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Low-cost dye-sensitized solar cells with novel counter electrodes based on activated carbon of *Rhododendron arboreum* plant wood

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Abstract

The activated carbon of wood of *Rhododendron arboreum* plant was prepared by carbonization method. The activated carbon was employed as a novel counter electrode material of dye-sensitized solar cells (DSCs). The DSCs with the activated carbon yielded the light photon-to-electricity conversion efficiency of 2.34% compared to 2.75% efficiency of a reference cell when the devices were tested in natural sunlight. Also, the activated carbon based DSCs exhibited good stability.

Keywords: *activated carbon, counter electrode, dye-sensitized solar cell, rhododendron arboreum*

1. Introduction

Dye-sensitized solar cells (DSCs) are third generation solar cells [1]. The major components of a DSC are photoelectrode, counter electrode, and liquid electrolyte. The first two components are two electrodes of the solar cell [2, 3]. The photoelectrode is a tin oxide-glass substrate with a thin film of titanium dioxide (TiO_2); the TiO_2 film is coated onto the tin oxide film. The TiO_2 film consists of sintered nano-crystalline TiO_2 particles and the film has porous morphology with high surface roughness. Furthermore, TiO_2 particles are coated with a mono-layer of light sensitive dye molecules [1-3]. Generally, the counter electrode is a tin oxide-glass substrate coated with a catalytic layer of platinum on the tin oxide film of the electrode. The liquid electrolyte, the other component of the solar cell, is a conducting liquid sandwiched between the two electrodes and it contains redox couple like iodide ions and tri-iodide ions [1-4].

When sunlight is allowed to fall on the glass-substrate of the photoelectrode, light photons arrive up to the dye molecules as both the glass substrate and the thin layer of tin oxide film are transparent to the visible part of the sunlight. The light photons incident on the dye molecules eject electrons from the dye molecules and the photo-electrons enter into the conduction band of TiO_2 particles. The ejected photo-electrons flow in the TiO_2 film and they arrive at the tin oxide film of the photoelectrode. The tin oxide layer is a conducting film and it is connected to an external circuit [1-3]. Generally, the external circuit consists of a load and one terminal of the load is connected to the tin oxide layer of the photoelectrode and the other terminal of the load is connected to the conducting layer of the counter electrode. Thus, the photo-electrons arrived at the tin oxide film flow in the external circuit, and they arrive at the counter electrode [3]. On the other hand, the regeneration of the oxidized dye molecules takes place by receiving electrons from the iodide ions in the electrolyte and the iodide ions are oxidized to tri-iodide ions. Similarly, the regeneration of the electrolyte takes place by reduction of the tri-iodides ions into iodide ions as the tri-iodide ions receive the photo-electrons at the counter electrode [2-6].

DSCs are appreciated for their low fabrication cost [7]. However, platinum, an expensive metal, has been dominantly used for preparation of their counter electrodes [3, 8]. Its use in DSCs may render these photovoltaic devices expensive. Thus, other materials like conducting polymers, nitrides, and various types of carbon have been used instead of platinum in DSCs [2, 4, 5, 8-14]. Recently, P. Joshi has used activated carbon prepared from *Choerospondias axillaris* seed-stones and *Alnus nepalensis* (which are locally called Lapsi and Utis plants in Nepal, respectively) as CE materials of DSCs [3]. However, the efficiencies of these solar cells were smaller than that of the DSCs with commercially available carbon paste as CE material: the reported efficiencies of DSCs based on the activated carbon of *Choerospondias axillaris* seed-stones and *Alnus nepalensis* were 0.94 % and 1.12 %, respectively, compared with that of 3.2 % efficiency from the DSC based on commercially available carbon paste named Elcocarb (Solaronix, Switzerland). Thus, there exists a need to search for other more efficient carbonaceous materials to use them as counter electrode materials. In this regards, the activated carbon prepared from *Rhododendron arboreum* (rhododendron) plant can be a novel counter electrode material for DSCs. Thus, we report low-cost DSCs with novel counter electrodes based on activated carbon of *Rhododendron arboreum* plant wood. Also, the stability of the DSCs with the CE based on the activated carbon was studied.

2. Materials and Methods

The experimental procedures for the preparation of activation carbon, fabrication of DSCs, and characterization of the solar cells adopted in this research are similar to those described by P. Joshi [3].

2.1 *Preparation of activated carbon*

The activated carbon of wood of rhododendron plant has been prepared by carbonization technique as described below. First of all, the branches of rhododendron plant (collected from the forest of Nepal) were cleaned and dried. The branches were turned into powder by rubbing them with a steel hand file and the powder was filtered using a screen of mess size 44. The filtered powder of the rhododendron plant wood was chemically treated with phosphoric acid in the ratio of 1:1 (wt:wt) and was left over for 24 hours for soaking. Then, it was dried in an oven at 110^0C for 2 hours. The dried sample was carbonized in a tubular furnace at 400^0C for 3 hours under an inert nitrogen atmosphere. Next, the carbonized sample was cooled to room temperature under continuous flow of nitrogen and the cooled sample was washed several times with distilled water. The washing process was continued till neutral pH was obtained. Thus obtained activated carbon was dried in an oven at 110^0C. Finally, the dried activated carbon was grinded into fine powder.

2.2 *Fabrication and characterization of DSCs*

Two types of DSCs were fabricated. They have identical photoelectrodes and liquid electrolyte but different counter electrodes. One type of the solar cells (DSCs-1) have CEs with the activated carbon as the catalyst for tri-iodide reduction and the other type of the solar cells (DSCs-2) have CEs with commercially available graphite based paste (Elcocarb from Solaronix, Switzerland). DSCs-2 were fabricated as reference solar cells to compare the photovoltaic performance of DSCs-1.

The CEs required for fabrication of the DSCs were prepared as described below. First of all, carbon paste was prepared by mixing 0.50 g of the activated carbon and 0.13 g of carbon methyl cellulose (CMC) sodium salt (as a binder). The mixture was grinded in a mortar using distilled water until the paste become viscous. Then, the paste was tape-casted (doctor-bladed) onto fluorine-doped tin oxide (FTO)-glass substrates (sheet resistance 8 Ω/□, Hartford Glass, USA). The tape-casted paste was sintered at 80˚C for 12 hours. Similarly, the CEs of DSCs-2 were fabricated by tape-casting Elcocarb paste onto the FTO-glass substrates and sintering the coated paste at 400°C for ~ 30 minutes.

Similarly, the photoelectrodes of DSCs-1 and DSCs-2 were prepared by tape-casting of the TiO_2 paste (Solaronix HT/SP) onto cleaned FTO-glass substrates. The TiO_2 film was sintered at ~100^0C for ~30 minutes and then at ~450^0 C for 45 minutes. The sintered TiO_2 film was cooled down to ~80^0C and immersed into the 0.3 mM of N-719 dye solution in anhydrous ethanol for ~12 hours. Finally, the photoelectrodes and the counter electrodes were assembled using parafilm as a sealant and the liquid electrolyte containing iodide/tri-iodide ions was injected into the space between the two electrodes.

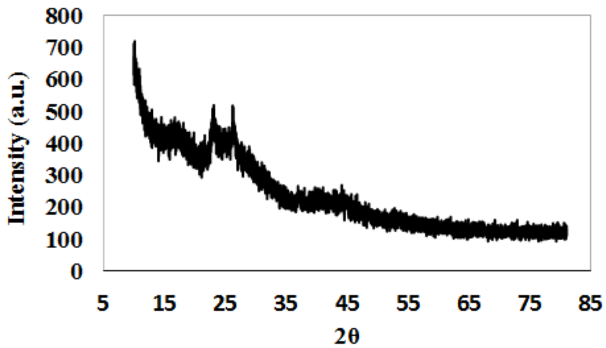

Fig. 1: XRD of activated carbon of Rhododendron plant

The DSCs were tested in natural sunlight at outdoor as described in reference [3].

3. Results and Discussion

Figure 1 is the X-ray diffraction (XRD) of the activated carbon prepared from rhododendron plant. The observed prominent X-ray diffraction maxima at diffraction angles (2θ) ~ 25˚ can be attributed to the diffraction from graphitized carbon [3, 4, 15]. Moreover, the spreading of the diffraction maxima (from ~23˚ to ~26˚ of 2θ) indicates low-degree crystallinity of the graphitized material [16].
Murakami et al. have mentioned that carbonaceous materials with low-degree crystallinity may be more efficient catalysts for tri-iodide reduction compared with highly ordered carbonaceous materials [12]. Thus, the activated carbon prepared from rhododendron plant can be expected to exhibit good catalytic property for the reduction of tri-iodide ions. Moreover, it has been reported that the activated carbon prepared from plant products can exhibit photo-catalytic activity for tri-iodide reduction in DSCs [3]. Hence, the activated carbon prepared from rhododendron plant can also be employed as another counter electrode material for DSCs.
Figure 2 shows the current voltage (I-V) curves of DSCs tested few hours after their fabrication in natural sunlight at outdoor. Figure 2a is the I-V curve of the DSC-1 and Figure 2b is the I-V curve (reference I-V curve) of the DSC-2. The DSC-1 yielded overall light-to-electricity conversion efficiency of 2.34 % which is comparable to 2.75 % efficiency of the reference DSC-2. Moreover, open-

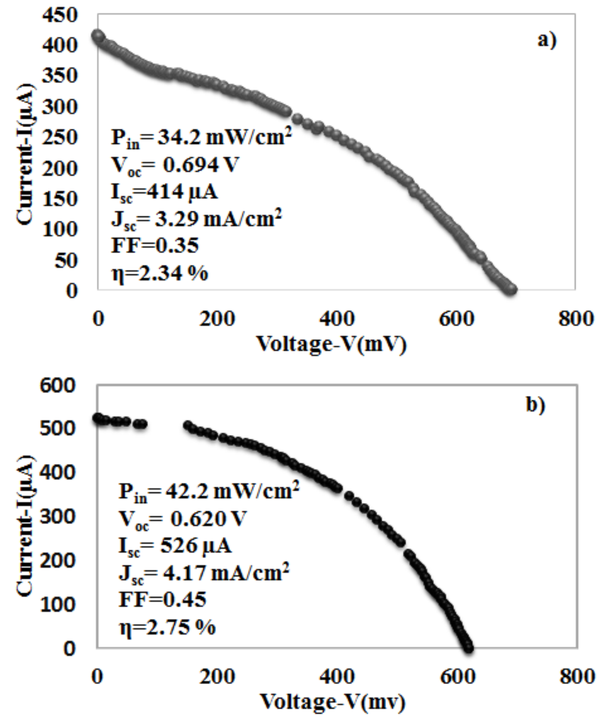

Fig. 2: I-V curves of a) DSC with CE based on activated carbon of rhododendron plant (DSC-1) and b) DSC with CE based on Elcocarb (DSC-2)

circuit voltage (V_{oc}) of DSC-1 was 0.694 V which is greater than 0.620 V that from the DSC-2. However, fillfactor (FF) of DSC-1 was 0.35 compared with 0.45 of the DSC-2. One of factors that can affect FF is the series resistance (R_s) of the solar cells; higher value of R_s can reduce the FF of the devices [4].
Figure 3 shows the I-V curve of the DSC-1 obtained by testing the solar cell in natural sunlight five days

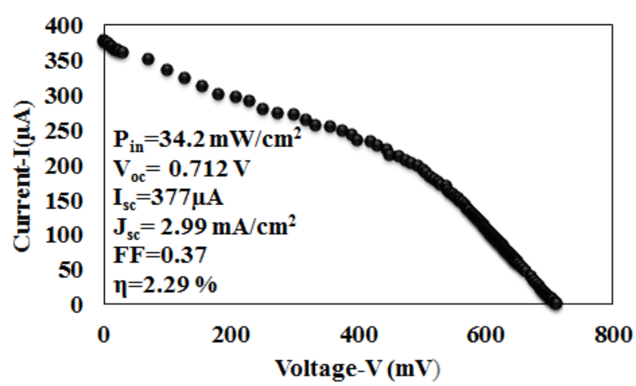

Fig. 3: I-V curve of DSC with CE based on activated carbon of rhododendron plant (DSC-1) tested in natural sunlight five days after fabrication

after its fabrication (the cell was kept in dark room after it was tested on the first day). Table 1 shows the various photovoltaic parameters of the DSC-1 when it was tested a few hours after fabrication and five day after fabrication. Though short circuit current density (J_{sc}) of the cell five days after fabrication decreases slightly, open circuit voltage (V_{oc}) and fillfactor (FF) of the cell increased compared with those from the cell when it was tested a few hours after fabrication. Similar trend of change in the photovoltaic parameters were reported by Ramasamy et. al when they run stability test of DSCs with CEs based on nano-carbon [15]. The difference in the efficiency of the freshly tested DSC-1 (a few hours after fabrication) and matured DSCs-1 (five days after fabrication) was small. This indicates that the DSC with CE based on the activated carbon is stable and this confirms that the activated carbon can be used as a reliable counter electrode material in DSCs.

4. Conclusions

The activated carbon of rhododendron plant has been used to fabricate novel and stable counter electrodes of DSCs. The photovoltaic performance of DSCs with the CEs based on the activated carbon was comparable to that of DSCs based on commercially available carbon paste. Moreover, the DSCs with the activated carbon of rhododendron plant exhibited stable photovoltaic performance even five days after the fabrication of the solar cell.

Table 1: Photovoltaic parameters of DSC-1 tested in natural sunlight few hours and five days after its fabrication. Active area of each cell was ~ 0.126 cm^2.

Photovoltaic parameters of DSC-1	Few hours after fabrication	Five days after fabrication
P_{in} (mW/cm^2)	34.2	34.2
I_{sc} (µA)	414	377
J_{sc} (mA/cm^2)	~3.29	~2.99
V_{oc} (V)	0.694	0.712
FF	0.35	0.37
η (%)	2.34	2.29

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