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Development of Photoactive Titanium Dioxide Doped Sodium Alginate Film for Dye Sensitized Solar Cell Application

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Abstract: Dye-sensitized solar cells (DSSCs) have attracted the attention of scientists all over the world because of their relatively high efficiency and low-cost production. But in order to increase the ionic conductivity and reduce the fragility of electrodes, there is a tendency to substitute some of these materials by polymers.[1] With the aim of understanding the electrical and physico-mechanical properties of polymer solar cell, we have fabricated and characterized an electro active nanocomposite using Na-alginate, Titanium dioxide (TiO_2) and natural dye. The conductivities of nanocomposites with different wt,%TiO_2 were studied with temperature. The highest conductivity (0.0472 S/m) was found for 8%TiO_2 at room temperature which increased by 38.34% with rise in temperature. The mechanical properties of nanocomposites were also observed by means of Tensile Strength (TS) and Elongation at break (Eb). The alginate based nanocomposite with 8 wt% TiO_2 showed highest TS of 16.31 MPa which was 454% greater than that of pure alginate. The UV-analysis of different compositions also justified the conductivity result.

Keywords: Dye Sensitized Solar Cell, Na-alginate, Titanium Dioxide, Nanocomposite, Photoconductivity, Polymer electrodes.

1 Introduction

Polymer photovoltaic devices offer great technological potential as a renewable, alternative source of electrical energy. The demand for inexpensive renewable energy sources is the driving force behind new approaches in the development of low-cost polymer photovoltaic devices [2-6]. Moreover, the mechanical flexibility and compatibility with a wide range of substrates of polymer would have a major impact on the development of polymer solar cells, even if the efficiencies of these types of photovoltaic devices up to now are smaller than the efficiencies achieved in inorganic solar cells.

In the development of the low cost photovoltaic solar cell liquid electrolyte containing an organic solvent such as acetonitrile or propylene carbonate, assures perfect regeneration of the dye by direct interaction between dye oxidized state and I^-/I^{3-} redox couple and leads to impressively high solar-to-electrical conversion efficiencies (7–11%) [7]. However, the stability and long-term operation of the cell are affected by solvent evaporation or leakage. Thus, the commercial exploitation of these devices needs the replacement of the liquid electrolyte by a solid charge-transport medium, which not only offers hermetic sealing and stability but also reduces design restrictions and endows the cell with shape choice and flexibility. Various approaches have been reported in the literature as replacements for the liquid electrolyte such as polymer gel electrolyte that conduct ions [8], ionic conducting polymers [9, 10] and organic hole transport materials [11]. Although the above systems presented high technological interest but their practical use encounters serious problems such as low conversion efficiencies and poor electric contact between the photo electrode and the electrolyte. In this view, recent researches are focused into the addition of inorganic fillers which generally improves the transportation properties, the resistance to crystallization and the electrode–electrolyte stability. During the last few years, many of the research works also occupied the investigation of the enhanced properties of conjugated polymer nanocomposites doped with inorganic filler for solar cell application. This are the case of poly thiophene sodium poly [2-(3-thienyl) ethoxy-4-butylsulfonate] (PTEBS) based composite doped with TiO_2 [12], organic solar cells based on PPV as donor and fullerene derivative (PCBM mono adduct) as acceptor molecules [13] and perylene/phthalocyanine hetero-p/n-junction solar cell. [14].

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Thus, in order to overcome the problems encountered with polymer electrolytes, in this paper we reported on the development and characterization of nanocomposite consists of sodium alginate (Na-Alg), natural dye (N-Dye) and titanium dioxide (TiO_2) served as polymer based solid electrolyte. In the present work, N-Dye was used as donor and TiO_2 as acceptor molecules which enhanced the stability and performance of solid electrolyte for the potential use in dye sensitized solar cell. The primary focus of this work is to investigate the electrical, optical and physico-mechanical properties of N-Dye included Na-Alg /TiO_2 nanocomposite.

2 Experimental

2.1 Materials

Na-alginate and TiO_2 used in this work was purchased from Merck, Germany. The molecular weight of TiO_2 was 79.866 g/mol. Dye was extracted from pomegranate bark in lab, other reagents were of lab grade.

2.2 Preparation of The Sample

All the films of pure Na-alginate and natural dye incorporated TiO_2/Na-alginate were prepared by solution casting. Firstly, for preparing the pure Na-alginate solution, 2.5gm Na-alginate was dissolved into 100 ml distilled water and was magnetically stirred for 90 minutes at 60°C temperature to have homogeneous mixture. The solution of pure Na-alginate was stirred again for 30 minutes at same temperature to reduce the volume up to 50 mL through evaporating water. Then the solution covered with aluminum foil was kept in autoclave for 20 minutes to sterilize and finally cast on a glass plate covered by silicon paper allowing the water to evaporate at room temperature under laminar air flow condition for 1days.

Similarly, to prepare natural dye and TiO_2 incorporated Na-alginate nanocomposite, at first pure Na-alginate solution was prepared and then TiO_2 & natural dye were added slowly. The mixture was magnetically stirred for 60 minutes at 60^0C temperature to reduce the volume up to 50mL by evaporation. Several aqueous solutions were prepared taking different weight ratios (TiO_2/Na-alginate: 0.02/2.5, 0.05/2.5, 0.1/2.5 and 0.2/2.5) of TiO_2 and Na-alginate where a constant amount of natural dye was added into all the solutions. Finally, the blend solutions covered with aluminum foil were sterilized in autoclave for 20 minutes and cast on glass plate covered with silicon paper to dry under laminar air flow for 1 day. All the dried films were coded as I, II, III, IV, and V respectively and were transferred into vacuum desiccators for further drying. The film thickness ranged 500±40 µm.

2.3 Electrical Properties Analysis

The temperature dependent conductivity of the nanocomposite were measured by Ecopia Hall Effect measurement system (HMS-5000 VER 5.6.1) with constant current and constant magnetic field B *at* $297\ k$ temperature. In order to make electrical contact samples were cut into rectangular shape and silver paste was pointed sharply as contact material at the four corners of each sample. The samples were dried at room temperature with 40% relative humidity.

2.4 Mechanical Test

Tensile strength (TS) and percent elongation at break (Eb) of the films were measured with universal testing machine (INSTRON, model 1011, UK). The load capacity was 500 N, efficiency was within ±1.5 %. The crosshead speed was 10 mm/min and Gauze length was 20 mm. TheTiO2 incorporated natural dye containing Na-alginate film were conditioned at <60 RH relative humidity and 250C for two days prior to the mechanical test.

2.5 Optical Characterization

T-60 UV-Visible spectrophotometer (PG electronics U. K.) was used to study the comparative UV- absorbance spectra of pure Na-alginate and natural dye incorporated Na-alginate/TiO_2 nanocomposites. The films of same thickness and surface area were placed at 15 cm apart from the light source. Irradiation times for all the samples were same and all irradiations were performed at room temperature in air.

3 Result

3.1 Temperature Dependence Of Conductivity

The effect of increasing temperature on ionic conductivity of N-dye included Na-Alg/TiO_2 nanocomposites with various wt% of TiO_2 is shown in figure 1. In figure, at room temperature, the conductivities of nanocomposites showed ascending nature with increasing order of TiO_2 (wt,%) which later increased linearly with further rise in temperature. The increase in conductivity with rising TiO_2 is due to improved filler contact with polymer matrix because, during higher concentrations, TiO_2 nanoparticles create overlapping paths in the network which allow the charge carriers to pass through the less resistant routes .[15, 16].

The nanocomposite containing 8 wt% TiO_2 responded maximum with temperature showing the conductivity 0.0653 S/m at 60°C. This increasing nature of conductivity is due to the negative thermal coefficient of resistance of sample which is mainly attributed to two main parameters,

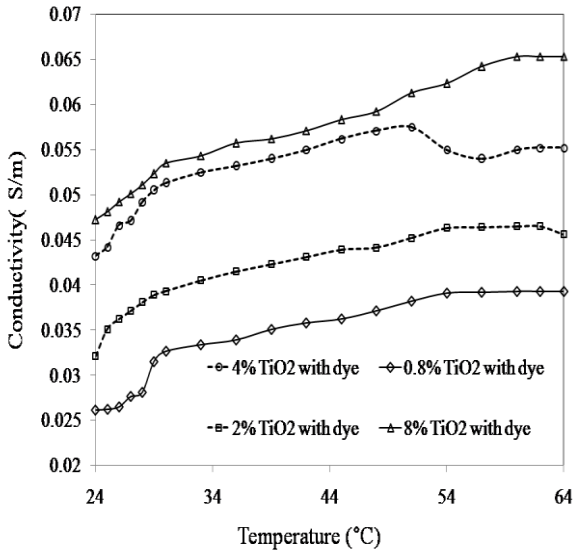

Figure 1. Variation of conductivity of different compositions with temperature.

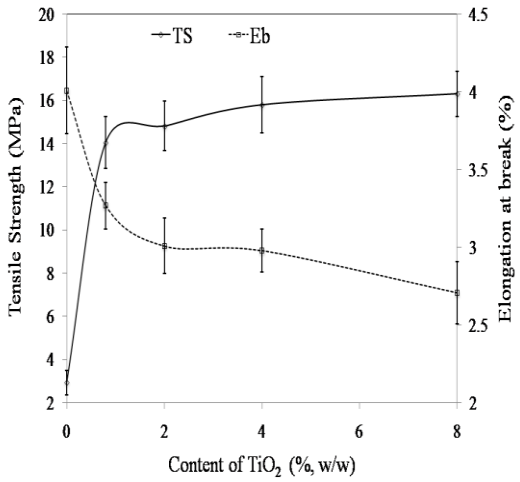

Figure 2. Variation of ultimate tensile strength and elongation at break of the nanocomposite films with composition.

charge carriers and mobility of these charges. Usually, the polymeric chains and TiO_2 particles act as traps for the charge carriers which transited by hopping process. On increasing temperature, the polymer segments start moving which is associated with molecular motion and release the trapped charges. Thus the number of charge carriers increase exponentially. Similarly, the mobility of charge carriers also depends on the temperature and structure of the material. [17]. Above 60°C temperature the conductivity patterns of each composition showed temperature independent plateau which would be followed by further decreasing trend due to the structural instability. The nanocomposite film with higher TiO_2 incorporation was not possible to make as it showed fragility after a certain critical composition of 8 wt% TiO_2.

3.2 Mechanical Properties

As can be observed in figure 2, the tensile strength (TS)of N-Dye included Na-Alg/TiO_2nanocomposite films increased significantly with increase in TiO_2(wt%) concentration. The maximum TS value of 16.31 MPa was found for 8 wt% TiO_2 composition which was 454% greater than that of alginate film with 0 wt% TiO_2. This increasing tendency of TS values might be attributed to the hydrogen bonding possibly formed between hydroxyl and carbonyl groups in alginate and TiO_2. [18]

In the mechanical analysis, the elongation at break (%Eb) was also studied for different compositions. From figure, it was clearly observed that the alginate film with 0 wt% TiO_2 showed maximum elongation of 4.01% which in turns gradually decreased with addition of increasing wt, % of TiO_2.

3.3 Optical Properties Analysis

Figure 3 showed the comparable UV-absorbance spectra among pure Na-alginate and maximum (8 wt%) TiO_2 incorporated nanocomposite with dye and in the absence of dye over the wavelength (λ) range 200-900 nm.

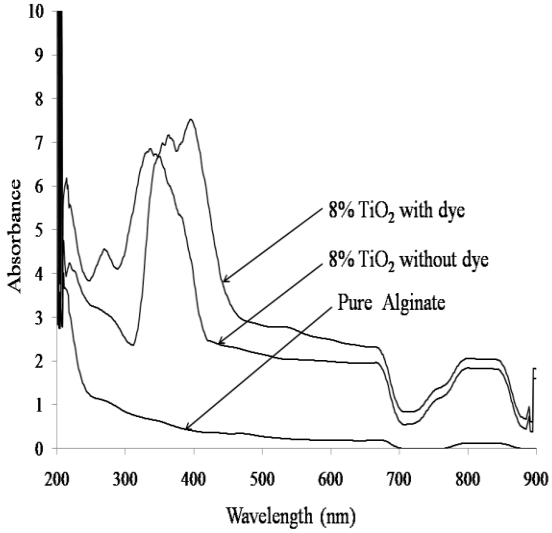

Figure 3. UV-absorbance analysis of pure alginate and nanocomposite as the effect of TiO_2 and natural dye

From figure it was observed that for pure Na-alginate film the absorbance remained high till 220 nm but after inclusion of 8 wt%TiO_2 and then natural dye with TiO_2into nanocomposite the maximum wave length λ_{max} shifted to

the greater value. The red shift of absorbance of nanocomposites represents an increase degree of conjugation as it is well known that increasing the length of the conjugated π-system generally moves the absorption to longer wavelengths.

4 Conclusions

Electrical properties of the nanocomposites were found to be improved due to better conjugation among Na-alginate, TiO_2 and natural dye. This composite film has semi conductive property because its conductivity increases with increasing temperature. Optical properties also suggesting the outstanding impact of TiO_2 incorporation in the alginate film for being an electro-active natural polymer. So, this biodegradable nanocomposite has great potential in the field of organic electronics especially in the field of organic semiconductor and organic photovoltaic solar cells, especially in the dye-sensitized solar cell.

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