

Materials science communication

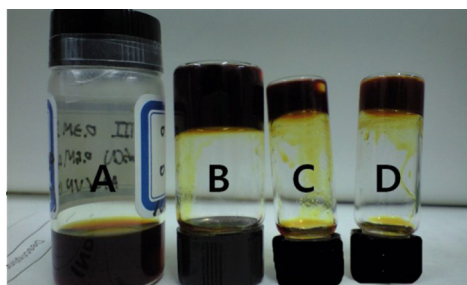
Improved power conversion efficiency of dye-sensitized solar cells using side chain liquid crystal polymer embedded in polymer electrolytes

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HIGHLIGHTS

- We developed the liquid crystal polymer embedded on polymer electrolyte for DSSCs.
- We fabricated the highly efficient DSSCs using polymer electrolyte.
- The best PCE achieved for P1 is 5.32% using polymer electrolyte.

GRAPHICAL ABSTRACT



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ABSTRACT

Side chain liquid crystal polymer (SCLCP) embedded in poly(vinylidene fluoride-co-hexafluoropropylene) (PVdF-co-HFP)-based polymer electrolytes (PVdF-co-HFP:side chain liquid crystal polymer (SCLCP)) was prepared for dye-sensitized solar cell (DSSC) application. The polymer electrolytes contained tetrabutylammonium iodide (TBAI), iodine (I₂), and 8 wt% PVdF-co-HFP in acetonitrile. DSSCs comprised of PVdF-co-HFP:SCLCP-based polymer electrolytes displayed enhanced redox couple reduction and reduced charge recombination in comparison to those of the conventional PVdF-co-HFP-based polymer electrolyte. The significantly increased short-circuit current density (J_{sc} , 10.75 mA cm⁻²) of the DSSCs with PVdF-co-HFP:SCLCP-based polymer electrolytes afforded a high power conversion efficiency (PCE) of 5.32% and a fill factor (FF) of 0.64 under standard light intensity of 100 mW cm⁻² irradiation of AM 1.5 sunlight.

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1. Introduction

The conversion of solar to electrical energy has become important due to the crisis in conventional energy sources. Various

natural resources are available to generate energy, such as converting solar energy into electrical energy. Silicon-based inorganic solar cells have been prominently utilized for the last few decades in this direction. However, drawbacks such as high manufacturing costs and a cumbersome fabrication process diverted research attention toward easily processable and low-cost materials. Since the report from the Grätzel group [1], dye-sensitized solar cells (DSSCs) have attracted much research attention. With a liquid

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electrolyte, the Grätzel group reported a power conversion efficiency (PCE) of 11%, which is very close to that of amorphous silicon-based inorganic solar cells [2]. Although DSSCs based on liquid electrolytes have attained a PCE of as high as 11% under AM 1.5G 1 sunlight intensity (100 mW cm^{-2}), this device suffers the demerit of liquid electrolyte loss due to leakage and/or volatility of the electrolyte solution, which is a major drawback that limits DSSC stability.

To solve these problems, polymer electrolytes or quasi-solid state hole conductors and ionic liquid electrolytes have been utilized to replace the liquid electrolyte. Among those, polymer electrolytes based on poly(vinylidene fluoride-co-hexafluoropropylene) (PVDF-co-HFP) have attracted the greatest interest due to their high stability and relatively high photoelectric conversion efficiency for DSSCs [3].

Recently, we published several articles examining liquid crystals embedded in polymer electrolytes for DSSC application. These devices may improve photovoltaic performance due to better transportation of redox species and high ionic conductivity [4–7].

Herein, we report the development of a polymer electrolyte using side chain liquid crystal polymer (SCLCP) and the photovoltaic performance of DSSCs. To the best of our knowledge, this is the first report on the investigation of SCLCP for polymer electrolyte components in DSSCs.

2. Experimental section

DSSCs were fabricated as follows. Screen-printable nc-TiO_2 pastes were prepared using ethyl cellulose (Aldrich), lauric acid (Fluka) and terpineol (Fluka), as described elsewhere [8]. The prepared nc-TiO_2 paste was coated on a fluorine-doped tin oxide (FTO) conducting glass (TEC8, Pilkington, $8 \Omega \text{ cm}^{-1}$, glass thickness of 2.3 mm), dried in air at ambient temperature for 5 min and sintered at 500°C for 30 min to produce a $13\text{-}\mu\text{m}$ -thick nanocrystalline TiO_2 film.

The thicknesses of the annealed films were measured with an Alpha-step IQ surface profiler (KLA Tencor). For dye adsorption, the annealed nc-TiO_2 electrodes were immersed in absolute ethanol containing 0.5 mM N719 dye ($\text{Ru}[\text{LL}'(\text{NCS})_2]_2$, L = 2,2'-bipyridyl-4,4'-dicarboxylic acid, and L' = 2,2'-bipyridyl-4,4'-ditetrabutyl ammonium carboxylate) for 24 h at ambient temperature. Pt counter electrodes were prepared by thermal reduction of a thin film formed from 7 mM H_2PtCl_6 in 2-propanol at 400°C for 20 min. The dye-adsorbed nc-TiO_2 electrode and Pt counter electrode were assembled using 60- μm -thick Surlyn[®] (Dupont 1702). Four different electrolyte solutions were probed (Fig. 1). The optimized PVdF-co-HFP-based polymer electrolyte consisted of PVdF-co-HFP (0.342 g), tetrabutylammonium iodide (TBAI) (0.5 M), and I_2 (0.05 M) in acetonitrile (5 mL). PVdF-co-HFP:SCLCP-based polymer electrolytes have the aforementioned composition with equal amounts of PVdF-co-HFP and two different concentrations of the SCLCP were added (0.5 and 5 wt%). The liquid electrolyte consisted of BMII (0.6 M), I_2 (0.03 M), GuSCN (0.1 M), TBP (0.5 M) in acetonitrile and valeronitrile (85:15 v/v) for comparison of the photovoltaic performances.

3. Results and discussion

Poly[3-(4'-cyanobiphenyl-4-yloxy)propyl]methylmethacrylate was synthesized as the SCLCP according to the literature [9] and used as a component of the polymer electrolyte for the fabrication of DSSCs in order to improve the photovoltaic performance. The SCLCP was selected as biphenyl mesogen having $-\text{CN}$ as the terminal group. Due to the nematic liquid crystal nature of SCLCP,

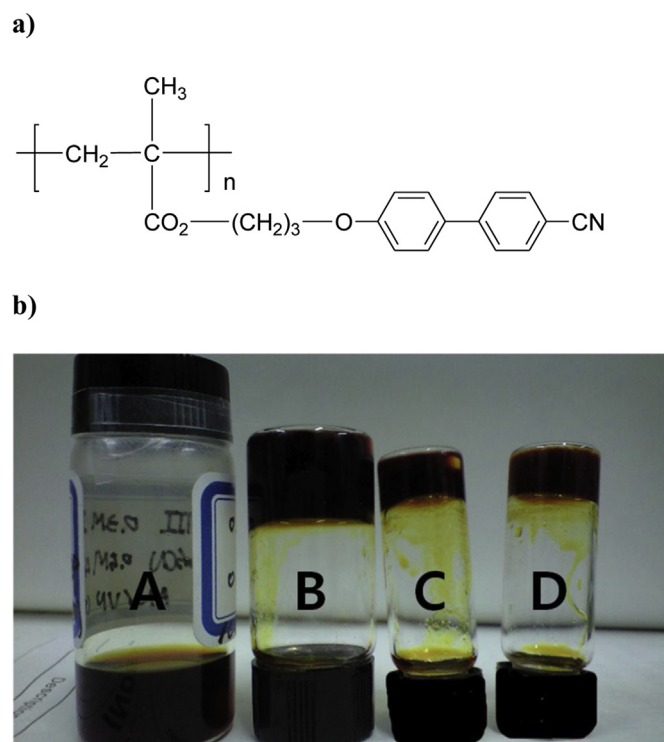


Fig. 1. (a) Molecular structure of SCLCP. (b) Photographs of electrolyte samples from left to right: (A) liquid electrolyte, (B) conventional PVdF-co-HFP-based polymer electrolyte (the vial is upside down), (C) 0.5 wt% PVdF-co-HFP:SCLCP-based polymer electrolyte (the vial is upside down), and (D) 5 wt% PVdF-co-HFP:SCLCP-based polymer electrolyte (the vial is upside down).

PVdF-co-HFP:SCLCP-based polymer electrolytes are able to form good interfacial contacts with electrode materials.

In general, the PCE of DSSCs is mainly dependent on the ionic conductivity of the polymer electrolyte. The ionic conductivity of polymer electrolytes can be increased by incorporating suitable plasticizers or additives [10,11]. The ionic conductivities of PVdF-co-HFP-based polymer electrolyte and PVdF-co-HFP:SCLCP-based polymer electrolyte are 1.897×10^{-3} and $2.119 \times 10^{-3} \text{ S cm}^{-1}$ at room temperature, respectively. Both the short-circuit current density (J_{sc}) and fill factor (FF) were influenced by the ionic conductivity of the polymer electrolyte, because low ionic conductivity

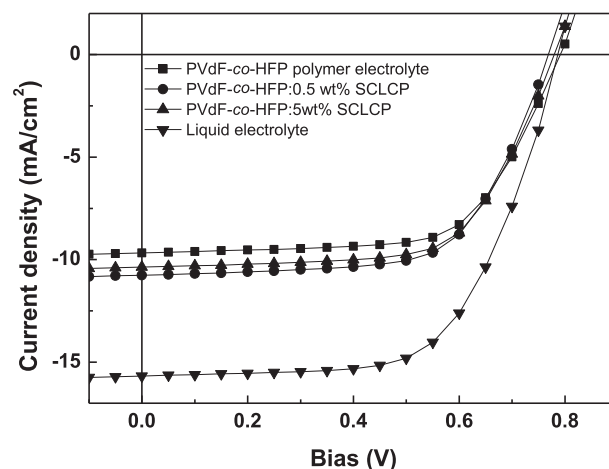


Fig. 2. Photocurrent density–voltage characteristics of the DSSCs fabricated under AM 1.5G 1 sun illumination (100 mW cm^{-2}).

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