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The Effects of the Adding V_2O_5 on the Oxide Semiconductor Layer of a Dye-sensitized Solar Cell

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Abstract. Photosensitizers certainly play a crucial role for highly efficient DSSCs and have been extensively investigated. In this study, we investigate the effect of V_2O_5 doping on the oxide semiconductor layer of a dye-sensitized solar cell. V_2O_5 - doped TiO_2 paste is prepared by sol gel process screen print method and measure the characteristics of surface and electrical. According to V_2O_5 addition, the grain size increased, and the DSSC doped with V_2O_5 showed and excellent characteristics, in which open-circuit voltage, short-circuit current, Fill Factor and conversion efficiency are 0.99V, 8.34mA/cm2, 0.53 and 4.42%, respectively.

Keywords: DSSC, V_2O_5-doped TiO_2, TiO_2, I-V curve

1 Introduction

Solar power is the most renewable and sustainable energy resources in order to relieve the energy crisis. Particularly, the Dye-sensitized solar cell (DSSC) has become a considerable interest in the area of solar cell research since Gratzel's pioneering report in 1991 [1] because of the low production cost and environmental friendliness during fabrication. Furthermore, the other key attributes of DSSC technology are its simple manufacturing procedures, light weight, flexibility, semi transparency and good performance in diverse light conditions [2]. However, a comparison with conventional solid-state junction devices made of crystalline silicon indicates that the DSSC has lower power conversion efficiency [3]. A standard DSSC is composed by a layer of transparent conducting oxide (TCO) on a glass substrate like figure 1. Then a nanostructured layer of TiO_2 which the dye is absorbed. At last there is the electrolyte and the counter electrode by Pt. The main principle of this DSSC is the dye-sensitization of wide band gap semiconductors such as TiO_2 layer. Photosensitizers certainly play a crucial role for highly efficient DSSCs and have been extensively investigated. In the recent, many research group have investigated the interface effects such as charge separation, reverse recombination and trapping of photo generated electrons in the semiconductor surfaces, independently by choosing appropriate combinations of materials and their assembly [4]. Especially, to optimize the overall energy conversion efficiency, it is important to determine a material architecture of various oxide semiconductor that lowers the recombination currents, enhances the light absorption and ensure a good electric connection. In this study, we investigate to

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improve the characteristics of the V_2O_5 doing on TiO_2 paste. Vanadium based oxides belongs to transitional metal oxides which are of particular interest because of their low cost, abundance in nature, good electrical conductivities, good catalytic activity and excellent atmospheric stability. Particularly, because V_2O_5 has lower conduction band than TiO_2, the flow of electrons will increase on DSSC. In order to investigate the characteristics of V_2O_5 doping, we measure the SEM images, XRD patterns and I-V curve.

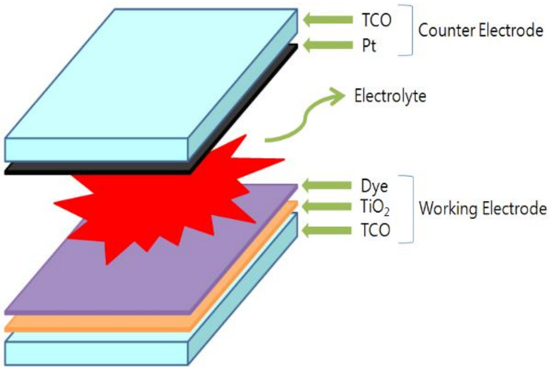


Fig. 1. A structure of standard dye-sensitized solar cell.

2 Experiment Method

2.1 Synthesis of V_2O_5 - doped TiO_2 paste

The paste was prepared by the TiO_2 paste and the V_2O_5 - doped TiO_2 paste for comparison. The TiO_2 paste was prepared by mixing the 2g of TiO_2 (anatase, 98.5%, junsei), ethanol 40ml, terpienol 1.0ml and ethyl cellulose 4.5g during 2 hours. The V_2O_5 - doped TiO_2 paste was prepared by mixing the TiO_2 paste and the 0.6g of V_2O_5 during 2 hours. The ratio of V_2O_5 was chosen by previous experiment. The 4.5g of ethyl cellulose was selected for optimal performance such as screen print and adsorption of dye among 3g, 4g, 4.5g and 5g.

2.2 Fabrication of DSSC

First, the working electrodes was prepared by the following methods. ITO coated TCO glass was used as working electrode of the device and was cut into small piece (1×2cm). This substrate were cleaned with 2-Propanel, acetonitrile and then distilled water by ultrasonic cleaner for 10min at each step. After the cleansing and drying process of the substrates, our produced the pastes (TiO_2, V_2O_5-doped TiO_2) were screen printed on the compact layered and the active areas were 0.25cm2. The paste layer was then heated at 450℃ for 30 min and then these samples were sensitized with N719 for 24hours. Second, the counter electrodes were prepared by the following methods. ITO coated glass was cut into the same dimensions as the working electrodes. A small hole (0.7mm) was drilled to facilitate the injection of electrolyte and the drilled substrates were cleaned the same methods. A commercial platinum paste (H_2PtCl_6) was used as received and fired at 450℃ for 30min in order to remove organic binders. The Pt electrode and the dye-adsorbed TiO_2 electrode were assembled as a sandwich-type. Iodide based low viscosity electrolyte (0.5M Lil, 0.05M I_2, 0.5M 4-tertbutylpyridine in acetonitrile) was injected into the structure via a capillary action.

2.3 Measurement of DSSC Characteristics

The morphology of the samples was determined using field emission scanning electron microscopy, FESEM instrument equipped with energy dispersive X-ray (EDX) spectrometer for the elemental analysis and surface mapping. The phase structure was characterized using X-ray diffraction (XRD) measurements with Cu Kα monochromatic radiation (λ = 1.541Å) at a scanning rate of 2°/min. The current-voltage curves these DSSC were obtained under AM1.5 illuminations with and intensity of 100mW/cm^2 and were recorded by a Keithley high-voltage source interfaced with a personal computer. We measured the photovoltaic characteristics of the DSSC by applying an external potential bias to the cell and measuring the generated photocurrent (Keithley source meter Model 2400). The illuminated active area of the cell was 0.25 cm^2. The open-circuit voltage (Voc) and short-circuit current (Isc) were obtained from the intersection of the voltage and current axes, respectively. The fill factor and the overall energy efficiency were calculated according to the following equations:

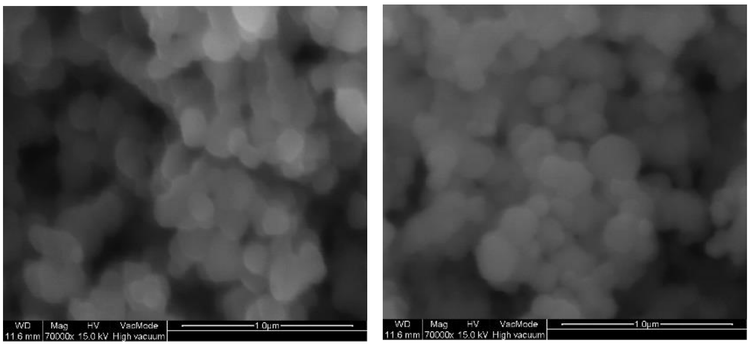
$$\text{Fill Factor : FF} = \frac{I_{max} \cdot V_{max}}{I_{OC} \cdot V_{OC}} \quad \textbf{(1)}$$

$$\text{Overall energy efficiency : } \eta = \frac{FF \cdot V_{OC} \cdot I_{SC}}{E_{in} \cdot A}$$

With Imax, Vmax, the current and the voltage at maximum power point, respectively; Voc is the open circuit voltage and Isc is the short circuit current. It is considered that the Isc and Voc are the highest current and voltage obtained from the cell. Ein is the incident irradiation power (100mW/cm^2).

3 Experiment Results

Figure 2 shows the SEM image of (a) TiO_2 paste and (b) V_2O_5-doped TiO_2 paste on the ITO substrate. Close inspection of SEM image shows the both paste have irregular shape and the particles of TiO_2 and V_2O_5 are uniformly distributed over the ITO substrate. Size of the particle varies from 100nm to 200nm and this nano-particle on the substrate provides the larger adsorption surface for dye molecule and enhance the performance of solar cell [5]. In case of V_2O_5-doped TiO_2 paste, the particles show bigger and lumper particles than pure TiO_2 paste.



(a) TiO_2 paste (b) V_2O_5-doped TiO_2 paste

Fig. 2. SEM image of (a) TiO_2 paste and (b) V_2O_5-doped TiO_2 paste.

Figure 3 shows the XRD pattern of TiO_2 and V_2O_5-doped TiO_2 paste printed on the ITO substrate. The synthesized TiO2 particles are of tetragonal crystals (JCPDS card no. 04-0477), assigned to the space group 141/amd with lattice contacts a = 3.783Å, b = 3.783Å, c = 9.51Å This diffraction peaks at 2h angle 25.29°, 37.79°, 48.01°, 53.91°, 55.06° and 62.57° corresponding to (101), (004), (200), (105), (211) and (204) plans confirms anatase phase and the crystalline nature of TiO_2. The V_2O_5-doped TiO_2 paste indicates the peak around 20° which is the typical peak of V_2O_5, and we show the distend figure between 20° to 30°.

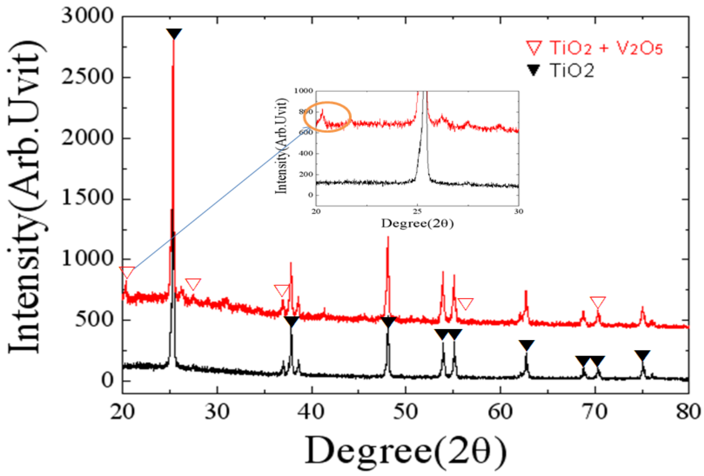


Fig. 3. XRD pattern of (a) TiO_2 paste and (b) V_2O_5-doped TiO_2 paste

The current-voltage curves characteristics of TiO_2 DSSC and V_2O_5-doped TiO_2 DSSC were shown in figure 4 and table 1. The open-circuit voltage (Voc) of the both DSSC is almost same as 1V and the short-circuit current (Isc) is 7.71mA for TiO_2 DSSC and 8.34mA for V_2O_5-doped TiO_2 DSSC. Thus, V_2O_5 doping brought about 1.1times raise of Isc, and that cause an increasing of fill factor (FF) and efficiency (ŋ). The doping of V_2O_5 which has lower conduction band than TiO_2 leads to reduce the recombination between dye and electrolyte. Therefore, the flow of electrons increase, and then the short-circuit current and efficiency increase.

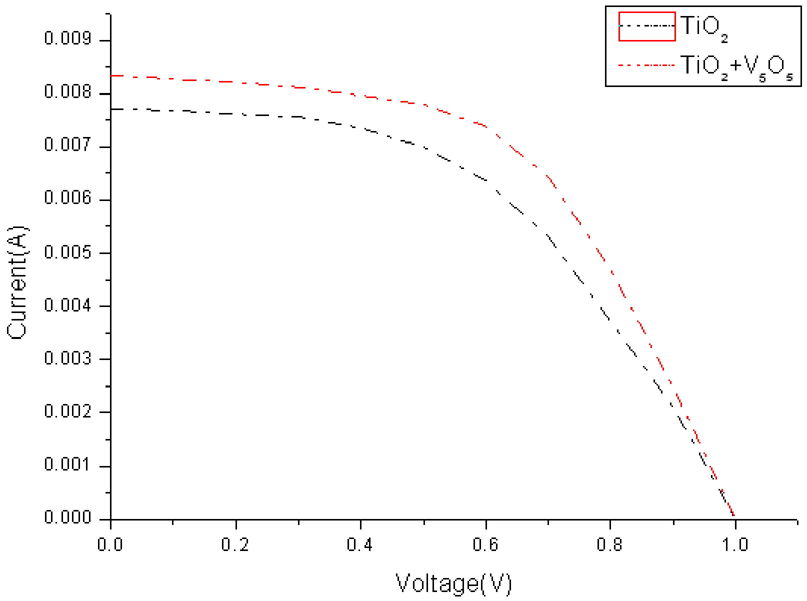


Fig. 4. I-V characteristics curve of TiO_2 DSSC and V_2O_5-doped TiO_2 DSSC

Table 1. I-V characteristics curve of TiO_2 DSSC and V_2O_5-doped TiO_2 DSSC

	Isc (mA)	**Voc (V)**	**FF**	**H (%)**
TiO_2	**7.71**	0.98	0.46	3.54
$TiO_2 + V_2O_5$	8.34	0.99	0.53	4.42

4 Conclusion

DSSCs show the most promising future due to their independence, environmentally friendly, low maintenance, and low cost. For more improvement of DSSC characteristics, we doped the V_2O_5 on the oxide semiconductor layer (TiO_2). First, we analyze the surface through SEM image and XRD pattern, and measure the photovoltaic characteristics of the DSSC. So we confirm the appropriate mixture TiO_2

and V_2O_5 paste, and the DSSC with V_2O_5 - doped TiO_2 paste increase the short-circuit current, fill factor and efficiency. Especially, the efficiency of V_2O_5 - doped TiO_2 paste increase 1.3 times than pure TiO_2.

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