

Optical Properties in ZnCdSe-ZnSe Multiple Quantum Wells

X. W. Fan, J. Y. Zhang, D. Z. Shen and B. J. Yang

Laboratory of Excited State Processes, Changchun Institute of Physics, Academia Sinica,
Changchun 130021, P. R. China

The optical properties of $Zn_{1-x}Cd_xSe$ -ZnSe multiple quantum wells (MQWs) have been investigated. The MQWs samples exhibit five photoluminescence peaks under the 457.9 nm line of an Ar ion laser excitation at 77 K. Three of these bands are attributed to different exciton emission: the $n=1$ heavy-hole exciton transition, the $n=1$ light-hole exciton transition and $n=1$ heavy-hole exciton transition with the emission of two LO phonons. The room-temperature nanosecond switching property has also been studied in $Zn_{1-x}Cd_xSe$ -ZnSe MQWs F-P-type optical bistable device operation in reflection, in which their switching threshold and contrast ratio are about 47 kW/cm² and 7:1, respectively. The origin of the major nonlinear mechanism for the optical switching property is due to the change of the refractive index caused by the effect of the excitonic saturating absorption effect in the ZnCdSe-ZnSe MQWs.

KEYWORDS: ZnCdSe-ZnSe MQWs, excitons, optical switching property

1. Introduction

The importance of electron-hole confinement in providing an increase in the binding energy and oscillator strength for excitons is now very well appreciated in I-IV semiconductor quantum well structures and they display a strong excitonic nature including photon absorption and emission processes, which may play an essential role in a laser operation mechanism in wide-band-gap I-IV quasi-two dimensional MQW systems.¹⁻³⁾ Some studies have been made in the optical characteristics.^{4,5)} These include studies on linear/nonlinear excitonic absorption and thermal stability.⁴⁾ In this letter the photoluminescence (PL) of ZnCdSe-ZnSe MQWs grown by atmospheric pressure metalorganic chemical vapour deposition (AP-MOCVD) was studied at different temperature and five emission bands were observed at 77 K for the first time. Three of these bands were attributed to the different exciton emission. We have also obtained nanosecond optical bistability (OB) of ZnCdSe-ZnSe MQWs F-P-type operation in reflection at room temperature (RT). The major nonlinear mechanism for the optical switching property was due to the change of the refractive index caused by the effect of the excitonic saturating absorption in above MQWs.

2. Experimental Procedure

The $Zn_{1-x}Cd_xSe$ -ZnSe MQWs ($x=0.32, 0.24$) studied here are grown on (100) GaAs by AP-MOCVD. Dimethylzinc, dimethylcadmium and H₂Se are used as the source materials. The sample contains 50 periods of 10 nm ZnCdSe wells and 10 nm ZnSe barriers. The ZnCdSe and ZnSe layers are alternately grown at 320°C. A 1 μm thick buffer layer of ZnSe is grown directly on a GaAs substrate.

The material system within the F-P cavity is a $Zn_{0.76}Cd_{0.24}Se$ -ZnSe MQWs of total thickness of 0.75 μm which consists of 50 periods of 5 nm $Zn_{0.76}Cd_{0.24}Se$ wells and 10 nm ZnSe barriers.

3. Experimental Results and Discussion

3.1 Luminescence properties

Figure 1 shows a typical X-ray diffraction pattern from $Zn_{0.68}Cd_{0.32}Se$ -ZnSe MQWs with 50 periods on a GaAs (100) substrate with a ZnSe (1 μm) buffer layer, measured by conventional diffraction using Cu K_α lines. It shows the satellite peaks with a good quality MQWs structure. Figure 2 shows the PL spectra of above sample at temperatures between 77 and 300 K measured by using a JY-T800 Raman spectra equipment and excited by the 457.9 nm line from an Ar ion laser. Some fine structures are observed in Fig. 2 at 77 K. The high energy band is located at 479.4 nm, and other bands in Fig. 2 are located at 515.0 nm (namely P₁), 530.5 nm (P₂), 543.0 nm (P₃) and 570.0 nm (P₄), respectively. The PL intensity of band P₂ (530.5 nm) is about six times stronger than that of the high energy band in the temperature region of 77-85 K. With an increase of temperature to 124 K, the high energy band disappears and band P₁ maintains only a small shoulder on the high energy side of band P₂. In addition, the emission in Fig. 2 mainly consists of bands P₂ and P₃ at 124 K because band P₄ disappears. With an increase of the temperature to 175 K, the emission intensity of band P₂ has clearly decreased and that of band P₃ becomes strong. Both bands P₂ and P₃ can be observed up to 230 K. Then band P₃ disappears with an increase of the temperature and band P₂ can be measured at 300 K. In this letter we are interested in the origin of above emission bands. Usually, the absorption and luminescence characteristics observed at RT in ZnCdSe-

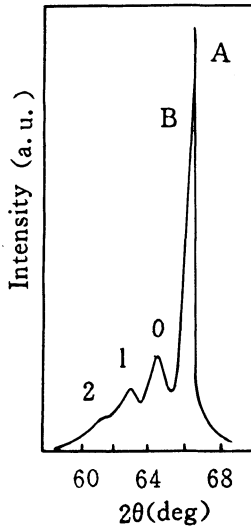


Fig. 1. X-ray diffraction pattern of $Zn_{1-x}Cd_xSe-ZnSe$ ($x = 0.32$) MQWs on GaAs substrate.

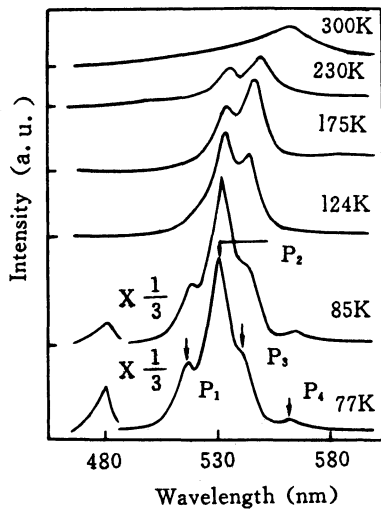


Fig. 2. PL spectra in $Zn_{0.68}Cd_{0.32}Se-ZnSe$ MQWs at 77–300 K by the 457.9 nm line of an Ar ion laser excitation.

ZnSe MQWs are thought to be due mainly to the $n = 1$ heavy-hole (HH) exciton recombination.¹⁻³⁾ In our case, band P_2 (530.5 nm) in Fig. 2 might be considered to be the $n = 1$ HH exciton recombination according to its emission characteristics. So the absorption spectra in above samples at 77 K are measured, as shown in Fig. 3 (a). Two well-defined structures (labeled LH and HH) are observed and they are located at 513 and 526 nm. These are attributed to the light and heavy-hole exciton ground states ($n = 1$) in the quasi-two-dimensional system.²⁾ The separation between the $n = 1$ light hole (LH) and the $n = 1$ HH excitons is approximately 78 meV. Curve (b) in Fig. 3 is the emission spectrum for the above MQWs at 77 K. From Fig. 3 it is found that band P_2 is located at the low ener-

gy side (530.5 nm) of the absorption peak (526 nm) and the peak energy is found to shift to the lower energy side (red shift) from the HH exciton ground quantum level. The amount of the red shift is about 24 meV; however, it exhibits a marked size effect. So band P_2 is attributed to the $n = 1$ HH exciton emission. According to Ref. [5], the calculation predicts a LH uniaxial strain splitting of 75 meV so that the LH state corresponds to a weakly type-I quantum well. From Fig. 2 and Fig. 3, the energy difference between bands P_2 and P_1 is about 70–78 meV and band P_1 (515 nm) is located at the low energy side of the absorption peak LH (513 nm). As mentioned above, it is reasonable to think that band P_1 is ascribed to the $n = 1$ LH exciton emission. It should be noticed that the weaker LH confinement is in agreement with the disappearance of band P_1 with increasing temperature in Fig. 2. The energy difference between bands P_2 and P_3 is 58 meV and

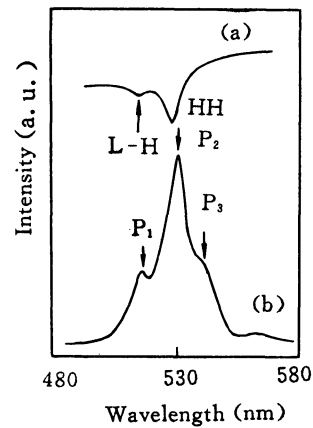


Fig. 3. Absorption (a) and emission (b) spectra in $Zn_{0.68}Cd_{0.32}Se-ZnSe$ MQWs at 77 K.

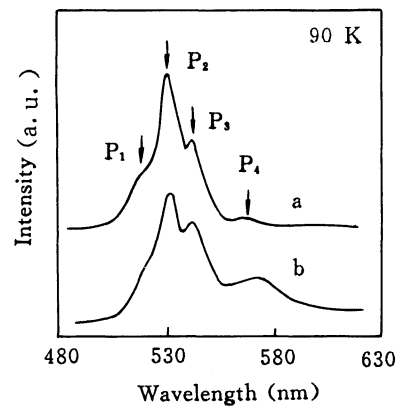


Fig. 4. PL spectra in $Zn_{0.68}Cd_{0.32}Se-ZnSe$ MQWs with different excitation wavelength. (a) 457.9 nm line; (b) 488.0 nm line.

this value corresponds to the energy of the 2LO phonon in ZnSe, where the 2LO phonon energy is 60 meV.⁶⁾ So it is possible to think that band P₃ is attributed to the n = 1 HH exciton recombination with 2LO phonons. If this explanation is correct, the energy difference between bands P₂ and P₃ should not be changed with excitation wavelengths. Figure 4 shows PL spectra of above samples at 90 K by using the 457.9 nm and the 488.0 nm lines of an Ar ion laser. From Fig. 4 the peak positions of bands of P₂ and P₃ are the same under two excitation wavelengths. This result further proves that band P₃ is the n=1 HH exciton recombination with the emission of two LO phonons. The origins of the additional high energy band located at 479.4 nm and band P₄ have not been clear to us.

3.2 Optical bistability

Before the OB is measured, the GaAs substrate is removed by etching to allow making F-P cavity on the MQWs surfaces. The F-P cavity is made by vacuum deposition with a thermal source under a pressure of 10⁻⁶ Torr. The quarter-wave layer, having ZnS and Na₃AlF₆ alternatively, are deposited on the down-side of the MQWs layer. The reflectivity of the up-side of the MQWs due to the smooth nature face of the MQWs layer is about 0.35. The reflectivity of down-side of the MQWs with the reflective layer is about 0.9. The excitation source is a tunable dye layer pumped by the 337.1 nm line of a UV-24 N₂ laser producing 6 ns pulses at the wavelength of 525 nm with repetition rate of 30 Hz. The receiver is a 4400 Boxcar average system with minimum gate width of 2 ns (the experimental setup seen Ref. 7).

The absorption spectrum of the Zn_{0.76}Cd_{0.24}Se-ZnSe MQWs is measured at RT by using a broad-band continuous wave light source, as shown in Fig. 5. The excitonic absorption peak in Fig. 5 is about at 525 nm and it is just at the region (525 nm) of excitation light. Figure 6 is the RT switching property of the Zn_{0.76}Cd_{0.24}Se-ZnSe MQWs F-P type optical bistable device operation in reflection. The experimental result indicates that the switching threshold and the contrast ratio for the optical bistable device operation in reflection are about 47 kW/cm² and 7:1, respectively. For comparison with the results of Fig. 6, the contrast ratio for the optical bistable device operation in reflection is calculated according to F-P cavity theory. For a F-P cavity, the reflectivity is:⁸⁾

$$R = \frac{E + F \sin^2 \phi}{1 + F \sin^2 \phi} \tag{1}$$

where

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

and
$$\phi = \frac{2\pi}{\lambda} nL \tag{1b}$$

with
$$R_e = (R_f R_b)^{\frac{1}{2}} e^{-\alpha L} \tag{1c}$$

Here the R_b and R_f are the exit-face and entrance-face reflectivities, respectively, n and α are the refractive index and absorption coefficient, respectively. λ is the incident light wavelength and L is the cavity length. In our case, the absorption coefficient α is about 3 × 10³/cm, L = 0.75 μm, R_f = 0.35 and R_b = 0.9. From the above parameter, the E and F are about 0.1 and 6, respectively. we obtain:

$$R = \frac{0.1 + 6 \sin^2 \phi}{1 + 6 \sin^2 \phi} \tag{2}$$

At high excitation intensity, the refractive index can be changed in the Zn_{0.76}Cd_{0.24}Se-ZnSe MQWs, the change of the refractive index should cause the change of the R. When the excitation intensity in Zn_{0.76}Cd_{0.24}Se-ZnSe is high enough, the positive feedback required for the optical switching property can be achieved by the F-P cavity with the change of refractive index in the Zn_{0.76}Cd_{0.24}Se-ZnSe MQWs. According to the equation (2), in our case, the idea contrast ratio (CR) for the giving F-P cavity is:

$$CR = \frac{R_{max}}{R_{min}} = 8.7:1 \tag{3}$$

The value calculated for the CR is close to the experimental value of 7:1. Obvious the CR can be very large by reducing the value of E. The switching threshold can be reduced by optimizing the ZnCdSe-ZnSe optical bistable device. From the absorption spectrum of Fig. 5 we consider that the

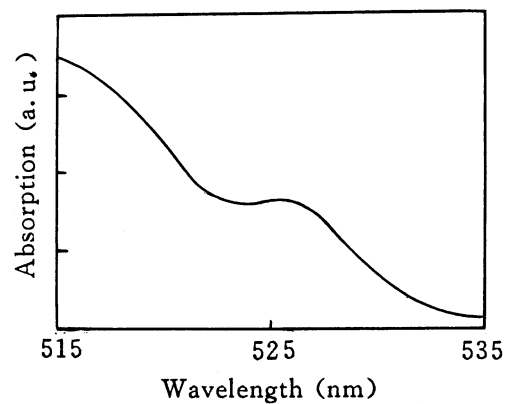


Fig. 5 The absorption spectrum of Zn_{0.76}Cd_{0.24}Se-ZnSe MQWs at room temperature.

optical bistable mechanism in Fig. 6 is associated with the excitons in ZnCdSe–ZnSe MQWs because the excitonic absorption peak in Fig. 5 is just at the wavelength region of the excitation light. On the basis of the excitonic and related nonlinear theories, the intensities in a MQWs required for the excitonic saturating absorption effect is smaller than that in the band gap effect in the MQWs. It is reasonable to consider that excitonic saturating absorption effect should firstly play a major role. Now we want to know whether the band gap nonlinear effect for the optical switching property of the optical bistable device should play a major role too. We change the wavelength of the excitation light to the position of 520 nm, in which the excitonic nonlinear

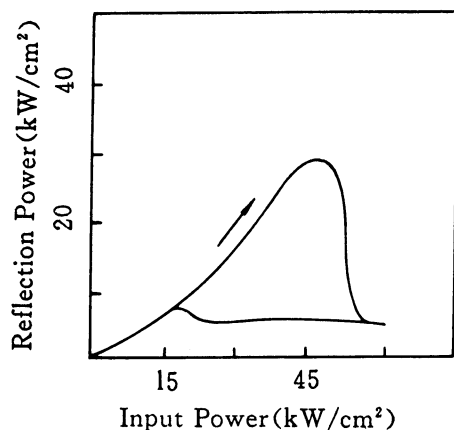


Fig. 6 The optical switching property of Zn_{0.76}Cd_{0.24}Se–ZnSe MQWs optical bistable device on reflection at room temperature.

refractive index caused by the excitonic saturating absorption effect is very small than that in the wavelength of 525 nm. When the intensity of the excitation light at 520 nm is about equal to 50 kW/cm², the optical switching property does not be observed in the experiment. The result indicates that the band gap nonlinear effect does not play a major role. Therefore the major nonlinear mechanism for the optical switching property is due to the exciton-

ic nonlinear refractive index caused by the excitonic saturating absorption effect in the Zn_{0.76}Cd_{0.24}Se–ZnSe MQWs.

4. Conclusion

We have observed five emission bands in Zn_{0.68}Cd_{0.32}Se–ZnSe MQWs at 77 K and the origin of these bands is discussed. Three of these bands are attributed to the n=1 HH exciton transition, the n=1 LH exciton transition and the n=1 HH exciton recombination with the emission of two LO phonons, respectively.

We have also obtained the optical switching threshold and contrast ratio for the optical bistable device of Zn_{0.76}Cd_{0.24}Se–ZnSe MQWs and they are about 47 kW/cm² and 7:1, respectively. The major nonlinear mechanism for the optical switching property is due to the change of the refractive index caused by the effect of the excitonic saturating absorption in the ZnCdSe–ZnSe MQWs.

Acknowledgements

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