Polymer and graphene layer to increase dye regeneration and suppress back electron transfer in dye sensitized solar cells

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Fabrication of Dye-Sensitized Solar Cells:

Fluorine-doped SnO₂ glass (TEC-15, 2.2 mm thickness, Solaronix) was used for transparent conducting electrodes. Before the deposition of the TiO₂ nanoparticle layer, the FTO (fluorine -doped SnO₂ glass; 8 Ω /sq; Solaronix) were cleaned. The FTO substrate was first cleaned in an ultrasonic bath using a detergent solution, acetone, and ethanol, respectively (each step was 25 min long). The FTO glass plates were immersed into a 40 mM aqueous TiCl₄ solution at 70 °C for 30 min and washed with water and ethanol. Then FTO plates were sintered 500 °C for 30 min. After that, attain at room temperature a 5-6 µm thick film of 20nm-sized mesoporous TiO₂ particles was first printed on the FTO. The TiO₂-coated electrodes (active area 0.16 cm²) were gradually heated under the air flow at 325 °C for 5 min, at 375 °C for 5 min, at 450 °C for 15 min, and 500 °C for 15 min. Then the scattering layer (3-4 µm thick) of 400-nm sized light anatase particles coated over the mesoporous TiO₂ particles, and again scattering layer -coated anatase particles were gradually heated under air flow at 325 °C for 5 min, at 375 °C for 5 min, at 450 °C for 15 min, and 500 °C for 15 min. After the sintering process, the TiO₂ film was treated with 40 mM TiCl₄ solution, then rinsed with water and ethanol. The electrodes were again heated at 500 °C for 30 min and after cooling (80 °C) were immersed for 22h into sensitizing baths containing 0.5 mM in ethanol solutions. After washing with ethanol to remove the unanchored dye and drying by air flow, electrolyte (AN-50, Solarnix, Switzerland) solution was introduced into the space between the photoanodes and Pt counter electrode.

P1-graphene preparation and coating on photoanode:

The different weight percentage of graphene were dispersed in o-Dichlorobenzene solvent contains P1- polymer (0.2g/0.5mL). Then P1-graphene solution was spin coated over the photoanode at 1200rpm for 50 sec and dried at 80 °C for 10 min.

Characterization

AFM was recorded with MM AFM LN supplied by Veeco Multimode in tapping mode. I-V measurements were done by using AM 1.5 sun intensity (100mW/cm²) PET solar simulators.

The Incident photon to current efficiency (IPCE) spectra was measured using a Newport IPCE system. To prepare thin film of P1, 0.2 g of the polymer was dissolved in 0.5 ml of solvent and spun on a FTO substrate. To prepare P1-G -0.09 film, 0.2 g of P1 was dissolved in the solvent and 0.09 wt% of grapheme was dispersed in the solution. The solution was spun on FTO. The spinning speed was 1200 rpm. The coating was carried out for 40 sec. Photoluminescence spectra were recorded using fluromax-4 spectrometer (HORIBA SCIENTIFIC). Bio-Logic SP-300 was used for electrochemical analysis Including cyclic voltammetry (CV) and impedance analysis. CV for the P1-graphene electrode using acetonitrile solution containing 0.1 M LiClO₄, 10 mM LiI, and 1 mM I₂ as supporting electrolyte with the scan rate of 30 mV·s⁻¹. Area of the working electrode was maintained at 0.149 cm² and exposed to the electrolyte by masking the remaining portion with an adhesive tape.



Scheme S1: Structure of polymer P1

Photoanode preparation



Scheme S2: Illustration showing the steps involved in the preparation of photoanode coated with P1-G.



Fig. S1: AFM images of a)P1 polymer and b)P1-G-0.09

Electrode	$V_{oc}(\mathbf{V})$	$J_{sc}(\mathrm{mA/cm^2})$	FF (%)	η (%)
STD (N719-TiO ₂)	0.714	15.5	68	7.51±0.2
N719-TiO ₂ -P1-G- 0.03	0.717	17.8	69	9.13±0.22
N719-TiO ₂ -P1-G-	0.721	18.2	70	9.8±0.18
N719-TiO ₂ -P1-G- 0.09	0.742	19.8	71	10.43±0.3
N719-TiO ₂ -P1-G- 0.12	0.73	18.6	71	9.62±0.25
N719-TiO ₂ -P1-G- 0.15	0.72	18.0	69	8.91±0.27

Table S1: Photovoltaic parameters various content of graphene photo anode for DSSC underAM 1.5 G sun illuminations (power 100 mW cm⁻²).

Average values are taken from 10 cells for each experiment.



Fig. S2: Impedance analysis as a function of illumination light intensitya) without polymer (STD)layer b) P1-G-0.09 c) impedance spectra.



Fig. S3: J-V curve of DSSC with function of illumination light intensity a) without P1polymer (STD) layer b) P1-G-0.09 c) V_{OC} as a function of light intensity calculated from J-V curves



Fig. S4: *J-V* characteristic of P1-G-0.09



Fig. S5: Stability of the DSSCs upon exposure to ambient conditions (100 h) a) Without P1-layer (STD) b) P1-G-0.09 C) PCE variation as a function of time.



Fig. S6: OCVD curve of DSSCs based on STD and P1-G-0.09 devices



Fig. S7: Diagram showing the energy level of TiO2, dye, P1, and iodolyte