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Surface morphology and device performance of $CuInS_2$ solar cells prepared by single and two step evaporation methods

Shohei Fukamizu[1], Toshihiro Kondo[1], Yusuke Oda[2], Takashi Minemoto[2] and Hideyuki Takakura[1]

[1]Ritsumeikan University, College of Science and Engineering
1-1-1 Nojihigashi, Kusatsu, Shiga 525-8577, Japan
Phone: +81-77-561-4836 E-mail: ro008066@ed.ritsumei.ac.jp
[2]Ritsumeikan University, Ritsumeikan Global Innovation Research Organization
1-1-1 Nojihigashi, Kusatsu, Shiga 525-8577, Japan

1. Introduction

The band gap (E_g) of $CuInS_2$ (CIS) films is 1.5 eV, which is close to the optimum E_g of 1.4 eV for light absorbing layers of solar cells. In CIS solar cells, the conversion efficiency of 12 % was achieved using the CIS films prepared by the two-step evaporation method [1-2]. The deposition of a CIS film with a Cu rich composition at the substrate temperature of > 500 ^oC resulted in a large grain growth but a rough surface morphology [3-4]. The rough surface would reduce open-circuit voltage (V_{oc}) and fill factor (*FF*) and hence the conversion efficiency. In contrast, the 600 ^oC annealing of the CIS film with a Cu rich composition deposited at the substrate temperature of 50 ^oC resulted in a large grain growth and better flatness. This would be due to the lower substrate temperature than melting point of In (156.6 ^oC) thus In was not agglutinated. However, the CIS film was peeled off from Mo-coated soda-lime-glass (SLG) when the Cu-rich CIS film was soaked in a KCN solution to control the composition to In-rich. In this study, CIS films were fabricated by two-step evaporation methods that Cu-rich Cu-In-S deposited at 50 ^oC in the first step and In-S deposited in the second step to control good flatness and In-rich CIS films.

2. Experimental

All CIS films were deposited on Mo-coated SLG using multi-source co-evaporation. Fig. 1 shows the deposition sequences of (a) two- and (b) single-step evaporation methods. In the two-step evaporation method, a Cu-rich Cu-In-S film was deposited at 50 ^oC for 25min. Then, the substrate temperature was increased to 550 ^oC and the film was annealed for 15 min under S irradiation. In the second step, In and S were irradiated to control the film composition to In rich (Cu/In = 0.8~0.9) for 30min and the film was annealed for 15 min under S irradiation. For the reference, a Cu-rich Cu-In-S film was deposited at 550 ^oC for 35min and the film was annealed for 15min under S irradiation. The film was soaked in a 10 wt% KCN solution for 2 min to adjust to a slightly In-rich composition. The thickness of both films was approximately 2 μm. The CIS solar cells consisted of ITO/ZnO/CdS/CIS/Mo/SLG structure were fabricated. The current–voltage (*J-V*) characteristics of the CIS solar cells were measured under 100 mW/cm^2, AM 1.5 G illumination at 25 ^oC.

3. Results and discussion

Fig. 2 shows the surface SEM images of the CIS films by (a) two-step evaporation method and (b) single-step evaporation method with the KCN etching. The surface of the CIS films obtained from two-step evaporation method was smoother than single one. Fig. 3 shows the cross SEM images of the CIS films by (a) two-step evaporation method and (b) single-step evaporation method with the KCN etching. The grain size of the CIS films by two-step evaporation method was similar to that by single one. Fig. 4 shows the *J-V* curves of the solar cells using the CIS films by (a) two- and (b) single-step evaporation methods. The higher V_{oc} of 0.677 V was obtained compared with 0.633 V for the single-step evaporation method. This would be due to the improvement of the flatness. However, the *FF* was low and the conversion efficiency was 6.4 %, which was lower than that of the single-step evaporation of 8.5 %. This might be due to the poor crystal quality of the CIS film by the two-step evaporation because the actual substrate temperature during the two-step evaporation was lower than that during the single-step one possibly due to the difference in the emissivity of CIS and Mo.

4. Conclusions

The CIS films were fabricated by the single- and two-step evaporation methods using the multi-source co-evaporation of Cu-In-S. As the results, the surface morphology of the film prepared by the two-step evaporation method was improved compared with the single one. The crystal grain of the film prepared by the two-step evaporation method was similar to that by the single one. Moreover, the higher V_{oc} of 0.677 V was obtained compared with 0.633 V for the single-step evaporation method. This would be due to the improvement of the flatness. However, the *FF* was low and the conversion efficiency was 6.4 %, which was lower than that of the single-step evaporation of 8.5 %. The precise control of the substrate temperature will be needed to improve the crystal quality for achieving high efficiency solar cells.

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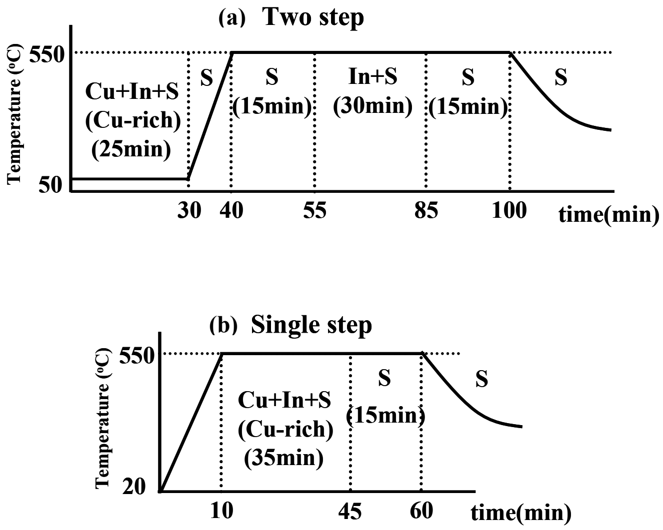

Fig. 1 Deposition sequences of CIS films by (a) two- and (b) single-step evaporation methods.

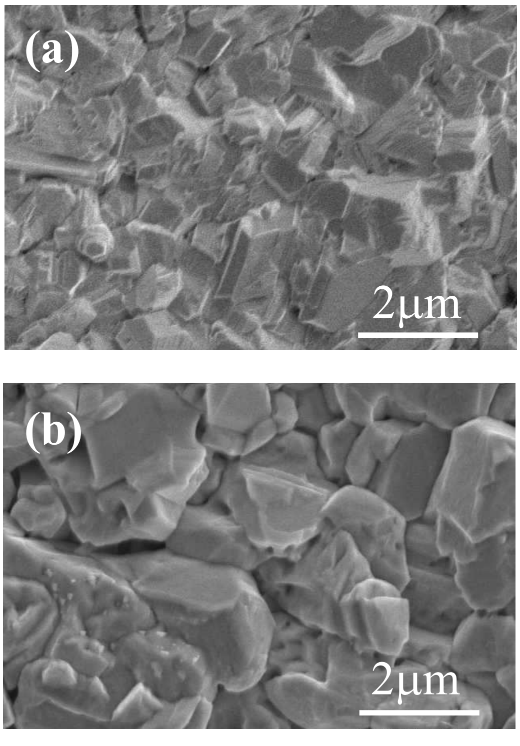

Fig. 2 Cross-sectional SEM images of CIS films by (a) two-step evaporation method and (b) single step evaporation method with the KCN etching.

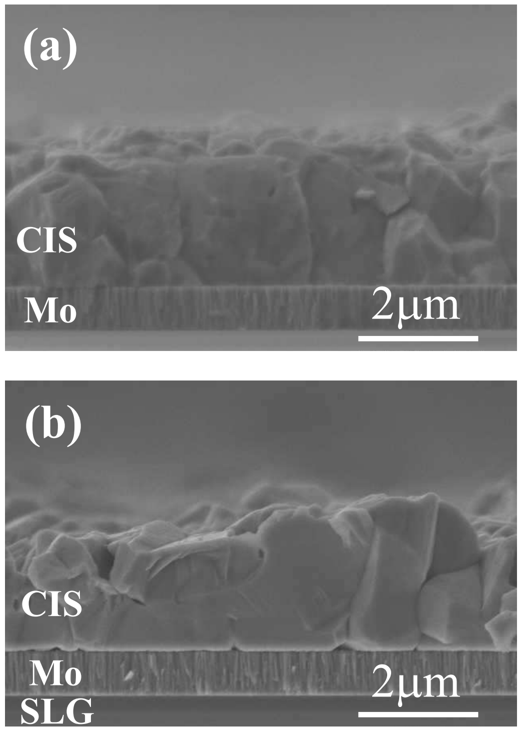

Fig. 3 Surface SEM images of CIS films by (a) two- and (b) single-step evaporation methods.

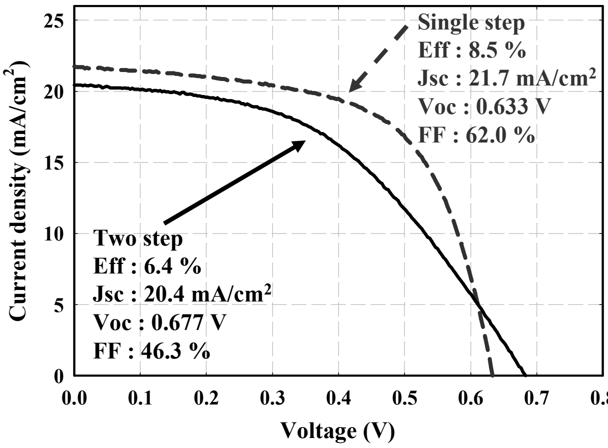

Fig. 4 Current density -voltage curves of CIS solar cells by two- and single-step evaporation methods.

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