Novel counter electrodes of dye-sensitized solar cells based on activated carbon prepared from wood of Choerospondias axillaris seed-stones and Alnus nepalensis plant

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***Abstract*— Activated carbon prepared by the carbonization of wood of *Choerospondias axillaris* (Lapsi) seed-stones and *Alnus nepalensis* (Utis) plant have been used as novel catalysts for reduction of tri-iodide ions in dye-sensitized solar cells (DSCs). The X-rays diffraction (XRD) and Raman spectroscopy of the activated carbons revealed that the carbonaceous materials contain amorphous and graphitic forms of carbon. The DSCs were tested in natural sunlight. The DSCs with counter electrodes (CEs) based on activated carbon of Lapsi seed-stones and Utis yielded efficiencies of 0.94 % and 1.12 %, respectively compared with 3.24 % of efficiency from the DSC with the CE based on commercially available graphite based carbon composite from Solaronix.**

***Index Terms*— Activated carbon, catalyst, counter electrodes, dye sensitized solar cells, efficiency.**

I. INTRODUCTION

Solar energy is a renewable and environmentally clean source of energy [1]. A solar cell converts sunlight into electricity [2]. There exits various types of solar cells like silicon solar cells, polymer solar cells, and dye-sensitized solar cells (DSCs). Basically, a DSC consist of two electrodes-- photo-electrode and counter electrode (CE) enclosing liquid electrolyte with iodide and tri-iodide ions (Fig. 1). Photo-electrode is a transparent conducting oxide (like Fluorine-doped Tin oxide--FTO) with a thin film of titanium dioxide sensitized with a monolayer of a dye. The CE is another piece of FTO with a thin film of platinum. When the photo-electrode is exposed to light, the dye molecule injects an electron into the TiO_2. The photo-electron flows in an external circuit with a load and the electron arrives at the CE. The oxidized dye (with a deficiency of an electron) is regenerated by receiving an electron from the iodide ion in the liquid electrolyte. The iodide converts into tri-iodide after losing the electron. Ultimately, the tri-iodide ion compensates its lost electron by gaining an electron from the CE and the tri-iodide ion is converted into an iodide ion. The platinum coated on the CE acts as a catalyst for fast transfer of the electron from the CE to the electrolyte [2], [4]. Platinum is a dominant counter material used in DSCs, but it is an expensive metal. Furthermore, the liquid electrolyte can corrode platinum coated on the CE of the DSCs [5]-[7].

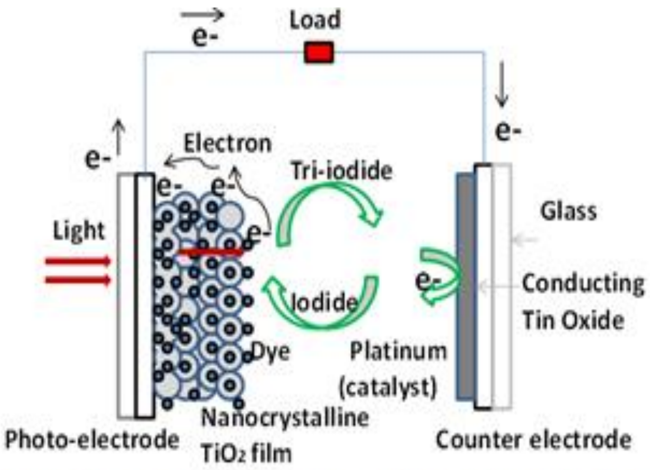

Fig. 1: A schematic of a DSC. Modified from ref. [3]

To solve these problems, various carbonaceous nano-materials like carbon black, carbon nanotubes, and carbon-nanofibers have been used as CE materials instead of platinum [5], [6], [8]-[10].

Additionally, Jiang, *et al.* demonstrated that the carbonaceous materials prepared by carbonization of wood from bamboo and oak tree as efficient counter electrode materials as platinum [11]. Rajabhandari *et al.* reported the activated carbon prepared by carbonization seed-stones of *Choeraspondia axillaris* (Lapsi), however, the activated carbon has been mainly used as an absorbent for purifying water [12]. In this report, the activated carbons prepared from the seed-stones of *Choerospondias axillaris* (Lapsi) and the wood of *Alnus nepalensis* (Utis) plant have been used as counter electrode materials of DSCs for the first time.

II. EXPERIMENTAL PROCEDURES

A. Preparation of activated carbon

The activated carbon of Lapsi seed-stones and Utis were prepared by carbonization of the materials in powder form. In order to prepare powder of Lapsi seed-stones, the seed-stones were

Fig. 2: (a) Lapsi seed-stone and (b) wood of Utis

extracted from Lapsi fruits (Fig. 2a). The cleaned seed-stones were dried and grinded. The powder of seed-stones was filtered using a metal screen of Mess size 44 (Filter #60) and the filtered powder was collected for carbonization. In case of the preparation of the powdered wood of Utis, the cleaned and dried branches of Utis tree (shown in Fig. 2b) were filed using a steel file. The powdered sample of Utis was filtered using the metal screen and the filtered powder was collected for carbonization. The powder of Laspi-seed stones and Utis wood were activated with phosphoric acid, and then they were separately carbonized in nitrogen at 400°C in a tube furnace.

B. Fabrication of DSCs

The procedures for the fabrication of DSCs with the activated carbons as CE materials are similar with the procedures described by Joshi et al. [10]. In order to fabricate the DSCs, first carbon pastes of the activated carbon of Lapsi seed-stones and Utis wood were prepared separately. The paste was prepared by grinding the mixture of the activated carbon and carboxymethyl cellulose (CMC) sodium salt (80:20) in distilled water; the CMC was used to as a binder. The paste was doctorbladed onto the Flourine-doped tin oxide (FTO)-glass substrates (purchased from Hardfort Glass, USA). The FTO-glass substrates with doctorbladed paste were sintered at ~80ºC for several hours. Additionally, in order to compare the catalytic activity for tri-iodide reduction of the plant based carbons with that of the commercially available carbon paste named Elcocarb (Graphite based carbon paste from Solaronix, Switzerland), the counter electrodes with the Elcocarb were prepared by doctorblading the carbon paste onto the FTO-glass substrates followed by sintering the FTO-glass substrates at 400ºC for about 30 minutes.

The photo-anodes of the DSCs were prepared by doctorblading the TiO_2 paste (Solaronix T/SP) onto the FTO-glass substrates. The FTO-glass substrates with doctorbladed TiO_2 paste were sintered at ~450º C for about an hour. The photo-anodes were cooled down to ~80º C and soaked into the 0.3 mM of N-719 dye (Solaronix) solution at room temperature for ~12 hours.

C. Characterization of the solar cells

The DSCs were tested under the natural sunlight following the method similar to the method described by Smestad [13]. The experimental set up for testing the solar cells is shown in Fig. 3. The light-to-current conversion efficiencies of the solar cells were determined by obtaining current versus-voltage (I-V) curve.

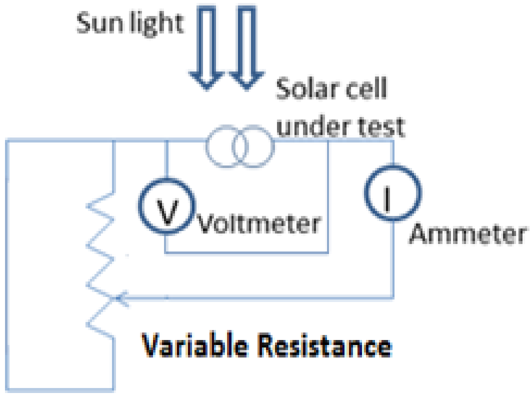

Fig. 3: The circuit diagram for testing solar cells. Modified from Ref. [13]

III. RESULT AND ANALYSIS

A. XRD and Raman spectroscopy

Fig. 4a and Fig. 4b show the XRD images of the activated carbons of Lapsi seed-stones and Utis wood, respectively. The intensity peaks at 2θ≈25° indicate that the activated carbons contain graphite [6], [10].

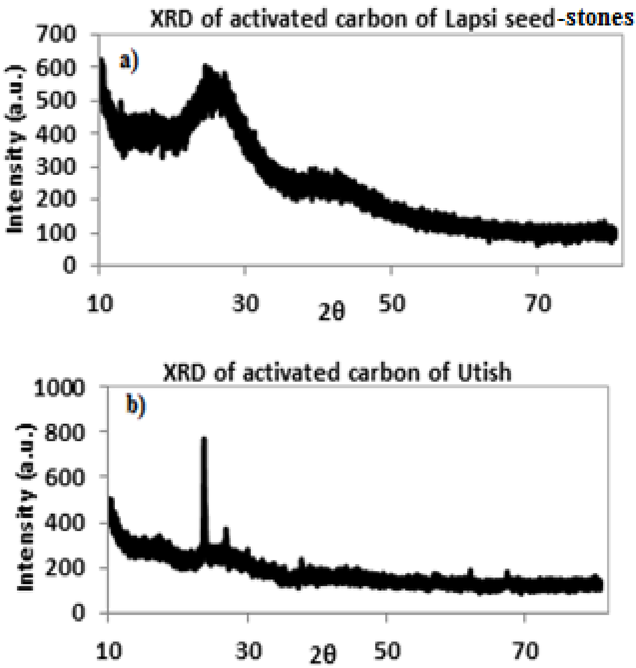

Fig. 4 : XRD of activated carbon of a) Lapsi seed-stones and b) Utis wood

Fig. 5a and Fig. 5b show the Raman spectra of the activated carbon of Lapsi seed-stones and Utis, respectively. The D-bands (at ~1340 cm^{-1}) and G-bands (at~1580 cm^{-1}) in the figures indicate the presence of disordered carbon and crystalline carbon (graphitic form of carbon), respectively. Kay and Gratzel have reported efficient solar panel made up of DSCs with counter electrode based on the composite of graphite

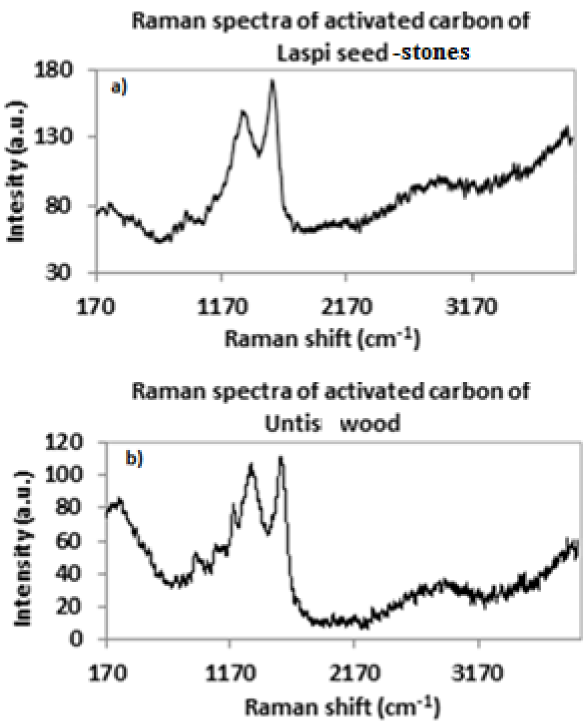

Fig. 5 : Raman spetra of activated carbon of a) Lapsi seed-stones and b) Utis wood

powder and carbon black (amorphous carbon) [14]. Hence, the activated carbons prepared from Laspi seed- stones and Utis wood can be used as the catalyst for tri-iodide reduction in DSCs. Also, the Raman ratio (R value) of the activated carbon of Lapsi seed-stones was ~0.87 and this indicates that the crystalline form of carbon dominates the amorphous form of the carbon. In case of the activated carbon of Utis, R was ~0.96, which indicates that the graphite and amorphous carbon are almost equally present in it [6], [10].

B. Current–voltage (I-V) curves of DSCs

Fig. 6a and Fig. 6b are the I-V curves of the DSCs with CEs prepared from FTO only (without any catalyst) and Solaronix carbon paste, respectively. These curves are presented here as reference I-V curves to compare the I-V curves of the DSCs with the activated carbon prepared from Laspi and Utis as

CE materials. The I-V curve of the DSC with CE prepared from FTO only shows the current (I) from the device decreases rapidly as voltage (V) applied across the device increases. The I-V curve of the DSC with Solaronix carbon paste (catalyst) shows that the decrease in current with the increase in the applied voltage is much slower compared with that of the DSCs with FTO only (without catalyst). From these curves it is understood that if the catalyst used in a DCS is good one, it generates an I-V curve which is similar to the I-V curve shown in Fig. 6 (b) and if the catalyst used in a DSC is not efficient, then I-V curve of the device will look like that shown in Fig. 6 (a). As the I-V curves of the DSCs with CEs based on Lapsi and Utis shown in Fig. 6c and Fig. 6d are more resemble to the I-V curve shown in Fig. 6b, it can be concluded that the activated carbon prepared from Lapsi and Utis can act as the catalyst for the reduction of tri-iodide in DSCs.

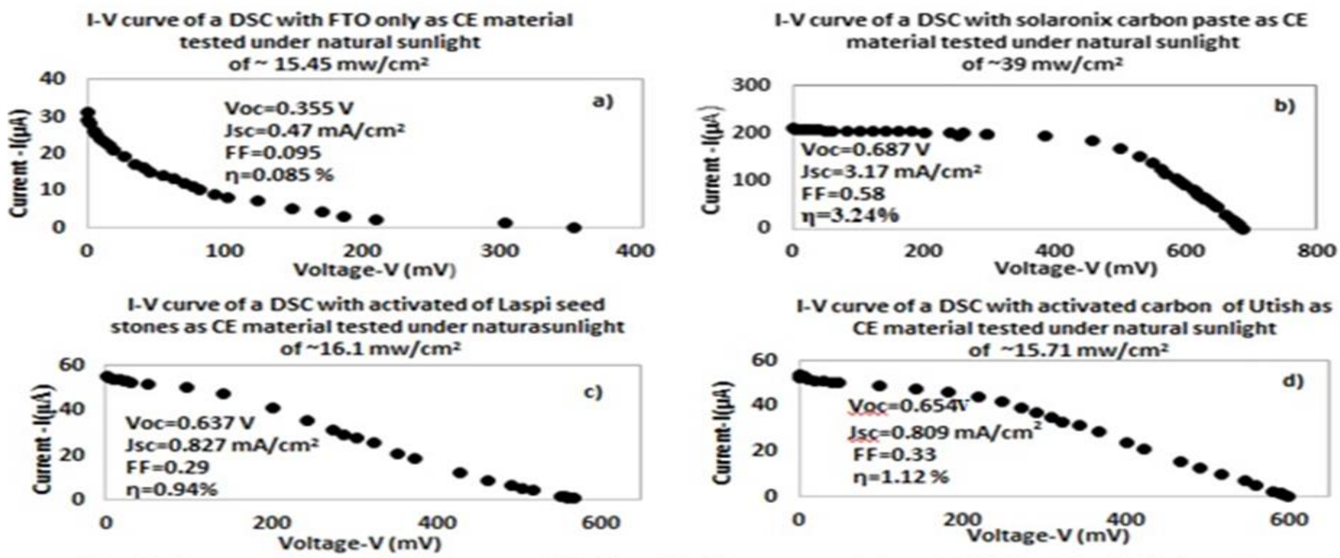

Fig. 6: Current-Voltage (I-V) curves of DSCs with CEs prepared from (a) FTO-only, (b) Solaronix carbon paste, (c) activated carbon of Laspi seed stones, and (d) activated carbon of Utis

Table I shows the photovoltaic parameters of the DSCs with CEs prepared from FTO-only, Solaronix carbon paste, activated carbon of Laspi seed stones, and activated carbon of Utis. P_{in} is input intensity of the natural sunlight on the device under test. The short circuit current density (J_{sc}), open circuit voltage (V_{oc}), fillfactor (FF), and efficiency (η) obtained from the DSC with FTO only as CE material were 0.47mA/cm^2, 0.355V, 0.095, and 0.085%, respectively. Similarly, J_{sc}, V_{oc}, FF, and η obtained from the DSC with Solaronix carbon paste as CE material were 3.17 mA/cm^2, 0.687V, 0.58, and 3.24%, respectively. The comparison of the photovoltaic parameters of the two cells mentioned above shows that the presence of a catalyst on the CE of a DSC, increases J_{sc}, V_{oc}, FF, and η significantly. The J_{sc}, V_{oc}, FF, and η from the DSCs with CEs materials prepared from Lapsi seed-stones and Utis are much larger than those from the DSCs with CE prepared from FTO only. This indicates that the activated carbon of Lapsi seed-stones and Utis can act as catalysts for the reduction of tri-iodides in DSCs.

The DSCs based on Lapsi seed and Utis yielded efficiencies of 0.94% and 1.12%, respectively, compared with 3.24% of efficiency from the DSC with CE based on commercially available Solaronix carbon paste. One of reasons of lower value of the efficiency of the Lapsi and Utis based DSC is due to low FF. The lower FF is attributed to higher value of the series resistance of a DSC [10]. Though, the efficiencies of the DSCs with Lapsi and Utis as CE materials are smaller than that of the DSC with Solaronix carbon paste, the activated carbons have exhibited catalytic ability for tri-iodide reduction in DSCs.

IV. Conclusion

The activated carbon prepared from carbonization of wood of Laspi and Utis have been used for the reduction of tri-iodide ions in DSCs. The XRD of the CE materials confirmed the presence of carbon while Raman spectroscopy indicated that the materials consist of both amorphous and graphitic forms of carbon. Though, the efficiencies of the DSCs with CEs based on Lapsi (0.94%) seed-stones and Utis (1.12 %) are less than the efficiency from the DSC with the CE based on commercially available carbon paste (3.24%), the activated carbons prepared from Lapsi and Utis have been demonstrated as novel CE materials for tri-iodide reduction in DSCs.

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