Characterization of Electron-Induced Defects in Cu (In, Ga) Se_2 Thin-Film Solar Cells using Electroluminescence

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ABSTRACT

CIGS solar cells were irradiated with 250 keV electrons, which can create only Cu-related defects in the cell, to reveal the radiation defect. The EL image of CIGS solar cells before electron irradiation at 120 K described small grains, thought to be those of the CIGS. After 250 keV electron irradiation of the CIGS cell, the cell was uniformly illuminated compared to before the electron irradiation and the observed grains were unclear. In addition, the EL intensity rose with increasing electron fluence, meaning the change in EL efficiency may be attributable to the decreased likelihood of non-radiative recombination in intrinsic defects due to electron-induced defects. Since the light soaking effect for CIGS solar cells is reported the same phenomena, the 250 keV electron radiation effects for CIGS solar cells might be equivalent to the effect.

INTRODUCTION

CIGS solar cells have high attractive solar cells for space applications, since the cells have the highest efficiency among all thin-film solar cells [1], are lightweight and flexible with film substrates [2, 3, 4], and have excellent radiation tolerance in a space environment [5]. In particular, their radiation tolerance has been proved; not only in ground-based radiation irradiation tests but also demonstrations with small satellites in space [6].

CIGS solar cells have excellent radiation tolerance, which means their electrical properties are

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not degraded by 1MeV electrons. Conversely, cell performance is impaired with exposure to proton irradiation, similar to other solar cell types. The radiation damage to the cells caused by proton irradiation gradually recovers when the irradiated cells are kept even at room temperature and the recovery rate is temperature-dependent [7]. The radiation defect in CIGS solar cells, which impair their performance, was reported as an In antisite defect [8]. However, it remains unclear whether the other types of defects, namely Cu, Ga and Se Frenkel-pairs in CIGS, which are simultaneously generated by radiation, degrade cell performance or not. Therefore, we investigated these defects in CIGS solar cells induced by low energy electrons, enabling the type of radiation defect in the solar cells to be selected.

The electrical output performance of CIGS solar cells was not degraded by 250 keV electron irradiation, which can generate Cu-related defects in CIGS [9] and the roll–over behavior featured in the current-voltage characteristic under light illumination was reduced by irradiation. The increased carrier density produced by 250 keV electrons was found to reduce the roll-over. These results suggest that Cu-related defects induced by 250 keV electrons differ from those generated during 1 MeV electron irradiation, which degrades the electrical performance of CIGS solar cells. However, the defect induced by 250 keV electrons is not revealed.

Electroluminescence (EL) is a powerful tool to analyze semiconductor defects. Using EL from the CIGS solar cells, metastable defects were investigated [10]. We analyzed the defects induced by 250keV-electrons in CIGS solar cells with the EL.

EXPERIMENTS

CIGS solar cells were fabricated on glass substrates with co-evaporation [11]. The [Ga]/([Ga]+[In]) composition ratio of the CIGS layers was about 0.4 and the solar cells were of the bare type without an anti-reflective coating. Specifically, the short circuit density Jsc, the open circuit voltage Voc, the fill factor FF, and efficiency under AM0 condition were 38.1 mA/cm^2, 702 mV, 0.721, and 14.29 %, respectively.

The electron irradiation tests were conducted using a Cockcroft Walton electron accelerator at Osaka Prefecture University (OPU). The cells were irradiated in a vacuum with electron energy at 250 keV. Since the electrons heated the cells during the tests, the cells were cooled to less than 150 K using LN_2 to prevent the thermal annealing effect. EL images of the cells were observed with a cooled InGaAs CCD Camera. The EL spectrum was measured by a small monochromator

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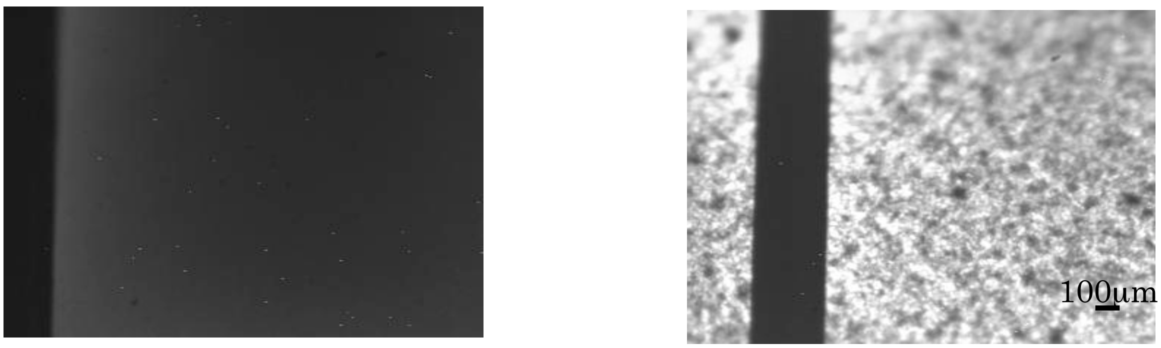
with a cooled Si array detector.

RESULTS and DISCUSSION

EL images of a CIGS solar cell before electron irradiation are shown in Fig. 1. The EL image at R.T. had uniform luminescence. In contrast, the image at low temperature appeared grainy, seemingly indicating CIGS grain boundaries. However, the images must be evaluated in detail to clarify the origin of the grains.



(a) R.T. (b) 120 K

Figure 1. EL images of CIGS solar cells before electron irradiation at (a) room temperature and (b) 120 K .

(a) before (b) after

Figure 2. EL images of CIGS solar cells (a) before and (b) after electron irradiation at 120 K. The electron fluence was 3×10^{15} cm^{-2}.

The EL image before electron irradiation at 120K displayed grains in Fig. 2 (a) equivalent to Fig. 1 (b), and local luminescence from the CIGS. Meanwhile, the luminescence from the CIGS cell-irradiated electrons in Fig. 2 (b) expanded uniformly and showed indefinite grains compared

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to that before electron irradiation. Fig. 3 shows the EL total intensity of the CIGS cell irradiated with electrons, with intensities estimated from the EL images. The intensity rose with increasing electron fluence. The EL spectrum in Fig. 4 indicates that near band-edge emission from CIGS layer was 1.24 eV and the intensity of the near band-edge emission also rose with increasing electron fluence. This result explains how the radiation recombination at the near band-edge rose with increasing electron fluence, as in Fig. 3. The change in EL efficiency may be attributable to the decreased likelihood of non-radiative recombination in intrinsic defects due to electron-induced defects. These results correspond to an improvement in the roll-over behavior in current-voltage characteristics under light condition because of the increase the carrier density in the cell by 250 keV electrons.

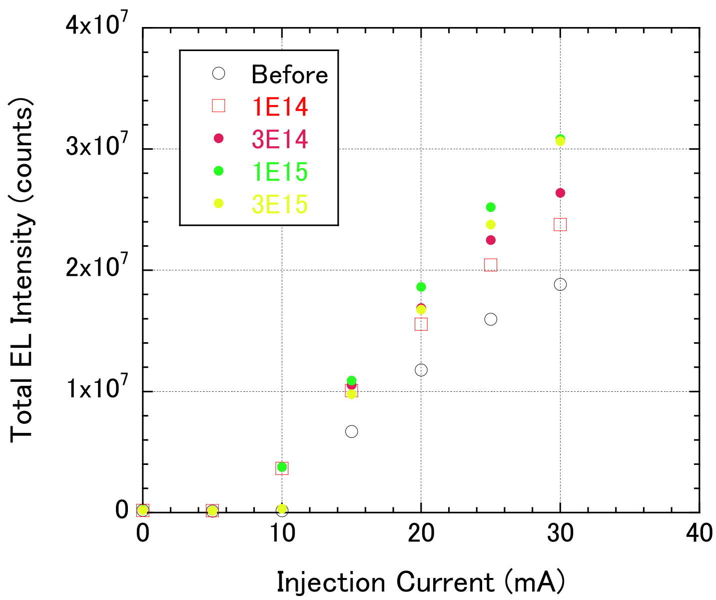

Figure 3. Total area EL intensities as a function of the injection current in the CIGS solar cell irradiated with electrons (Note that 1E14, 3E14, 1E15 and 3E15 denote irradiations to fluencies of 1×10^{14}, 3×10^{14}, 1×10^{15} and 3×10^{15} cm^{-2}, respectively.) as estimated by the EL images at 120 K.

The increased intensity of EL and carrier density characterized the light-soaking effect for CIGS solar cells [10]. This effect is said to be due to the change in charge in the V_{Cu}-V_{Se} metastable defect in CIGS solar cells by electrons generated by light. These results suggest that the 250 keV electron radiation effects for CIGS solar cells might be equivalent to the light soaking effect.

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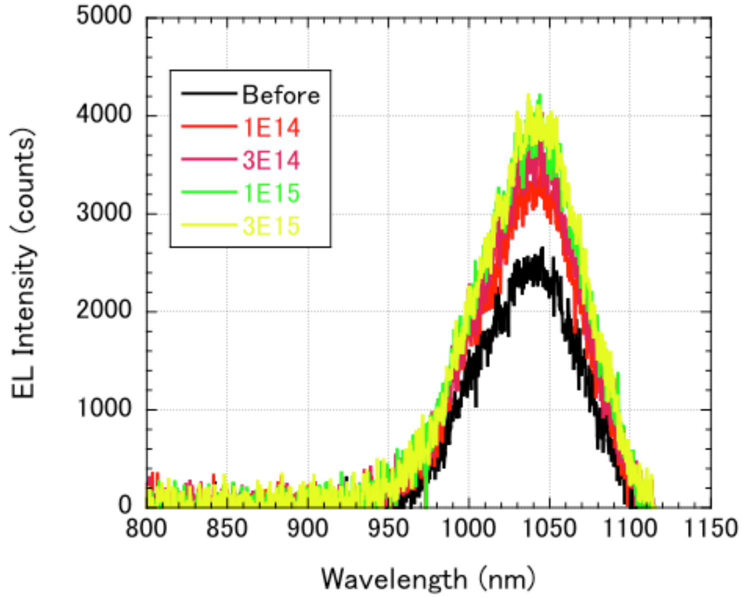

Figure 4. EL spectrum measured at 120 K in CIGS solar cells irradiated with electrons.

CONCLUSION

The effect of low-energy electrons on CIGS solar cells was evaluated to solve the mechanism of radiation-induced defects in cells by measuring EL. Electrons with 250 keV can create Cu-related defects in CIGS cells, which were detected the increased EL intensity for the cell. This result differs from the decreasing EL intensity for CIGS solar cells irradiated with proton and electrons with over 1 MeV. An increase in carrier concentration and improved roll-over behavior featured in current-voltage characteristic under light condition were reported for CIGS solar cells irradiated with 250 keV electrons. The mechanism is deduced to be equivalent to that of the light-soaking effect for CIGS solar cells, since these phenomena showed this effect. Therefore, Cu-related defects in CIGS may not be radiation capable of impairing cell performance in CIGS solar cells.

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