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ZnO-based semiconductors for visible light emission devices

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1. Introduction

Wurzite-type ZnO has some typical features such as a direct bandgap of 3.3 eV and a large exitonic binding energy of 60 meV at room temperature. We have successfully demonstrated $Zn_{1-x}Cd_xO$ systems utilizing remote plasma enhanced metalorganic chemical vapor deposition (RPE-MOCVD), exhibiting a bandgap down to 1.8 eV[1]. In addition, we have recently achieved $Zn_{1-x}Cd_xO/Mg_yZn_{1-y}O$ double heterostructures on a-sapphire substrates with blue-green photoluminescence emission[2]. In this paper, we discuss typical growth features associated with RPE-MOCVD and refractive indices of these ZnO-based semiconductors for enabling to design highly-efficient optical devices. White electroluminescence emission from current-injected ZnO-based heterojunction is briefly described.

2. Experimental

ZnO-based films have been grown by remote plasma enhanced metalorganic chemical vapor deposition (RPE-MOCVD) using diethyl zinc (DEZn), dimethyl cadmium (DMCd), Bis-ethylcyclopentadienyl magnesium ($EtCp_2Mg$) and oxygen radical generated by a radio frequency (RF) of 13.56 MHz as material sources. A-plane sapphire substrates and, in addition, p-SiC substrates for electroluminescence measurements were used. The substrate temperatures were maintained between 250 and 500 ^oC during the growth. The RF power was controlled between 0 and 90 W. The Cd and Mg contents of the films were controlled by changing group -II flow ratio. The heterojunction basically consists of ZnO cap layer, $Mg_{0.12}Zn_{0.88}O$ cladding layer and $Zn_{1-x}Cd_xO$ active layers on p-SiC substrates. Indium and aluminum were used as the electrodes.

We have characterized the bandgaps using optical transmission measurements and photoluminescence analysis. The contents were analyzed by atomic absorption spectroscopy. The refractive indices are analyzed by ellipsometry at 632.8 nm (1.96 eV). The dispersions of refractive indices are calculated by optical reflection with UV-VIS-NIR scanning spectrometer.

3. Experimental results and discussion

Figure 1(a) shows typical relationship between the Cd content of $Zn_{1-x}Cd_xO$ films and the group –II flow ratio R. R is defined as a mole fraction of [DMCd]/[DEZn+DMCd] and the substrate temperature is chosen as an experimental parameter. The typical RF power was 60 W. Here, the wurzite-type structures are maintained with Cd content x of up to 0.7 with typical substrate temperature of 350 ^oC, which are examined by X-ray analysis. Figure 1(b) shows the Cd content and growth rate dependencies on the RF power of the RPE-MOCVD system. It is found that oxygen radical plays an important role of growing $Zn_{1-x}Cd_xO$ system.

Figure 2(a) is summarizing the bandgap energy as a function of the Cd content of wurzite-type $Zn_{1-x}Cd_xO$, including wurzite-type $Mg_yZn_{1-y}O$ system grown by RPE-MOCVD. This relationship indicates that ZnO-based semiconductors are candidates for optical devices with the visible and UV wavelength range. Figure 2(b) shows that the refractive indices increased linearly from 1.9 through 2.8 corresponding to the increase of the bandgap. The calculated result by HV model[3] is also shown in the figure. The experimental data agree well with theoretical values above x=0.2. Figure 3 shows the relationship between refractive index and incident photon energy for various $Zn_{1-x}Cd_xO$ and $Mg_yZn_{1-y}O$ films. The refractive indices of each film increased exponentially near the bandgap energy, which is a similar behavior with $In_zGa_{1-z}N$ films[4].

The heterojunction utilizing these ZnO-based material systems, which is grown on p-SiC, shows white electroluminescence (EL) emission at room temperature, as shown in Fig. 4. The operation voltage is 15V. EL intensities increased as injected current increased. Two peaks emissions at 430 nm and 540 nm are coming from $Zn_{1-x}Cd_xO$ active layers, which suggests an application to monolithic white light emitting diodes.

4. Conclusion

We have demonstrated wurzite-type ternary alloy systems of $Zn_{1-x}Cd_xO$ and $Mg_yZn_{1-y}O$ grown by RPE-MOCVD, showing

bandgap energy variation from 1.8 eV up to 3.7 eV. The refractive indices measured by ellipsometry vary from 2.78 to 1.90, respectively. We have also successfully observed white EL emission from the ZnO-based heterojunction.

References

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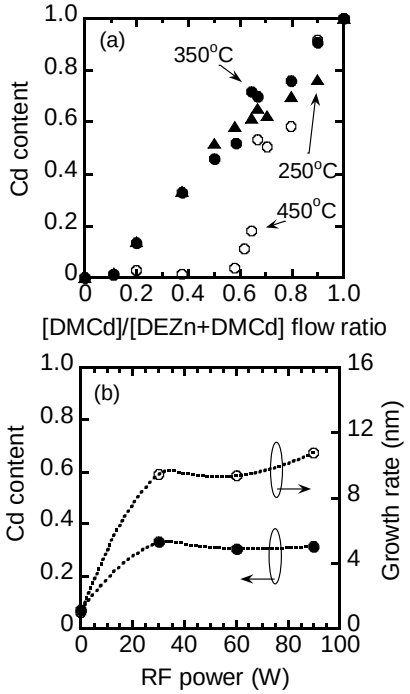
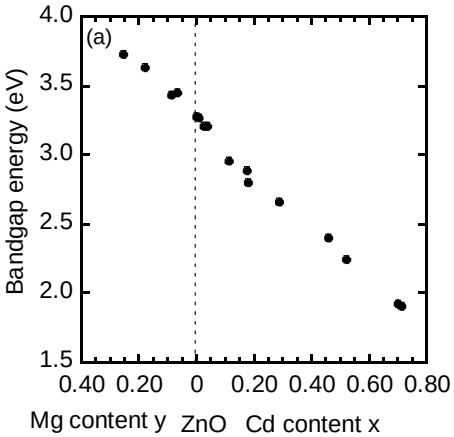


Fig. 1. (a) The Cd content of $Zn_{1-x}Cd_xO$ films as a function of the group-II flow ratio.
(b) RF power dependence on Cd content and growth rate of $Zn_{1-x}Cd_xO$ films.



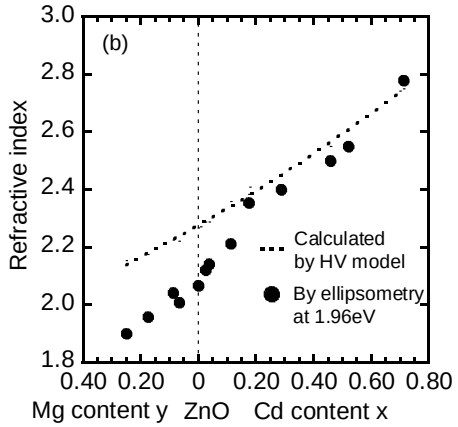


Fig. 2. (a) Bandgap energy of wurzite-type $Zn_{1-x}Cd_xO$ films versus their contents.
(b) The refractive index versus Cd and Mg contents.

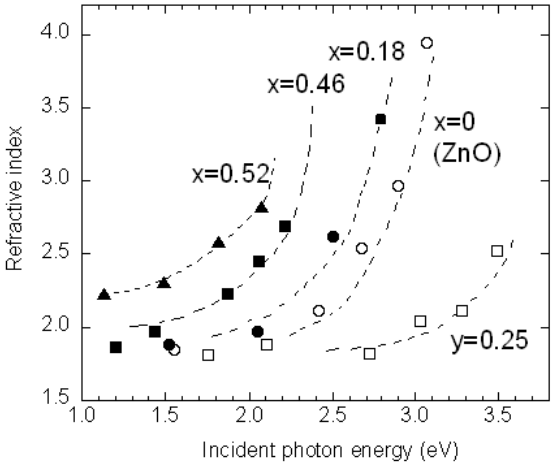


Fig. 3. Refractive index versus incident photon energy in $Zn_{1-x}Cd_xO$ and $Mg_yZn_{1-y}O$ systems.

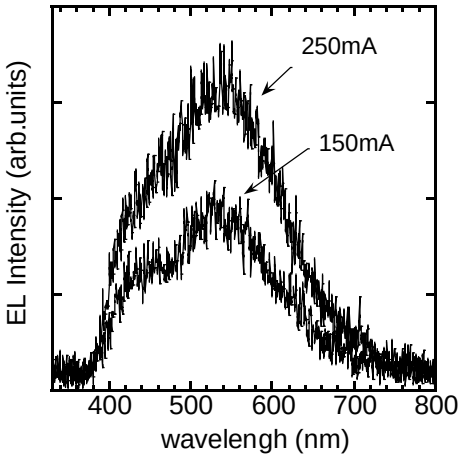


Fig. 4. EL spectra from current injected ZnO-based heterojunction at 300K and operation voltage is 15V.