Temperature Dependences of the Intensity and the Position from Photocurrent and Photoluminescence Spectra in CdS Layers

J. H. Yu, H. J. Yang, T. S. Kim, T. S. Jeong and C. J. Youn*

Semiconductor Physics Research Center (SPRC), School of Semiconductor and Chemical Engineering, Chonbuk National University, Jeonju 561-756, Korea

K. J. Hong

Department of Physics, Chosun University, Gwangju 501-759, Korea

(Received 24 February 2012, in final form 16 April 2012)

Using the hot wall epitaxy method, we grew CdS epilayers on GaAs substrates. From the photocurrent (PC) measurement, the peaks corresponding to excitons A and B were observed in the short-wavelength region. Also, a crystal field splitting of 0.026 eV was extracted through the PC spectroscopy method. The PC intensities decreased with decreasing temperature. In the log \( J_{ph} \) vs. \( 1/T \) plot, the dominant level was observed in the high-temperature region, and its activation energy was 33.9 meV. From the photoluminescence (PL) experiment, the PL intensities of the free exciton were exponentially reduced with increasing temperature. From the relations of log \( I_{PL} \) vs. \( 1/T \), an activation energy of 29.7 meV was observed in the high-temperature region. By comparing the PC and the PL results, we found that these activation energies were the thermal dissociation energies of the free exciton at the ground state and corresponded to the binding energies of the free exciton. Thus, we suggest that this trapping center limits the PC signal with decreasing temperature. Furthermore, the band gap energy of CdS as a function of temperature was well described by

\[
E_g(T) = 2.581 - (6.1 \times 10^{-4})T^2/(248 + T).
\]

PACS numbers: 78.20.-e, 78.56.-a

Keywords: CdS, Hot wall epitaxy, Photocurrent, Photoluminescence, Band gap

DOI: 10.3938/jkps.60.1927

I. INTRODUCTION

Cadmium sulfide (CdS), which has a band gap energy of 2.42 eV at room temperature, is used in optoelectronic devices applicable to the visible region [1]. Therefore, for device applications of CdS, it is vital to know the electro-optical properties of this material. The electro-optical properties of CdS are mainly determined by the point defects associated with individual the atoms forming compounds. Such point defects originate from the stoichiometric deviation of the CdS generated during the growth or the additional thermal treatment. This stoichiometric deviation occurs because the vapor pressure of sulfur is higher than that of cadmium during the growth. Thus, the CdS property is deeply related to native defects because they have a high self-compensation of shallow donor and deep acceptor states. Therefore, photoluminescence (PL) is able to explore optically active recombination centers in CdS. It provides useful information about impurity and defect centers. Furthermore, observation of the low-temperature PL can allow us to obtain valuable information about the electronic structure and the structural quality of CdS. These PL characterizations were intensively investigated through bulk CdS crystals only [2,3].

In spite of the significant role of PL for impurity and defect centers, a portion of the photo-generated carriers in CdS disturbs the photocurrent (PC) generation due to radiative and nonradiative recombination. The presence of these defect traps not only makes the photoreponse slow and causes the relaxation curves to deviate from an exponential nature but also causes a variation in the PC at some power of radiation intensity. Thus, some of these contribute to the PC loss of solar cell devices due to optical absorption in the CdS window layer. Therefore, investigating the photocconductivity changes of photoconductive CdS caused by incident radiation is also important. In fact, investigations of the PC are necessary for applications to photodetection and radiation measurements [4].

On the other hand, the growths of CdS layers have been achieved by using several methods: vacuum evaporation, sputtering, electrodeposition, metal-organic vapor phase epitaxy (MOVPE), spray pyrolysis, molecular
beam epitaxy, and chemical bath deposition [5–13]. Generally, low-temperature growth is known to reduce the native defects of CdS. Hot-wall epitaxy (HWE) is suitable for growing a high-purity CdS layer because HWE is a low-temperature growth technology, so layers can be grown under condition near thermodynamics equilibrium [14,15]. Thus, this method requires a low temperature and has a low cost as compared to other methods.

In this research, the CdS epilayers were grown on GaAs(100) substrates at low temperature by using the HWE method. Thus, PC and PL spectroscopy measurements were carried out in the photoconductive layer. Based on our results, we discussed the temperature dependences of the position and the intensity for these signals.

II. EXPERIMENT

CdS layers were grown on semi-insulating GaAs(100) by using the HWE method. The GaAs(100) substrate was cleaned ultrasonically for 1 min in successive baths of trichloroethylene, acetone, methanol, and 2-propanol and were etched for 1 min in a solution of H2SO4:H2O2:H2O (5:1:1). The substrate was degreased in organic solvents and rinsed with deionized water (18.2 MΩ). After the substrate had been dried, the substrate was immediately loaded onto the substrate holder in the HWE system. The GaAs substrate was annealed at 580 °C for 20 min to remove the residual oxide on the surface of the substrate. The optimum temperatures for the GaAs substrate and the source containing the CdS powder were 350 and 600 °C, respectively.

Figure 1 shows the rocking curve of the as-grown CdS/GaAs layer measured through the double-crystal rocking curve (DCRC) experiment. The full width at half maximum (FWHM) of the rocking curve corresponding to the (0002) plane of the hexagonal CdS layer was 722 arcsec, as shown in Fig. 1. This value is better than the value obtained when using MOVPE [8]. Furthermore, it suggests that the CdS layer is epitaxially crystallized on the GaAs substrate. The thickness of the grown CdS layers as measured by using a profilometer (Tencor, α-step 200) were 1 µm. By measuring the Hall effect, we found the grown CdS layers to be n-type. The carrier density and the Hall mobility were obtained to be 6.46 × 10^{17} cm^{-3} and 2.18 × 10^{2} cm^{2} V^{-1}s^{-1} at 300 K, respectively, but these values were found to be 3.82 × 10^{16} cm^{-3} and 1.75 × 10^{2} cm^{2} V^{-1}s^{-1} at 13 K, respectively.

For the PC and the PL spectroscopy measurements, the samples were mounted on the cold finger of a cryostat; then, they were measured at various temperatures from 13 to 300 K (room temperature) by using a cryogenic helium refrigerator (AP, CSA-202B). For the PL observation, the light source was the 325-nm line of a HeCd laser (Nippon, 40 mW). Thus, the light emitted from the sample was detected by using a photomultiplier tube through a monochromator. Also, two Au electrodes with a coplanar geometry were fabricated on the CdS layer by using an e-beam evaporator; then, the PC spectroscopic measurements were taken while the monochromatic light emitted from a halogen lamp (650 W) illuminated the sample. The light coming from the halogen lamp was converted to monochromatic light by passing it through the monochromator. Thereafter, the detected PC and PL signals were amplified by using a lock-in amplifier and were recorded on an x-y recorder.

III. RESULTS AND DISCUSSION

1. Analysis of PC and PL Spectra

For a photosensitive material, the volume lifetime is much larger than the surface lifetime; therefore, a maximum in the spectral response occurs when a transition is made from surface excitation (exciting photon energy greater than band gap) to volume excitation (exciting photon energy smaller than band gap) with increasing wavelength [16]. In the PC experiment, the absorbed photons with energy higher than the band gap energy create electron and hole carriers. If an external electric field is applied, the electrons and holes move in opposite directions. These carriers instantly flow out through the electrodes and produce PC signals. Thus, the origin of the maximum in the spectral PC response is the intrinsic transition caused by the band-to-band transition [17,18].

The band structure for the transitions in CdS follows the selection rules. Figure 2 presents the energy-band