Efficient plastic film dye-sensitized solar cells prepared with binder-free low-temperature coating pastes of TiO_2 nanocrystals

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Introduction

Manufacture of flexible plastic-based dye-sensitized solar cells enables significant cost reduction in industry by roll-to-roll mass production. This requires low-temperature, continuous coating process for TiO_2 nano-particles. We have previously showed [1] the usefulness of electrophoteric deposition of TiO_2 combined with TiO_2 sol chemical treatment, which achieved a high solar conversion efficiency exceeding 4%. In this study, as an alternative to the above method, we have developed a simple doctor-blade coating process to achieve efficiency comparable with the above method, by preparing a viscous (printable) paste of nanocrystalline TiO_2 free of insulating polymer binders.

Experimental

To prepare a binder-free paste, we have focused on utilizing highly cohesive property of nanocrystalline TiO_2 particles when mixed with an acidic TiO_2 sol and dried in the presence of aqueous solvents. TiO_2 pastes (TiO_2 content, 14 wt%) were composed of a mixture of nanocrystalline TiO_2 powders (average sizes of 30, 50, 60, 90, and 150 nm), acidic nanocrystalline TiO_2 sol (TiO_2 content, 15 wt%, TiO_2 size, 10-35 nm) and *tert*-butyl alcohol and water as solvents. The paste was coated on a ITO-PET film substrate (188 μm, 15-16 ohm/square) by the doctor-blade printing technique, dried at room temperature, and heated at 150 ℃ for 5 min to form a mesoporous semiconductive TiO_2 layer. The TiO_2 layer was dye-sensitized with a Ru complex (N719) and used as a photo-anode of a sandwich-type cell using electrolyte solution (0.1 M LiI, 0.6 M DMPImI, 0.05 M I_2, 0.5 M TBP in methoxyacetonitrile) and a Pt-coated FTO-glass or ITO-PET-plastic cathode. The I-V characteristics of the cell was measured under the irradiation of A.M 1.5G.

Results and discussion

Figure 1 exhibits a characteristic profile for dependence of short-circuit photocurrent density on average TiO_2 particle size used for the paste. A highest photocurrent was obtained in a range between 50 and 100 nm. This may indicate that electric conductivity within the mesoporous layer, *i.e.* inter-particle connection, is optimized by adjusting size distribution.

Figure 2 shows photocurrent density-voltage (I-V) characteristics of a plastic dye-sensitized photoanode bearing an optimized composition of binder-free coating. Short-circuit photocurrent density (J_{sc}), open-circuit photovoltage (V_{oc}), fill factor (*FF*), and energy conversion efficiency (η) were 11 mA cm^{-2}, 0.72 V, 0.52, and 4.3%, respectively, under 1 sun (100 mW cm^{-2}) and 2.9 mA cm^{-2}, 0.67 V, 0.62, and 5.2%, respectively, under 1/4 sun (23 mW cm^{-2}). The efficiency range, 4.3-5.2%, obtained by this method is amply high as a low-temperature coating on plastic electrode. Relatively low *FF* is attributable to smaller pore size of the present mesopore, which can be improved by adjusting size distribution by mixing of large particles. IPCE spectrum for the electrode, as shown in Fig. 3, yielded a maximum of 43%.

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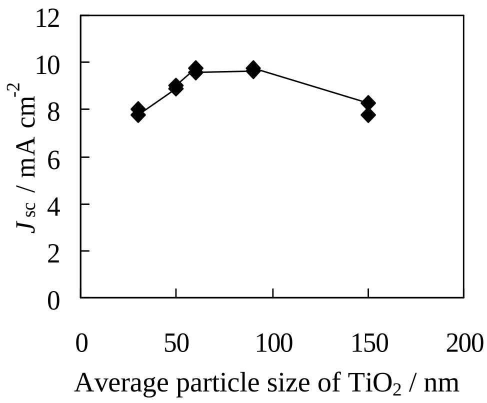

Figure 1 Dependence of short-circuit photocurrent density (J_{sc}) on average particle size of nanocrystal-line TiO_2 particles

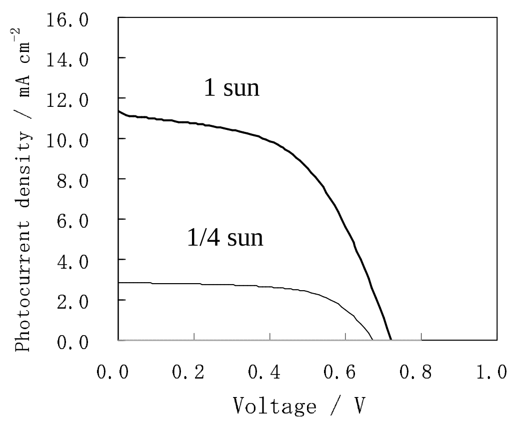

Figure 2 Photocurrent-voltage characteristics of the dye-sensitized ITO-PET electrode prepared by low-temperature coating of binder-free TiO_2 paste.

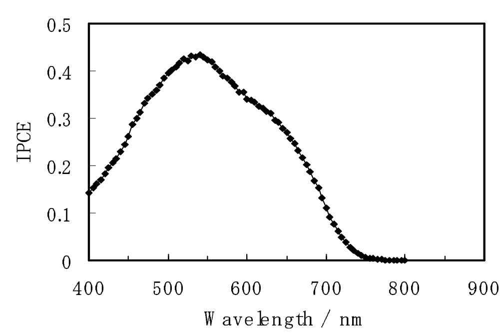

Figure 3 Incident photon to current conversion efficiency action spectrum for the film electrode as presented in Fig. 2.

1. T. Miyasaka and Y. Kijitori, *J. Electrochem. Soc.*, in press