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Investigation of Cu-atomic ratio in the second step of the 3-stage deposition process of Cu(In,Ga)Se2 thin film solar cells

The high efficiency $CuIn_{1-x}Ga_xSe_2$ (CIGS) solar cells are usually fabricated by the 3-stage deposition process for the CIGS layer. The Cu/[III] atomic ratio (CGI or y) in the 2^{nd} step of the 3-stage process is considered as one of important deposition parameters to achieve high efficiency devices, where [III] refers to group-III elements. In the 3-stage process, the formation of the CIGS layer has to evolve from Cu-poor (Cu/[III] < 1) to Cu-rich (Cu/[III] > 1) in the 2^{nd} stage and finish with slightly Cu-poor in the 3^{rd} stage. In this work, the highest value of Cu/[III] atomic ratio in the 2^{nd} stage was varied from 1.0 to 1.5 while the Ga/[III] atomic ratio (GGI or x) was set at 0.37 as in other works during the 1^{st} and 3^{rd} stages of the deposition process in all devices. The typical thickness of the CIGS layer is approximately 2 microns. The effects of the Cu/[III] atomic ratio were investigated in terms of the elemental depth profiles, cross-sectional images, photovoltaic parameters and quantum efficiency of the CIGS devices. It was discovered that the optimal Cu/[III] atomic ratio of 1.3 yielded the most efficient devices. In addition, the depth profiles also showed the double-grading in the Ga/[III] atomic ratio with high Ga toward the front and back surfaces of the CIGS layer with the minimum Ga/[III] atomic ratio or the notch in the conduction band at approximately one micron below the surface of the CIGS layer. The photovoltaic parameters were obtained under AM1.5 standard test condition with the highest efficiency of 16.8% with V_{OC} of 670 mV, J_{SC} of 33.2 mA/cm^2 and fill factor of 75.5%. The J_{SC} was found to increase in comparison to other Cu/[III] atomic ratio conditions due to the improvement in the spectral response in the short wavelength region.

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