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Optical properties of $Cu(In,Ga)Se_2$ thin films with ultra-thin β-$Cu(In,Ga)_3Se_5$ capping layer

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The presence of β-$Cu(In,Ga)_3Se_5$ phase on Cu-poor $Cu(In,Ga)Se_2$ thin film surface could play an important role in the efficiencies of $Cu(In,Ga)Se_2$ thin film solar cells. The β-$Cu(In,Ga)_3Se_5$ with various thicknesses were deposited after a completion of the three-stage co-evaporation process of $Cu(In,Ga)Se_2$ films. The optical absorption measurement is used to obtain their optical band gap energies. The optical band gap energy of the β-$Cu(In,Ga)_3Se_5$ and $Cu(In,Ga)Se_2$ thin films, themselves, are 1.44 and 1.15 eV, respectively. The absorption edges of CIGS thin films with β-$Cu(In,Ga)_3Se_5$ layer shift towards shorter wavelengths. As a result, the band gap energy increases as the thickness of $Cu(In,Ga)_3Se_5$ increases. Likewise, the temperature-dependent and excitation power-dependent photoluminescence (PL) spectra for CIGS with various thicknesses of β-$Cu(In,Ga)_3Se_5$ are identified as donor-to-acceptor pairs (DAPs) and free (conduction band) -to-bound (acceptor) transitions. The higher PL transition energy is found with β-$Cu(In,Ga)_3Se_5$ less than 80 nm thick. These minimal defect layers results in larger band gap energy.

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