Photocurrent Derivative Spectra of ZnCdSe-ZnSe Double Multi-Quantum Wells

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Photocurrent (PC) spectra of ZnCdSe-ZnSe double multi-quantum wells are measured at different temperature. Its corresponding photocurrent derivative (PCD) spectra are obtained by computing, and the PCD spectra have greatly enhanced the sensitivity of the relative weak PC signals. The polarization dependence of the PC spectra shows that the transitions observed in the PC spectra are heavy-hole related, and the transition energy coincide well with the results obtained by envelope function approximation including strain. The temperature dependence of the photocurrent curves indicates that the thermal activation is the dominant transport mechanism of the carriers in our samples. The concept of saturation temperature region is introduced to explain why the PC spectra have different temperature dependence in the samples with different structure parameters. It is found to be very useful in designing photovoltaic devices.

Key words: Double multi-quantum wells, photocurrent spectra, ZnCdSe-ZnSe

INTRODUCTION

ZnCdSe-ZnSe multi-quantum wells (MQWs) and superlattice structures have been extensively studied for applications to optoelectronic devices such as blue and blue-green light emitters[1] and electro-optical modulators[2] for their suitable energy gap and large exciton binding energy. The temperature properties of excitons and carrier are useful in designing photo detectors and other photovoltaic devices. There has been much work in revealing the exciton and carrier properties in two dimension systems.[3,4] PC spectrum, which can provide direct the information on the photo absorption probabilities and carriers transport process, is widely used to determine the electronic parameters and to study the photo-generated transport properties of the carriers.[3,4] PCD spectrum, which is the derivative of the PC spectrum, can enhance the sensitivity of photocurrent spectrum due to its derivative characteristic. In this article, we present a detailed study of the temperature dependence of PC and PCD spectra of a double MQWs structures, as well as its transport and polarization properties.

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EXPERIMENT

The sample is grown by low pressure MOCVD on the GaAs (001) substrate. Two groups of ZnCdSe-ZnSe MQWs with different Cd compositions are embedded in an 800 nm ZnSe buffer layer and a 100 nm ZnSe cap layer. Both the MQWs have five periods, well width 10.5 nm, barrier width 31.5 nm. The first part (part I) near the buffer layer has Cd composition 26%, and the second part (part II) has Cd composition 16%. Between the two parts there is a 35 nm ZnSe isolating layer. We call the structure double MQWs, it has a potential application for electro-optical device applications.[5]

The measurement adopts a standard lock-in technique, a model 5210 lock-in amplifier was used in the measurement. The sample is made into a Schottky diode by evaporating a semi-transparent gold film on the upper surface, indium is used to form a ohm contact on the substrate. The sample is mounted on a cold finger by a closed cycle helium cryostat, the temperature of which was varied from 20 to 300 k during the measurement. A 70-W halogen lamp is used as the light source. The chopper frequency is 183 Hz. The PC signals are collected by a computer.

RESULTS AND DISCUSSION

In Fig. 1, we show the room temperature PC spectrum as a function of energy under nearly perpendicular incidence. The corresponding PCD spectrum obtained by a personal computer is also presented. As can be seen there are two shoulders on the low energy side of the PC spectrum and two corresponding oscillators in the PCD spectrum, there is a corresponding relationship between the two curves. It can be seen that the signals in PCD are more distinct than that in the PC spectrum if compared to the value of the original PC curve.

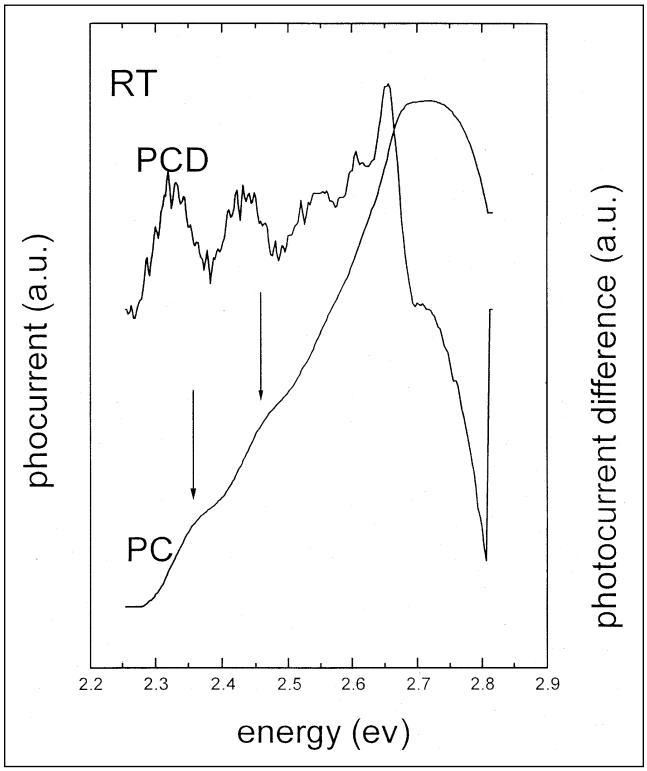

Fig. 1. The PC and PCD spectra of the sample at RT.

The measured PC spectra of the sample at different temperature are shown in Fig. 2. The corresponding PCD spectra are shown in Fig. 3. It can be seen that the peaks are red shifted and the oscillators become more stronger with increasing the temperature.

To identify the properties of the two transitions, we also studied the polarization dependence of the PC curves. We recorded the PC spectra excited by a linearly polarized incident light at an angle of about 45° relative to the growth direction "z" with different linear polarization direction (see the insert in Fig. 4). Contrary to the light-hole related exciton transitions, heavy-hole related transitions are allowed only for polarization in the QW plane.[6] By varying the in-plane component of electric field, the origin of the transitions can be deduced. During our measurements at room temperature (RT), we put the sample perpendicular to the horizontal, tuning the linear polarization plane from perpendicular to the horizontal

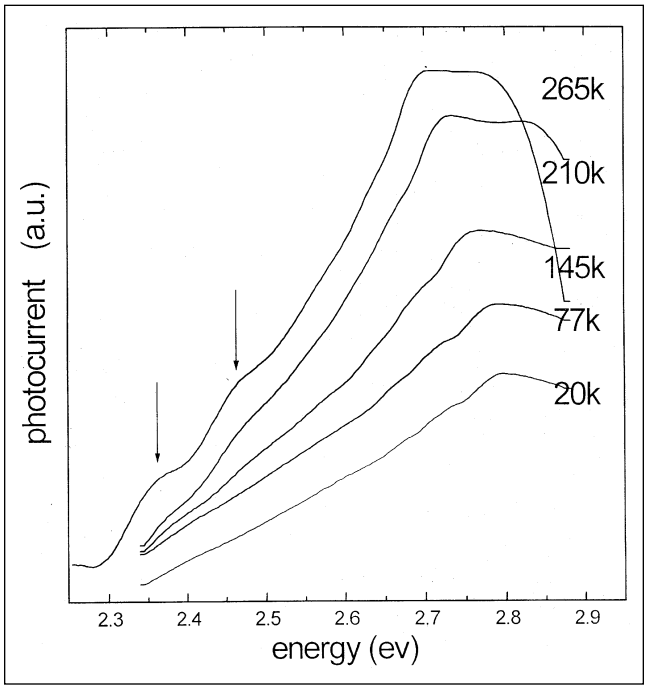

Fig. 2. The PC spectra of the sample measured under different temperature fom 20 to 265k.

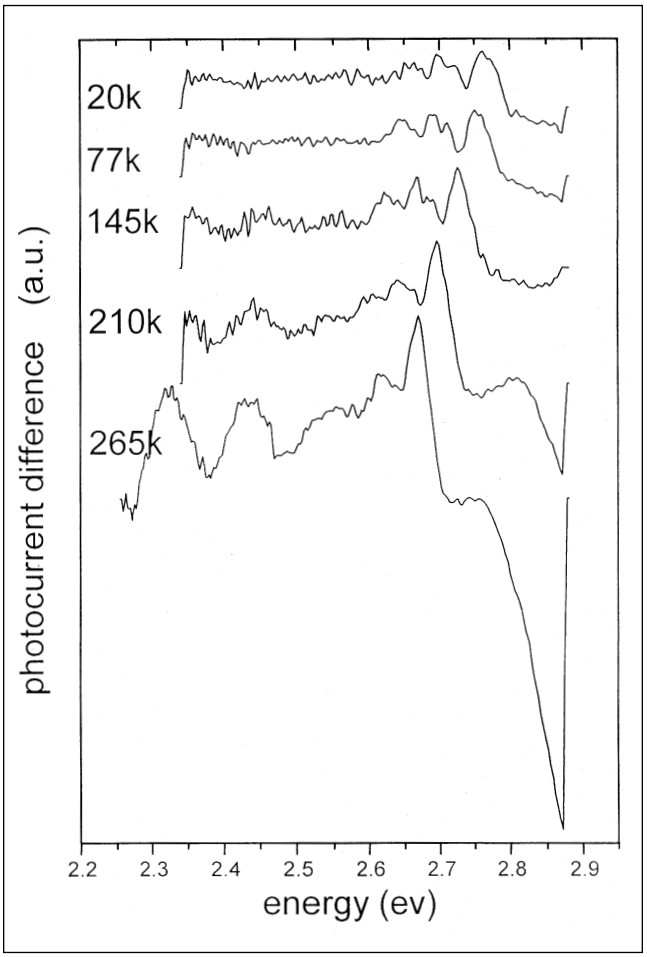

Fig. 3. The corresponding PCD spectra of Fig. 2.

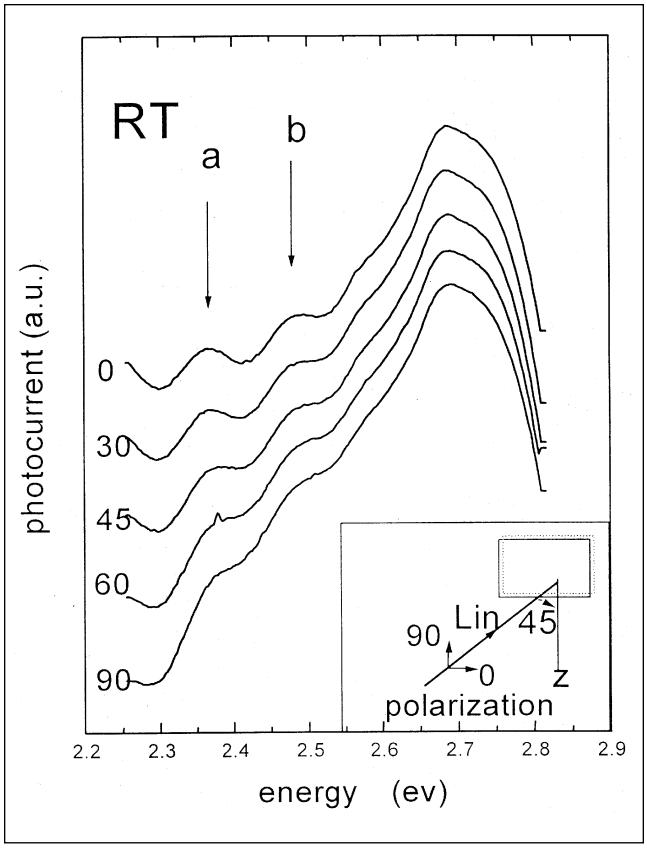

Fig. 4. The PC spectra of the sample measured under different polarization conditions, the incident light (Lin) direction is 45° with the sample growth direction "z," from the bottom to the above. The angle between the incident light polarization plane and the horizontal are 90, 60, 45, 30, and 0°. The insert shows shematically the PC configuration.

to parallel to the horizontal. As can be seen in Fig. 4, both the transition intensities increase with increasing the component along z direction. Based on the analysis above,[7] we identify them as heavy-hole related transitions.

In order to further describe the transitions located at 2.367 and 2.480 ev observed in the experiment, the exciton energies are calculated by envelope function method including the strain.[7] All the parameters used in calculation are taken from Ref. 3. According to Hill,[8] the energy gap of bulk $Zn_{1-x}Cd_xSe$ alloy is

$$E_g(x) = E_{gCdSe} + (E_{gZnSe} - E_{gCdSe} - b)x + bx^2 \quad (1)$$

where b is the bowing parameter, and the value is 0.301 in $Zn_{1-x}Cd_xSe$ alloy.[9]

Band offset is an important parameter in the calculation of the energy shift caused by quantum confinement. There have been many different values in previous articles, according to the analysis of Pellegrini,[10] we set the conduction band offset "Qc" equal 0.67 in our calculation. Because the well width of the sample is 10.5 nm, which is more than twice the value of the exciton Bohr radius, the exciton binding energies are small. We estimate the values to be 24 and 22 mev for part I and part II, respectively, according to the results in Ref. 11. The final calculated ground state exciton transitions energy at room temperature for part I and part II are 2.371 ancl 2.485 ev, so we attribute the peaks (signed "a" and "b") in Fig. 4 to the ground state exciton transitions in part I and part II, respectively. This is in accordance with the polarization results shownl above.

From Fig. 2 and Fig. 3, we can see that the signals become strong and distinct with increasing the temperature up to RT, which is a little different from the results in Refs. 3 and 4. It can be seen from the Fig. 2 in Ref. 4 that the PC spectra become wide and indistinct just above 150k, we believed the different PC spectra characteristics are due to the material's intrinsic properties, which can be explained by the concept of' "saturation temperature region." In fact, the formation of the PC spectrum in quantum wells includes three processes. The first progress is that the electron in the wells is excited from the valance band to the conduction band to form an exciton. The second progress is the ionization of the exciton. This progress depends on the binding energy in the well. Normally at zero bias, the thermal ionization is dominant, and the thermal ionization probability increases with increasing the temperature. The third progress is the transport of the ionized electron and hole. Shown in Fig. 5 are the energy bands of the sample with a Schottky barrier and the transport diagram of the free carriers in the depleted region of the Schottky structure. It can be seen that, the transport of the free carriers includes thermal activation over the barrier and tunneling through the barrier, and there is competition between them. At low temperature (normally <40K)[10,14] and the barriers thickness is in the range that free carriers can penetrate, the tunneling mechanism is dominant.[10] With increasing the temperature or (and) the effective thickness of the barrier, the tunneling probability decreases and the thermal ionization probability increases, or vice versa.

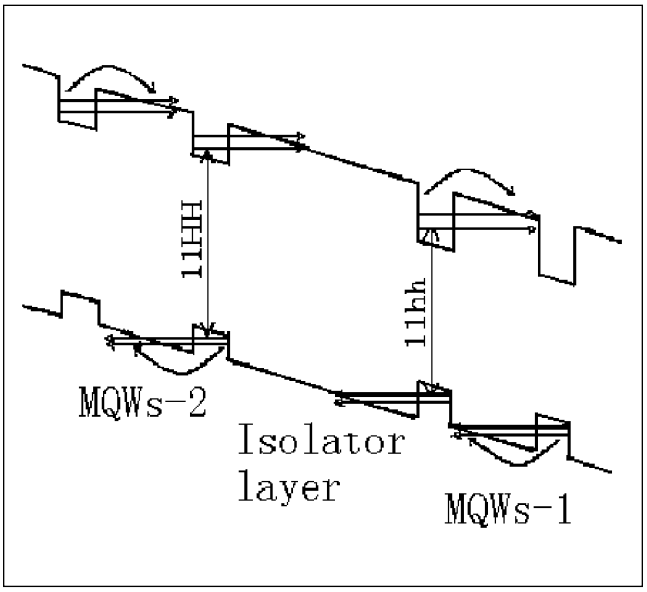

Fig. 5. The energy bands of the sample and the transport diagram of the free carriers in the depleted region of the Schottky structure.

At high temperature range, for each QW sample there is a critical temperature region (normally within a few K) which is decided by its structure parameters, such as the thickness of the well and the barrier, the confining energy in the conduction band and valance band and the exciton binding energy. Under certain structure parameters, there is corresponding critical temperature region, we call it saturation temperature region. When the crystal temperature is lower than it, the excitons ionization probability and the free carriers escape probability in the wells increase with increasing temperature, which results in an enhancement of the PC signals. When the crystal temperature is higher than the saturation temperature, the escape efficiency is close to 100%.[14,15] With increasing the temperature, the PC signals saturate and become indistinct and wide due to the thermo-activated nonradiative processes.[12] Just because the existence of the saturation temperature region, we can see different PC results in samples with different structure parameters. In our ZnCdSe-ZnSe multi-quantum wells, although the effect thickness of the isolating layer, caplayer, and buffer layer decrease under the weak built-in electronic field, the buffer layer and the cap layer are all thicker than 100 nm, and the carriers can only tunnel a few nanometers, so the benefit from the tunneling part is weak and ignoble. In this case, only the thermal activation dependence of the PC signals can be seen. From the calculation above, the confining energies in the wells are large for ground state excitons, so the saturation temperatures are high, and we can see stronger and more distinct signals at RT. According to Ref. 13, under certain temperature and under zero bias, the thermionic transport current J_{th} is given by

$$J_{th} = \frac{4\pi q m^* k^2 T^2}{h^3} \exp\left(-V_n / kT\right) \qquad (2)$$

where q is the electronic charge, m^* is the effect mass of free carriers and V_n is the barrier height in the quantum wells, k and h are the Bolzmann and the Planck constants. At a certain confine energy V_n, from Eq. (2), we can see that with increasing the crystal temperature T, the current density J_{th} increases, and the PC signal become stronger. This is consistent with our results and analysis. It should be pointed out here that if a photo detector is made to work under certain temperature, the saturation temperature region must be considered. Hence, the concept of saturation temperature region is very important in designing photovoltaic devices.

CONCLUSION

The transitions from a double ZnCdSe-ZnSe MQWs sample are seen in the PC measurements, the corresponding PCD spectra make the weak signals more distinct. The polarization dependence of the PC spectra show that the transitions are heavy-hole related, and the transitions energy coincide with the theory values. The temperature dependence of the transitions intensity indicates that the thermal activation is the dominant mechanism in the sample. The concept of saturation temperature region is introduced to explain the different results in different sample. Such a concept is very useful in the design of photo detector and other photovoltaic devices.

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