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Electronic Supplementary Information (ESI)

High efficiency dye-sensitized solar cell with a UV cured polymer gel electrolyte and nano-gel electrolyte double layer

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1. Materials

All of the chemicals in this study were purchased and used without further purification. UV-curable polyurethane acrylate (Aliphatic Urethane Acrylate) was purchased from Sartomer co. and Photo initiator 1-Hydroxy-cyclohexyl-phenyl-ketone (Mw=204.3g/mole, Irgacure 184) was purchased from BASF. Iodine (I_2, 99.8%), Lithium iodide (LiI, 99%), 4-*tert*-Butylpyridine (TBP, 96%), Sodium thiocyanate (NaSCN, 98%) and 3-Methoxypropionitrile (MPN, 98%) were purchased from Aldrich. 1-Butyl-3-methylimidazolium iodide (BMII) was purchased from C-TRI. Fumed silica nanoparticles (Aerosil200) were purchased from Evonik Industries AG.

The transparent conductive glass plates (Pilkington TEC 8, Thickness 2.3mm) were purchased from Nippon Sheet Glass co. and sensitizing dye $RuL_2(NCS)_2$:2TBA (where L=2,2´-bipyridyl-4,4´-dicarboxylic acid; TBA=tetrabutylammonium) was purchased from Ohyoung Industrial Co. TiO_2 paste (Ti-Nanoxide T), Pt paste (Platisol T/SP) and Surlyn film (Meltonix 1170-60) were purchased from Solaronix.

2. Preparation of electrolytes

Liquid electrolytes were prepared by dissolving 0.05M I_2, 0.1M LiI, 0.48M TBP, 0.12M NaSCN, and 0.6M BMII in Methoxypropionitrile. The system was continuously stirred at room temperature for 12h in order to obtain a homogeneous solution.

Polymer gel electrolytes were prepared by the addition of UV-curable polyurethane acrylate in Liquid electrolyte at 12:10 weight ratio and the addition of 5 wt% Photo initiator in the total solution. The system was continuously stirred at 60 °C for 12h in order to obtain a homogeneous solution.

Nano-gel electrolytes were prepared by the addition of 7 wt% fumed silica nanoparticles in the Liquid electrolyte described above. The system was continuously stirred at room temperature for 1h in order to obtain a homogeneous one.

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3. Fabrication of DSSCs

A porous TiO_2 film with an area of 0.20 cm^2 (5mm × 4mm) was deposited on the transparent conductive glass plate by the screen-printing method followed by sintering at 550°C for 30min in a muffle furnace. The resulting TiO_2 electrode was sensitized with Ruthenium dye by dipping in a 3×10^{-4} M ethanol solution of N719 (Solaronix) at 40 °C for 21h. Then, the dye sensitized TiO_2 electrode was rinsed with ethanol, dried, and was used for the fabrication of DSSCs with different type electrolytes.

Four electrolytes, one liquid electrolyte and three gel electrolytes (Nano-gel, UV Polymer, Nano-gel on UV Polymer) were used.

For the fabrication of DSSCs with UV cured Polymer gel electrolyte, the polymer gel precursor was screen printed on the dye sensitized TiO_2 film, which was then cured by subjecting it to 1kW of UV irradiation for 30 s. And, for the fabrication of the DSSCs with nano-gel electrolyte, the nano-gel was dropped on the dye sensitized TiO_2 film.

Transparent counter electrodes were prepared by screen printing Pt paste on the transparent conductive glass, followed by sintering at 400°C for 30min. The counter electrode was assembled with the working electrode and they were separated by 60 μm Surlyn film and then sealed by heating.

4. Measurements

Photovoltaic performance of DSSCs was evaluated using a 1600W Ozone free lamp with a 'Class A' Air Mass 1.5G filter in a solar simulator (Newport-94083A) and an exposure control instrument (Newport-68951) at conditions of input power 100mW/ cm^2, delay time 100ms in reverse scan direction and temperature 25°C.

Incident photon to current efficiency (IPCE%) values have been measured by illumination of the samples with a 200W Xenon Arc light sources through a filter monochromator and optical chopper in the absence of bias light (Newport-CS260). The

lamp spectrum over the 350~1100nm range satisfactorily simulates solar radiation at the surface of the earth. A dual channel Merlin lock-in amplifier was utilized for the sensitive optical power and current measurements, which comes with a built-in chopper controller in order to control optical chopper with one two-aperture blade. (Newport-QE-PV-SI)

Electrochemical Impedance measurements of the DSSCs were recorded with an EIS potentiostat (McScience-K3400) under the conditions of blue LED 460 nm, photon flux 2.36×10^{17}/ $cm^2 \cdot S$, intensity 0.1 mW/cm^2, applied bias 0.5 V, applied ac amplitude 10mV, and the frequency range from 1000Hz to 0.5Hz.

Intensity-modulated photovoltage spectroscopy (IMVS) was recorded with an Optical Impedance measurement system (McScience-K3400) under the conditions of blue LED 460nm, photon flux $2.36 \times 10^{17}/cm^2 \cdot S$, intensity 0.1 mW/cm^2, applied bias 0.5V, applied ac amplitude 10mV, and the frequency range from 1000Hz to 0.5Hz.

In light-soaking tests, the cells were irradiated at open circuit using a 1000W Xenon Arc lamp at conditions of 100 mW/cm^2 with an Air Mass 1.5G filter and ambient temperature (McScience-K201).

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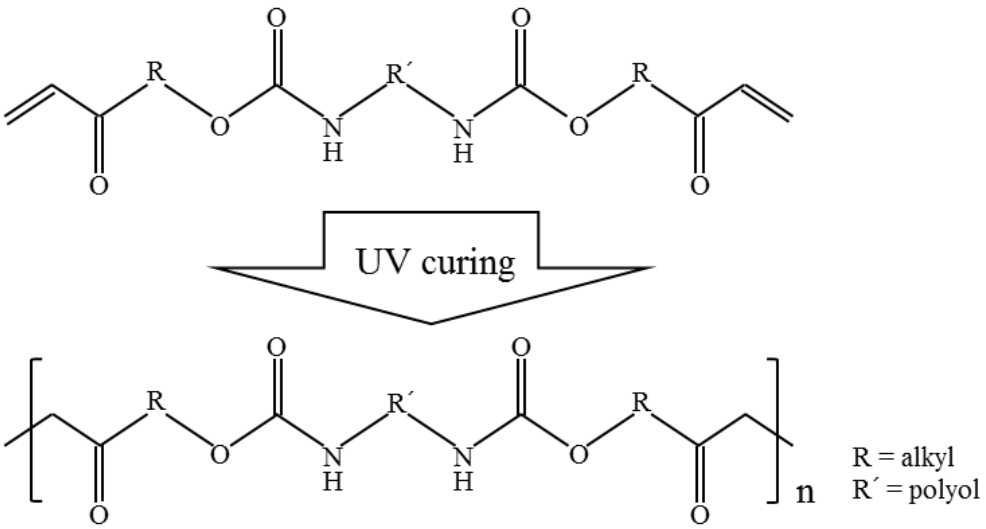

Fig. S1. UV-cured polyurethane matrix

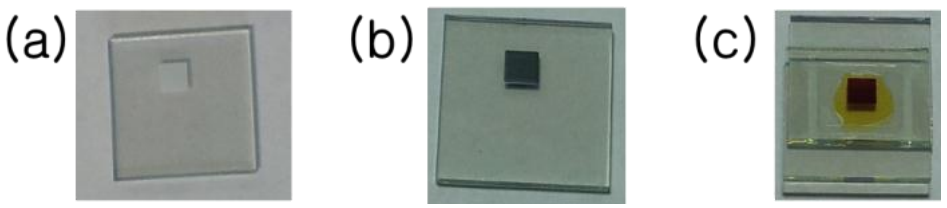

Fig. S2. (a) TiO_2 electrode, (b) TiO_2 electrode coated with UV cured polymer gel electrolyte and (c) Assembled DSSC with nano-gel electrolyte on UV cured polymer gel electrolyte.

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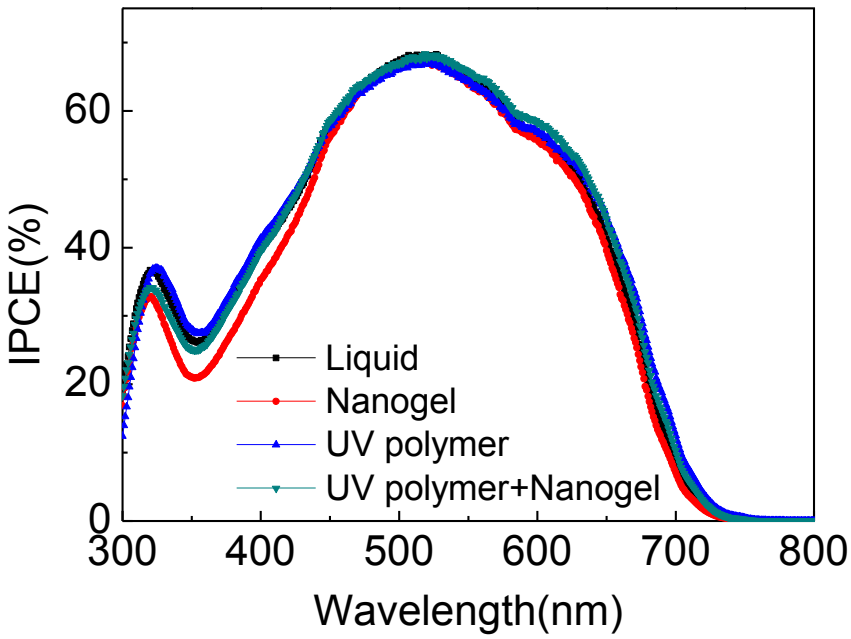

Fig. S3. The incident photon-to-current efficiencies (IPCE) of the DSSCs with four different electrolytes.

Table S1. External quantum efficiencies of the DSSCs with four different electrolytes by the IPCE measurement at chopper frequency 5Hz in the absence of bias light.

	Liquid	**Nanogel**	**UV polymer**	**UV polymer+Nanogel**
Wavelength at Peak (nm)	527	513	517	527
IPCE (%)	68.3	67.5	67.1	68.2