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Laser action in ZnCdSe/ZnSe asymmetric double-quantum-well

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Abstract

Lasing from the wide well of ZnCdSe/ZnSe asymmetric double-quantum-well structures is studied. Owing to the difference of the energy levels between the wide well and the narrow well, the carriers tunnel from the narrow well to the wide well, which can influence the emission effectively. The carrier tunneling is conducive to lasing from the wide well. The threshold can be lowered by optimizing the structure. © 1999 Elsevier Science Ltd. All rights reserved.

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There has been a dramatic increase of interest in short-wavelength semiconductor laser diodes (LD) because of its wide applications in fields such as optical storage, optical communication, laser printing and full-color display. Fortunately, in the past few years, rapid progress has been made both in ZnSe-based LD and in GaN-based LD [1,2], and it is assumed that the short wavelength LD would be commercialized in a not too distant future. The success is attributed to a rational design of the structure, good-quality epitaxy and effective doping intensity. Improving the structure in order to improve the quantum efficiency and to lower the threshold current density is one of the most important steps to increase the LD's lifetime. Usually, both the ZnSe-based LD and the GaN-based LD use a single-quantum-well or multiple-quantum-well structure as the active layer where light is emitted, as experimentally quantum wells have been proven to be an effective structure for the active layer.

In this article, the lasing is studied in a special kind of quantum-well structure—ZnCdSe/ZnSe asymmetric double-quantum-well (ADQW)—in order to try a new structure for the LD's active layer. Fig. 1 shows the band structure of the ADQW that includes two different width quantum wells, a wide well (WW) and a narrow well (NW), coupled by a thin barrier. As a result of the different widths of the two quantum-wells, the $n = 1$ electronic energy levels, E_{1we} corresponding to the WW and E_{1ne} corresponding to the NW, are different. Then electrons excited in the NW can tunnel through the thin barrier to the WW, and so can holes. It has been shown that when the energy difference ΔE_{1e} between E_{1we} and E_{1ne} is larger than an LO phonon energy (E_{LO}), the electron tunneling can be assisted by LO phonons, which is a fast process, and the tunneling time (T_t) may be smaller than the lifetime of the electrons in the NW (T_{ne}) [3–9]. Therefore, most of the electrons in the NW tunnel to the WW before recombination with holes in the NW [10,11]. However, because of the small

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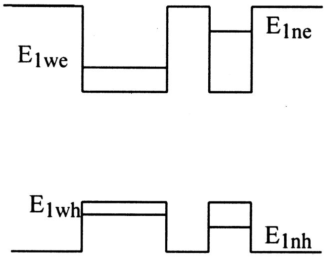
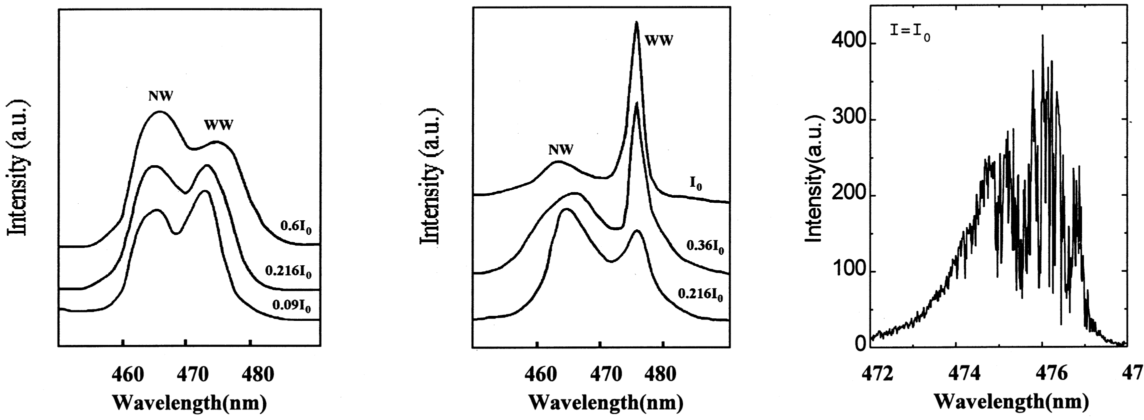


Fig. 1. Band structure of the asymmetric double-quantum-well.

discontinuity of the valence band (for the ZnCdSe/ZnSe ADQW) and the large effective mass of the heavy holes, it is difficult to design a structure with the energy difference (ΔE_{1h}) between E_{1wh} and E_{1nh} larger than E_{LO}, where E_{1wh} and E_{1nh} are $n = 1$ heavy hole energy levels in the WW and NW, respectively. As a result the hole tunneling from the NW to the WW can not be assisted by LO phonons. According to Krol [12], however, nonresonant delocalization of hole wave functions combined with alloy scattering can provide an efficient mechanism for fast hole transfer from the NW to the WW at finite in-plane momenta, and the holes tunnel to the WW before reaching the lowest subband in the NW. As both kinds of carriers have a fast tunneling process, the quantity of carriers in the WW of the ADQW should be more than that in a normal quantum well, and the efficiency of irradiative recombination of carriers in the WW of the ADQW may be higher than that of a normal quantum-well, which is the main topic of our study in this article. Although in II–VI compound semiconductors the carriers exist as excitons due to the large coulomb interactions between electrons and holes, it does not prevent carriers from tunneling [13–15].

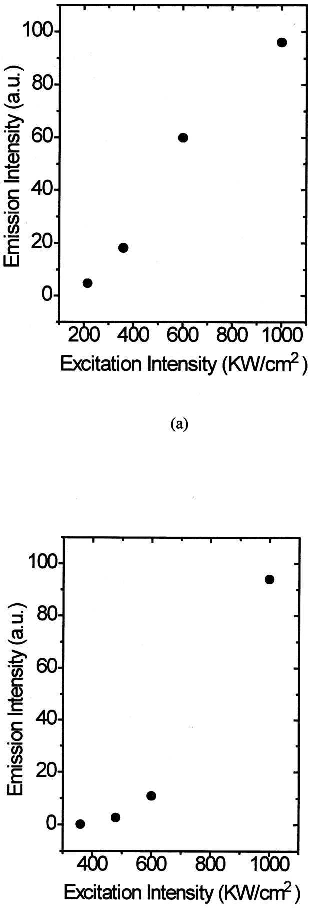
The ZnCdSe/ZnSe ADQW samples studied were grown on (100) Si-doped GaAs substrates by LP-MOCVD and consisted of a 1 μm ZnSe buffer layer, 10 periods of the following structure: 40 nm ZnSe barrier/5 nm $Zn_{0.72}Cd_{0.28}Se$ well/L_b nm ZnSe thin barrier/3 nm $Zn_{0.72}Cd_{0.28}Se$ well (ADQW), and a 60 nm cap layer, where L_b is the thickness of the thin barrier between the WW and the NW. These samples are denoted as 5 nm/L_b/3 nm. Two samples were studied with the barrier widths $L_b = 3$ and 5 nm, respectively. The selection of the structure parameters was according to our calculation in order to meet the fast tunneling condition. Photoluminescence (PL) and photopumped stimulated emission spectra were excited by the 337.1 nm line of a N_2 laser working at 10 Hz, and the signals were measured at 77 K using a 44 W grating monochromator with an RCA-C31034 cooled photomultiplier. The samples used in the stimulated emission measurement were cleaved to approximately 1 mm wide resonators, and the Fabry–Perot (F–P) cavities were formed by the natural facets of the sample bars.

Fig. 2(a) shows the PL spectra from top surface



(a) (b) (c)

Fig. 2. Emission spectra of the sample of 5 nm/3 nm/3 nm structure at 77 K ($I_0 = 1$ MW/cm^2) (a) surface emission, (b) edge emission, (c) oscillating modes of the lasing shown in Fig. 2 (b).



(a)

(b)

Fig. 3. Dependence of edge emission from the WW on the excitation for two samples (a) 5 nm/3 nm/3 nm,(b) 5 nm/5 nm/3 nm.

emission of the sample of a 5 nm/3 nm/3 nm structure and Fig. 2(b) shows the emission from the cleaved edge of this sample. We can see that the emission intensities from different wells in Fig. 2(a) and (b) change differently with the excitation intensity (I_{ex}). Under the condition of surface emission, the emission intensity from the NW (I_n) changes faster than that from the WW (I_w) with the excitation, and the emission from the NW dominates the spectrum at a high excitation intensity. In contrast, under the condition of edge emission, the lasing arises from the WW and dominates the spectra with increasing I_{ex}. The lasing feature is proven by oscillating modes of this emission shown in Fig. 2(c).

According to our previous work [16], for surface emission in the ADQW with a fast tunneling process, because the tunneling time T_t (here T_t refers to both electrons and holes) is shorter than the carriers lifetime $T_{e(h)}$ in the WW and the NW, a large amount of carriers excited in the NW tunnel into the WW, are accumulated in the WW under high excitation intensity, and block further carrier tunneling. Additionally, the different tunneling times between electrons and holes cause different densities of electrons and holes in the NW and WW, and thus internal electric field is formed, which blocks the tunneling further. For these two reasons, the tunneling rate is lowered and the carrier density in the NW grows faster than that in the WW with increasing I_{ex}. Therefore I_n becomes stronger and even dominates the spectrum with increasing I_{ex}, as shown in Fig. 2(a). Under the condition of edge emission, because of the formation of an F–P cavity, the lasing arises from the WW at a certain I_{ex}, which changes the lifetime of carriers in the WW. The relationship between the lifetimes of the stimulated emission and the spontaneous emission is expressed as: $T_{st} = T_{sp}/n_L$, where T_{st}, T_{sp} are the lifetimes of the stimulated and spontaneous emission, respectively, and n_L is the photon quantity in the L mode. From the equation, it is easy to find $T_{st} < T_{sp}$. The n_L increases with I_{ex}, which causes T_{st} much smaller than T_{sp}; and at a certain I_{ex}, T_{st} is similar to the carriers tunneling time T_t, even smaller than T_t. At that time, there are not many carriers accumulated in the WW, and carrier tunneling cannot be blocked strongly. Therefore most of the carriers excited in the NW tunnel to the WW before recombination in the NW, and they recombine in the WW. Then the lasing arises from the WW and dominates the spectra at high excitation, as shown in Fig. 2(b). As a result of the fast tunneling process, the carriers excited in the two wells accumulate and recombine in the same well WW, which is the reason, why we think the quantum efficiency can be improved.

The thickness of the thin barrier L_b is one of the important factors that influence the tunneling process in the ADQW [3,13,17]. Fig. 3 shows the dependence of the intensity of the edge emission from the WW on I_{ex} for two samples with different L_b. It is obvious that the lasing threshold of the sample with $L_b = 3$ nm is lower than that of the sample with $L_b = 5$ nm. The relationship between T_t and L_b can be expressed as

[17]:

$$T_t \sim \exp\left(\frac{4\pi L_b}{h}\sqrt{2m(V-E)}\right) \quad (1)$$

where V is the barrier height, E and m are the energy and effective mass of the particle, respectively. In other words, the thinner the barrier is, the smaller the tunneling time is. Therefore, more carriers tunnel from the NW to the WW in the ADQW with a thinner barrier, which means that the carrier density of the WW in the sample with a thinner barrier is larger than that with a thicker barrier at the same excitation. Therefore, the threshold of the sample 5 nm/3 nm/3 nm is lower than that of the sample 5 nm/5 nm/3 nm.

In summary, we have studied the laser action in a ZnCdSe/ZnSe ADQW structure. The carrier tunneling through the thin barrier is conducive to the lasing from the WW, and the threshold can be lowered by optimizing the structure. We think this work would be useful for the design of laser structure.

Acknowledgements

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