Area 2 Thin-Film Compound Semiconductor PV

IMPACTS OF LONG-TERM HEAT-LIGHT SOAKING ON CIGS SOLAR CELLS WITH KF POST-DEPOSTION TREATMENT

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The chalcopyrite compound $Cu(In,Ga)Se_2$ (CIGS) has the potential to be used as a semiconductor material in thin-film photovoltaic devices with high conversion efficiencies. Chirilă et al. demonstrated the effectiveness of subjecting the CIGS surface to KF post-deposition treatment (KF-PDT) [1] and many studies on high-efficiency CIGS solar cells with KF-PDT have been reported. However, CIGS solar cells with KF-PDT cannot always retain these high conversion efficiencies for a long time; that is, the degradation of conversion efficiency frequently occurs. Although the degradation mechanism of CIGS solar cells has not yet been clarified, the acceptor concentrations in CIGS layers easily decrease when the cells are kept in the dark, even at room temperature. Light soaking has been reported as an effective method to increase the acceptor concentrations of CIGS layers [2]. Light-induced acceptors are thought to be metastable, and high acceptor concentrations are generally considered beneficial for high conversion efficiency. In this study, we examine whether heat-light soaking is useful to enhance the conversion efficiency of CIGS solar cells with KF-PDT. CIGS solar cells were fabricated on soda lime glass (SLG) substrates. A 0.8-μm-thick Mo back contact was deposited by sputtering on a SLG substrate. A 2.0-μm-thick CIGS layer was deposited by evaporation using a three-stage process. After CIGS deposition, KF and NaF post-deposition treatments were performed at 350°C. A 35-nm-thick CdS layer was formed by chemical bath deposition. A 60-nm-thick intrinsic ZnO layer and a 350-nm-thick n-type Al-doped ZnO (AZO) layer were deposited at 150°C by facing-target magnetron sputtering deposition. An aluminum electrode was fabricated on the AZO layer by evaporation, and the devices were separated by mechanical scribing. A 110-nm-thick MgF_2 layer was deposited as an anti-reflection coating. Heat-light soaking was performed at 90°C in a dry nitrogen atmosphere with the dew point below −50°C. A metal-halide lamp and halogen lamp were adopted as light sources with wide wavelength ranges, and illuminance was fixed at 50,000 lx. For reference, dark heating at 90°C and light soaking at room temperature were also performed.

At first, we compared the conversion efficiencies obtained with dark heating and light soaking in order to investigate the effects of heat-light soaking. Figure 1 shows box plots with the median solar cell efficiencies for the CIGS solar cells subjected to dark heating, light soaking, and heat-light soaking for 250 h. Each group had the same number of samples (n = 16). At the initial time (0 h), the median efficiencies and the ionized acceptor concentrations (N_{CV}) agreed well among the groups. In the group treated by dark heating, the conversion efficiency decreased distinctly after 100 h. The saturation current density (J_0) and ideality factor (n) improved slightly, but N_{CV} significantly decreased. The reduction in N_{CV} results in the decreasing of V_{oc} and FF, thus causing the conversion efficiency to deteriorate. Light soaking slightly improves the conversion efficiency and considerably increases N_{CV}. However, the saturation current density and ideality factor are not improved by light soaking, and N_{CV} is too high to achieve high conversion efficiency. Therefore, the improvement in efficiency obtained by light soaking is not significant. On the other hand, heat-light soaking obviously increased the conversion efficiencies of the solar cells; the median efficiency was 21.0% after 250 h. The N_{CV} increased after heat-light soaking, and the concentrations were suitable to obtain high conversion efficiency while maintaining high J_{SC}. The saturation current density and ideality factor are dramatically improved after heat-light soaking because the passivation of recombination centers at CIGS grain boundaries and CdS/CIGS interfaces may occur. Therefore, V_{oc} and FF increase significantly, and high conversion efficiencies are achieved.

[1] A. Chirilă, et al., Nat. Mater. **12**, 1107 (2013).
[2] T. Nakada, et al., IEEE Transactions on Electron Devices, **46**, 2093 (1999).

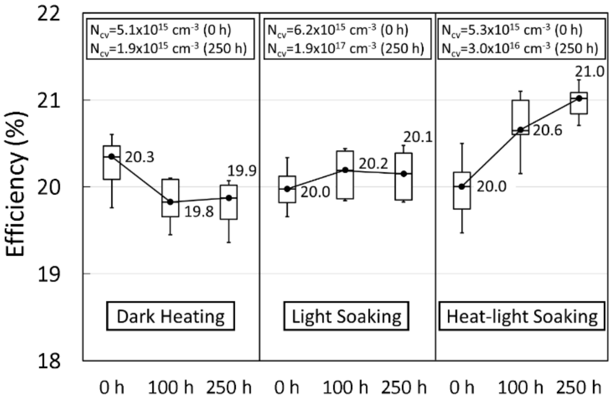

Figure 1: Box plots showing the median efficiencies of CIGS solar cells