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Fabrication of Polycrystalline CdTe Thin-Film Solar Cells using Carbon Electrodes with Carbon Nanotubes

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Abstract

The effects of the addition of carbon nanotubes (CNTs) to carbon back electrodes in polycrystalline CdTe thin-film solar cells were investigated. Fill factor (F.F.) was improved by the effects of the CNT addition with CNT concentration from 1 to 5 wt%. The improvement of F.F. was mainly due to the decrease in series resistance. Furthermore, open-circuit voltage (V_{OC}) was improved by the CNT addition, and V_{OC} of 0.842 V was achieved using the carbon electrode with a CNT concentration of 1 wt%.

1. Introduction

CdTe is one of the most promising photovoltaic (PV) materials for use in low-cost, high-efficiency thin-film solar cells. Recently, First Solar, Inc., announced the highest ever reported efficiencies of 20.4% for a CdTe solar cell [1] and 16.1% for a CdTe PV module [2] prepared by vapor transport deposition (VTD). The annual production of CdTe PV modules reached more than 1 GW in 2009 [3].

In conventional CdTe solar cells, a carbon electrode has generally been used as a back contact [4-6]. However, the carbon electrode relatively has high resistivity. CdTe solar cells have high series resistance as compared with other solar cells such as Si-based and CIGS-based solar cells [4, 5]. High resistance of the carbon back electrodes is one of the factors of high series resistance of the CdTe solar cells. In this work, we investigated the effects of the addition of carbon nanotubes (CNTs) to carbon back electrodes in polycrystalline CdTe thin-film solar cells for the reduction of the series resistance.

2. Experimental Procedure

Figure 1 shows a schematic of the cross-sectional structure of the CdTe solar cell. Polycrystalline CdTe thin-film solar cells with a glass / indium tin oxide (ITO) / CdS / CdTe / Cu-doped carbon / Ag structure were fabricated. The substrate was glass (Corning 1737) with a 250-nm-thick ITO film. The CdS layers were deposited by chemical vapor deposition (CVD). The thickness of the CdS layers was approximately 60 nm. The CdTe films were deposited by close-spaced sublimation (CSS). The substrate and source temperatures in the CSS process were 595 and 610°C, respectively. The total system pressure was kept at approximately 1 Torr in Ar atmosphere. The deposition time was 40 s. The thickness of the CdTe films was approximately 8 μm.

Following the deposition of CdTe, $CdCl_2$ treatment was performed for improving solar cell performance [4], [5]. The CdTe films were coated with 0.3 M $CdCl_2$ aqueous solution and then annealed at 415 °C for 15 min.

After the $CdCl_2$ treatment, Cu-doped carbon electrodes were prepared by screen printing and then heated at 120 °C for 60 min to dry them. After the formation of the Cu-doped carbon electrode, the samples were heat-treated to induce Cu diffusion to the CdTe layer. The heat treatment was performed at 325°C for 15 min [5, 6].

Finally, a Ag electrode was prepared by screen printing. The active area of the CdTe solar cells was 3×8 mm^2.

In this work, CNTs was added in carbon paste (F104W, Nippon Graphite Industries) for the screen printing of the carbon back electrode. High-purity CNTs produced by JFE Engineering Corporation were used [7]. CNT concentration in the carbon paste was varied from 1 to 17 wt%. After the addition of CNTs, the carbon paste was kneaded using a mixer (ARE250, THINKY), and then Cu was added to the carbon paste. Cu concentration in the carbon paste was 50 ppm.

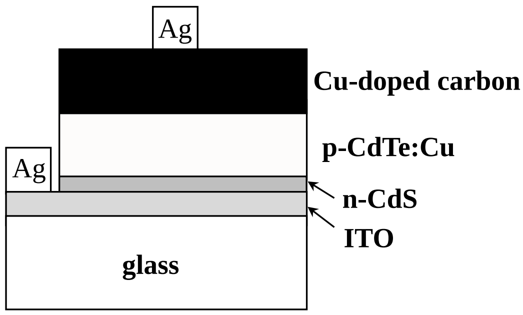

Fig. 1 Cross-sectional structure of the CdTe solar cell.

3. Results and Discussion

Figure 2 shows the cell parameters of CdTe thin-film solar cells as a function of the CNT concentration in the carbon paste. In CNT concentrations lower than 5 wt%, conversion efficiency increased with increasing the CNT concentration. In particular, fill factor (F.F.) was improved. The improvement of F.F. was mainly due to the decrease in series resistance (R_S) by the effects of the CNT addition. We achieved 14.1% efficiency (V_{OC} : 0.829 V, J_{SC} : 25.0 mA/cm^2, F.F.: 0.681, 0.24 cm^2, AM 1.5) using the CNT-doped carbon back electrode with a CNT concentration of 5 wt%. This result indicates that the CNT addition is effective in the decrease of the series resistance. Furthermore, open-circuit voltage (V_{OC}) was improved by the CNT addition, and V_{OC} of 0.842 V was achieved using the carbon electrode with a CNT concentration of 1 wt%. The mechanism of V_{OC} improvement is not clear yet. On the other hand, the conversion efficiency, V_{OC}, short-circuit current density (J_{SC}) and F.F. decreased above a Cu concentration of 9 wt%, which indicates that excessive CNT addition degrades solar cell performance.

In order to confirm the reduction of the resistance of the carbon electrode, we measured sheet resistance (R_{Sheet}) of the carbon electrodes in the fabricated CdTe solar cells. The sheet resistance was measured using a resistivity meter (Loresta-GP, MCP-T610, Mitsubishi Chemical). Figure 3 shows the sheet resistance of the carbon electrode as a function of the CNT concentration in the carbon paste. The series resistances of the CdTe solar cells are also shown for comparison. The sheet resistance decreased with increasing the CNT concentration below 5 wt%, and increased with increasing the CNT concentration above 9 wt%. This result suggests that the improvements of F.F. and series resistance were mainly due to the decrease in the resistance of the carbon back electrode by the effects of the CNT addition.

4. Conclusions

We investigated the effects of the addition of CNTs to carbon back electrodes in polycrystalline CdTe thin-film solar cells. Fill factor (F.F.) was improved by the effects of the CNT addition with CNT concentration from 1 to 5 wt%. The improvement of F.F. was mainly due to the decrease in series resistance. This result indicates that the CNT addition is effective in the decrease of the series resistance. Furthermore, open-circuit voltage (V_{OC}) was improved by the CNT addition, and V_{OC} of 0.842 V was achieved using the carbon electrode with a CNT concentration of 1 wt%.

References

[1] First Solar, Inc., press release (February 25, 2014).

[2] First Solar, Inc. [http://investor.firstsolar.com/releasedetail.cfm?releaseid=755244] (April 9, 2013).

[3] M. A. Green, *Proc. 35th IEEE Photovoltaic Specialists Conf.* (2010) 550.

[4] X. Wu, Sol. Energy **77** (2004) 803.

[5] T. Okamoto, Y. Matsuzaki, N. Amin, A. Yamada, and M. Konagai, Jpn. J. Appl. Phys. **37** (1998) 3894.

[6] T. Okamoto, Ryoji Hayashi, S. Hara, and Y. Ogawa, Jpn. J. Appl. Phys. **52** (2014) 102301.

[7] Y. Nishi, H. Mukai, and D. Ozamoto, U.S. Patent 7,625,545 (2009).

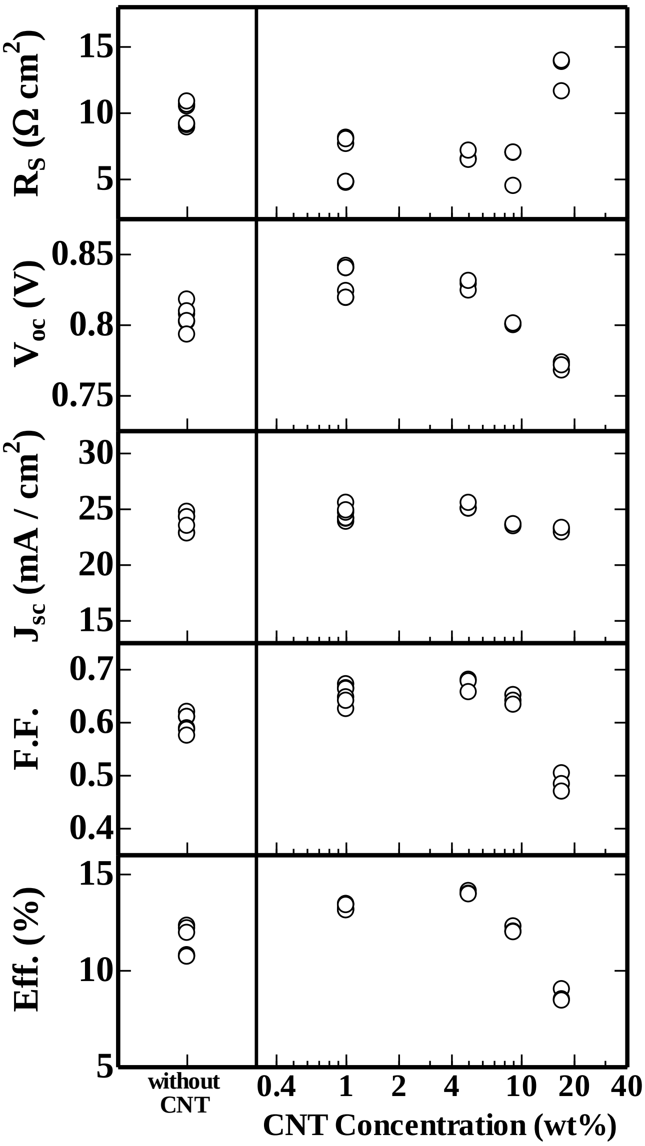

Fig. 2 Cell parameters of CdTe thin-film solar cells as a function of the CNT concentration in the carbon paste.

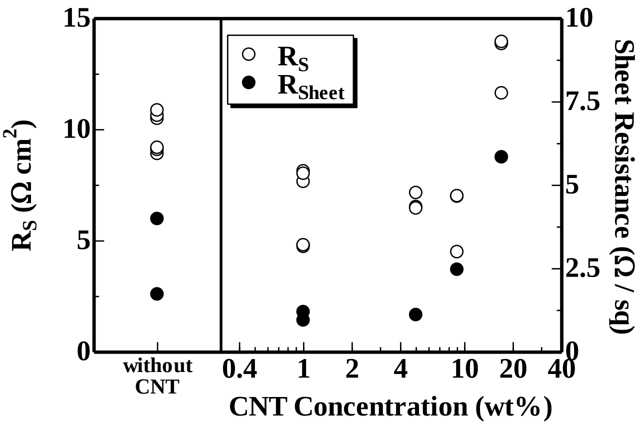

Fig. 3 Cell parameters of CdTe thin-film solar cells as a function of the CNT concentration in the carbon paste.