Effect of 250keV Electron Irradiation on Properties of CIGS Thin-Film Solar Cells

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Keyword(s):Solar Cell, CIGS, Radiation

Abstract

Electrons with energy of 250keV introduce copper-related defects. The cells were irradiated with the electrons at below 150 K because the radiation defects could be recovered with a thermal annealing effect. The carrier density increased with increasing electron fluence. The electrons can generate Cu-related Frenkel-pairs. Copper vacancy could result in increased carrier density since the shallow acceptor level V_{Cu} is assumed to be the main defect in the CIGS absorbing layer. In contrast, a drop in the carrier density of CIGS solar cells irradiated with 1MeV electrons has been reported. In addition, activation energies of defects induced by 250 keV electrons with thermal annealing differ from those by 1MeV electrons. These results indicates that copper-related defects in CIGS induced by radiation do not degrade the CIGS solar cells.

1. Introduction

Cu (In, Ga) Se_2 (CIGS) solar cells have excellent radiation tolerance and their electrical properties are not degraded by high-energy electrons. Conversely, similarly to other types of solar cells, the cell performance does decline with exposure to high-energy proton irradiation. The radiation damage to cells due to proton irradiation gradually recovers when the irradiated cells are kept even at room temperature. In addition, the recovery rate is temperature-dependent[1)]. The radiation defect in CIGS solar cells, causing their performance to decrease, has been reported as an In antisite defect[2)]. However, it is unclear whether the other types of defects in CIGS, namely Cu, Ga, In and Se Frenkel-pairs, which are simultaneously generated by radiation, result in cell performance declining. Therefore, we have investigated these defects in CIGS solar cells induced by low energy electrons that can select the type of radiation defect in the solar cells.

2. Experimental Details

2.1CIGS Solar Cells

CIGS solar cells on glass substrate were fabricated using a co-evaporation method[3)]. The [Ga] / ([Ga + In]) composition ratio of the CIGS layers was about 0.4. The solar cells were of the bare type without anti-reflective coatings and cover glass. The electrical performance under AM 0 condition was described in Fig. 1.

2.2 Irradiation Experiments

The electron irradiation experiments were carried out using a Cockcroft Walton electron accelerator at Osaka Prefecture University (OPU). The cells were irradiated with electrons at an energy of 250 keV in a vacuum. The cells were cooled to less than 150K during experiments to prevent the thermal annealing effect using LN_2[4)]. Carrier profiling by capacitance-voltage (C-V) was carried out by using an HP 4284A impedance analyzer. Light current-voltage characteristics (LIV) were measured using an HP 4155C semiconductor analyzer and AM0 solar simulator with one Xe light source. These measurements were alternately performed during the irradiation experiments and executed at each designated fluence stage until the fluence reached the final value.

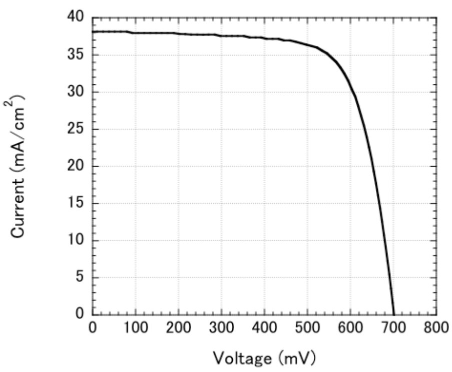

Fig. 1. Current-Voltage characteristic under AM0 condition of the CIGS solar cell.

3. Results & Discussions

Fig. 2 shows the relation between electron energy and the CIGS defect introduction rate. Our calculation indicated that the threshold energy of electrons to recoil Cu in CIGS is around

200keV, while that to recoil Ga atoms exceeds 350 keV, as illustrated in Fig. 2. Therefore, only the Cooper-related Frenkel-pair, namely, radiation defects can be generated in a CIGS cell that is irradiated with 200 – 300 keV electrons. According to these electron irradiation tests for CIGS solar cells, it is confirmed whether Cu related defects are radiation-related, which could degrade the electrical performance of the solar cells.

A 250keV electron irradiation test was carried out for a CIGS solar cell. The temperature during electron irradiation peaked at 150K. Figure 3 shows the carrier profile of the cell before and after electron irradiation, as calculated by the C-V measurement. The carrier density increased with increasing electron fluence. Conversely, it was reported that the density of the CIGS solar cell declined with increasing fluence of 1MeV electrons, which degraded the electrical performance[5]. This result implies that the defect introduced by 250 keV electrons is not radiation-related, which would impair the performance of the CIGS solar cells.

The defect induced by 250keV electrons is Cu-related, since the electrons can recoil only copper in CIGS. V_{Cu} defect is said to be the dominant accepter in P type of CIGS. Therefore, the increased carrier density would result in the V_{Cu} defect generated by the electrons.

Figure 4 indicates change in the LIV characteristics of the cell irradiated with electrons. Note that 1E14, 3E14, 1E15, 3E15, and 1E16 denote irradiations to fluences of 1×10^{14}, 3×10^{14}, 1×10^{15}, 3×10^{15}, and 1×10^{16} cm^{-2}, respectively.The feature of the LIV is the blocking behavior of the diode forward bias called “roll-over”. The roll-over behavior is due to a second junction in the CIGS solar cells[6] and may be related to the Na-content in a CIGS absorber layer[7]. The Na in CIGS eases this effect, since the Na increases the accepter density. According to the result of the carrier profile of the CIGS solar cell irradiated with 250keV, the electrons increased the carrier density in the CIGS solar cell. Therefore, the increased carrier density reduced the roll-over of the cells, as in the Na effect for CIGS solar cells.

Annealing tests for the irradiated cell were performed to investigate the origin of the defect introduced by 250 keV electrons in CIGS. Figure 5 illustrates the change in the CIGS carrier profile following thermal annealing at 180 K. It is observed that the carrier density is reduced by thermal annealing. The reduction rate was estimated by the change of carrier density at 0V. It was established that the recovery rate of the carrier density has two types, namely fast and slow rates. The relationship between the reduction rate and temperature within the temperature range 140K to 200K is described in Figure 6. The activation energies of thermal annealing were calculated at 0.1 and 0.14eV, respectively. In constant terms, the activation energy, which was observed in the 1MeV electron irradiation test for CIGS solar cells, was reported at 1.0 eV[8]. This result is not consistent with our result. Thereby the Cu-related defect differs from the radiation defect that can impair the electrical performance of CIGS solar cells.

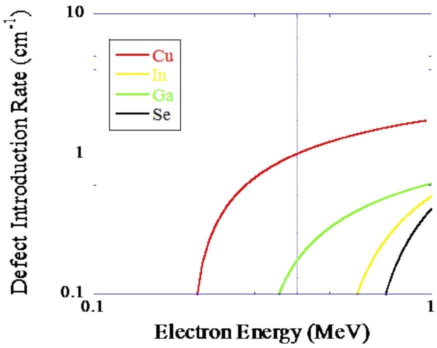

Fig. 2. Defect introduction rate of CIGS solar cells by electrons.

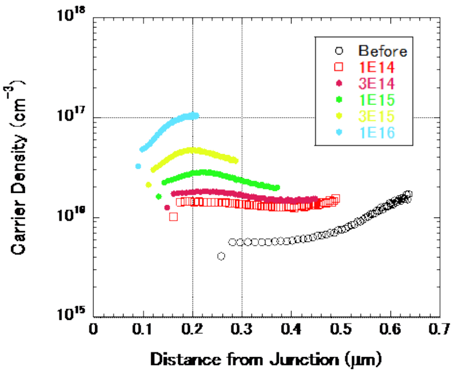

Fig. 3. Carrier profile of the CIGS solar cell irradiated with electrons.

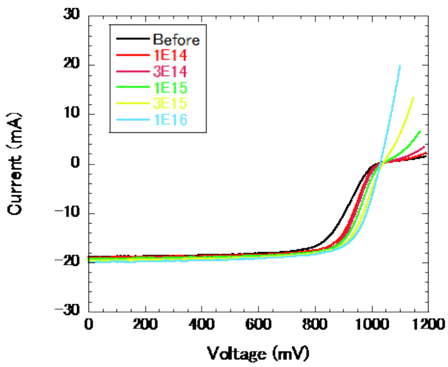

Fig. 4. Current-Voltage characteristics under AM0 condition before and after electron irradiation at 120K.

Furthermore the reduction in carrier density is attributable to the light soaked effect for CIGS solar cells[9]. The activation energy is reported to be 0.35eV. This effect is said to be attributable to metastable defects that are V_{Se}-V_{Cu} complex defects. However, the defect induced by 250keV electrons differs from the metastable defect since the activation energy does not correlate well to the energy introduced by the light soaked effect.

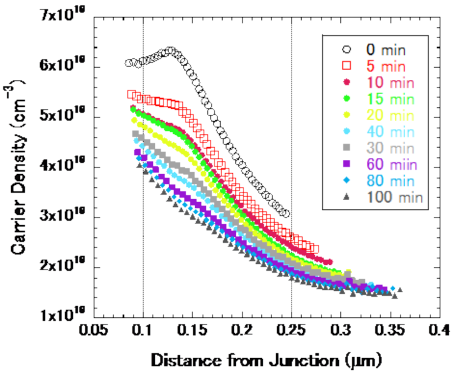

Fig. 5. Carrier profile of the CIGS solar cell conducted with a thermal annealing test at 180K.

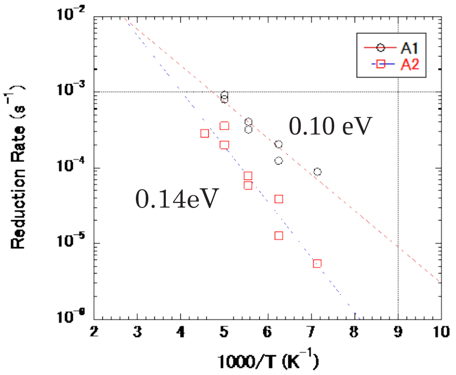

Fig. 6. Relationship between temperature and reduction rate of the CIGS solar cells.

4. Conclusions

The electrical performance of CIGS solar cells was not degraded by 250 keV electrons. In addition, the roll–over in the LIV feature was reduced by the electrons.It is revealed that the increase in carrier density produced by electrons caused this reduction in the effect. Although this phenomenon is similar to those that were founded in the Na and light soaked effects for CIGS solar cells, the activation energies of the defects with the thermal annealing differs from those by these effects. These results suggest that Cu-related defects introduced by electrons differ from defects that degrade the electrical performance of CIGS solar cells.

Acknowledgments

We would like to thank Mr. Takashi Oka of OPU and Mr. Mitsunobu Sugai of Advanced Engineering Services for their great help with the electron irradiation tests and electrical measurements.

References

[1] S. Kawakita, M. Imaizumi, M. Yamaguchi, K. Kushiya, T. Ohshima, H. Yoh, S. Matsuda, Jpn. J. Appl. Phys., **41**,(2002) L797.

[2] J. F. Guillemoles, L. Kronik, D. Cahen, U. Rau, A. Jasenek, H. W. Schock, J. Phys. Chem. B. **104** (2000) 4849.

[3] S. Ishizuka, K. Sakurai, A. Yamada, H. Shibata, K. Matsubara, M. Yonemura, S. Nakamura, H. Nakanishi, T. Kojima, S. Niki, Jpn. J. Appl. Phys. ,**44** (2005) L679.

[4] S. Kawakita et al., *Proceedings of the 29th Photovoltaic Specialists Conference*, (IEEE, New Orleans, 2002) p.978.

[5] A. Jaseneck, U. Rau, J. Apply. Phys., **90** (2001) 650.

[6] Y. J. Lee, J. L. Gray, Proceedings of the 12th European Photovoltaic Solar Energy Conference, Amsterdam, The Netherland, April 11-15, 1994, p.1561.

[7] R. Caballero, C. A. Kaufmann, T. Eisenbarth, A. Grimm, I. Lauermann, T. Unold, R. Klenk, H. W. Shock, App. Phys. Lett. **96** (2010) 902104.

[8] A. Jasenek, H. W. Schock, J. H. Werner, U. Rau, App. Phys. Lett. **79** (2001) 2922.

[9] M. Igalson, A. Urbaniak, A. Krysztopa, M. Edoff, Proceedings of the 25th European Photovoltaic Solar Energy Conference, Valencia, Spain, September 6-10, 2010, p.3436.