Organized mesoporous TiO₂ Bragg stacks (om-TiO₂ BS) consisting of alternating high and low refractive index organized mesoporous TiO₂ (om-TiO₂) films were prepared to enhance dye loading, light harvesting, electron transport, and electrolyte pore-infiltration in dye-sensitized solar cells (DSSCs). The om-TiO₂ films were synthesized via a sol-gel reaction using amphiphilic graft copolymers consisting of poly(vinyl chloride) backbones and poly(oxyethylene methacrylate) side chains, i.e., PVC-g-POEM as templates. To generate high and low index films, the refractive index of om-TiO₂ film was tuned by controlling the grafting ratio of PVC-g-POEM via atomic transfer radical polymerization (ATRP). A polymerized ionic liquid (PIL)-based DSSC fabricated with a 1.2-μm-thick om-TiO₂ BS-based photoanode exhibited an efficiency of 4.3%, which is much higher than that of conventional DSSCs with a nanocrystalline TiO₂ layer (nc-TiO₂ layer) (1.7%). A PIL-based DSSC with a heterostructured photoanode consisting of 400-nm-thick organized mesoporous TiO₂ interfacial (om-TiO₂ IF) layer, 7-μm-thick nc-TiO₂, and 1.2-μm-thick om-TiO₂ BS as the bottom, middle and top layers, respectively, exhibited an excellent efficiency of 7.5%, which is much higher than that of nanocrystalline TiO₂ photoanode (3.5%).

Since Gratzel’s breakthrough discovery in 1991, dye-sensitized solar cells (DSSCs) have received great attention as promising alternatives to traditional silicon-based photovoltaic devices. These DSSCs are especially attractive because of their high power conversion efficiency, low cost, and facile eco-friendly fabrication. A standard DSSC consists of a wide band gap semiconductor nanocrystalline film deposited on a fluorine-doped tin oxide (FTO) glass as the photoanode, a photosensitizer (dye), a platinum-coated FTO glass as the counter electrode, and a liquid redox electrolyte typically based on an iodide/triiodide (I₂/I₃⁻) redox couple in an organic solvent. Although high photovoltaic conversion efficiencies have been reported, these DSSCs typically utilize liquid electrolytes with solid materials have been devoted; examples include quasi-solid or solid polymers, conducting polymers and organic ionic plastic crystal electrolytes. In addition, there has been active progress in recent years in fabricating high efficiency solid/quasi-solid DSSCs with perovskites. In addition to these developments involving solid-state electrolytes, further improvements in the design of mesoporous TiO₂ photoanode could potentially lead to highly efficient solid/quasi-solid DSSCs. In this regard, well-organized mesoporous TiO₂ that our group has developed represents an excellent photoanode material because of its inherent high porosity, ordered pores, and interconnectivity.

In addition to using organized mesoporous TiO₂ photoanode, an additional method to enhance the performance of DSSCs is to enhance the light harvesting by incorporating photonic structures into the devices. For example, one-dimensional photonic crystals, such as Bragg stacks (BS), have been applied to liquid-based and solid-state DSSCs to enhance their light harvesting properties and in turn the power conversion efficiency. In previous reports, BS were prepared directly on top of the photoanode or positioned behind the counter electrode so that light transmitted through the photoanode would be reflected back into the electrode, which in turn improves the likelihood of successful harvesting.

SiO₂ and TiO₂ constitute the most common pair of nanomaterials used to achieve high quality BS layers because they have large refractive index contrast (SiO₂: 1.45, TiO₂: 2.44) and can be prepared simply from liquid phases by spin or dip coating. However, the use of BS structures based on SiO₂/TiO₂ pairs in the DSSC...
An om-TiO₂ BS, which comprises of high (2.0) and low (1.7) refractive index om-TiO₂ layers, is prepared via a sol-gel process using two TiO₂ precursors. The high and low refractive index layers were used to form a Bragg diffraction peak, which is directly related to the optical properties and structure of the reflector. The position of the Bragg diffraction peak was calculated using the following equation (1). The central wavelength of the Bragg reflection is given by:

\[ m \lambda = 2(n_1 d_1 + n_2 d_2) \]  

where \( m \) is the diffraction order, \( n_i \) is the refractive index of each layer, and \( d_i \) is the thickness of each layer. In addition, the refractive index is directly correlated with porosity. If each layer is assumed to be composed of anatase phase, porosity can be calculated using the following equation (2):

\[ \text{Porosity} = 1 - \left( \frac{n^2 - 1}{n_0^2 - 1} \right) \]  

where \( n \) is the refractive index of each om-TiO₂ layer and \( n_0 \) is the refractive index of the pure anatase TiO₂ layer. Using ellipsometry, the refractive index, thickness, and porosity of the high refractive index om-TiO₂ layers were determined to be 2.0 ± 0.05, 125 ± 5 nm, and 0.38 ± 0.02, respectively. The corresponding values for the low refractive index om-TiO₂ layer were 1.7 ± 0.05, 130 ± 5 nm.
and 0.62 ± 0.02, respectively. The fabricated om-TiO₂ BS was adjusted to have one of the higher order reflectance peaks at approximately 480 nm.

Figure 2(a) shows a cross sectional FE-SEM image of the om-TiO₂ BS templated by PVC-g-POEM graft copolymers, and Figures 2(b,c) show a plan-view FE-SEM image of high and low refractive index om-TiO₂ layers, respectively. The plan-view FE-SEM images clearly demonstrate that porosity and pore size distribution (refractive index) of each om-TiO₂ layer can be controlled using the two graft copolymer templates with different grafting density. The cross sectional FE-SEM image confirms the long range order and crack-free structure of the high and low refractive index om-TiO₂ layers used to generate the BS reflector. Although spin-coating conditions were identical for each om-TiO₂ layer, the first layer deposited on the FTO glass was thicker than the subsequently deposited om-TiO₂ layer likely due to the different surface wetting properties of the FTO glass and om-TiO₂ layers ④. The om-TiO₂ BS reflector deposited on FTO glass function as a highly efficient back reflector as well as the dye adsorbable active layer. This combination likely increases the beam path of solar irradiation within the photoanode due to reflection at each interface between high and low-index layers, which we believe improves the light harvesting efficiency of the photoanode. Compared to conventional TiO₂ nanoparticle-based nanocrystalline (nc-TiO₂) layers (D20, Solaronix), the om-TiO₂ BS has a larger specific surface area due to high porosity, which also enhances the amount of dye loading. The surface area of the om-TiO₂ BS prepared with high (84.1 m²/g) and low (75.3 m²/g) refractive index om-TiO₂ layers was larger than that of the photoanode prepared with nc-TiO₂ layers (56.1 m²/g), as determined using N₂ adsorption-desorption measurements. The om-TiO₂ BS with high porosity is expected to improve electron transport and solid electrolyte infiltration, which eventually would lead to lower charge recombination and enhanced interfacial properties in DSSCs.

Next, we characterized the photonic properties of the om-TiO₂ BS photoanode. An om-TiO₂ BS with high uniformity and quality was fabricated over a large area of at least 2 × 3 cm² without striations and cracks, as shown in Figure 3(a). The photonic performance was compared with that of a control cell based on commercial nanocrystalline TiO₂ nanoparticles (nc-TiO₂ cell). The thickness of two types of photoanode was maintained at approximately 1.2 µm, and at least three cells were prepared and tested for comparison. Figure 3(b) shows the reflectance spectra of the nc-TiO₂ layer and om-TiO₂ Bragg stack. The nc-TiO₂ layer showed low reflectance in the entire visible wavelength region, which indicated that unabsorbed light passed through the nc-TiO₂ layer. However, the om-TiO₂ BS exhibited high reflectance in the entire visible wavelength region, which is a direct consequence of the structure of the om-TiO₂ layers. As expected from the Bragg condition (equation 1), the om-TiO₂ BS has the Bragg reflectance peak around 480 ~ 520 nm, which overlaps with one of the strong absorption peaks of ruthenium N719 dye ⑤. The maximum reflectance value of om-TiO₂ BS was 50% higher than nc-TiO₂ layer when nine stacks of alternating high and low refractive index om-TiO₂ layers were deposited. Based on these results, it is expected that the beam path of the incident light is extended within the om-TiO₂ BS photoanode, which is expected to improve the light harvesting efficiency of DSSCs.

We tested the device performance of a solid PIL-based DSSC fabricated with the om-TiO₂ BS as the photoanode and compared its light harvesting efficiency to that of a DSSC generated with a nc-TiO₂ layer as its photoanode. Poly((1-(4-ethenylphenyl)methyl)-3-butyl-imidazolium iodide) (PEBII) ⑥ was synthesized via free radical polymerization and utilized as the solid electrolyte without any additives. The synthesized PEBII showed high mobility and ionic conductivity (2.0 × 10⁻⁴ S/cm at 25°C) due to facile ion transport through well-organized structures with π-π stacking interactions and low glass transition temperature (≈−4°C). The IPCE measurements of the om-TiO₂ BS was 50% higher than that of the photoanode prepared with nc-TiO₂ layers (56.1 m²/g), as determined using N₂ adsorption-desorption measurements. The om-TiO₂ BS with high porosity is expected to improve electron transport and solid electrolyte infiltration, which eventually would lead to lower charge recombination and enhanced interfacial properties in DSSCs.
were performed under normal incident light from the front side as a function of wavelength from 400 nm to 800 nm. The IPCE efficiency ($\eta_{IPCE}$) was determined for each device and is closely related to light harvesting efficiency ($\eta_{lh}$) through

$$\eta_{IPCE} = \eta_{lh} \eta_{inj} \eta_{col}$$

where $\eta_{inj}$ is electron injection efficiency and $\eta_{col}$ is electron collection efficiency\(^\text{44}\). Figure 4 clearly shows that DSSCs based on the om-TiO\(_2\) BS have significantly higher IPCE over the entire spectrum compared to the nc-TiO\(_2\)-based DSSCs. The higher light harvesting efficiency resulting from enhanced dye adsorption (high specific surface area) and extended beam path length are the major contributors to the enhanced IPCE in the DSSCs based on the om-TiO\(_2\) BS. In addition, the IPCE spectra in Figure 4a show that maximum efficiency is located at approximately 520–540 nm, which corresponds to the absorption peak of the N719 ruthenium dye. We also believe that using highly interconnected om-TiO\(_2\) BS layers with high porosity and large pores will have positive effects on the electron collection efficiency ($\eta_{col}$). Such enhancement will be discussed more in depth in our analyses of recombination resistances ($R_{rec}$) and electron lifetime ($t_e$).

EIS measurements were carried out to demonstrate the effects of om-TiO\(_2\) BS on the performance of DSSCs. Figure 4b shows the EIS Nyquist plots of the DSSCs with om-TiO\(_2\) BS and nc-TiO\(_2\) layers at open circuit under one sun illumination. Internal/interfacial impedances were determined by fitting experimental data with an equivalent circuit (inset image), which consists of an Ohmic series resistance of the substrate ($R_s$), starting point of the first semicircle in the EIS Nyquist plot), charge transport resistance at the Pt counter electrode ($R_1$, first semicircle in the EIS Nyquist plot), charge transfer resistance at the TiO\(_2\) photoanode/dye/electrolyte ($R_2$, second semicircle in the EIS Nyquist plot), Warburg diffusion in the electrolyte ($R_p$, third semicircle in the EIS Nyquist plot), and constant phase element of capacitance corresponding to $R_1$ (CPE1) and $R_2$ (CPE2)\(^\text{34}\).

Here, we focused on the second semicircle of the plot to investigate charge transfer characteristics at the TiO\(_2\) photoanode/dye/electrolyte. $R_2$ values determined from the real component ($Z_R$) of the om-TiO\(_2\) BS-based DSSC (16 $\Omega$) were less than 2/3 of nc-TiO\(_2\) layer-based DSSCs (25 $\Omega$), as shown in Figure 4b. This result likely is because the om-TiO\(_2\) BS has high porosity, large pores, and sufficient interconnectivity to allow pore-infiltration of solid electrolyte. Complete pore filling facilitates efficient ion transport and dye regeneration. The EIS Nyquist result also implies that the incorporation of an om-TiO\(_2\) BS decreased charge transfer resistance at the TiO\(_2\) photoanode/dye/electrolyte, which improves the fill factor (FF) value. The mechanism underlying the photovoltaic performance improvement of the om-TiO\(_2\) BS-based DSSCs was further investigated by measuring the recombination resistance ($R_{rec}$) and electron lifetime ($t_e$) of the devices as a function of bias voltage as shown in Figure 5. The product of the recombination resistance and the electron transfer capacitance represents the electron lifetime ($t_e$) of the DSSC. Larger recombination resistance and longer electron lifetime were obtained in the om-TiO\(_2\) BS-based DSSCs, indicating suppressed recombination process with more efficient electron transfer. This result is attributed to the high porosity and large pores of the om-TiO\(_2\) BS layer, which was templated by the two PVC-g-POEM graft copolymers. In short, the om-TiO\(_2\) BS-based DSSC exhibited efficient electron transport due to the suppression of charge recombination, which in turn improves its $V_{oc}$ compared to the nc-TiO\(_2\) layer based cell\(^\text{15,20}\).

The photovoltaic performance of om-TiO\(_2\) BS-based cells with N719 dye and PEBII solid electrolyte was measured under a simulated AM 1.5 G illumination intensity of 100 mW/cm\(^2\), as shown in Figure 6. Table 1 summarizes photovoltaic parameters such as open-circuit voltage ($V_{oc}$), short-circuit current density ($J_{sc}$), fill factor (FF), light-to-electricity conversion efficiency ($\eta$), and amount of dye loading. The Beer-Lambert law was used to determine the amount of ruthenium dye (N719) chemisorbed onto different types of photoanodes\(^\text{17}\). As expected, a large enhancement was attained for $J_{sc}$ and FF for the DSSC with om-TiO\(_2\) BS compared to the commercial TiO\(_2\) nanocystal-based cell (nc-TiO\(_2\) photoanode). The $V_{oc}$, $J_{sc}$, FF, and $\eta$ of the DSSC using a nc-TiO\(_2\) photoanode were determined to be 0.83 V, 3.8 mA/cm\(^2\), 0.54, and 1.7%, respectively. In contrast, the om-TiO\(_2\) BS photoanode-based DSSC had a $V_{oc}$ of 0.84 V, $J_{sc}$ of 8.2 mA/cm\(^2\), FF of 0.62, and $\eta$ of 4.3% with a 1.2 $\mu$m photoanode thickness. The $V_{oc}$ was slightly improved for the om-TiO\(_2\) BS photoanode-based DSSC, which is attributable to its well-organized interconnected structure. This structure results in a more effective electron transport pathway and reduces the possibility of electron trapping for charge recombination. The enhanced $J_{sc}$ for the om-TiO\(_2\) BS photoanode-based DSSC is attributed to improved light harvesting efficiency derived from (1) increased light reflection caused by a periodic Bragg stack structure and (2) better dye adsorption due to high specific surface area. As a result of both contributions, $J_{sc}$ was enhanced up to 115% compared to the control cell. There was also an enhancement in FF for the om-TiO\(_2\) BS photoanode-based DSSC, which resulted from the high porosity structure of the photoanode. This structure allowed facile and sufficient penetration of solid state electrolyte into TiO\(_2\) nanopores without affecting cell kinetics.
Further enhancements in photovoltaic performance were achieved when the photoanode was prepared with 0.4 μm om-TiO2 IF, 7 μm NC-TiO2, and 1.2 μm om-TiO2 BS as the bottom, middle, and top layers, respectively. The om-TiO2 IF/NC-TiO2/om-TiO2 BS photoanode gives the highest light-to-electricity conversion efficiency of 7.5%, which is an increase of 341% compared to the 1.2 μm-thick nc-TiO2 (1.7%)-based DSSC and 74% compared to the 1.2 μm-om-TiO2 BS photoanode-based DSSC (4.3%). Also, we note that a DSSC with only a 7-μm-thick nc-TiO2 photoanode exhibited an energy conversion efficiency of 3.5% (Figure S1, Table S1)23. The obtained efficiency of 7.5% is even higher than those obtained from the solid PIL-based DSSCs involving Bragg stacks with TiO2 and SiO2 layers as summarized in Table S223,24. The enhanced \( J_{sc} \) value obtained with om-TiO2 IF/nc-TiO2/om-TiO2 BS photoanode-based DSSCs is attributed primarily to enhanced light harvesting by TiO2 films. The increased surface area of om-TiO2 IF/nc-TiO2/om-TiO2 BS photoanode-based DSSCs allows more dye molecules to anchor on the surface of TiO2 films, leading to better optical absorbance. As shown in Table 1, the amount of dye loading on TiO2 films was 10.5 nmol/cm2 for nc-TiO2, 18.3 nmol/cm2 for om-TiO2 BS, and 91.3 nmol/cm2 for the om-TiO2 IF/nc-TiO2/om-TiO2 BS photoanode. The \( J_{sc} \) of the om-TiO2 IF/nc-TiO2/om-TiO2 BS photoanode structure provides approximately 40% enhancement compared to the z highly reflective om-TiO2 BS layer allows not only reflection as well as scattering of the unabsorbed photons back into the cell but also high dye loading (Figure S1, Table S1), resulting in a noticeable improvement of efficiency. This results in an increase of the photovoltaic light harvesting performance without any adverse effects.

The effectiveness of the om-TiO2 BS layer can be more clearly demonstrated by characterizing the transmission properties of the ssDSSCs assembled with 7 micron-thick nc-TiO2 photoanode and the PIL electrolyte (Figure S2). The spectrum clearly shows that rather significant transmission (about 20%) exists between 480 and 520 nm, which is close to one of the absorption peaks of the N719 ruthenium-based dye. This result implies that more than 20% of light is not absorbed by the 7 micron-thick nc-TiO2 photoanode in the target wavelength region and that the om-TiO2 reflects unabsorbed photons back to the photoanode. The use of Bragg stacks which have reflection peaks around 480 ~ 520 nm have also been shown to enhance the performance DSSCs by redirecting the unabsorbed photons back to the photoanodes20,21.

**Conclusions**

We proposed the use of the om-TiO2 BS layer, composed of high and low refractive index of om-TiO2, as a means to improve the not only light harvesting efficiency but also electron transport and electrolyte infiltration in solid-state DSSCs. The om-TiO2 layers with different refractive indices were prepared via a sol-gel process using graft copolymers as templates. Inspired by their multifunctional structure, the om-TiO2 BS layer based DSSCs (1.2 μm) with solid state electrolyte demonstrate increased light reflection, improved dye loading, reduced charge recombination, and decreased interfacial resistance than DSSCs made with NC TiO2 layer photoanodes, and consequently high \( \eta \) of 4.3%, a 150% improvement compared to the NC TiO2 layer-based DSSCs. Moreover, the DSSCs based on the om-TiO2 IF/NC-TiO2/om-TiO2 BS heterostructured photoanode shows a \( \eta \) of 7.5% accompanying a \( V_{oc} \) of 0.83 V, a \( J_{sc} \) of 16.5 mA/cm2, and a FF of 0.55, which is much higher than that of conventional nanocrystalline TiO2 photoanode (3.5%). This work clearly shows that the BS based on om-TiO2 layers is a very promising material which has good potential for application in optical sensing, radiation shielding, and energy field.

**Methods**

**Materials.** Poly(vinyl chloride) (PVC, Mnw = 97,000 g mol⁻¹, Mm = 55,000 g mol⁻¹), poly(oxymethylene methacrylate) (POEM, poly(ethylene glycol) methyl ether methacrylate, Mnw = 475 g mol⁻¹), 1,1,4,7,10,10-hexamethylidyhexylene tetramine (HMTETA, 99%), copper(I) chloride (CuCl, 99%), titanium(IV) isopropoxide (TTIP, 97%), hydrogen chloride solution (HCl, 37 wt %), sodium hydroxide (NaOH), 1-butylimidazole, 4-chloromethylstyrene, lithium iodide (LiI), magnesium sulfate (MgSO4), 2,2’-azobisisobutyronitrile (AIBN), and chloroplatinic acid hexahydrate.
Preparation of the TiO₂ sol-gel solution using two kinds of graft copolymer treatment was performed in a furnace at 500 °C for 30 min each and then dried in air. The om-TiO₂ BS multilayer layer structures were fabricated by the spin coating method. In the current experiment, two types of materials (high and low refractive index TiO₂ sol-gel solution) for om-TiO₂ BS were prepared separately. Before fabricating an om-TiO₂ BS layer, the FTO glasses were ultrasonically cleaned sequentially in isopropanol and deionized water at room temperature for 3 hours. The reaction was carried out at 90 °C for 1 hour to remove water bonded to TiO₂ nanoparticle surfaces and mechanically stabilize the entire structure. The purities of chemicals used in this work were higher than 99%, and all chemicals were utilized without additional purification.

Synthesis of the two kinds of graft copolymer templates (PVC-g-POEM). The two kinds of graft copolymer templates were synthesized via an atomic transfer radical polymerization (ATRP) process according to our previously reported method. In brief, PVC-g-POEM (6 g) was dissolved in 50 mL of NMP by stirring at 90 °C for 4 h. After cooling to room temperature, various amounts (9 g and 36 g) of POEM, 0.1 g of CuCl₂ and 0.23 mL of HMTETA were added to the solution. The green mixtures were stirred until homogeneous and then purged with nitrogen for 30 min. The reaction was carried out at 90 °C for 18 h. After polymerization, resultant mixtures were diluted with THF. After passing the solutions through a column with activated Al₂O₃, the solutions were precipitated into methanol. The graft copolymer templates were purified by dissolving THF and reprecipitating into methanol three times. Then, the graft copolymer templates were dried in a vacuum oven overnight at room temperature. By using different weight ratios of PVC: POEM, graft copolymer templates for different refractive index were obtained.

Preparation of the TiO₂ sol-gel solution using two kinds of graft copolymer templates. The TiO₂ sol-gel solution based on graft copolymer template was prepared via a previously reported simple sol-gel process using titanium isopropoxide (TTIP), THF, HCl solution, and deionized water at room temperature for 3 hours. As a brief synthetic procedure, 0.05 g of two kinds of PVC-g-POEM graft copolymer templates (weight ratios of PVC: POEM = 1:6 and 1:1.5, referred to as type 1 and type 2) were first dissolved in 3 ml of THF. Separately, a titanium precursor containing sol was obtained by slowly adding concentrated HCl (0.15 mol, 37 wt %) to TTIP (0.3 mL) under vigorous stirring. An additional 0.15 mL of DI water was slowly added to the TTIP solution. In this case, the volume ratio of [TTIP]:[HCl]:[H₂O] = 2:1:1. After aging for 15 min, the TTIP solution was slowly added to the PVC-g-POEM graft copolymer solution under stirring. This solution was subsequently aged under mild stirring at room temperature for 3 hours to prepare two kinds of om-TiO₂ BS layer structures.

Fabrication of om-TiO₂ BS layer based on photoanode. In a previous report, we showed that SiO₂ colloidal suspensions and TiO₂ sol-gel solution form a uniform and transparent om-TiO₂ BS layer by the spin coating method. In the current experiment, two types of materials (high and low refractive index TiO₂ sol-gel solution) for om-TiO₂ BS were prepared separately. Before fabricating an om-TiO₂ BS layer, the FTO glasses were ultrasonically cleaned sequentially in isopropanol and chloroform for 30 min each and then dried in air. The om-TiO₂ BS multilayer structure was constructed by alternate deposition of a high refractive index om-TiO₂ BS structure based on type 1 (PVC-g-POEM graft copolymer with a high-grafting degree) and low refractive index om-TiO₂ BS structure based on type 2 (PVC-g-POEM graft copolymer with a low-grafting degree). These were deposited on as-prepared clean FTO glasses by spinning at 2000 rpm. Between each layer deposition, heat treatment was performed in a furnace at 500 °C for 1 hour to remove water bonded to the TiO₂ nanoparticle surfaces and mechanically stabilize the entire structure. The sequence of om-TiO₂ BS deposition was as follows: high refractive index om-TiO₂ BS layer, low refractive index om-TiO₂ BS layer, and so on. Finally, om-TiO₂ BS was slowly heated at 450 °C for 30 min under air conditions to decompose the graft copolymer templates and ensure interconnection between TiO₂ nanoparticles.

Dye adsorption of photoanode. To adsorb the dye molecules, the prepared photoelectrode based on om-TiO₂ BS layers were immersed into 10⁻⁴ M ruthenium dye (N719) solution in ethanol, and sensitized for one night at 50 °C in a dark room. Afterward, this photoanode was rinsed with absolute ethanol in order to remove physisorbed ruthenium dye molecules.

Preparation of counter electrode. Transparent glasses coated with FTO glass were used for counter electrodes. The glasses were cleaned by sonication in isopropanol and then in chloroform. The counter electrodes were fabricated by thermal depositing H₃PtCl₄ solution (4 wt% in isopropanol) onto the conductive FTO glass followed by thermal sintering at 450 °C for 30 min and cooling to 30 °C over 8 h.

| Photoanode | Vₜₚ (V) | Jmax (mA/cm²) | FF | η (%) | Dye loading (nmol/cm²) |
|------------|--------|---------------|----|-------|-----------------------|
| nc-TiO₂    | 0.83   | 3.8           | 0.54 | 1.7   | 10.5                  |
| om-TiO₂ BS | 0.84   | 8.2           | 0.62 | 4.3   | 18.3                  |
| om-TiO₂ IF | 0.83   | 16.5          | 0.55 | 7.5   | 91.3                  |

Table 1 | Photovoltaic properties and dye loading values of a solid PIL-based DSSCs fabricated with three kinds of photoanodes at 100 mW/cm² (AM 1.5)
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### Author contributions
J.T.P., D. L. and J.H.K. contributed to the conception and design of the experiment, analysis of the data and writing the manuscript with assistance from W.S.C. and S.J.K. J.T.P. carried out synthesis of materials, preparation of the devices, device performance measurements together with W.S.C. and S.J.K.

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