Trapping centers due to native defects in the $CdIn_2S_4$ films grown by hot wall epitaxy

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Abstract: $CdIn_2S_4$ (110) films were grown on semi-insulating GaAs (100) by a hot wall epitaxy method. Using photocurrent (PC) measurement, the PC spectra in the temperature range of 30 and 10 K appeared as three peaks in the short wavelength region. It was found that three peaks, A-, B-, and C-excitons, correspond to the intrinsic transition from the valence band states of $\Gamma_4(z)$, $\Gamma_5(x)$, and $\Gamma_5(y)$ to the exciton below the conduction band state of $\Gamma_1(s)$, respectively. The 0.122 eV crystal field splitting and the 0.017 eV spin orbit splitting were obtained. Thus, the temperature dependence of the optical band gap obtained from the PC measurement was well described by $E_g(T) = 2.7116$ eV $-$ $(7.65 \times 10^{-4}$ eV/K$)T^2/(425 + T)$. But, the behavior of the PC was different from that generally observed in other semiconductors. The PC intensities decreased with decreasing temperature. This phenomenon had ever been reported at a PC experiment on the bulk crystals grown by the Bridgman method. From the relation of log J_{ph} vs 1/T, where J_{ph} is the PC density, two dominant levels were observed, one at high temperatures and the other at low temperatures. Consequently, the trapping centers due to native defects in the $CdIn_2S_4$ film were suggested to be the causes of the decrease in the PC signal with decreasing temperature.

Keywords: $CdIn_2S_4$, ,trapping center, photocurrent, spin orbit splitting, optical band gap

I. INTRODUCTION

Cadmium indium sulfide ($CdIn_2S_4$) is a semiconducting ternary chalcogenide of the type A^{II}-B_2^{III}-C_4^{VI}. The band gap of $CdIn_2S_4$ with direct transition is 2.62 eV at room temperature. In this paper, the $CdIn_2S_4$ films were grown by a hot wall epitaxy (HWE) method. From the PC measurement, we present the valence band splitting for electronic transitions restricted by a selection rule. In addition, PC generation on the $CdIn_2S_4$ films will be also discussed, as well as the temperature dependences of the band-gap energy and the PC intensity.

II. RESULTS AND DISCUSSION

A. Temperature dependence of the band-gap energy and the PC intensity

Figure 1 displays the variation of the band-gap energy obtained from the PC spectra as a function of temperature. The line curve of the fitted band gap was described by Varshni's equation:[23]

$$E_g(T) = E_g(0) - \alpha T^2/(T + \beta) \quad (1)$$

where α is a constant and β is approximately the Debye temperature. Also, $E_g(0)$ is the optical energy gap at absolute zero. From the result of the optical absorption measurements, $E_g(0)$, α, and β were determined to be 2.7116 eV, 7.65×10^{-4} eV/K, and 425 K, respectively.

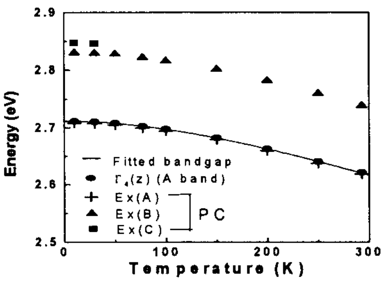

FIG. 1. Experimental values of the peak energies and the

band-gap energy obtained from the PC spectra as a function of temperature.

As shown in Fig. 1, the A band obtained from the PC measurement is in good agreement with the curvature plotted by Eq. (1). To understand the PC generation, we consider the total current density in an n-type semiconductor.[14] The current density of an n-type semiconductor in the dark is given by $J \approx en\mu_n E = \sigma E$ since the hole contribution can generally be neglected. Here, n and μ_n, are the electron carriers and the electron mobility, respectively. Also, E and σ are the electric field and the conductivity, respectively. Therefore, the PC density, J_{ph}, is described by

$$J_{ph}=eG\mu_n\tau_n E=\sigma_{ph}E \quad (2)$$

where τ_n and G are the lifetime of the electrons and the generation rate, respectively, and σ_{ph} is the photoconductivity induced by the photon energy. Figure2 presents a plot of log J_{ph} vs 1/T for the PC response of the PC peaks corresponding to Ex(A) as a function of temperature.

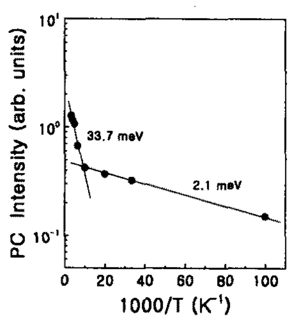

FIG. 2. Plot of log J_{ph} vs 1/T for the PC response of the PC peaks corresponding to Ex(A) as a function of temperature.

The strength of the excitonic PC, thus, is related to τ. Therefore, if the electron carrier lifetime of Eq. (2) is long enough, we can collect the charge and observe a strong PC signal. From the hypothesis of Simmons and Taylor, σ_{ph} for the region (ii) can be expressed by

$$\sigma_{ph}=e\mu_n[GN_o/(\upsilon\sigma_t N_t)]^{1/2}\exp[-(E_c-E)/2kT] \quad (3)$$

where υ is the thermal velocity of electrons, σ_t, the capture cross section of E, and k, the Boltzmann constant. Here, N_c and N_v, which are the effective density of states of the conduction and the valence bands, respectively, are assumed to be equal to N_o. N_t is the density of E. Thus, E is a trap level energy in the forbidden gap of a photoconductor. Therefore, Eq. (3) can be concisely expressed as $J_{ph} \propto A\exp(-\Delta E_{ph}/2kT)$, where ΔE_{ph} is the activation energy and A is substituted for $e\mu_n[GN_o/(\upsilon\sigma_t N_t)]^{1/2}$. As Fig. 2 shows, the PC intensity rapidly decreases at high-temperatures between 300 and 100 K. Also, at low-temperatures between 100 and 10 K, the PC intensity shows a moderate slope. Thus, ΔE_{ph} obtained from the plots of log J_{ph} vs 1/T in these two temperature regions are estimated to be 33.7 and 2.1 meV, respectively.

Ⅲ. CONCLUSIONS

$CdIn_2S_4$ films were grown on a semi-insulator substrate of GaAs by using the HWE method. The optical band gap obtained from the PC measurement was well described by the Varshni's equation, $E_g(T) = 2.7116$ eV $-$ (7.65×10^{-4} eV/K)$T^2/(425 + T)$. It has now become clear that the band-gap energy can be easily extracted through PC spectroscopy. Also, contrary to our expectation, the PC intensities decreased with decreasing temperature. In the log J_{ph} vs 1/T plot, two dominant levels were observed, one at high temperatures and the other at low temperatures. These levels, corresponding to 2.1 and 33.7 meV were associated with the binding energies of the free exciton and the neutral donor bound exciton, respectively.

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