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Growth and electro-optical characteristics of CdSe/GaAs epilayers prepared by electron beam epitaxy

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전자빔 증착법에 의한 CdSe/GaAs epilayer의 성장과 그 전기-광학적 특성

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Abstract An improved technique based upon an electron beam evaporation system has been developed to prepare cubic thin films in crystalline semiconductors. Zinc blende CdSe epilayers were grown on GaAs(100) substrate by an e-beam evaporation method. The lattice parameter obtained from (400) reflection is 6.077 Å, which is in excellent agreement with the value reported in the literature for zinc blende CdSe. The orientation of the as-grown CdSe epilayer is determined by electron channeling patterns. The crystallinity of epitaxial CdSe layers were investigated on the double crystal X-ray rocking curve. The carrier concentration and mobility of epilayers deduced by Hall effect measurement are about $10^{18} cm^{-3}$, $10^2 cm^2/V \cdot sec$ at room temperature, respectively. The photocurrent spectrum peak of the epilayer at 30 K exhibits a sharp change at 1.746 eV due to the free exciton of cubic CdSe.

요 약 Electron beam 증착법을 보완하여 GaAs(100)기판위에 cubic(zinc blende) CdSe

에피층을 성장시켜 그의 특성을 조사하였다. CdSe 에피층의 격자 상수는 6.077 Å였으며, 배향성은 ECP 패턴에 의하여 확인되고 결정성은 DCXR curve로 관찰하였다. 상온에서 측정된 Hall data로는 에피층의 운반자 농도와 이동도는 각각 $10^{18}cm^{-3}$, $10^2cm^2/V \cdot sec$ 정도임을 알았고 30 K에서 측정한 PC spectra peak는 cubic CdSe의 free exciton에 기인된 것으로 1.746 eV에서 예리하게 나타나고 있음을 보여주고 있다.

1. Introduction

There has been a growing interest in II-VI compounds for their applications to opto-electronics in the visible region [1,2]. In particular, Cd(S,Se) semiconductors having a wide band gap together with excellent optical and electrical properties can be utilized as photoconductive devices such as photosensors, phototubes, visible-light filters, etc [3].

Recentry, we have successfully deposited crystalline zine blende CdSe films by electron beam technique. In contrast to conventional heating modes, the evaporation is heated by electron beam that impinges directly onto its surface. The greatest portion of the kinetic energy in the beam is converted into heat and this causes some significant advantages. Evaporation from the water-cooled crucible allows the production of high purity films as reactions with the crucible walls are avoided almost completely [4,5].

In this work, we have deposited cubic zinc blende CdSe epilayers on GaAs(100) substrates using an improved e-beam evaporation technique. Structural, electrical and optical characteristics of CdSe/GaAs epilayers are reported here.

2. Experimental procedures

CdSe films were deposited on GaAs (100) substrate by the VI-5R electron beam evaporation system (Anelva Co.). Bulk targets were made from 5N CdSe powder (Rare Metallic Co.). GaAs substrate were cleaned with acetone and tricloroethylene, and then etched in a mixed solution of H_2SO_4, H_2O_2, and H_2O for 10 minutes. They were set on the holder in an ultrahigh vacuum chamber of 10^{-8} torr range, and etched again thermally at 520℃ for 10 minutes to desorb surface impurities.

Target materials were irradiated by low density electron beam for 30 minutes to preheat the surfaces. The distance between target and substrate was about 10 cm. In the nominal deposition case, acceleration voltage of 4 kV, current of 2.5 mA and substrate temperature of 300℃ were employed. After 1 hour deposition, the thickness of CdSe film was approximately 0.36 μm.

The structures and lattice constants of the films were characterized by X-ray diffractometry (model D-3F, Rigaku Denki Co.) with a Cu-$K\alpha_1$ line (1.542 Å) source and an electron channel pattern

(ECP) obtained by scanning electron microscopy (SEM). The Hall data was obtained by van der Pauw technique using Hall effect measurement system (Keitheley Co.). The photocurrent were measured by irradiation technique using the spectroscopy system consisting of cryostat, monochromator (Jarrel Ash, 82-0200), and lock-in-amp (Ithaco, 391A) etc.

3. Results and discussion

3.1. *Crystal structure*

The XRD pattern of CdSe/GaAs film is shown in Fig. 1. From this figure, it was found that the peaks obtained from (200) and (400) reflections of CdSe film is the structure of cubic zinc blende. The lattice parameters obtained from (400) reflections of CdSe films with the different thicknesses are described in Fig. 2. The lattice constant of 6.077 Å was obtained and did not depend on the thickness of film. It is in good agreement with the value reported in the literature for zinc blende CdSe film [6].

The orientation of as-grown CdSe epilayer was determined by electron channeling patterns (ECP) obtained using scanning electron microscopy (SEM). The ECP observed from a (100) orientation of CdSe film is shown in Fig. 3. There are four

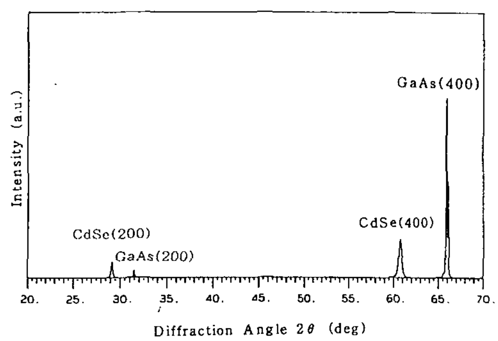

Fig. 1. X-ray diffraction patterns of CdSe/GaAs film.

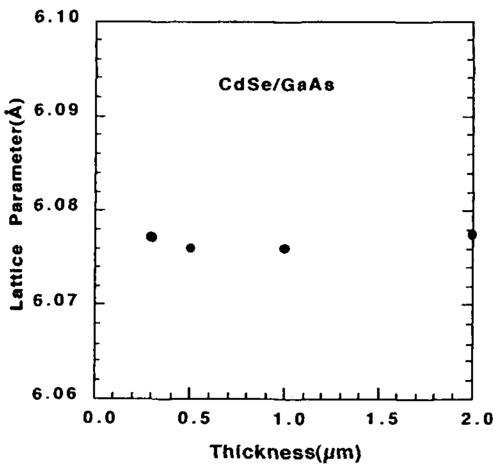

Fig. 2. Lattice parameter as a function of thickness of CdSe epilayer.

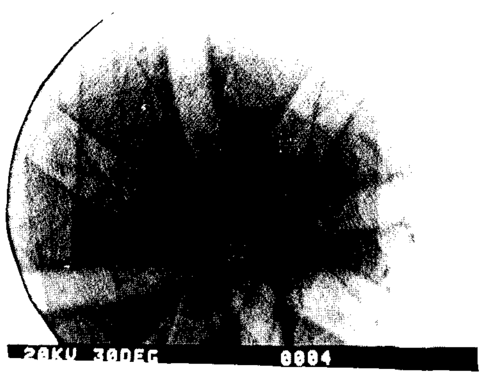

Fig. 3. Electron channeling pattern (ECP) obtained from a (100) orientation of CdSe film.

major bands with equally spaced two sets of lines intersected in one point. The double symmetry which corresponds to crystallographic symmetry about the (100) direction is shown at this point. It was also found that (100) orientation of CdSe film is the same as that of cubic diamond from the indexing guide [7]. From these results, it can be concluded that CdSe film prepared at our laboratory has single crystal structure (cubic z.b.), and it agrees with the result of X-ray diffraction discussed in the previous section.

The crystallinity of CdSe/GaAs films was characterized by the double crystal X-ray rocking curves (DCXR). The full width at half maximum (FWHM) of the (400) reflections of films with different thickness is shown in Fig. 4 and is inversely related to the layer thickness.

The dislocation densities by the formula related with FWHM

$$N_D = (F^2 - f^2) / 9b^2 \qquad (1)$$

here, F : DCRC FWHM of film,
f : FWHM of 1st crystal,
b : magnitude of Burgers vector,

are also listed in Table 1. In the cases(1), the lattice parameters of 6.077 Å obtained from X-ray diffraction and the FWHM of first crystal (GaAs) of 13 arcsec were used. In the cases of CdSe/GaAs films with thicknesses more than 2 μm, the FWHM was approached to the crystal value of 1900 arcsec and showed similar tendency to the results reported for the CdTe/GaAs films by Pesek [8].

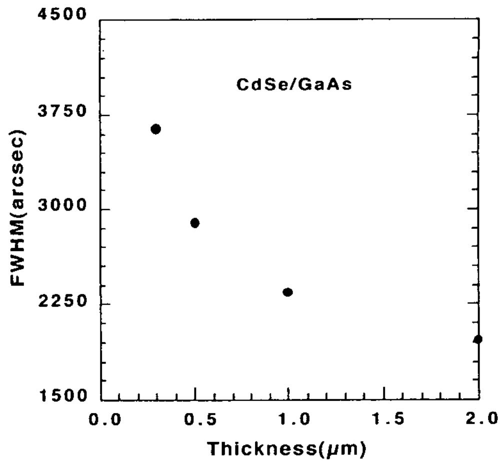

Fig. 4. As a function of film thickness obtained from DCXR of CdSe/GaAs (400) reflection.

Table 1
Crystallinity of CdSe/GaAs films with different thicknesses

Thickness (μm)	FWHM (arcsec)	Dislocation density ($\times 10^9/cm^2$)
0.3	3642	18
0.5	2897	12
1.0	2347	7.8
2.0	1964	5.5

3.2. Electro-optical properties

The Hall effect was measured using the standard van der Pauw method at room temperature. The Hall data of CdSe/GaAs films are listed in Table 2. The negative (−) sign of Hall coefficient is interpreted that CdSe film is n-type semiconductor.

Table 2
Hall data of CdSe/GaAs film (0.3-μm-thick)

Resistivity (Ohm-cm)	Hall co-efficient (cm^3/C)	Mobility ($cm^2/V \cdot sec$)	Carrier concentration (cm^{-3})
4.09×10^{-2}	-7.98	1.96×10^2	7.83×10^{17}

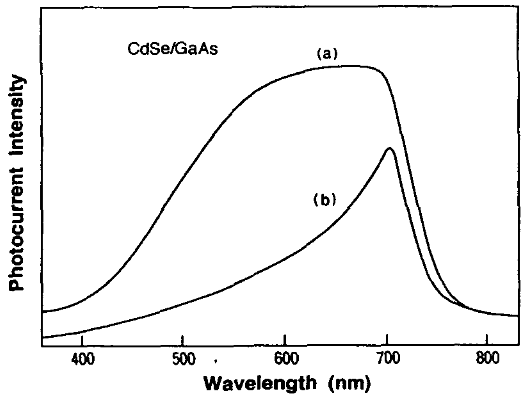

Fig. 5. Photocurrent spectra of 1-μm-thick CdSe epilayer at (a) high temperature (293 K) and (b) low temperature (30 K) (normalized to 2 times scale of original data).

The photocurrent (PC) spectrum of 1 μm-thick CdSe film measured at two different temperatures (a. 293 K, b. 30 K) are shown in Fig. 5. The photocurrent decreases after peak point because the life time of the conduction electron excited is much smaller than that of the conduction electron with increasing wavelength [9]. The peak point corresponding to the absorption edge is the one generated by band to band transition called intrinsic transition [10]. The PC spectrum at high temperature (293 K) show intensive, broad range and that at low temperature (30 K) changes sharply at 1.746 eV due to free exciton of cubic CdSe film.

The results are in good agreement with those reported in other literature [11].

4. Conclusion

Cubic crystalline CdSe films were prepared by electron beam technique successfully, and their structural, electrical and optical properties were characterized.

The results of X-ray diffraction showed that its crystal structure is cubic zinc blende with the lattice constant of 6.077 Å. The orientation of CdSe epilayer was determined by ECP and found that it is similar to that of cubic diamond. The crystallinity of epitaxial CdSe layer were also investigated from DCRC. In the case of 2-μm-thick film, the FWHM of 1964 arcsec and the dislocation density of $5.5 \times 10^9/cm^2$ was found.

The electrical properties of this film at room temperature were also investigated. We found that this film is n-type semiconductor with conductivity of 25 $(Ohm\text{-}cm)^{-1}$, mobility of 1.95×10^2 $cm^2/V \cdot sec$ and carrier concentration of 7.83×10^{17} cm^{-3}. The electro-optical properties were analyzed with the PC spectra. At the temperature of 30 K, the PC spectrum for 1 μm- thick CdSe epilayer was sharply changed at 1.746 eV due to free exciton of cubic CdSe film.

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