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Short Communication

Sol-Gel Derived Carbon Electrode for Dye-Sensitized Solar Cells

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Abstract

This work is based on the procedure for obtaining carbon paste electrode through the sol-gel technique and its application as counter electrode for dye-sensitized solar cells. Through the hydrolysis of the precursor (tin II chloride), followed by polycondensation reaction, we were able to obtain our colloidal suspension. Our carbon paste comprises an equal amount of well blended powdered activated carbon (PAC) and natural graphite powder (NGP) mixed with the polymeric sol. The carbon paste was squeezed onto a fluorine doped tin oxide (FTO) glass substrate. We were able to reduce the sheet resistance of the carbon electrode from 212.1 ohms/square to 15.4 ohms/square. A dye-sensitized solar cell (DSSC) fabricated with the carbon paste electrode and sensitized with chlorin dye showed a photoelectric energy conversion efficiency of 1.01%.

Key Words: Dye sensitized solar cell, carbon, sheet resistance, sol-gel.

Introduction

The sol-gel process has been widely used to prepare electrochromic thin films and nanocrystalline materials[1,2]. In this process, the sol (or solution) evolves gradually towards the formation of a gel-like network containing both a liquid phase and a solid phase. Typical precursors are metal alkoxides and metal chlorides, which undergo hydrolysis and polycondensation reactions to form a colloid. The basic structure or morphology of the solid phase can range anywhere from discrete colloidal particles to continuous chain-like polymer networks[3,4].

Carbon electrodes are of great importance for dry batteries and dye-sensitized solar cells (DSSCs). Dye-sensitized solar cells are a prominent member of the large group of thin film photovoltaics[5]. Generally, a DSSC consists of an indium-tin oxide (ITO) or fluorine-doped tin oxide (FTO), dye modified titanium dioxide electrode, electrolyte and a platinized counter electrode[6-8]. Usually, the counter electrodes were fabricated by depositing platinum in FTO glass using thermal decomposition, sputtering, or electrodeposition of $H_2PtCl_6$9, where the platinum served as the catalyst for triiodide reduction. The deposition techniques mentioned above are sophisticated, and although platinum metal shows superior electrocatalytic activity for the triiodide reduction, it is too expensive[9]. Thus, the development of simpler deposition techniques and new counter electrode material will lower the cost of DSSC and enable the fabrication of large-scale DSSC device.

Meanwhile, several varieties of carbonaceous materials such as active carbon, carbon black, carbon nanotube and graphite have been employed as catalyst for counter electrode in recent years[9,10]. In this research work, we were able to fabricate carbon paste electrode using the sol-gel technique. The performance of the carbon electrode was optimized by varying film composition and thickness. Sheet resistance of each electrode was measured after sintering at 200^0C. We obtained a carbon electrode with sheet resistance as low as 15.4ohm/square. The current-voltage characteristics of a DSSC fabricated with the carbon counter electrode is shown in figure 3. The titanium dioxide photo-electrode used for the DSSC fabrication was sensitized with chlorin dye which is a local dye extracted from bahama grass[11].

Material and Methods

Reagents and solutions: Tin (II) chloride, carboxy ethyl cellulose (NATROSOL), 25% hydrochloric acid, powdered activated carbon (PAC) and a kind of natural graphite powder (NGP). High purity de-ionized water was used to prepare the solutions at a temperature of 25 ± 2^0C. The chemicals were of analytical grade and used without further purification.

Preparation of the electrodes: We dissolved 12g of tin (II) chloride in 50ml de-ionized water and titrated with about 1ml of 25% HCl. The solution became colourless and there was a noticeable fall in temperature. Then 2g of NATROSOL was dissolved in 50ml de-ionized water and stirred properly. We mixed the two solutions and stirring continued. This mixture was heated to 300^0C using a hot-plate. Stirring continued as the heating lasted for about 39 seconds. The resulting solution (about 16ml) was allowed to stay overnight at room

temperature. It was further heated on the following day for about 7 minutes to get the polymeric colloidal sol of about 12ml.

18g of powdered activated carbon PAC was ground in a porcelain mortar for about 30 minutes. The conducting side of a 2.5cm x 2.5cm FTO was identified and covered on each of the two parallel edges with a single layer of masking tape to control the thickness of the electrode. Before deposition, the glass substrate was cleaned with acetone, then methanol and etched through plasma treatment for 1min. The sheet resistance of the FTO was measured. The carbon paste was prepared by hand mixing the well-blended PAC and the sol. The resulting sol-gel film was applied at one of the edges of the conducting glass and distributed with a squeegee sliding over the tape-covered edges. A hot air blower was used to dry the electrode for about 3 minutes before removing the adhesive tapes. The edges were cleaned with ethanol and the carbon electrode was sintered at 200^0C in a furnace for about 15 minutes. On obtaining the PAC/sol proportion with low sheet resistance and stable at sintering temperature, we then prepared another carbon powder comprising an equal amount of PAC and NGP. 15g of PAC was ground for 30 minutes before an equal amount of NGP was added and this mixture was ground for another 30 minutes[11,12]. The thickness of the carbon paste electrode was varied by using double and triple layers of the masking tape and with this we were able to reduce the sheet resistance from 212.1 Ω/ to 15.4 Ω/.

Apparatus: Ainsworth DE – 100, Max 100g, e = 0.0001g chemical balance was used to weigh the chemicals. Carbolite 201 tubular furnace was used for the sintering process. The thickness of both electrodes was measured using Dektak stylus 7.0 surface profiler. Measurement of sheet resistance was done using dual-Pro 301 auto calculating 4 pt. Probe resistivity test system.

Results and Discussion

We obtained 14.55 Ω/ as sheet resistance of the FTO. The values of sheet resistance for carbon paste electrode fabricated using different proportions of the PAC-sol mixture are shown in Table 1.

Table 1
Optimization of sheet resistance of the carbon paste electrode by mixing different proportions of the powdered activated carbon and the colloidal sol

Quantity of carbon (g)	Quantity of sol-gel (g)	Concentration (g/ml)	Sheet resistance (Ω/)
0.60	0.50	1.20	212.14
1.00	0.50	2.00	139.52
1.40	0.50	2.80	90.29
1.50	0.50	3.00	66.59
1.00	0.25	4.00	60.71

Concentration of 4.00 g/ml gave the least sheet resistance but the carbon paste was pealing after sintering. But 3.00 g/ml gave a comparable sheet resistance and the carbon film was stable and smooth after sintering, so we considered it for further optimization using double and triple layers of the masking tape. Figure 1 shows the effect of multiple layer deposition on the sheet resistance.

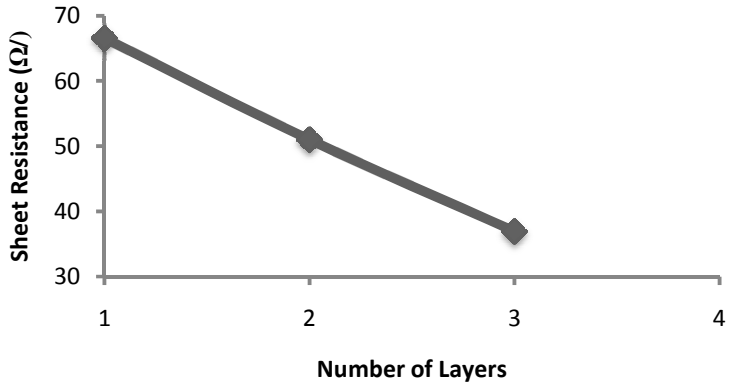

Figure – 1
Sheet resistance versus number of layers for 3.0g/ml PAC electrode

We obtained 36.95 Ω/ as sheet resistance for the triple layer deposition. The triple-layered carbon electrode was slightly stable but we considered it for further optimization by using a well-blended mixture of equal amount of PAC and NGP to obtain our carbon paste. The effect of adding an equal amount of NGP to PAC is shown in figure 2.

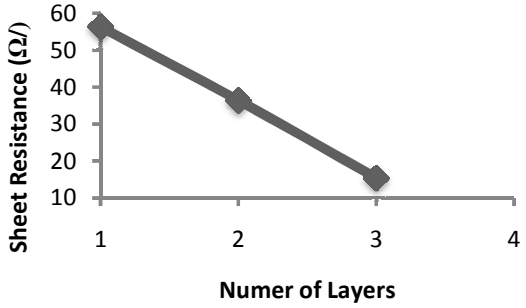

Figure – 2
Sheet resistance versus number of layers for 3.0g/ml PAC-NGP electrode

Both the single, double and triple layer deposition gave stable carbon paste electrode. We were able to reduce the sheet resistance from 56.36Ω/ to 15.40Ω/ . We obtained 5.26 µm, 6.31 µm and 6.82 µm as the film thickness for the single, double and triple layer electrodes respectively.

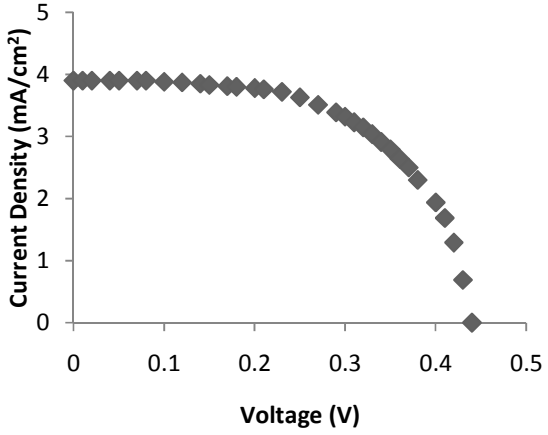

Figure – 3
The I-V curve for DSSC sensitized with chlorin dye

The DSSC of active surface area 1.8cm^2 was fabricated with titanium dioxide photoelectrode which was sensitized with chlorin dye. Figure 3 is the current-voltage characteristics of the DSSC at illumination intensity of 100W/m^2 using an Oriel class A solar simulator. The cell parameters were; open circuit voltage (0.44V), short circuit photocurrent (3.9mA/cm^2), fill factor (0.59) and photoelectric conversion efficiency (1.01%). The results can be compared to those obtained by Waita et al using platinium as the counter electrode[8].

Conclusion

Carbon counter electrode for dye-sensitized solar cell was successfully fabricated using the sol-gel process. The experimental results show that the sheet resistance of carbon paste electrode depends on composition and film thickness. The least value of sheet resistance (15.40Ω/) obtained is comparable to the value obtained for the FTO and hence the carbon electrode can perform optimally when deposited on the substrate. The results obtained from the current-voltage characterization showed that the carbon counter electrode is effective in the regeneration of redox couples on electrolyte and thus is suitable for fabrication of counter electrode on dye sensitized solar cells.

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