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This is an **author produced version** of a paper published in:

Angewandte Chemie International Edition 58.12 (2019): 3653-4064

**DOI:** <https://doi.org/10.1002/anie.201812397>

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## Solar Cells

International Edition: DOI: 10.1002/anie.201812397  
German Edition: DOI: 10.1002/ange.201812397

## Controlling Interfacial Charge Transfer and Fill Factors in CuO-based Tandem Dye-Sensitized Solar Cells

Oliver Langmar, Ettore Fazio, Peter Schol, Gema de la Torre, Rubén D. Costa, Tomás Torres,\* and Dirk M. Guldi\*

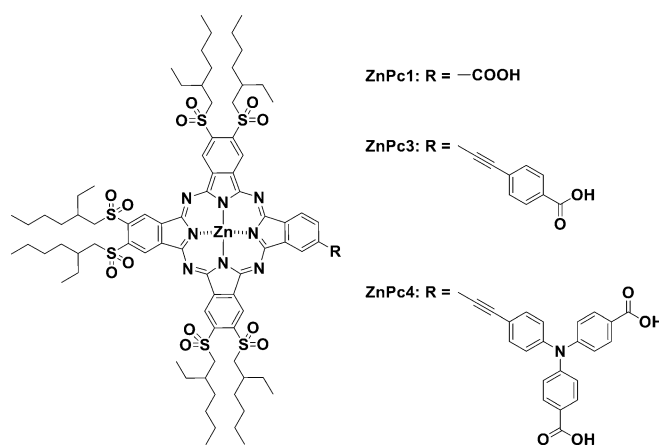
**Abstract:** ■■■please check author list: Peter Schol not in list in Editorial Manager? ■■■We designed and synthesized a series of novel electron-accepting zinc(II)phthalocyanines (ZnPc) and probed them in p-dye sensitized solar cells (p-DSSCs) by using CuO as photocathodes. By realizing the right balance between interfacial charge separation and charge recombination, optimized fill factors (FFs) of 0.43 were obtained. With a control over fill factor in p-DSSCs in hand we turned our attention to t-DSSCs, in which we combined for the first time CuO-based p-DSSCs with TiO<sub>2</sub>-based n-DSSCs using ZnPc and N719. In the resulting t-DSSCs, the V<sub>OC</sub> of 0.86 V is the sum of those found in p- and n-DSSCs while the FF remains around 0.63. It is only the smaller J<sub>sc</sub> in t-DSSCs, which limits the efficiency to 0.69 %. ■■■title made clearer ■■■

**D**ye-sensitized solar cells (DSSCs) have emerged as a viable alternative to silicon solar cells. The most notable incentives are low production costs and a wide range of applicability.<sup>[1]</sup> State-of-the-art power conversion efficiencies of 14.3 % are seen for n-type TiO<sub>2</sub> photoanodes (n-DSSC).<sup>[2]</sup> As a complement to n-DSSCs, p-type semiconductors, such as NiO, are utilized as photocathodes (p-DSSC).<sup>[3]</sup> p-DSSCs efficiencies are, however, with 2.5 % rather moderate.<sup>[4]</sup> In the last decade, the focus was placed on a better performance of p-DSSCs. New photosensitizers were developed to assist in a better light-harvesting.<sup>[5]</sup> Novel p-type semiconductors, such as copper(I)delafossites or CuO, were explored as photocathode materials.<sup>[6–8]</sup>

Efficient p-DSSCs are of great importance, especially in tandem-DSSCs (t-DSSCs), where the photoinactive platinum counter electrode of a n-DSSC is replaced by a dye-sensitized photocathode.<sup>[3]</sup> Importantly, t-DSSCs have the potential to surpass the Shockley-Queisser limit.<sup>[9]</sup> But, photosensitizers with complementary absorptions are needed for the n- and p-DSSCs. At the same time, the photocurrents should be of the same order of magnitude.<sup>[10]</sup> Interest in t-DSSCs has been moderate after the initial breakthrough by Nattestad et al. in 2009.<sup>[10]</sup> Recent attempts to realize better performances were largely based on increasing the short-circuit current density (J<sub>sc</sub>). This was achieved by employing optically transparent thiolate/disulfide-based electrolytes and/or by developing novel photosensitizers with improved light-harvesting properties.<sup>[11–13]</sup> These approaches let to t-DSSC efficiencies up to 4.10 %.

We recently documented that the poor fill factor (FF) of NiO-based p-DSSCs is the major bottleneck in high-performance t-DSSCs.<sup>[14]</sup> To this end, we have synthesized a class of novel electron accepting Zn<sup>II</sup> phthalocyanines (ZnPc)—**ZnPc3** and **ZnPc4**—featuring electronic distributions that favor a better interfacial charge separation. We have modified the structure of **ZnPc1** (Figure 1), which we previously tested in CuO-based p-DSSCs.<sup>[8]</sup> The basic idea behind **ZnPc3** and **ZnPc4** is to introduce conjugated spacers, namely ethynyl-phenyl and ethynyl-triphenylamine, between the electron-accepting ZnPc and the carboxylic-anchor, Figure 1. An increased electron donor–acceptor separation when going, for example, from **ZnPc1** to **ZnPc3**/**ZnPc4** is expected to go hand-in-hand with a suppression of charge recombination. At the same time, creating a “push-pull” system in, for example,

[\*] O. Langmar, P. Schol, Dr. R. D. Costa, Prof. D. M. Guldi

Department of Chemistry and Pharmacy  
Interdisciplinary Center for Molecular Materials  
University of Erlangen-Nürnberg  
Egerlandstrasse 3, 91058 Erlangen (Germany)  
E-mail: dirk.guldi@fau.deE. Fazio, Dr. G. de la Torre, Prof. T. Torres  
Universidad Autónoma de Madrid  
c/Francisco Tomás y Valiente 7  
28049 Madrid (Spain)  
E-mail: tomas.torres@uam.esProf. T. Torres  
Instituto Madrileño de Estudios Avanzados (IMDEA)-Nanociencia  
c/ Faraday 9, Cantoblanco, 28049 Madrid (Spain)  
Dr. R. D. Costa  
Instituto Madrileño de Estudios Avanzados (IMDEA)-Materiales  
c/Eric Kandel, 2, Tecnogetafe, 28906 Getafe, Madrid (Spain)Supporting information and the ORCID identification number(s) for the author(s) of this article can be found under:  
<https://doi.org/10.1002/anie.201812397>.

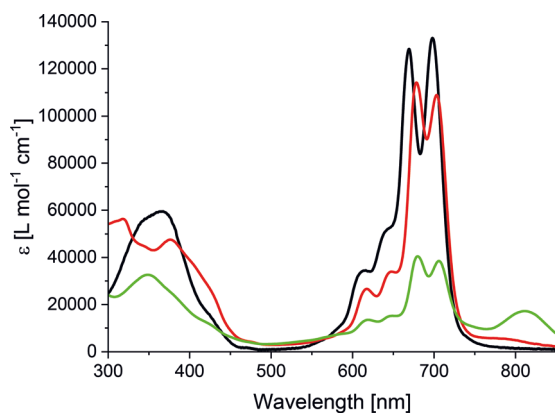
**Figure 1.** Structure of the newly developed electron-accepting **ZnPc3** and **ZnPc4**, as well as the previously reported **ZnPc1**.

**ZnPc4**, by linking an electron-donating triphenylamine to the electron-accepting ZnPc, is expected to facilitate the charge separation. Both of these strategies have led to excellent results in the past.<sup>[15]</sup> In addition, ZnPcs feature strong and low-energy absorptions and their electronic properties are easy tunable through peripheral substitution.<sup>[16]</sup> All of the aforementioned features make ZnPcs ideal for t-DSSCs in combination with high-energy absorbing ruthenium(II)-based photosensitizers, such as **N719**.<sup>[17]</sup> Regarding the p-type photocathodes we chose CuO as suitable material, since it shows less recombination with the  $I^-/I_3^-$  redox couple and a faster charge transport compared to NiO-based electrodes.<sup>[18,19]</sup> Both are crucial for realizing high FFs.<sup>[20,21]</sup> To this end, we probed **ZnPc3** and **ZnPc4** as low-energy photosensitizers in CuO-based p- and t-DSSCs. It is, to our knowledge, the first example of a t-DSSC featuring dye-sensitized photocathodes based on CuO.

**ZnPc3** and **ZnPc4** (Scheme S1 in the Supporting Information) were synthesized by a cross-coupling reaction between iodo-functionalized ZnPc (**1**) and different ethynyl-based anchors. In detail, the synthesis of **ZnPc3** was accomplished by a Sonogashira coupling with methyl 4-ethynylbenzoate followed by basic hydrolysis of the ester group in **2**. Similarly, **1** reacted under Sonogashira conditions with triphenylamine (TPA) **3** to obtain the TPA-functionalized ZnPc (**4**).<sup>[22]</sup> Subsequent hydrolysis of the ester groups yielded the final **ZnPc4** bearing two carboxylic acids (Scheme S1).

Steady-state absorption spectra of **ZnPc3** and **ZnPc4** revealed Soret-band absorptions around 300–400 nm and split Q-band absorptions between 670–700 nm (Figure 2). When compared to **ZnPc1**, red-shifted Q-band absorptions were noted for **ZnPc3** (10 nm) and **ZnPc4** (11 nm). For **ZnPc4**, an additional absorption band was seen around 811 nm (Table S1).<sup>[8]</sup> Furthermore, a strong fluorescence quenching (Figure S2) evolved for **ZnPc4**, with quantum yields of 0.016 (**ZnPc4**), 0.16 (**ZnPc3**), and 0.29 (**ZnPc1**).

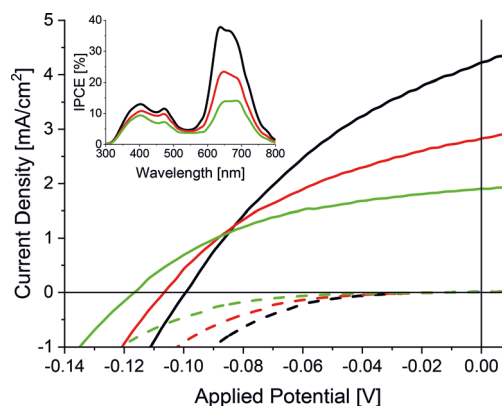
Square-wave voltammetry (SWV) assays (Figure S3) revealed one quasi-reversible oxidation at +1.26 V for **ZnPc3** and at +1.24 V for **ZnPc4**, and one quasi-reversible reduction at −0.32 V for **ZnPc3** as well as −0.38 V for **ZnPc4**—all values are given



**Figure 2.** Extinction coefficients ( $\epsilon$ ) for **ZnPc1** (black), **ZnPc3** (red), and **ZnPc4** (green) in THF.

versus the normal hydrogen electrode (NHE). To our surprise, the oxidation potentials of **ZnPc3** and **ZnPc4** are nearly identical, despite the presence of TPA in **ZnPc4**. In previous SWV assays, the oxidation of TPA was determined to be +1.24 V vs. NHE.<sup>[23]</sup> From this, we postulate that the oxidations of TPA and ZnPc overlap in **ZnPc4**, leading to a shared electronic contribution to the highest occupied molecular orbital (HOMO). Overall the oxidations and reductions of **ZnPc3** and **ZnPc4** were up shifted compared to **ZnPc1**. With the aforementioned data at hand, exergonic driving forces were estimated for the charge injection ( $-\Delta G_{inj}$ ) and the ZnPc regeneration ( $-\Delta G_{reg}$ ) (Table S1).<sup>[24]</sup> Upon closer inspection of  $-\Delta G_{inj}$ , it is reasonable to assume that **ZnPc4** devices should show a less efficient charge injection due to a lower  $-\Delta G_{inj}$  (Table S1): −0.72 eV (**ZnPc4**); −0.83 eV (**ZnPc1**); −0.80 eV (**ZnPc3**). Considering similar  $-\Delta G_{reg}$ , only marginal differences are expected in terms of regeneration between the different ZnPcs.

State-of-the-art CuO nanoparticles were employed and the devices were filled with a recently optimized  $I^-/I_3^-$  based electrolyte.<sup>[19,25]</sup> Figure 3 shows the current density versus



**Figure 3.**  $J$ - $V$  curves under 1 sun AM 1.5 (line) and dark (dashed) conditions for **ZnPc1**/CuO p-DSSC (black), **ZnPc3**/CuO p-DSSC (red), and **ZnPc4**/CuO p-DSSC (green). Inset: corresponding IPCE spectra.

voltage ( $J$ - $V$ ) curves and the incident photon-to-current efficiency (IPCE) spectra, while the device figures-of-merit are summarized in Table S2. Reference devices, that is, **ZnPc1**/CuO, showed a  $V_{oc}$  of 99.1 mV, which increased to 104.0 and 117.8 mV for **ZnPc3**/CuO and **ZnPc4**/CuO, respectively. The trend in  $J_{sc}$  is, however, different: 4.14 mA cm<sup>−2</sup> (**ZnPc1**), 2.74 mA cm<sup>−2</sup> (**ZnPc3**), and 1.72 mA cm<sup>−2</sup> (**ZnPc4**). An inspection of the IPCE at, for example, 670 nm, gave rise to the same trend: **ZnPc1** > **ZnPc3** > **ZnPc4**. FF ranged from 0.36 and 0.38 to 0.43 for **ZnPc1**, **ZnPc3**, and **ZnPc4**, respectively. Taking all of the aforementioned into count, the efficiencies ( $\eta$ ) were determined to be 0.146 % (**ZnPc1**), 0.108 % (**ZnPc3**), and 0.087 % (**ZnPc4**).<sup>[26]</sup> Reference devices based on NiO photocathodes showed substantially lower figures-of-merit compared to analogous CuO p-DSSCs (Figure S4 and Table S3).

We conclude that the newly synthesized ZnPcs perform poorer than **ZnPc1** in CuO-based p-DSSCs and a significant decrease in  $J_{sc}$  is mainly responsible for it. At first glance, this

trend seems counterintuitive considering the higher dye loadings. Lower extinction coefficients (Figure 2) for **ZnPc3** ( $1.1 \times 10^5 \text{ L mol}^{-1} \text{ cm}^{-1}$  at 679 nm) and **ZnPc4** ( $4.0 \times 10^4 \text{ L mol}^{-1} \text{ cm}^{-1}$  at 680 nm) than for **ZnPc1** ( $1.3 \times 10^5 \text{ L mol}^{-1} \text{ cm}^{-1}$  at 669 nm) and subtle differences in  $\Delta G_{\text{inj}}$ , explain, however, the decrease in  $J_{\text{sc}}$ . Differences in terms of charge injection, whose rates are governed by the nature of the linker, and spacial orientation on the electrode surface, should not be ruled out as contributing factors.<sup>[16,27]</sup>

Despite the low  $J_{\text{sc}}$ s for **ZnPc3**/CuO and **ZnPc4**/CuO, a number of important aspects should be highlighted.  $V_{\text{oc}}$ s for **ZnPc3** and **ZnPc4** are up to 20 mV higher compared to those of **ZnPc1**. Higher dye loadings, which result in an effective blocking of the electrode surface, and an increase in spatial distance between **ZnPc3**/**ZnPc4** and the CuO electrode are likely responsible for a suppressed charge recombination. Better FFs are the direct consequence of both: 0.36 for **ZnPc1**/CuO; 0.38 for **ZnPc3**/CuO; 0.43 for **ZnPc4**/CuO.

A closer look at the  $J$ - $V$  curves under AM 1.5 conditions (Figure 2) revealed that the shunt resistance ( $R_{\text{sh}}$ ) is the main factor that impacts FF. In NiO p-DSSCs, low FFs of around 0.35 to 0.4 stemmed from a significant charge recombination between the reduced sensitizer and the NiO photocathode.<sup>[5,20,28,29]</sup> This is, however, effectively suppressed in our **ZnPc3** and **ZnPc4** based p-DSSCs, see above. In **ZnPc4**, charge separation was further augmented by the “push-pull” nature. It should be noted that the **ZnPc4**/CuO FF is among the highest reported for p-DSSCs.<sup>[5]</sup>

Electrochemical impedance spectroscopy (EIS), open circuit voltage decay (OCVD), and intensity modulated photovoltage spectroscopy (IMVS) contributed to a sound understanding of charge injection and recombination.<sup>[18,30,31]</sup> Figure S5 displays, for example, the charge transfer resistance ( $R_{\text{CT}}$ ) and the recombination resistance ( $R_{\text{rec}}$ ) based on the EIS assays under AM 1.5 and dark conditions, respectively.

Under AM 1.5 conditions,  $R_{\text{CT}}$  at  $J_{\text{sc}}$  gradually increased from 25.8 to 51.5 and to 140.3  $\Omega \text{ cm}^2$  for **ZnPc1**/CuO, **ZnPc3**/CuO, and **ZnPc4**/CuO, respectively.<sup>[18,32]</sup> We relate the  $R_{\text{CT}}$ s under these conditions to the charge injection, which decreases from **ZnPc1** to **ZnPc3** and to **ZnPc4**, and, which matches the trend seen for  $J_{\text{sc}}$ s, see above.<sup>[8,18]</sup>

Plateauing of  $R_{\text{CT}}$  at around  $J_{\text{sc}}$ , which is a common feature for NiO- and CuO-based p-DSSCs, was not observed.<sup>[8,28]</sup> It is hypothesized that the dye/electrode recombinations or the surface adsorption of lithium ions, which promote the formation of ( $\text{I}^-$ ,  $\text{I}^-$ ) pairs, facilitate the plateauing.<sup>[25,28]</sup> In the case of **ZnPc1**/CuO and **ZnPc3**/CuO, linear  $R_{\text{CT}}$  trends contrast p-DSSCs built with **ZnPc4**/CuO, for which an exponential change in  $R_{\text{CT}}$  is noted. Exponential changes are known to occur in  $\text{TiO}_2$ -based n-DSSCs, where the dye/electrode charge recombination is several orders of magnitude slower than the dye regeneration.<sup>[33]</sup>

EIS assays under dark conditions provided insights into the electrode/electrolyte charge recombination (Figure S5).<sup>[18,28]</sup>  $R_{\text{rec}}$  increased from 1045.3 (**ZnPc3**), to 1406.0 (**ZnPc1**), and to 4602.4  $\Omega \text{ cm}^2$  (**ZnPc4**) at  $J_{\text{sc}}$ . In other words, the slowest charge recombination was found for **ZnPc4** and this corroborated its highest  $V_{\text{oc}}$ , see above. We attribute this

to the better dye loading when compared to **ZnPc1** and to the surface shielding effect of TPA.<sup>[14]</sup>

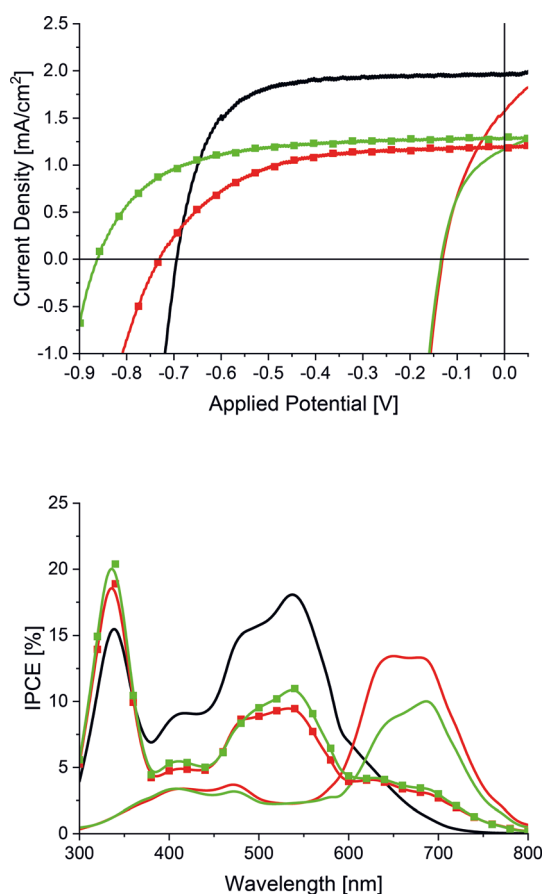
As we expected lower recombination for devices based on **ZnPc3** due to a higher dye loading, the trend for **ZnPc1** and **ZnPc3** with lower  $R_{\text{rec}}$ s at zero applied voltage case is puzzling. We are, however, unable to exclude **ZnPc3** instabilities during the two hours that the EIS analyses took. Thus, we probed a fresh set of devices by means of OCVD and IMVS (Figure S6). Time scales of the OCVD and IMVS measurements are much shorter than that of the EIS measurements and device instabilities and/or decompositions play only a minor if any role. In contrast to EIS under dark conditions, OCVD and IMVS assays provided complementary information on the recombination of the reduced ZnPs with the electrode.<sup>[34,35]</sup> In OCVD assays, slower voltage decays were noted for **ZnPc3**/CuO and **ZnPc4**/CuO than for **ZnPc1**/CuO, from which we infer a slower charge recombination. IMVS assays pointed to the same trend. At a  $V_{\text{oc}}$  of 55 mV,  $\tau_{\text{h}}$  with 26.33 ms (**ZnPc4**), 24.14 ms (**ZnPc3**), and 18.35 ms (**ZnPc1**) is in the same order. After all, devices based on **ZnPc3** and **ZnPc4** were subject to fewer charge recombination events relative to **ZnPc1**.

When compared to **ZnPc1** devices, **ZnPc3** or **ZnPc4** devices give rise to both lower  $J_{\text{sc}}$  and  $\eta$ . Lower  $\varepsilon$  and unfavorable charge injection are mainly responsible for these trends. However, larger distances between the ZnPs and the electrode surface as well as higher dye loadings inhibit dye/electrode recombinations for **ZnPc3**/CuO and **ZnPc4**/CuO. This all resulted in better  $V_{\text{oc}}$  and FF values. Note that low FFs are the major bottleneck not only in p-type DSSCs, but also in t-DSSCs.<sup>[14,36]</sup>

In the next step, we integrated **ZnPc3**/CuO and **ZnPc4**/CuO into t-DSSCs. t-DSSCs were assembled by using p-type CuO photocathodes in combination with **ZnPc1**, **ZnPc3**, and **ZnPc4** as low-energy absorber, and n-type  $\text{TiO}_2$  photoanodes that were functionalized with **N719** as high-energy absorber (Figure S7). A modified electrolyte, namely 1.0 M 1-ethyl-3-methylimidazolium iodide (EMII), 0.2 M  $\text{I}_2$ , 0.2 M lithium bis(trifluoromethane)sulfonimide ( $\text{LiNTf}_2$ ), 0.2 M 4-*tert*-butylpyridine (4-*tbp*), was selected to control recombination at the  $\text{TiO}_2$ -based photoanode. Special care was taken of matching the photocurrents of both photoelectrodes. This was done by reducing the electrode thickness of the photoanode.<sup>[10]</sup> Figure 4 depicts  $J$ - $V$  curves and IPCE spectra of the  $\text{TiO}_2$ /**N719** n-DSSCs and **ZnPc**/CuO p-DSSCs together with the  $\text{TiO}_2$ /**N719**/**ZnPc**/CuO t-DSSCs illuminated from the  $\text{TiO}_2$  side (Table 1).<sup>[37]</sup>

Analyses of the IPCEs confirmed the panchromatic light harvesting ranging from 300 to 800 nm, owing to complementary light absorption of **N719** and the respective ZnPs. t-DSSCs with **ZnPc1**/CuO and **ZnPc3**/CuO showed similar figures-of-merit, that is,  $V_{\text{oc}}$  of 728.0 and 730.0 mV,  $J_{\text{sc}}$  of 1.21 and 1.20  $\text{mA cm}^{-2}$ , FF of 0.57 and 0.56, and  $\eta$  of 0.50 % and 0.49 %, respectively. Even better figures-of-merit were determined for **ZnPc4**/CuO in t-DSSCs: 863.0 mV ( $V_{\text{oc}}$ ), 1.28  $\text{mA cm}^{-2}$  ( $J_{\text{sc}}$ ), 0.63 (FF), and 0.69 % ( $\eta$ ). It should be noted that the lower  $\text{I}_2$  concentration and the addition of 4-*tbp* to the t-DSSC electrolyte reduce the dye regeneration and charge injection in CuO-based p-DSSCs and, in turn, resulted





**Figure 4.** Top:  $J$ - $V$  curves of  $\text{TiO}_2/\text{N719}$  n-DSSC (black),  $\text{ZnPc3}/\text{CuO}$  p-DSSC (red),  $\text{ZnPc4}/\text{CuO}$  p-DSSC (green),  $\text{TiO}_2/\text{N719}/\text{ZnPc3}/\text{CuO}$  t-DSSC (red square), and  $\text{TiO}_2/\text{N719}/\text{ZnPc4}/\text{CuO}$  t-DSSC (green square). Bottom: Corresponding IPCE spectra.

**Table 1:** Device figures-of-merit for the  $\text{TiO}_2$ - and CuO-based reference devices and the respective t-DSSCs illuminated from the  $\text{TiO}_2$  side

Device	$V_{oc}$ [mV]	$J_{sc}$ [ $\text{mA cm}^{-2}$ ]	FF	$\eta$ [%]
$\text{TiO}_2/\text{N719}$	694.0	1.98	0.69	0.95
$\text{ZnPc1}/\text{CuO}$	97.5	1.88	0.36	0.066
$\text{ZnPc3}/\text{CuO}$	131.7	1.57	0.37	0.075
$\text{ZnPc4}/\text{CuO}$	134.1	1.17	0.44	0.069
t-DSSC $\text{ZnPc1}$	728.0	1.21	0.57	0.50
t-DSSC $\text{ZnPc3}$	730.0	1.20	0.56	0.49
t-DSSC $\text{ZnPc4}$	863.0	1.28	0.63	0.69

in lower  $J_{sc}$  and  $\eta$  (Table S2 and Table 1). ■ refs [18,25] in German version, please unify ■

A closer look at the t-DSSC device figures-of-merit gave rise to an increase in  $V_{oc}$  for the t-DSSCs relative to the respective n- and p-DSSCs.<sup>[3,13]</sup> In stark contrast, the  $\eta$  of the t-DSSCs was lower compared to what was seen for the n-DSSCs. Overall, a clear correlation between FF and  $\eta$  for the p-DSSCs and for the corresponding t-DSSCs is discernible: High FF for  $\text{ZnPc4}/\text{CuO}$  relates to high  $\eta$  of 0.69% and FF of 0.63 for the corresponding t-DSSCs.<sup>[38]</sup>  $\text{ZnPc1}/\text{CuO}$  and  $\text{ZnPc3}/\text{CuO}$  devices showed lower FFs, which resulted for the respective t-DSSCs in lower  $V_{oc}$ s, FFs, and  $\eta$ s. Independ-

ent support for this notion came from the fact that  $\text{ZnPc3}/\text{CuO}$  and  $\text{ZnPc4}/\text{CuO}$  devices displayed almost the same high  $V_{oc}$  (Table 1), but the  $V_{oc}$  for the respective t-DSSCs was rather different with 730.0 mV (t-DSSC  $\text{ZnPc3}$ ) and 863.0 mV (t-DSSC  $\text{ZnPc4}$ ). In other words, high FFs, which were found for the  $\text{ZnPc4}/\text{CuO}$  devices, stemmed from a more better dye design and had a direct influence on the  $V_{oc}$  of the respective t-DSSCs and, in turn, on the  $\eta$ . Notably, our t-DSSCs exhibited lower values of  $J_{sc}$  and  $\eta$ , when compared to state-of-the-art NiO-based t-DSSCs –910.0 mV ( $V_{oc}$ ), 6.73  $\text{mA cm}^{-2}$  ( $J_{sc}$ ), 0.66 (FF), and 4.10% ( $\eta$ ).<sup>[13]</sup> However, the FFs were comparable and corroborate the overall success in implementing CuO photocathodes together with low-energy light absorbing ZnPCs into t-DSSCs.<sup>[11–13]</sup> Furthermore, it was demonstrated that  $\eta$  is controlled by the FF of the respective p-type sub-cell.

In conclusion, a new family of electron-accepting ZnPCs featuring phenyl-ethynyl ( $\text{ZnPc3}$ ) and triphenylamine-ethynyl ( $\text{ZnPc4}$ ) spacers was synthesized and probed in p- and t-DSSCs. The main objective was to control the charge recombination between the CuO photocathode and the reduced ZnPC, and to implement a “push-pull” design in the case of  $\text{ZnPc4}$ . When used in CuO-based p-DSSCs,  $\text{ZnPc3}$  and  $\text{ZnPc4}$  performed better in terms of  $V_{oc}$  and FF than our previously reported  $\text{ZnPc1}$ . EIS, OCVD, and IMVS assays suggested more favorable charge recombination due to higher dye loadings and a more efficient charge separation. Unfortunately, moderate  $J_{sc}$ s, which correlate with the low  $\epsilon$  of  $\text{ZnPc3}/\text{CuO}$  and  $\text{ZnPc4}/\text{CuO}$  and their poor charge injection, counter-balanced the  $\eta$  values of the devices.

A high  $V_{oc}$  and FF, determined for p-DSSCs based on  $\text{ZnPc3}$  and  $\text{ZnPc4}$ , along with the low-energy absorptions of ZnPCs, prompted us to test them in t-DSSCs. To our knowledge, our work is the first demonstration of CuO-based t-DSSCs. Of great value is the direct dependence between efficient t-DSSCs and a high FF in p-DSSCs. Overall, t-DSSCs, in which  $\text{ZnPc4}$  was immobilized onto p-type CuO photocathodes showed the highest FF of 0.63 and the best  $\eta$  of 0.69%. As such, the current work documents the benefits of a tailored design of electron-accepting ZnPCs with better charge-transfer characteristics. This is crucial for pushing the performance boundaries of p- and t-DSSCs. In future work, we will focus on developing more efficient ZnPCs, for which efficient charge separation goes hand-in-hand with high extinction coefficients to enable CuO-based t-DSSCs with higher  $J_{sc}$  and, eventually, better  $\eta$ .

## Acknowledgements

We thank the German Science Council (DFG) for the financial support in the framework of the Cluster of Engineering of Advanced Materials (EAM). Furthermore, we are grateful for the financial support of the MINECO, Spain (Grant CTQ2017-85393-P), and the Comunidad de Madrid, Spain (FOTOCARBON, S2013/MIT-2841). IMDEA-Nanociencia acknowledges support from the “Severo Ochoa” Program for Centres of Excellence in R&D (MINECO, Grant SEV-2016- 0686). R.D.C. acknowl-

edges the Ramón y Cajal program “Spanish MINECO (RYC-2016–20891)”.

### Conflict of interest

The authors declare no conflict of interest.

**Keywords:** copper(II)oxide · panchromatic light absorption · dye-sensitized solar cells · tandem device · zinc(II)phthalocyanine

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- [38] Please note that the FF of **ZnPc4**-based t-DSSCs (0.63) is similar to **TiO2/N719** (0.69).

Manuscript received: October 29, 2018

Accepted manuscript online: December 27, 2018

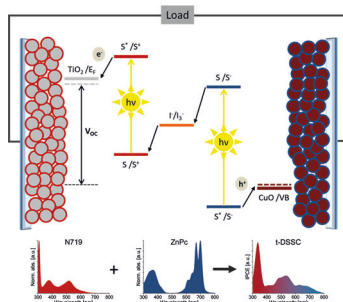
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## Communications

## Solar Cells

O. Langmar, E. Fazio, P. Schol,  
G. de la Torre, R. D. Costa, T. Torres,\*  
D. M. Guldi\*

Controlling Interfacial Charge Transfer  
and Fill Factors in CuO-based Tandem  
Dye-Sensitized Solar Cells



**Combined harvester:** A novel class of electron-accepting zinc(II)-phthalocyanine (ZnPc) based photosensitizers with better charge separation is prepared. p- and tandem-DSSCs based on CuO photocathodes and the novel ZnPcs show improved fill factors and panchromatic light harvesting from 300 to 800 nm.



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Oliver Langmar

Ettore Fazio

Peter Schol

Dr. Gema de la Torre

Dr. Rubén D. Costa

Prof. Tomás Torres

Prof. Dirk M. Guldi <http://orcid.org/0000-0002-3960-1765>