Transactions of the Materials Research Society of Japan 32[2] 321-324 (2007)

Characteristics of Dye-Sensitized Solar Cells Using Various Dyes

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Dye-sensitized solar cells have been fabricated using dyes of ruthenium, NKX-2553, rosehip, blueberry, coffee, and hibiscus, and the characteristics of the dye-sensitized solar cells fabricated have been measured. As a result, it is found that the conversion efficiency of the dye-sensitized solar cell in which ruthenium-dye is used is about 8%, whereas those of the dye-sensitized solar cells in which dyes of rosehip, blueberry, coffee, and hibiscus are used are 0.023, 0.019, 0.015, and 0.015 %, resp(2007)ly. We have also proposed the perfectly solid-state dye-sensitized solar cell using the poly(dimethyl silane) thin film which is fabricated by the vacuum evaporation technique.

Key words: Dye-Sensitized Solar Cell (DSSC), Photocurrent-Voltage Characteristics, Ruthenium Complex, Coumarin Dye, Poly(dimethyl silane)

1. INTRODUCTION

Dye-sensitized solar cells are expected to be used as future clean energy [1-11]. Ruthenium-dye is used for most of the recent researches. However, ruthenium can not be used for all of the dye-sensitized solar cells produced in the world, because its product is very small. In this paper, dye-sensitized solar cells are fabricated using dyes of ruthenium, NKX-2553, rosehip, blueberry, coffee, and hibiscus, and the characteristics of the dye-sensitized solar cells fabricated are measured. As a result, it is found that the conversion efficiency of the dye-sensitized solar cell in which ruthenium-dye is used is about 8 %, whereas those of the dye-sensitized solar cells in which dyes of rosehip, blueberry, coffee, and hibiscus are used are 0.023, 0.019, 0.015, and 0.015 %, respectively. The fill factors of the dye-sensitized solar cells fabricated using dyes of rosehip, blueberry, coffee, and hibiscus are 0.554, 0.502, 0.486, and 0.464, respectively. The open circuit voltages of those solar cells are 0.450, 0.415, 0.372, and 0.400 V, respectively.

We have also proposed the perfectly solid-state dye-sensitized solar cell using the poly(dimethyl silane) $[Si(CH_3)_2]_n$ thin film prepared by the vacuum evaporation technique. Poly(dimethyl silane) is the most fundamental organopolysilane, and is now commercially available. However, it is not solved in organic solvent at room temperature. The orientation of the poly(dimethyl silane) film can be controlled by changing evaporation rate, substrate temperature, and vacuum pressure during the deposition [12-14]. The direction of the poly(dimethyl silane) chain is perpendicular to the substrate surface in the film used for the dye-sensitized solar cell. The film is electrically unisotropic. The electric conductivity parallel to the molecular chain is larger by about one order of magnitude than that perpendicular to the molecular chain. The results are discussed in details on the bases of the obtained data.

2. EXPERIMENTAL PROCEDURE

Experimental procedure in order to fabricate the dye-sensitized solar cell is as follows: First, oxide semiconductor past (TiO_2) was coated onto ITO / Glass substrate. Then, the specimen was annealed using the electric heater. In this paper, annealing temperature and annealing time were varied, and various dye-sensitized solar cells were fabricated. Conversion efficiencies of the dye-sensitized solar cells fabricated were measured, and the optimum annealing condition was determined. On the other hand, Pt film was sputtered onto other glass substrate. Then, electrolyte solution was injected between these two glass substrates. Structure of the dye-sensitized solar cell is shown in Fig.1.

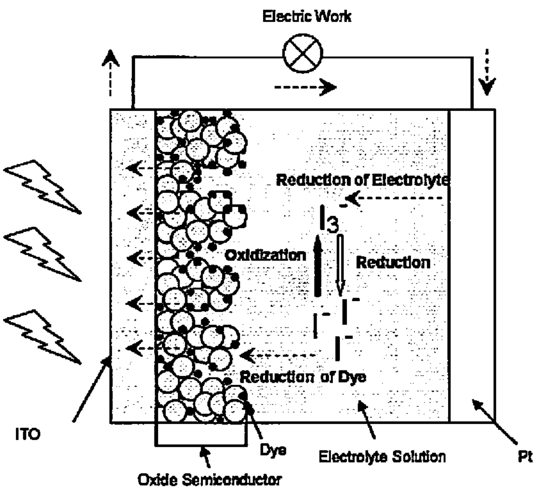

Fig.1 Structure of the dye-sensitized solar cell fabricated in this study.

The oxide semiconductor film in the dye-sensitized solar cell should be porous, because the large effective surface dimension causes large short circuit current. Figure 2 shows the scanning electron microscope photograph of the oxide semiconductor surface. As shown in Fig.2, the oxide semiconductor becomes porous. This causes large short circuit current.

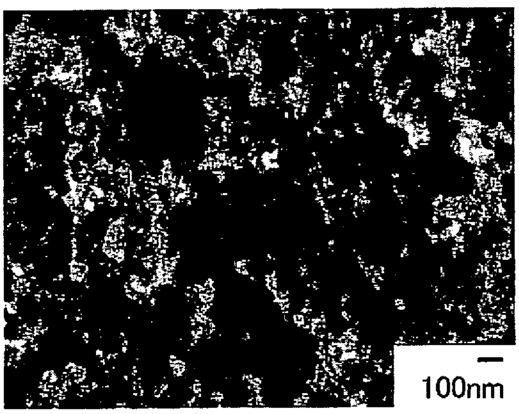

Fig.2 Scanning electron microscope photograph of the oxide semiconductor.

Conversion efficiency was measured using a halogen lamp whose power was 50mW. The cell dimension was 0.5cm×0.5cm.

3. RESULTS AND DISCUSSION

3.1 Optimization of Annealing Condition

Figure 3 shows the conversion efficiencies of the dye-sensitized solar cells as a function of annealing temperature of the oxide semiconductors. In this case, dye of hibiscus is used. As shown in Fig.3, the conversion efficiency becomes largest when the annealing temperature is 450℃. Usually, optimum annealing temperature of TiO_2 past is over 500℃. The present optimum annealing temperature is lower by 50℃ than 500℃. This may be due to the decrease of the electric conductivity of ITO film over 450℃.

In this case, the electrolyte solution consists of 0.6M DMPImI (1,2-dimethyl-3-*n*-propylimidazoliumiodide), 0.1M LiI, and 0.05M I_2 in acetonitrile.

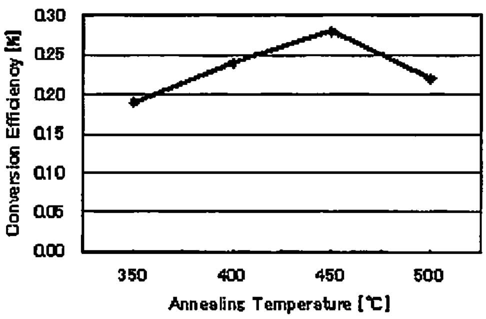

Fig.3 Conversion efficiencies of the dye-sensitized solar cells as a function of annealing temperature of the oxide semiconductors.

Figure 4 shows the conversion efficiencies of the dye-sensitized solar cells as a function of annealing time of the oxide semiconductors. In this case, annealing temperature is kept constant at 450℃. For these dye-sensitized solar cells, dye of hibiscus is also used. As shown in Fig.4, the conversion efficiency becomes largest when the annealing time is 45 min.

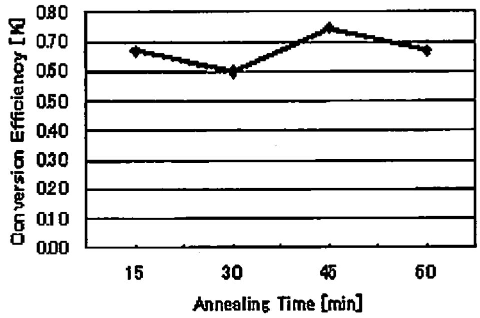

Fig.4 Conversion efficiencies of the dye-sensitized solar cells as a function of annealing time. In this case, annealing temperature is kept constant at 450℃.

3.2 Limit of Current of Electrolyte Solution

In order to measure the limit current [15], the specimen having Glass / Pt / Electrolyte Solution / Pt / Glass structure has been fabricated. Figure 5 shows the obtained current as a function of applied voltage. In Fig.5, electrolyte solution ① consists of 0.7M LiI and 0.56M TBP (4-*tert*-butylpyridine), whereas electrolyte solution ② consists of 0.7M DMPImI (1,2-dimethyl-3-*n*-propylimidazoliumiodide), 0.1M LiI, 0.05M I_2, and 0.56M TBP. As shown in Fig.5, the current is larger than that of the dye-sensitized solar cells shown afterward (see Table 1), indicating that there are no problems concerning the limit current.

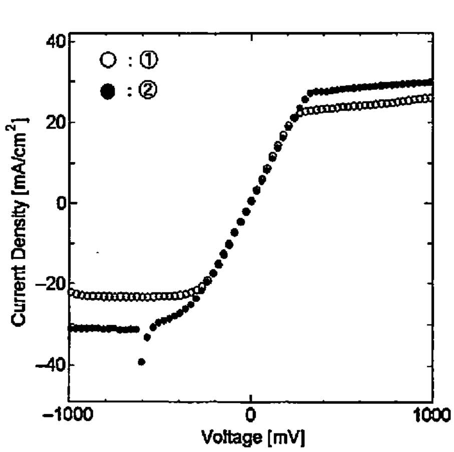

Fig.5 Current-voltage characteristics of the specimen having Glass / Pt / Electrolyte Solution / Pt / Glass structure.

3.3 Characteristics of Dye-Sensitized Solar Cells Using Various Dyes

In this paper, dye-sensitized solar cells have been fabricated using dyes of ruthenium, NKX-2553, rosehip, blueberry, coffee, and hibiscus, and the characteristics of the dye-sensitized solar cells fabricated have been measured. Figure 6 shows the optical absorption spectra of dyes of rosehip, blueberry, coffee, and hibiscus. The conversion efficiency of the dye-sensitized solar cell in which ruthenium-dye is used is about 8 % (our data). Figure 7 shows the current-voltage characteristics of the dye-sensitized solar cells in which dyes of rosehip, blueberry, coffee, and hibiscus are used. The obtained characteristics are summarized in Table 1. As shown in Table 1, the conversion efficiencies of these solar cells are 0.023, 0.019, 0.015, and 0.015 %, respectively. The fill factors of the solar cells fabricated using dyes of rosehip, blueberry, coffee, and hibiscus are 0.554, 0.502, 0.486, and 0.464, respectively. The open circuit voltages of those solar cells are 0.450, 0.415, 0.372, and 0.400 V, respectively.

Dyes of rosehip, blueberry, and hibiscus mainly consist of anthocyanin, whereas dye of coffee mainly consists of coffee melanoidins. The larger open circuit voltages for rosehip, blueberry, and hibiscus may be due to the difference of the LUMO level of anthocyanin from that of coffee melanoidins.

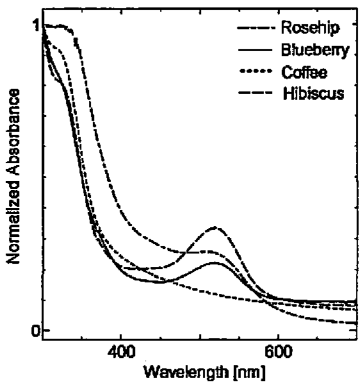

Fig.6 Optical absorption spectra of dyes of rosehip, blueberry, coffee, and hibiscus.

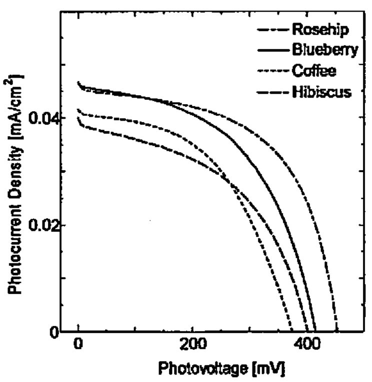

Fig.7 Current-voltage characteristics of the dye-sensitized solar cells in which dyes of rosehip, blueberry, coffee, and hibiscus are used.

Table 1 Characteristics of the dye-sensitized solar cells in which dyes of rosehip, blueberry, coffee, and hibiscus are used.

Sample	Jsc [mA/cm^2]	Voc [V]	F.F.	η [%]
Rosehip	0.047	0.450	0.554	0.023
Blueberry	0.047	0.415	0.502	0.019
Coffee	0.042	0.372	0.486	0.015
Hibiscus	0.040	0.400	0.464	0.015

3.4 Solid-State Dye-Sensitized Solar Cell Using Poly(dimethyl silane) Thin Film

In order to fabricate the perfectly solid-state dye-sensitized solar cell [16], poly(dimethyl silane) thin film prepared by the vacuum evaporation technique is used. Figure 8 shows the structure of the perfectly solid-state dye-sensitized solar cell fabricated in this study. The direction of the poly(dimethyl silane) chain is perpendicular to the substrate surface in the film used for the dye-sensitized solar cell. The direction of the chain becomes perpendicular to the substrate surface when the evaporation rate is low and the substrate temperature is high. Therefore, it is considered that the chain becomes perpendicular to the substrate surface on the thermally equilibrium condition. The film is electrically unisotropic. The electric conductivity parallel to the molecular chain is larger by about one order of magnitude than that perpendicular to the molecular chain. The thickness of the poly(dimethyl silane) film is about 1 μ m. The dye used in the solid-state cell is chlorophyll. A xenon lamp is used as a light source. The conversion efficiency of the solid-state solar cell fabricated is about 0.1 %, which is smaller than that of the dye-sensitized solar cell using the electrolyte solution. In the present solid-state cell, electrolyte solution is not used. Therefore, poly(dimethyl silane) does not enter the narrow space in the porous TiO_2 film. This causes the small conversion efficiency. However, it is expected as a stable and long life-time solar cell in the future.

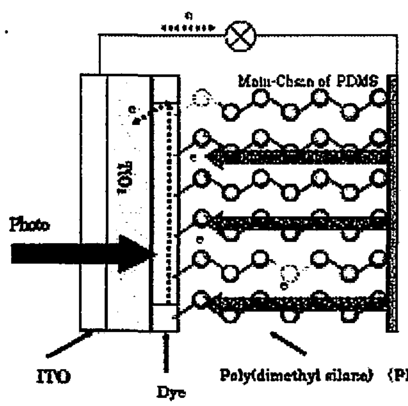

Fig.8 Structure of the perfectly solid-state dye-sensitized solar cell fabricated using PDMS.

4. SUMMARY AND CONCLUSION

In this paper, dye-sensitized solar cells have been fabricated using dyes of ruthenium, NKX-2553, rosehip, blueberry, coffee, and hibiscus, and the characteristics of the dye-sensitized solar cells fabricated have been measured. As a result, it is found that the conversion efficiency of the dye-sensitized solar cell in which ruthenium-dye is used is about 8 %, whereas those of the dye-sensitized solar cells in which dyes of rosehip, blueberry, coffee, and hibiscus are used are 0.023, 0.019, 0.015, and 0.015 %, respectively. The fill factors of the dye-sensitized solar cells fabricated using dyes of rosehip, blueberry, coffee, and hibiscus are 0.554, 0.502, 0.486, and 0.464, respectively. The open circuit voltages of those solar cells are 0.450, 0.415, 0.372, and 0.400 V, respectively. We have also proposed the perfectly solid-state dye-sensitized solar cell using the poly(dimethyl silane) thin film prepared by the vacuum evaporation technique. This solid-state solar cell is expected as a stable and long life-time cell in the future.

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(Received December 10, 2006;Accepted February 17, 2007)