed curve) I_t pulses (a) in ZnSe–ZnTe MQWs on CaF_2 at room temperature under high excitation densities. The resulting hysteresis (b).

intensities, respectively, and figs. 2b and 3b give the resulting hysteresis loops $I_t = f(I_0)$. The results show that the temporal shapes of the incident I_0 and transmitted I_t pulses are quite similar under low incident light intensities. However, the 1 ns incident I_0 pulse was compressed into a 250 ps transmitted I_t pulse under high incident light intensities. These facts indicate that the dependence of the transmitted intensity I_t on the incident intensity in the case of low and high incident intensities is linear and nonlinear, respectively. In our case, because of the low reflectivity (about 0.1) of both faces in the ZnSe–ZnTe MQWs with poor surfaces, the simple Fabry–Pérot cavity due to the natural faces of the MQW material does not play a major role for the transmitted I_t pulse. Therefore, the optical bistability obtained here can be attributed to pure absorption optical bistability. The clockwise direction of hysteresis loop in fig. 3b indicates that the major nonlinear mechanism for the optical bistability is due to the effect of increasing absorption [8]. In order to investigate the origin of increasing absorption in the optical bistability of ZnSe–ZnTe MQWs on CaF_2 at room temperature, the absorption spectrum of ZnSe–ZnTe MQWs was measured at room temperature. It was found that the absorption coefficient of the ZnSe–ZnTe MQWs decreases with increasing probe wavelength, therefore the effect of increasing absorption can be explained by the red shift of the absorption edge in ZnSe–ZnTe MQWs.

Because the electronic affinity of ZnSe is larger than that of ZnTe, the ZnSe–ZnTe MQWs sys-

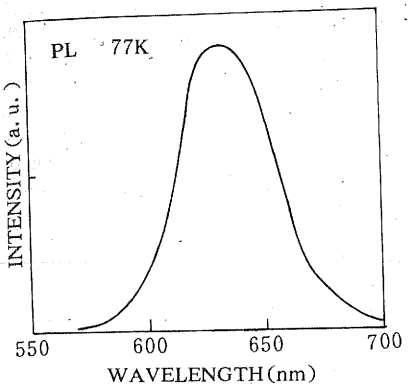

Fig. 4. The photoluminescence spectrum of ZnSe–ZnTe MQWs on CaF_2 at 77 K.

tem has a type-II band line up [5]. In this quantum well structure, the excited electronic recombination is from the levels in the conduction band of the ZnSe layer to the levels in the valence band of the ZnTe layer, the formation of a quantum well structure has been supported by the observation of excitonic emission in ZnSe–ZnTe MQWs [6], and a similar result has been obtained for our samples, as shown in fig. 4.

Here the wavelength of the excitation light is 532 nm, and the corresponding energy is 2.33 eV. It is greater than that of the energy gap of ZnTe in ZnSe–ZnTe MQWs, but it is less than that of ZnSe in ZnSe–ZnTe MQWs. Therefore, the electron is excited directly from the levels of the valence band in the ZnTe layer of ZnSe–ZnTe MQWs to the levels of the conduction band in the ZnTe layer of the ZnSe–ZnTe MQWs. In the case of low incident intensities, the low electron and hole densities in the ZnTe layer of ZnSe–ZnTe MQWs cannot cause the change of absorption edge of the ZnSe–ZnTe MQWs, and they rapidly relax to the levels of the conduction band of the ZnSe layer in ZnSe–ZnTe MQWs. As the incident intensity increases, the electron and hole densities become so high that the many-body effect will cause band gap shrinkage [9]. This band gap shrinkage will further cause an increase of the absorption coefficient of ZnSe–ZnTe MQWs at the wavelength position of the excitation light (532 nm), and make the electron densities in the conduction band of the ZnTe layer of the ZnSe–ZnTe MQWs increase further, and so on. Thus, a positive feedback mechanism is established. On the basis of the analysis of the results above, we can conclude that the increasing absorption giving the optical bistability is due to the effect of band gap shrinkage due to the high electron and hole densities in the ZnTe layer of the MQWs. Because electrons excited to the conduction band of the ZnTe layer of the ZnSe–ZnTe MQWs rapidly relax to the conduction band of the ZnSe layer of ZnSe–ZnTe MQWs within the time of a ps or less, we can observe ps switching times in ZnSe–ZnTe MQWs. This is very favorable for us to get a high speed optical bistability switching device at room temperature.

3. Conclusions

In conclusion, we give the first observation of optical bistability at room temperature with picosecond switching times in ZnSe–ZnTe MQWs grown by MOCVD on transparent $CaF_2(111)$ substrates. The results indicate that the major positive feedback mechanism for the optical bistability is due to the effect of increasing absorption, and the major origin of the nonlinearity giving the increasing absorption is the band gap shrinkage due to the high electron–hole densities in the conduction and valence bands of the ZnTe layer of the MQWs respectively. In this material system, the fastly relaxation process at the conduction band from ZnTe layer to ZnSe layer allowed us to get a high speed switching device by using the properties of optical bistability at room temperature.

Acknowledgements

This work is supported by the "863" High-Technology Research Program in China and the National Natural Science Foundation of China.

References

[1] D.R. Andersen, L.A. Kolodziejski, R.L. Gunshor, S. Datta and A.E. Kaplan, Appl. Phys. Letters 48 (1986) 1559.

[2] N. Peyghambarian, S.H. Park, S.W. Koch, A. Jellery, J.E. Potts and H. Cheng, Appl. Phys. Letters 52 (1988) 182.
[3] D. Lee, J.E. Zucker, A.M. Johnson, R.D. Feldman and R.F. Austin, Appl. Phys. Letters 57 (1990) 1132.
[4] D.Z. Shen, X.W. Fan, G.H. Fan and J.Y. Zhang, J. Luminescence 48 (1991) 299.
[5] H. Fujiyasu and K. Mochizuki, J. Appl. Phys. 57 (1985) 2960.
[6] M. Kobayashi, N. Mino, H. Katagiri, R. Kimura, M. Konagai and K. Takahashi, J. Appl. Phys. 60 (1986) 773.
[7] X.W. Fan, G.H. Fan, F.Y. Jiang and Z.P. Guan, presented at Intern. Symp. on Spectra and Optoelectronic Properties in Semiconductors and Related Material, Shanghai, 1990.
[8] D.Z. Shen, X.W. Fan, G.H. Fan, L.C. Chen, C.F. Li and Y.D. Liu, Acta Opt. Sinica 10 (1990) 643.
[9] V.P. Gribkovskii, L.G. Zimin, S.V. Gaponenko, I.E. Malinovskii, P.I. Kuznetsov and G.G. Yakushcheva, Phys. Status Solidi (b) 150 (1988) 761.