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Application of sputtered $ZnO_{1-x}S_x$ buffer layer for $Cu(In, Ga)Se_2$ solar cells

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1. Introduction

$Cu(In,Ga)Se_2$ (CIGS) solar cells are a representative of the high efficiency thin film solar cells. Currently, a CdS thin film is utilized as a buffer layer in high efficiency CIGS solar cells [1-3]. The CdS film is prepared by chemical bath deposition (CBD). However, in the view of the environmental impact of cadmium, there is a need to find an alternative to CdS films. Although many interests and efforts are concentrated on the developments of CIGS solar cells using Cd-free buffer layers, it has not been reported that the performances of solar cells with Cd-free buffer layers exceed those with CdS. We have proposed (Zn,Mg)O buffer layers as Cd-free buffer layers [4]. The (Zn,Mg)O films are prepared by co-sputtering of ZnO and MgO. The band gap energy (E_g) of (Zn,Mg)O films can be controlled by changing the Mg content. But the CIGS solar cells using the (Zn,Mg)O buffer layers have not achieved a higher conversion efficiency than those using CdS. This would be due to the sputtering damage on the CIGS surface. On the other hand, $ZnO_{1-x}S_x$ films are considered as alternative buffer layers [5-7]. The band gap of $ZnO_{1-x}S_x$ can be controlled by changing the S content. Also, the S in the $ZnO_{1-x}S_x$ films may passivate the defects on the CIGS surface. In this study, we have applied the $ZnO_{1-x}S_x$ by co-sputtering of ZnO and ZnS, which should have high controllability of the compositional ratios of O and S. The E_g of the $ZnO_{1-x}S_x$ films was compared with that of the CdS thin films, and the performance of CIGS solar cells with the $ZnO_{1-x}S_x$ and CdS buffer layers are discussed.

2. Experimental

The $ZnO_{1-x}S_x$ thin films were prepared by a radio frequency (RF) magnetron sputtering from ZnO and ZnS targets. The S content in the thin film was controlled by varying the sputtering power applied to each target to control the sputtering rates. The CdS thin film was prepared by CBD. Fig. 1 shows the band alignments of (a) CIGS and $ZnO_{1-x}S_x$ and (b) CIGS and CdS layers. The E_g of $ZnO_{1-x}S_x$ can be controlled from 2.8 eV to 3.7 eV. The E_g of the $ZnO_{1-x}S_x$ and CdS thin films were derived from a plot of $(\alpha h\nu)^2$ as a function of photon energy ($h\nu$). The $ZnO_{1-x}S_x$ thin film with the S content (x) of 0.18 was used. Fig. 2 shows the structures of CIGS solar cells with (a) $ZnO_{1-x}S_x$ and (b) CBD-CdS buffer layers. The CIGS solar cells consisting of Al/NiCr/ITO/$ZnO_{1-x}S_x$/CIGS/Mo/soda-lime glass (SLG) and Al/NiCrITO/ZnO/CdS/CIGS/Mo/SLG structures were fabricated [1]. The CIGS layer by three stage process [8] had the Cu/(In+Ga) ratio of 0.91 and the Ga/(Ga+In) ratio of 0.29. The E_g of the CIGS layer was about 1.1 eV. The current-voltage (*J-V*) characteristics of the CIGS solar cells were measured under 100 mW/cm^2, AM 1.5G illumination at 25^{o}C. The external quantum efficiency (EQE) of the CIGS solar cells was also measured.

3. Results and discussions

Fig. 3 shows the $(\alpha h\nu)^2$ plots of the $ZnO_{1-x}S_x$ and CdS thin films as a function of photon energy ($h\nu$) to measure the E_g. The absorption coefficient (α) was obtained from the transmittance. The E_g of the $ZnO_{1-x}S_x$ and CdS thin films were 2.9 eV and 2.6eV, respectively. The $ZnO_{1-x}S_x$ film had a wider band gap than CdS. Fig. 4 shows *J-V* curves of the CIGS solar cells with (a) $ZnO_{1-x}S_x$/CIGS and (b) ZnO/CdS/CIGS structures. The CIGS solar cell with the $ZnO_{1-x}S_x$ buffer layer had a higher short-circuit current density (J_{sc}), and a lower open-circuit voltage(V_{oc}) and a fill factor (*FF*). Thus, the efficiency of 11.1% approaching to that of the CdS/CIGS solar cell was obtained. Fig. 5 shows the EQE of the CIGS solar cells with the $ZnO_{1-x}S_x$ and CdS buffer layers. This result indicates that the CIGS solar cell with the $ZnO_{1-x}S_x$ buffer layer showed significantly enhanced EQE in the spectral region between 300 and 500 nm than that with the CdS buffer layers. The CIGS solar cells with the $ZnO_{1-x}S_x$ buffer layers can decrease the absorption loss than the cells with the CdS buffer layer.

4. Conclusions

The $ZnO_{1-x}S_x$ thin films were prepared by co-sputtering of ZnO and ZnS targets. The E_g of the $ZnO_{1-x}S_x$ and CdS thin films were 2.9 eV and 2.6eV, respectively. The $ZnO_{1-x}S_x$ film had a wider band gap than CdS. The CIGS solar cells with the $ZnO_{1-x}S_x$ buffer layer showed the efficiency approaching to that of the cell with the CdS buffer layer. The CIGS solar cell with the $ZnO_{1-x}S_x$ buffer layer had a higher J_{sc} than that with the CdS buffer layer. The CIGS solar cells with the $ZnO_{1-x}S_x$ buffer layers can decrease the absorption loss than the cells with the CdS buffer layer. The $ZnO_{1-x}S_x$ has a wider band gap than CdS and can be expected to provide a useful buffer layer of solar cells that improves the overall efficiency by decreasing the absorption loss.

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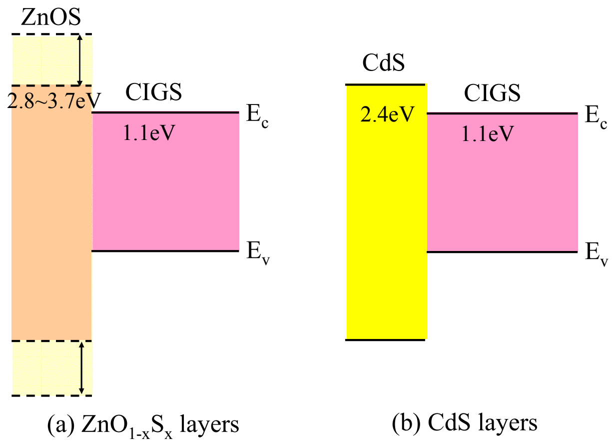

Fig. 1 Schematics band diagrams of $ZnO_{1-x}S_x$/CIGS and CdS/CIGS layers.

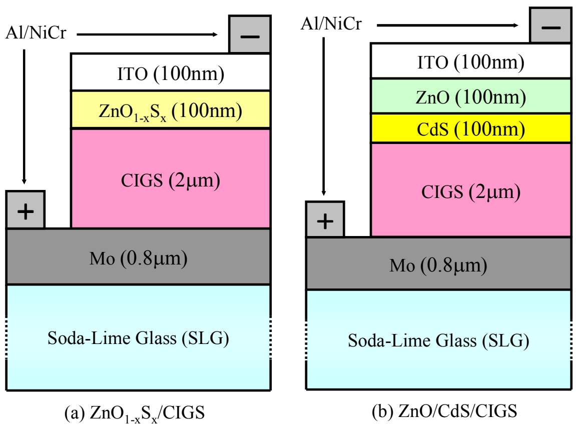

Fig. 2 Schematic structure of CIGS solar cells.

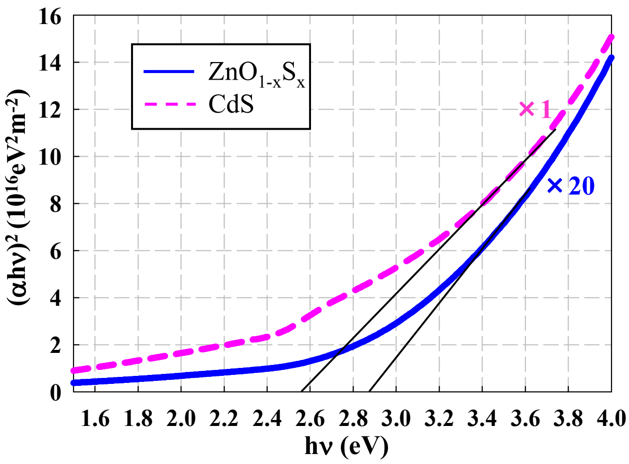

Fig. 3 $(\alpha h\nu)^2$ of $ZnO_{1-x}S_x$ films (x=0.18) and CdS as a function of photon energy($h\nu$).

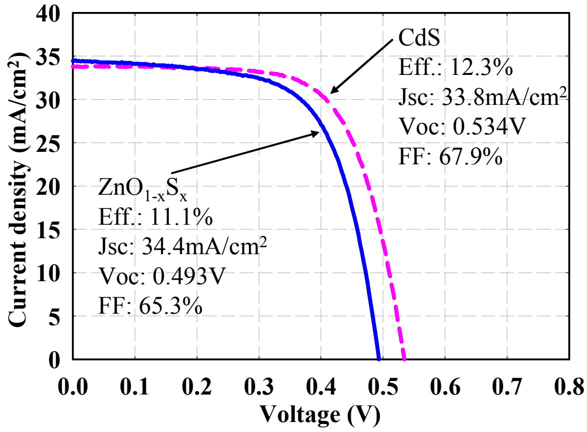

Fig. 4 *J-V* curves of CIGS solar cell with $ZnO_{1-x}S_x$ and CdS buffer layers.

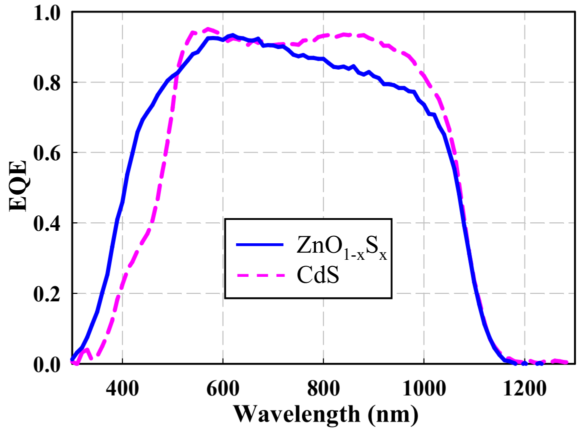

Fig. 5 EQE of CIGS solar cell with the $ZnO_{1-x}S_x$ and Cds buffer layers.

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