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Spontaneous and stimulated emission in ZnCdTe–ZnTe quantum wells grown by LP-MOCVD

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Abstract

ZnCdTe–ZnTe quantum-wells (QWs) have been grown on GaAs(100) substrate by low-pressure metal–organic chemical vapor deposition (LP-MOCVD). The emergence of multi-order satellite peaks in the X-ray diffraction (XRD) pattern indicates the formation of a periodic structure. The stimulated emission, which has rarely been reported in this structure before, is observed at 77 K, where the emission intensity grows superlinearly and the peak position slightly red-shifts with increasing excitation intensity. The origin of the stimulated emission can be attributed to the exciton–exciton collision process. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

Spontaneous and stimulated emission in quantum wells has been a field of enormous interest and effort in recent years, because almost all kinds of semiconductor optoelectronic devices, such as laser diodes (LD) and light-emitting diodes (LED), are based on these processes. II–VI alloy quantum wells, ZnCdTe–ZnTe, for example, have been highlighted because they can offer direct bandgaps throughout the visible spectrum that are unattainable with III–V systems. CdTe–CdZnTe systems with low zinc concentration have been extensively studied [1–3]. Unfortunately, the controllability and uniformity drastically deteriorated at high zinc concentrations during the growth of the ZnCdTe alloy system [4–8]. Therefore, it is difficult, but important, to grow high-quality ZnCdTe–ZnTe QWs with high zinc content, which is essential for realizing blue–green lasers based on this structure. In previous reports in the literature, high-quality ZnCdTe–ZnTe structures were prepared either by molecular beam epitaxy (MBE) [9] or by temperature-gradient vapor-transport deposition (TGVTD) [10], and studies on the metal–organic chemical vapor deposition (MOCVD) of ZnCdTe–ZnTe QWs have rarely been reported. Furthermore, only a few works reported on the spontaneous and stimulated emission of this structure [11], and stimulated emission spectra were not available at all.

2. Experimental

In the present work, $Zn_xCd_{1-x}Te$–ZnTe QWs with high zinc concentration ($x=0.9$) were grown on GaAs(100) substrate in a home-made LP-MOCVD system at 420°C with a growth pressure of 220 torr. The precursors were dimethylzinc (DMZn), dimethylcadmium (DMCd) and diethyltelluride (DETe). The GaAs substrate was chemically polished in $H_2SO_4/H_2O_2/H_2O=3:1:1$, and then boiled in hydrochloric acid. After

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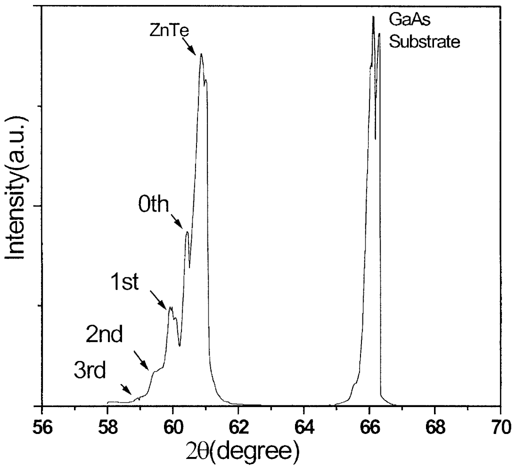

Fig. 1. X-Ray diffraction pattern of ZnCdTe–ZnTe QWs grown on GaAs(100) substrate.

being loaded into the reaction chamber, the substrate was annealed at 600°C in a hydrogen atmosphere for 10 min to avoid the gallium and arsenic oxide layer, which has been demonstrated to be an effective method to remove the oxide layer and residual surface contaminants [12]. The sample investigated here consists of a 0.45-μm ZnTe buffer layer followed by 20 periods of $Zn_{0.9}Cd_{0.1}Te$–ZnTe QWs and then a 30-nm ZnTe cap layer. The thickness of the well layer is 9 nm and barrier layer 12 nm. There is a 30-s growth interruption at each interface. The properties of our samples were determined by XRD measurements and PL spectra. The 337.1-nm line of a pulsed N_2 laser with a duration of 10 ns duration and a frequency of 10 Hz was used as the excitation source for spontaneous and stimulated emission, and the signals were measured using a 44-W monochromator grating with a RCA-C31034 cooled photomultiplier. The sample used in the photopump was cleaved to approximately 2-mm-wide resonators, and Fabry–Perot (F-P) cavities were formed by the natural facets of the sample bars.

3. Results and discussion

In Fig. 1, the (004) reflection of our sample is shown. It is evident that besides the diffraction peaks of the GaAs substrate and ZnTe at 66.2° and 60.85°, distinct superlattice satellites up to the third-order located at 58.99°, 59.45°, 59.92° and 60.39° can be observed. The appearance of equal-spaced satellite peaks indicates the formation of a periodic structure. Also from the X-ray diffraction pattern, we can determine that the periodic length of the sample investigated here is 22 nm, which is slightly larger than the value obtained by the growth rate determined by scanning electron microscopy (SEM) (21 nm). It is thought that the discrepancy is due to the compressive stress that the substrate exerts on the epilayer, which increases the lattice constant perpendicular to the substrate ($a^{\perp}$). A detailed investigation of the correlation between the growth conditions and structure parameters derived from the XRD and optical properties is beyond the scope of this report, and they will be detailed later.

Fig. 2 shows the typical spontaneous emission spectra of $Zn_{0.9}Cd_{0.1}Te$–ZnTe QWs at 77 K and room temperature. The emission peak is considerably red-shifted at room temperature compared to the peak at 77 K, which is a combined effect of the detrapping of the exciton-induced blue shift and the temperature-induced red shift of the bandgap. According to Stanley et al. [13], the emission dominating the spectrum comes from the recombination of excitons at room temperature. However, an asymmetry appears in the emission line, with a tail on the high-energy side. Stanley et al. [13] attributed this tail to the recombination of free carriers. The real origin of the tail needs to be further investigated. The broad full-width at half-maximum (FWHM) is due to both the non-uniformity of the ZnCdTe alloy and the fluctuation of the well layer.

In Fig. 3, the stimulated spectra of ZnCdTe–ZnTe QWs under different excitation intensity at 77 K are shown. It is evident that two peaks appear in the spectrum; the one on the high-energy side is due to the top of the sample bar, while that on the low-energy side is due to the edge of the bar [14]. With increasing excitation intensity, the edge emission on the low-energy side grows superlinearly and shows a considerable red shift and narrowing, while the spontaneous emission on the high-energy side saturates and exhibits no obvious red shift. The above results are in agreement with reports on ZnSe [15], CdS [16] and ZnCdSe–ZnSe [14] systems. The red shift in our experiment can be explained by the theory of exciton–exciton collision. The photon energy for the exciton–exciton collision process can be expressed by the following formula [15]:

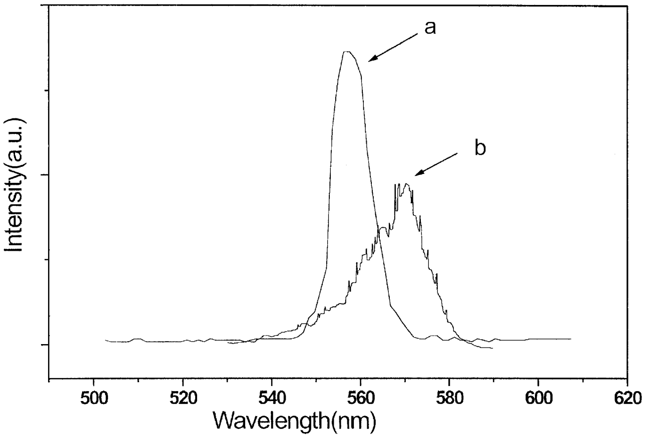

Fig. 2. Photoluminescence spectra of $Zn_{0.9}Cd_{0.1}Te$–ZnTe QWs at (a) 77 K and (b) room temperature.

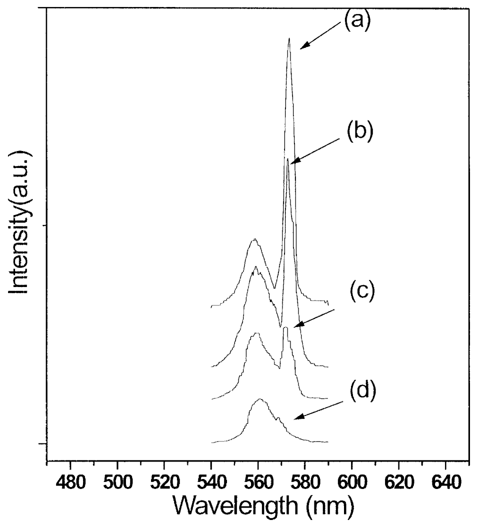

Fig. 3. Emission spectra taken from the cleaved edge of the sample under excitation intensity of: (a) I_0; (b) 0.9 I_0; (c) 0.36 I_0; and (d) 0.13 I_0 at 77 K, where $I_0 = 1$ MW/cm^2.

$$h\nu = E_g - 2E_{ex} - \delta E_k$$

where E_g is the bandgap of the well layer, E_{ex} is the exciton binding energy and δE_k is the kinetic energy of related electrons and holes. When the excitation intensity is small, it can be assumed that the conduction band and the valence band are almost empty, and then the emitted electrons and holes with very little kinetic energy can fill the levels near the Γ point. However, when the excitation intensity increases, the bands are filled with free carriers; only the free carriers having higher kinetic energy can reach the unfilled states, and thus δE_k increases. Then $h\nu$ decreases, and the emission peak red-shifts. The dependence of the intensity and FWHM of the edge emission on the excitation intensity is shown in Fig. 4; it is clearly evident that with increasing excitation intensity, the edge emission increases superlinearly and the FWHM of the emission decreases considerably, which characterizes the emergence of stimulated emission.

4. Conclusions

ZnCdTe–ZnTe quantum wells have been grown by LP-MOCVD. The structural property of the sample was assessed by X-ray diffraction patterns. The photoluminescence spectra at 77 K and room temperature were also measured. A tail appears on the high-energy side with a red-shift in the spectrum at room temperature compared to that at 77 K. In addition, stimulated emission is observed at 77 K. With increasing excitation intensity, the emission intensity grows superlinearly and the FWHM decreases significantly, which characterizes the emergence of stimulated emission. The mechanism is thought to be exciton–exciton collision.

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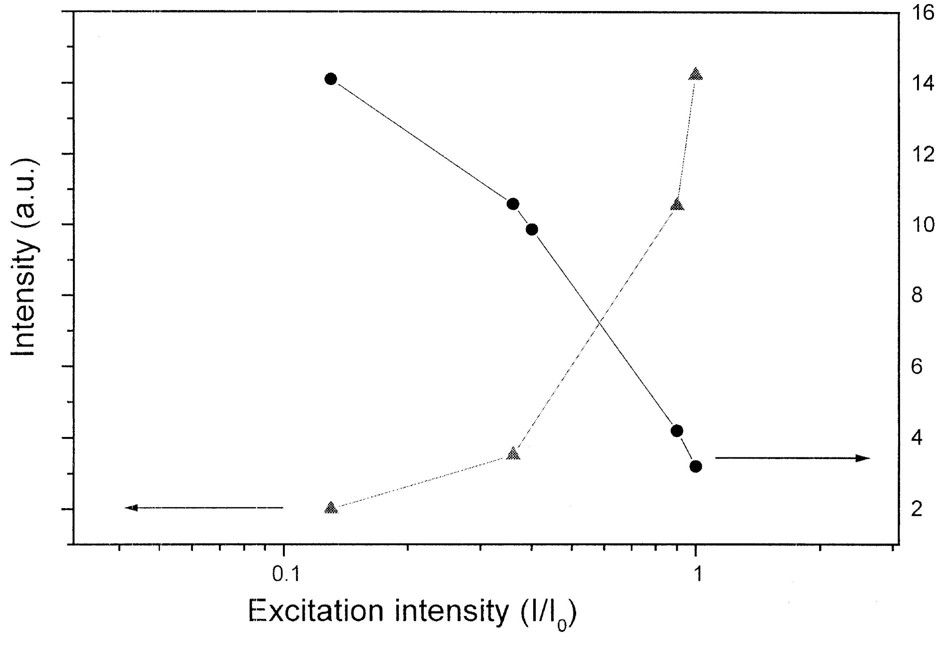

Fig. 4. The dependence of the edge emission intensity (left) and the FWHM (right) of ZnCdTe–ZnTe QWs on the excitation intensity.

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