Proc. Int. Conf. Optical Properties of Nanostructures, Sendai, 1994
Jpn. J. Appl. Phys. Vol. 34 (1995) Suppl. 34-1, pp. 68-70

Stark Localization in ZnSe-ZnCdSe Superlattices under an Electric Field

Z. P. Guan, J. Y. Zhang and X. W. Fan
Changchun Institute of Physics, Academia Sinica
Changchun, 130021, China

Photoluminescence measurements have been carried out in ZnSe-ZnCdSe Strained-layer superlattices subjucted to an electric field. It is observed that luminescence quenching and the peak shift toward the lower energy side due to the excitonic Stark effect for small electric fields. Subsequently, we find reversal to a blue shift and the luminescence peak enhancement for higher electric field, which is explained by a field-induced localization of carriers to isolated quantum wells.

KEYWORDS: ZnSe-ZnCdSe, superlattices, electric field

1. Introduction

A new generation of Ⅱ — Ⅵ semiconductor devices are being developed for visible optoelectronic systems for displays and optical recording. The first blue — green laser diodes were reported by Haase et al. [1] and many new reports on the development of visible lasers have been published. [2-5] More recently, Wang et al. [6,7] demonstrated the first Ⅱ — Ⅵ p—i—n modulator structure based on the quantum confined Stark effect. On application of a field two important changes in the absorption spectrum occur. First there is a shift of the absorption to longer wavelength (red shift) and, second, the asymmetry of the electron and hole wave function reduces the absorption strength[8]. These large electro — optic effects have been used in a wide range of devices for modulation and optical bistability. Some works have reported these red shift phenomena[6,7,9,10] in Ⅱ — Ⅵ compound semiconductor superlattices. Schultheis et al. [11] observed the blue shift of excitonic peak for high electric field and attributed to the mixing with continuum state. Taguchi et al. [12] reported the blue shift of excitonic peak in ZnS — ZnCdS strained — layer superlattices (SLSs) and considered that the bound excitons dissociated into free excitons under electric fields the increased density of free excitons can enhance the emission intensity of the higher — energy side of the excitonic band. In this paper, we report the results of perpendicular electric field on the exciton ground state in ZnSe — ZnCdSe SLSs. Under lower bias voltage the emission peak decrease and shift toward low energy side, while for higher bias voltage the emission peak enhance and blue shift.

2. Experimental

The ZnSe — ZnCdSe SLSs sample for the present photoluminescence (PL) measurements were grown on a Si doped n^+ GaAs (100) substrate and a semi — transparent Au was then evaporated onto the SLSs as a Schottky — barrier electrode. The SLSs (100 cycles) of No. 1 consisted of 4 nm $Zn_{0.8}Cd_{0.2}Se$ well layers and 6 nm ZnSe barrier layers, while the sample of No. 2 with 5 nm well and 6 nm barrier and they are all without buffer layer. The Hg lamp (365 nm) was used as an excitation source.

3. Results and Discussion

Figure 1 shows the effect of electric field on the PL of ZnSe (6 nm) — $Zn_{0.8}Cd_{0.2}Se$ (4 nm) SLSs (No. 1) at 77 K with and without an applied field. A spectral shift is clearly induced by the applied bias, the shift is towards lower photon energies. A Schottky — barrier diode (as seen in the insert of Fig. 1) was fabricated to investigate the behavior of the excitons under reverse bias conditions. Fig. 2 shows the intensity and the peak position of the excitonic emission as a function of the applied voltage. It is observed the significant quenching of the PL intensities as well as shifts in the PL energies with increasing reverse bias voltage. Because of the photocurrent much small, the quenching of excitonic emission is caused by the spatial separation of carriers induced by the electric field. This field — induced spatial separation of conduction electrons

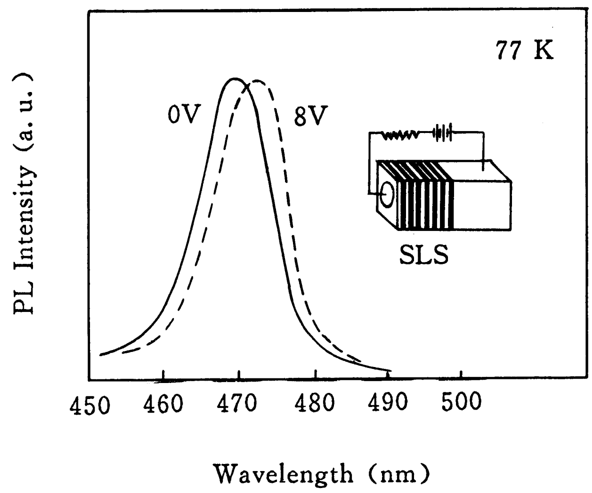

Fig. 1. PL spectra of ZnSe (6 nm)-$Zn_{0.8}Cd_{0.2}Se$ (4 nm) SLSs at 77 K with and without applied bias. Insert shows the schematic structure of the SLSs.

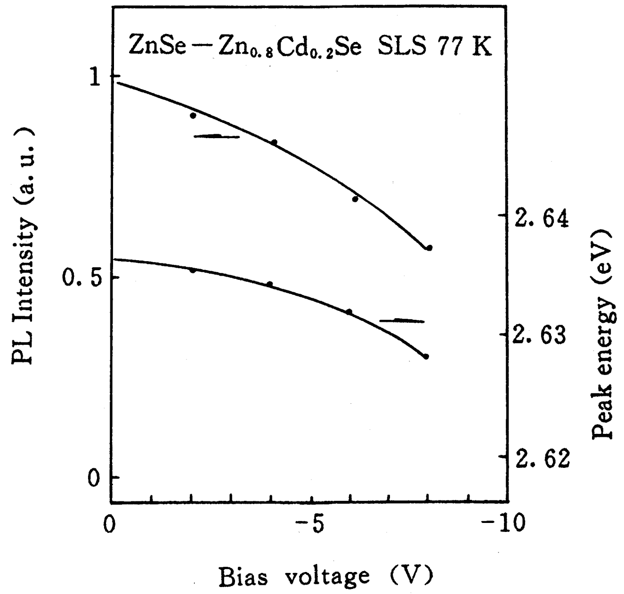

Fig. 2. The exciton peak position and its emission intensity for a ZnSe (6 nm)-$Zn_{0.8}Cd_{0.2}Se$ (4 nm) SLSs as function of reverse bias at 77K.

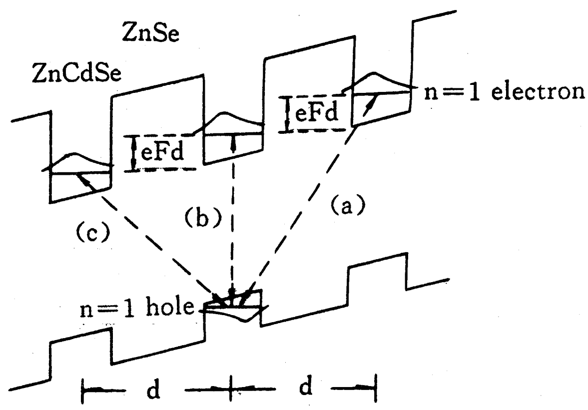

Fig. 4 Schematic illustrated band lineup of ZnSe-ZnCdSe SLSs under electric field (a), (b) and (c) indicate the optical transitions under applied bias condition.

and valence holes in ZnCdSe quantum wells decreases the overlap between their associated wave function, leading to a reduction of interband recombination. The intensity of excitonic peak decrease about 58 % corresponding without bias voltage, and the red shift is amount of 8 meV. Pertubation — theory calculations that assume infinite barrier height, the values of $\triangle E$ and the electric field of F for the shift of the ground state[13],

$$\triangle E = - 2.19 \times 10^{-3} \frac{m^* e^2 F^2 L^4}{h^2} \quad (1)$$

where m^* is the effective mass and L is the well

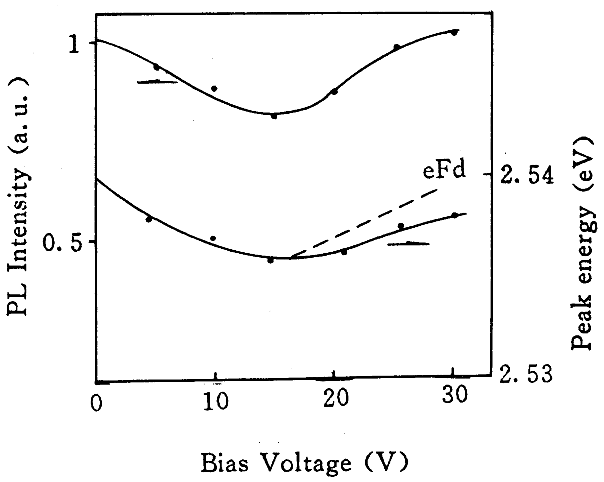

Fig. 3. The exciton peak position and its emission intensity for a ZnSe (6 nm)-$Zn_{0.8}Cd_{0.2}Se$ (5 nm) SLSs as a function of forward bias at 77 K.

width. The experimental results is agreement with the relation of E and F^2 as seen in Fig. 2.

Figure 3 shows the PL intensity and the peak position of the excitonic emission as a function of forward bias voltage for a ZnSe (6 nm)−$Zn_{0.8}Cd_{0.2}Se$ (5 nm) SLSs (No. 2). Up to 15 V, the PL intensity decrease about 8 % compare with zero bias, and then increases with increasing electric field. At the same time, the peak energy is about 5 meV higher in energy than that at 15 V bias voltage. This peak shift is in the opposite sense to that usually observed for a quantum confined Stark shift[14].

The quantum well parameters have been calculated using the method of Van de Wall,[6] the conduction band offset is large at 174 meV and the valence band offset is 72 meV. When a bias is applied, a difference in transition energy of *eFd* for the two transitions is created and, at the same time, the overlaps of the envelope wavefunctions change as seen in fig. 4. It would be possible to observe transitions involving electron and hole wave functions peaked in different quantum wells or, similarly, involving different levels of a Stark ladder. An electric field F along the axis of the superlattices decreases coupling between quantum wells, which is at the origin of miniband formation, and produces a splitting of each miniband into discrete states. As a result, the probability of the higher energy transition (a) exceeds the lower energies (b) and (c), and the peaks shift towards the higher energy side. The total energy shift of optical transition (a) taking into account the ordinal quantum confined Stark shifts will be given by

$$\triangle E = eFd + (E_e + E_h) \quad (2)$$

where E_e and E_h are Stark red shift of electron and hole subband, d is period of SLSs as show in equation (1). In fig. 3 a broken line shows the energy shift caused by band—bending (eFd). As the bias increases, the PL intensity is enhanced because of the increase in the overlap probability of electron and hole wavefunctions for ZnSe—ZnCdSe SLSs.

4. Conclusions

It has been investigated the effect of an electric field on the emission properties of ZnSe — ZnCdSe SLSs. Under lower bias, the PL intensity decreased and the PL peak position shifted toward the lower energy side, which is due to the spatial separation of carrier. In addition, with increasing electric field we have shown that a strong electric field induces a carrier localization in ZnSe — ZnCdSe SLSs, which is turn produces a "blue" shift of its interband optical transition and a significant increase of the PL intensity under higher bias.

Acknowledgements

This work was supported by Laboratory of Excited State Processes, Changchun Institute of Physics, Chinese Academy of Science and the National Natural Scienec Foundation of China.

1). M. A. Haase, J. Qiu, J. M. Depuydt and H. Cheng, Appl. Phys. Lett., **59**,1272 (1991)
2). H. Jeon, J. Ding, A. V. Nurmikko, W. Xie, D. C. Grillo. M. Kobayashi, R. L. Gunshor, G. C. Hua and N. Otsuka, Appl. Phys. Lett., **60**, 2045 (1992)
3). Z. Yu, J. Ren, B. Sneed, K. A. Bowers, K. J. Gossett, C. Boney, Y. Lansari, J. W. Cook, J. F. Schetzina, G. C. Hua and N. Otsuka, Appl. Phys. Lett., **61**, 1266 (1992)
4). K. Ohkawa, A. Tsujimura, S. Hayshi, S. Yoshii, and T. Mitsuyu, Physca B**185**, 112 (1992)
5). S. Y. Wang, J. Simpson, H. Stewart, S. J. A. Adams, I. Hauksson, Y. Kawakami, M. R. Taghizadth, K. A. Prior, and B. C. Cavenett, Physica B**185**, 508 (1993)
6). S. Y. Wang, Y. Kawakami, J. Simpson, H. Stewart, K. A. Prior, and B. C. Cavenett, Appl. Phys. Lett., **62**, 1715 (1993)
7). S. Y. Wang, G. Horsburgh, P. Thompson, I. Hauksson, J. T. Mullins, K. A. Prior and B. C. Cavenett, Appl. Phys. Lett., **63**, 857 (1993)
8). D. A. B. Miller, D. S. Chemla, T. C. Damen, A. C. Gossard, Phys. Rev., B**32**, 1043 (1985)
9). Qiang Fu, A. V. Nurmikko, L. A. Kolodziejski, R. L. Gunshor and J. W. Wu, Appl. Phys. Lett., **51** 578 (1987)
10). T. Yokogawa, T. Saitoh and T. Narusawa, J. Crystal Growth **101**, 550 (1990)
11). L. Schultheis, K. Kohler and C. W. Tu, Phys. Rev. B**36**, 6609 (1987)
12). T. Taguchi, Y. Eudoh and Y. Nozue, Appl. Phys. Lett., **59**, 3434 (1991)
13). E. E. Mendez, and F. Agulo — Rueda, J. Lumin. **44**, 223 (1989)
14). G. Bastard, E. E. Mendez, L. L. Chang and L. Esaki, Phys. Rev. B**28** 3241 (1983)