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Use of gel polymer electrolytes to integrate photoelectric conversion and energy storage

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ABSTRACT

Solar energy is considered as one of the effective and alternative solutions for the power crisis as predicted to be taken place within next few years. But, there is a serious challenge existing with solar energy. That is to storing it for usage when required. Redox capacitors have been identified as a good energy storage device and this study is based on fabricating a dye sensitized solar cell (DSSC) and employing a redox capacitor to store solar energy produced by the DSSC. DSSC was fabricated using a gel polymer electrolyte (GPE) with an optimized composition. Redox capacitor was based on a GPE and two identical conducting polymer electrodes. Main reason for selecting a GPE for the DSSC and the redox capacitor is that most of the research work has been carried out with liquid electrolytes and they have undergone adverse effects including short life time, leakage and spilling. Open circuit potential, short circuit current density, fill factor and efficiency of DSSC were found out as 0.68 V, 0.00033 A cm^{-2}, 0.24 and 0.05% respectively. Redox capacitor was charged by the DSSC for 722 s and discharged galvanostatically. Within 36 s, it was possible to discharge the redox capacitor completely. The stability of the integrated device was satisfactory. This study is an initial attempt to explore the possibility of using a redox capacitor to store solar energy.

1. Introduction

Rapid growth of energy requirements, dwindling fossil fuel reserves and predicted energy crisis have forced the scientific community to reassess their research priorities and to shift towards alternative, viable and environmental friendly energy resources. Different types of energy technology including tidal, solar photovoltaic, bio mass, solar thermal and wind have been proposed as suitable alternatives. Among them, solar photovoltaic has received a greater attention since long ago. In this technology, solar light is directly converted to electrical energy through the photovoltaic process by a solar cell [1]. Based on the type of the materials used and the mechanism of converting light energy to electrical energy, there are mainly two types of solar cells. They are dye sensitized solar cells (DSSCs) and silicon based solar cells. A wealth of studies has triggered on DSSCs after the first report made by Gratzel and O'Regan in 1991 [2]. They have used titanium dioxide (TiO_2) electrodes for the DSSC and have achieved an efficiency of 10% under simulated solar light. In general, a DSSC consists of a counter electrode, an electrolyte and a photo anode. Research on DSSCs has intensified throughout the world due to their fascinating features such as low cost, high power and simple preparatory methods [3]. As a result, various development strategies have been adopted for DSSCs. Major progress has been taken place with the electrolyte which is playing a major role in a DSSC. Since long ago, liquid electrolyte has been the common choice for DSSCs because of the resulting higher efficiency. But, those electrolytes exhibited some drawbacks of evaporation and leakage of liquid parts. This limited the life time as well as created problems related to safety [4]. Attention has been diverted towards alternative electrolytes and in that line, gel polymer electrolytes (GPEs) have been identified as a better solution. They are consisted of a polymer host within which a liquid electrolyte is trapped. So, they possess conductivities comparable to liquid electrolytes and mechanical properties similar to solid electrolytes. A large number of research groups engage in research activities on DSSCs based on GPEs tremendously [5,6]. Apart from the commonly used GPE compositions, Salvador et al. have used cellulose and ionic liquid based GPES [7]. Further, some have studied about mixing of iodide salts and use of large cation based salts [8–10].

Even though solar energy is well recognized as a kind of feasible renewable energy, limitation of its availability only for about 10–

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12 h has put a challenge for getting uninterrupted supply. To address this issue, designing effective storage devices has become of paramount importance. Batteries and super capacitors are well known as energy storing devices though they have their own merits and demerits. In supplying high power during a short duration, super capacitors are placed in the front [11]. There are two categories of super capacitors as redox capacitors and electrochemical double layer capacitor (EDLC)s. Their main difference is the type of the electrode material. Redox capacitors use metal oxide or conducting polymer based electrodes whereas EDLCs use carbon based electrodes. Conducting polymers have been used for the fabrication of redox capacitors in mid 1990s. They are generally attractive because they possess high charge density and they are inexpensive too [12]. Polyaniline, polypyrrole, polythiophene are some of the conducting polymers that have been investigated upto date extensively.

Much research work has been devoted on redox capacitors based on liquid electrolytes. Although they show high performance, they exhibit some disadvantages such as short life time, evaporation, leakage, corrosion, self discharge, spilling and flammability [13,14].

A great deal of investigations has been done to fabricate and develop DSSCs as well as redox capacitors.

In this study, it was attempted to fabricate a DSSC based on a GPE and to investigate its ability to charge a redox capacitor based on a GPE as shown in Fig. 1. In addition, investigations have been carried out to evaluate the stability of the integrated device.

2. Material and methods

2.1. Preparation of the gel polymer electrolytes

Polyacrylonitrile (PAN) (Aldrich), ethylene carbonate (EC) (Aldrich,98%), propylene carbonate (PC) (Aldrich,99%) and sodium iodide (NaI) (Aldrich, 99%) were used as received. First, the required amounts of NaI, EC and PC were weighed by a chemical balance and dissolved in by magnetic stirring. When NaI was dissolved completely, PAN was added to the mixture. After stirring for some time, the resultant mixture was heated at 130 °C for 1 $^1/_2$ h. Then, the hot mixture was pressed in between two well cleaned glass plates and left overnight in a vacuum desiccator. On the following day, the glass plates could be separated and a thin, bubble free film could be obtained.

2.2. Optimizing the GPE composition

GPE samples were prepared varying the concentrations of NaI and PAN. A circular shape sample was cut from GPE electrolyte and it was loaded in side a sample holder having two stainless steel electrodes. Impedance data were gathered in the frequency range, 0.01 Hz–0.4 MHz at room temperature using Metrohm M101 frequency response analyzer. Bulk electrolyte resistance (R_b) values were extracted from the Nyquist plots drawn between imaginary and real values of impedance. This procedure was repeated for each sample having different NaI and PAN concentrations.

2.3. DC polarization test

DC polarization test was done with two stainless steel (SS) electrodes first and then with two iodide (I_2) electrodes to identify the nature of conductivity (ionic or electronic and if ionic, cationic or anionic). A circular shape sample was loaded in side a sample holder in between the respective electrodes. Measurements were taken as reported by us previously [5].

2.4. Fabrication of DSSCs

Fluorine doped tin oxide (FTO) glass strips were cleaned well using detergents and cotton buds. Then, they were washed with sulphuric acid (H_2SO_4) and distilled water. In order to remove water, they were heated in propon-2-ol and dried well. Titanium dioxide (TiO_2) (P 25 Degussa) was ground well for some time. Acetic acid, Triton-X and ethanol were added gradually to get a uniformly mixed slurry. It was applied on FTO strips using doctor blade method. Sintering was carried out at 450 °C for 45 min [15]. The total effective area of the DSSCs was kept at 0.25 cm^2. After cooling down to room temperature, they were dipped in ethanolic Ruthenium dye solution for 24 h. The highest conducting GPE was sandwiched in between the photo anode and a Pt counter electrode to fabricate the DSSC.

2.5. Study the photo voltage-current characteristics

Photo current variation with photo voltage was monitored by placing the fabricated DSSC under an illumination of 100 mW cm^{-2}. Open circuit voltage (V_{oc}) and short circuit current density (J_{sc}) were found out using the photo voltage-current characteristic

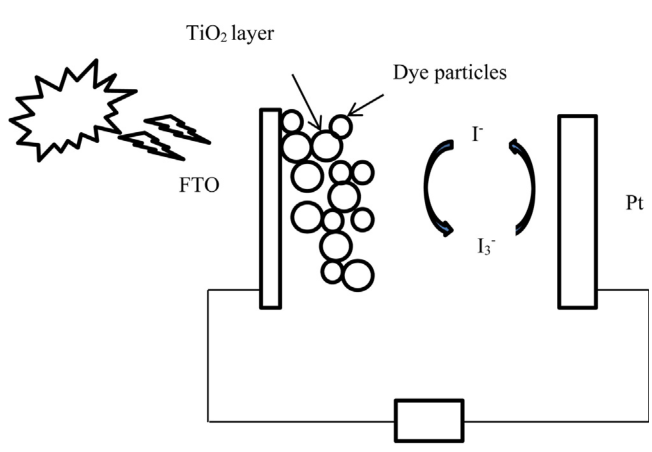

Fig. 1. Schematic diagram that illustrates the storing of solar energy using a DSSC and a redox capacitor.