Application of $Zn_{1-x}Mg_xO$:Al to transparent conductive oxide of $Cu(In,Ga)(S,Se)_2$ solar cell

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19.47%-efficient $Cu(In,Ga)(Se,S)_2$ (CIGSSe)-based solar cell is obtained by replacing traditional CdS/ZnO buffer layers with $Cd_{0.75}Zn_{0.25}S/Zn_{0.79}Mg_{0.21}O$ layers to increase short-circuit current density since its external quantum efficiency is increased in a short wavelength range of 320-520 nm. In addition, it was theoretically reported that difference of conduction band minimum (E_C) between transparent conductive oxide (TCO) layer and absorber plays a role in reducing carrier recombination at interface for enhancing the conversion efficiency (η), especially open-circuit voltage (V_{OC}) and fill factor (FF) [1]. In this work, $Zn_{1-x}Mg_xO$:Al was utilized as alternative TCO layer in CIGSSe solar cell to experimentally investigate influence of the E_C difference between TCO layer and CIGSSe absorber to boost cell performances, especially V_{OC} and FF. The difference of E_C between $Zn_{1-x}Mg_xO$:Al layer and CIGSSe absorber is optimized by varying [Mg]/([Mg]+[Zn]), x. It is demonstrated that $Zn_{1-x}Mg_xO$:Al films with [Mg]/([Mg]+[Zn]) of 0.1-0.12, enhancing band-gap energy (E_g) to 3.72-3.76 eV, are appropriate as TCO because of their enhanced mobility and decreased carrier density. The addition of 12% Mg into ZnO:Al for TCO layer effectively decreases surface carrier recombination and improves V_{OC} and FF. This is first experimental proof of the concept for optimizing E_C difference between TCO and absorber to minimize surface carrier recombination. Ultimately, conversion efficiency of CIGSSe solar cell with alternative $Cd_{0.75}Zn_{0.25}S/Zn_{0.79}Mg_{0.21}O/Zn_{0.88}Mg_{0.12}O$:Al layers is improved over 20% as illustrated in the figure.

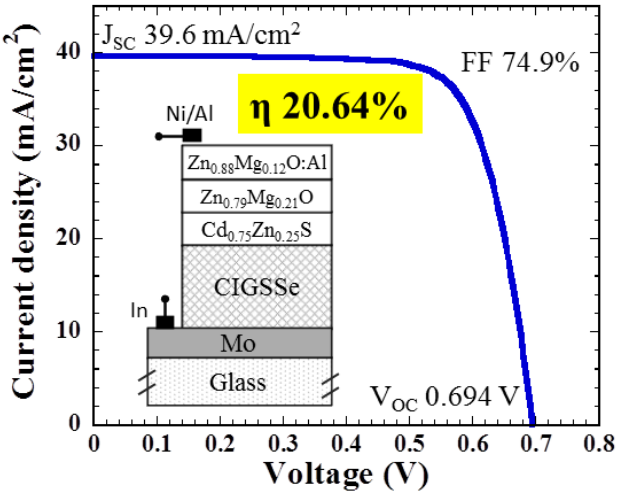

Figure Photo-J-V characteristic of CIGSSe solar cell with alternative $Cd_{0.75}Zn_{0.25}S$ buffer/$Zn_{0.79}Mg_{0.21}O$ window/$Zn_{0.88}Mg_{0.12}O$:Al (TCO) layers.

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