# Study of the electrical properties of $CuGaSe_2$ thin-film solar-cells using admittance spectroscopy

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Chalcopyrite $Cu(In,Ga)Se_2$ (CIGS), a binary alloy of $CuInSe_2$ and $CuGaSe_2$, is a promising material for high-efficiency thin-film solar-cells. Band-gap of the $CuInSe_2$ is 1.04 eV, while it becomes 1.68 eV for the $CuGaSe_2$. Thus, band-gap of $CuGaSe_2$ is close to the ideal band-gap of the absorber-layer to achieve highest possible efficiency. Moreover, larger band-gap makes $CuGaSe_2$ suitable for the top-cell in the tandem solar-cell structure together with $CuInSe_2$ as a bottom-cell. Nevertheless, so far, $CuGaSe_2$ solar cells with a CdS buffer have achieved efficiency of around 11%. Therefore, to achieve the efficiency beyond current limit, an extensive study of the $CuGaSe_2$-material including defect-study with various compositions is indispensable. In this paper, we have used admittance spectroscopy to study the defect properties of $CuGaSe_2$ thin-film solar cells, where $CuGaSe_2$ thin-films were grown with various Se-flux ($P_{Se}$) conditions.

Polycrystalline $CuGaSe_2$ thin-films with 2 μm of thickness were grown over Mo-coated soda lime glass (SLG) substrates through three-stage co-evaporation process. Several samples were deposited by changing the $P_{Se}$-conditions. Admittance spectroscopy (AS) was carried out in the dark within the temperature range, 50 ~ 380 K using Agilent 4284A LCR meter. Modulation frequency was varied from 1 kHz to 1 MHz. For AS measurement, we considered the depletion region as a parallel combination of capacitance, $C_p$ and conductance, $G_p$, thus admittance becomes, $Y = G_p + i\omega C_p$. Since, imaginary part $C_p$ and real part $G_p$ in the admittance term are related explicitly by Kramers- Kronig relations, similar information can be obtained from both $C_p$ and $G_p$. Here, we used both parameters to investigate the nature of the trap signatures found in our measurement.

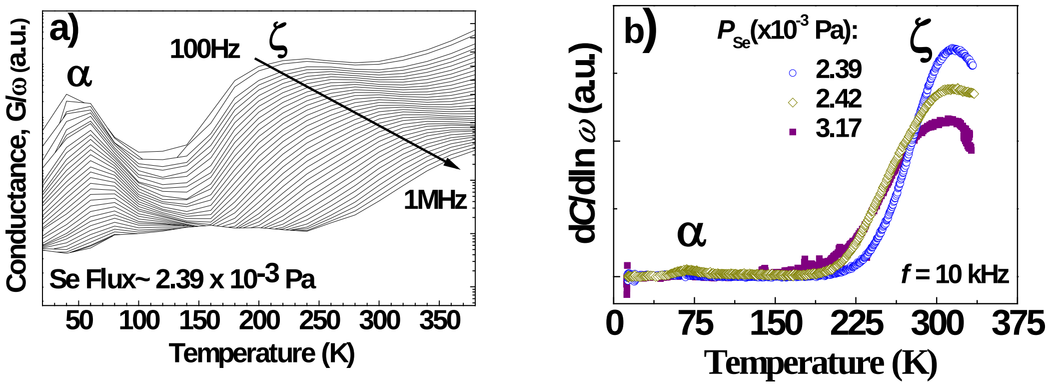


Fig. 1 Admittance spectra of (a) $CuGaSe_2$-based solar-cell structure (ZnO/CdS/$CuGaSe_2$/Mo/SLG) at various frequencies; (b) $CuGaSe_2$ solar cells with various $P_{Se}$ conditions during $CuGaSe_2$ growth.

Shown in Fig. 1(a), is the temperature dependence admittance spectra of a $CuGaSe_2$- based solar cells at various frequencies, where $CuGaSe_2$ films were deposited with low Se-flux condition of $2.39 \times 10^{-3}$ Pa. AS spectra shows two major peaks, α and ζ. Peak-α is usually attributed to the Cu-vacancy in the $CuGaSe_2$ material, while peak-ζ corresponds to the electrical response of a defect-level within the band-gap of the $CuGaSe_2$. Increase in the temperature shifts the AS-peaks (*i.e.*, characteristic frequency, $\omega_0$ ) to the higher value. Thus, activation energy, $E_A$ of a particular defect could be calculated from the slope of the corresponding Arrhenius plots, $\ln(\omega_o/T^2)$ versus 1/T. Here, T is the temperature of the AS-peak. $E_A$ of the Peak-α and ζ was calculated as ~ 50 meV and 350 meV above valance band ($E_V$) of the $CuGaSe_2$, respectively. As seen from the Fig. 1(b), in general, intensity of the peak-ζ increases with a decrease in the $P_{Se}$ -condition during growth of the $CuGaSe_2$ films.

Defect-parameters including defect-density, capture cross-section *etc.* were calculated, and compared with the $P_{Se}$-condition during growth. In general, $CuGaSe_2$ samples grown with higher $P_{Se}$ show lower defect density (peak- ζ), and improved solar-cell performances. Origin of the peak- ζ has been discussed. Temperature-dependent *AC*-conductance (G), and capacitance-voltage (*C-V*) measurement was performed to obtain transport properties, charge-density *etc.*, and discussed in relation to the Se-flux condition during deposition of the $CuGaSe_2$ films.