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Characteristics of dye-sensitized solar cells using natural dye

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ABSTRACT

Dye-sensitized solar cells are expected to be used for future clean energy. Recently, most of the researchers in this field use Ruthenium complex as dye in the dye-sensitized solar cells. However, Ruthenium is a rare metal, so the cost of the Ruthenium complex is very high. In this paper, various dye-sensitized solar cells have been fabricated using natural dye, such as the dye of red-cabbage, curcumin, and red-perilla. As a result, it was found that the conversion efficiency of the solar cell fabricated using the mixture of red-cabbage and curcumin was about 0.6% (light source: halogen lamp), which was larger than that of the solar cells using one kind of dye. It was also found that the conversion efficiency was about 1.0% for the solar cell with the oxide semiconductor film fabricated using polyethylene glycol (PEG) whose molecular weight was 2,000,000 and red-cabbage dye. This indicates that the cost performance (defined by [conversion efficiency]/[cost of dye]) of the latter solar cell (dye: red-cabbage) is larger by more than 50 times than that of the solar cell using Ruthenium complex, even if the effect of the difference between the halogen lamp and the standard light source is taken into account.

1. Introduction

Dye-sensitized solar cells are expected to be used for future clean energy [1,2]. Among the dye-sensitized solar cells, the dye-sensitized solar cell using Ruthenium complex shows a high conversion efficiency of about 11–12%. However, Ruthenium is a rare metal, so the cost of the Ruthenium complex is very high. On the other hand, natural dye is easy to obtain, and its cost is very low [3].

In this paper, various kinds of dye-sensitized solar cells have been fabricated using natural dye, such as the dye of red-cabbage, curcumin, and red-perilla [4]. As a result, it was found that the cost performance (defined by [conversion efficiency]/[cost of dye]) of the dye-sensitized solar cell using the dye of red-cabbage was more than 50 times larger than that of the dye-sensitized solar cell using Ruthenium complex.

2. Experimental

In order to fabricate the solar cells, oxide semiconductor paste was prepared at first [5–10]. In this study, oxide semiconductor paste was prepared using two kinds of TiO_2. One was P-25 whose average TiO_2 particle size was 26 nm, and the other was PC-101 whose average TiO_2 particle size was 20 nm. P-25 (0.14 g) and PC-101 (0.06 g) were set in a shaker, and HNO_3 (0.6 ml) was inserted into the shaker. Then, polyethylene glycol (PEG) was added into it. In this work, two kinds of PEGs were used. One was the PEG whose molecular weight was 500,000, and the other was the PEG whose molecular weight was 2,000,000. The obtained TiO_2 paste was coated onto the FTO glass, which was cleaned using ethyl alcohol and acetone. Thus the obtained substrate was set in an electric heater and annealed at 400 °C for 1 h.

Then, the dye was adsorbed onto the oxide semiconductor film surface by dipping the substrate into the dye solution. In this study, three kinds of dyes were used. One was the dye of red-cabbage, and the others were the dye of curcumin and red-perilla. The chemical structures of dyes mainly contained in red-cabbage, curcumin, and red-perilla are shown in Fig. 1. Their mole density was 0.6 mM. The solvent of the solutions of red-cabbage and red-perilla was water, and the solvent for curcumin was ethyl alcohol.

The electrolyte solution was prepared using I_2, LiI, DMPImI (1-propyl-2,3 dimethylimidazolium iodide), TBP (4-*tert*-butyl pyridine), and PC (propylene carbonate). The weights of I_2, LiI, DMPImI, TBP, and PC were 0.0317, 0.33, 0.342, 0.189, and 3 g, respectively. The obtained electrolyte solution was inserted between the two substrates. One was the FTO glass coated by the oxide semiconductor film. The other was the ITO glass coated by the Pt film which was prepared by the sputtering technique.

The characteristics of the obtained dye-sensitized solar cells were measured using a halogen lamp as a light source. The power was 50 mW/cm^2. The conversion efficiency measured using the halogen lamp was about 5% larger than that measured using the standard light source which was constructed by our laboratory. In our standard light source system, visible and infrared components were partly eliminated by the optical filter.

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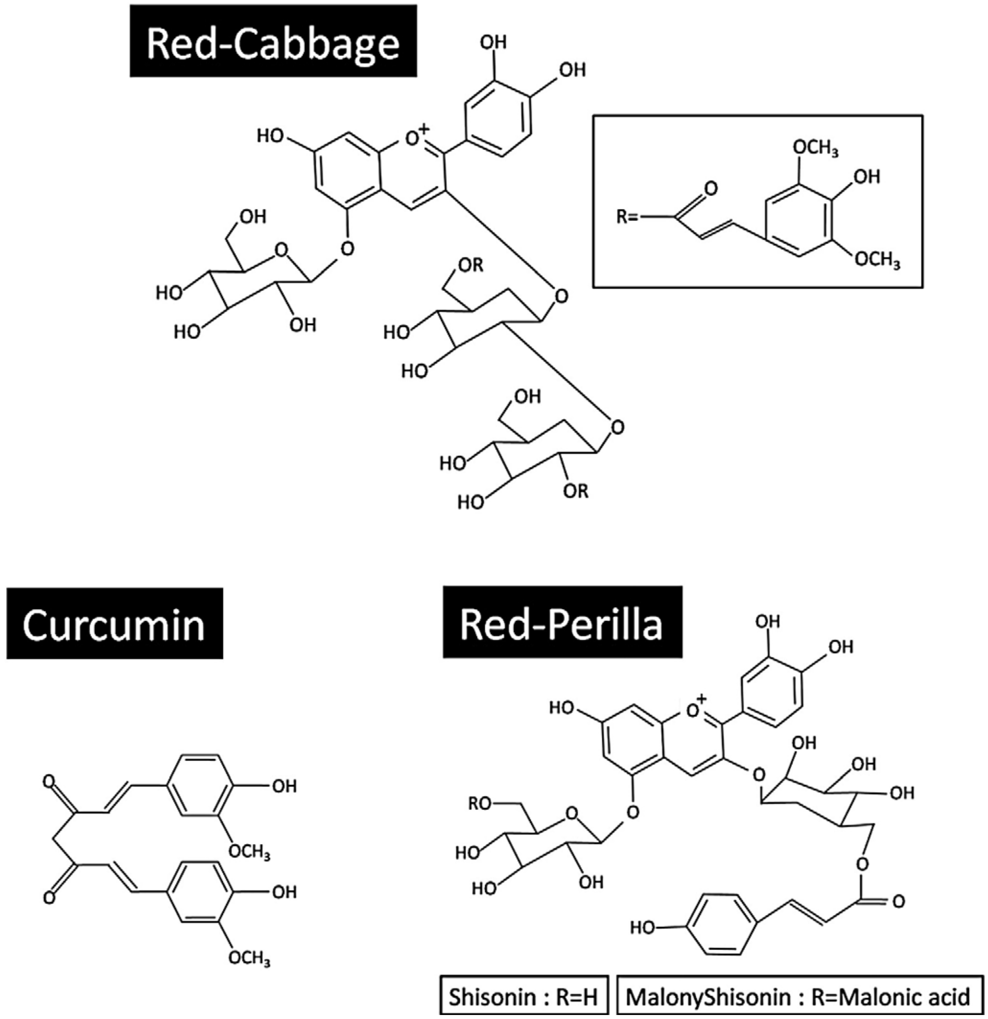

Fig. 1. Chemical structures of dyes mainly contained in red-cabbage, curcumin, and red-perilla.

3. Results and discussion

3.1. Characteristics of dye-sensitized solar cells using dye of red-cabbage and curcumin

Fig. 2 shows the optical absorption spectra of the mixed dye of red-cabbage and curcumin. The optical absorption strength of curcumin is larger than that of red-cabbage as shown in Fig. 2 (a). Therefore, the ratio of red-cabbage to curcumin was changed in order to obtain strong absorption in wide band (see Fig. 2 (b)). When the ratios changed from 50:1 to 100:1, two large absorption peaks appeared at about 430 and 550 nm as shown in Fig. 2 (b). The strength of the absorption peak that appeared at about 430 nm was changed when compared with that of the peak at about 550 nm. This is because the absorption at about 430 nm is due to dye of curcumin, whereas the absorption at about 550 nm is due to dye of red-cabbage (see Fig. 2 (a)).

Fig. 3 shows the photocurrent–voltage characteristics of the dye-sensitized solar cell fabricated using the mixed dye whose ratio is 70:1.

Table 1 shows the obtained characteristics of the dye-sensitized solar cells which were fabricated by the mixture of red-cabbage and curcumin. Three kinds of solar cells have been prepared for each fabrication condition. In Table 1, Jsc (sc: short circuit), Voc (oc: open circuit), Pmax, F.F., and η are short circuit photocurrent density, open circuit photovoltage, maximum power, fill factor, and conversion efficiency, respectively. The average conversion efficiencies of the dye-sensitized solar cells using red-cabbage and curcumin are 0.50 and 0.41%, respectively, as shown in Table 1. On the other hand, the conversion efficiency of the dye-sensitized solar cell using the mixture of red-cabbage and curcumin (70:1) is 0.60%, which is larger than those of the solar cells using red-cabbage (10:0) and curcumin (0:10). The reason is considered as follows. That is, when the ratios are from 100:1 to 70:1, the strength of the absorption peak at about 430 nm increases as shown in Fig. 2 (b). This may cause an increase of short circuit current, resulting in an increase of conversion efficiency. Similarly, when the ratios are from 70:1 to 50:1, the strength of the absorption peak at about 430 nm increases as shown in Fig. 2 (b). However, for the latter case, the strength of the absorption peak at about 550 nm decreases. This may cause a decrease of short circuit current, resulting in a decrease of conversion efficiency. Concerning the durability, the conversion efficiency of the solar cells using red-cabbage was not changed after 24 h (the solar cells were continuously illuminated by the halogen lamp), and that of the solar cells using curcumin was decreased by about 5% after 24 h.

3.2. Dependence of molecular weight of PEG on conversion efficiency

Tables 2 and 3 show the characteristics of the dye-sensitized solar cells with the oxide semiconductor films prepared using PEGs with molecular weights of 500,000 and 2,000,000, respectively. Five kinds of solar cells have been prepared for each fabrication condition. As shown in Tables 2 and 3, the average conversion efficiency of the dye-sensitized solar cells prepared using a PEG with a molecular weight of