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Finely tuning electrolytes and photoanodes in aqueous solar cells by experimental design

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- Finely tuning electrolytes and photoanodes in aqueous 1 solar cells by experimental design 2 3 Simone Galliano,¹ Federico Bella,^{2,*} Giulia Piana,² Giulia Giacona,^{1,2} 4 Guido Viscardi,¹ Claudio Gerbaldi,² Michael Grätzel,³ Claudia Barolo^{1,4,*} 5 6 1) Department of Chemistry, NIS Interdepartmental Centre and INSTM Reference 7 Centre, Università degli Studi di Torino, Via Pietro Giuria 7, 10125 - Torino, 8 9 Italy 2) GAME Lab, Department of Applied Science and Technology - DISAT, Politecnico 10 di Torino, Corso Duca degli Abruzzi 24, 10129 – Torino, Italy 11 3) Laboratory of Photonics and Interfaces, Institut des Sciences et Ingénierie 12 Chimiques, Ecole Polytechnique Fédérale de Lausanne (EPFL), Station 3, CH1015 13 14 - Lausanne, Switzerland 4) ICxT Interdepartmental Centre, Università degli Studi di Torino, Lungo Dora 15 *Siena 100, 10153 – Torino, Italy* 16 17 18 **Corresponding authors**: Federico Bella (federico.bella@polito.it, +39 0110904643) and Claudia Barolo (claudia.barolo@unito.it, +39 0116707594). 19 20 21 Abstract: If opportunely developed and optimized, aqueous dye-sensitized solar cells 22 23 can be considered a truly low impact photovoltaic device, with no toxic components. Here we report the use of design of experiments as a useful chemometric technique for 24 the concurrent investigation of a series of experimental factors that directly influence 25 the proper operation of these photoelectrochemical cells. Results obtained enlighten that 26 27 a solid mathematical-statistical approach is fundamental to support the researchers and 28 effectively drive the experiments towards the achievements of optimal operating 29 conditions of any new energy device, thus bypassing the energy/time consuming of traditional monovariate one-factor-at-a-time method. 30 31 32 Keywords: Dye-sensitized solar cell; Aqueous electrolyte; Sustainability; Design of experiments; Multivariate approach; Electrode/electrolyte interface. 33 34 35 1. Introduction 36 37 The introduction of aqueous electrolytes is contributing to the rebirth of dye-sensitized solar cells (DSSCs), the low-impact photoelectrochemical device for the conversion of 38
- 39 solar energy into electricity (Bella et al., 2015). Aqueous DSSCs represent a truly
- 40 sustainable and very limited environmental impact technology, which might
- 41 successfully pinpoint the concept of artificial photosynthesis often been evoked within

the scientific community in the last two decades (Bella et al., 2017; Click et al., 2017;

43 Imperiyka et al., 2014; McConnell et al., 2010; Yang et al., 2010).

Several research groups worldwide recently focused their efforts towards the 44 investigation of a series of new factors, such as photoelectrode wetting (Dong et al., 45 46 2014; Galliano et al., 2017), novel sensitizers (Leandri et al., 2014; Li et al., 2017; Lin et al., 2015), the solubility and the diffusion behavior of various redox pairs in water 47 (Daeneke et al., 2012; Xiang et al., 2013; Yang et al., 2015), the cathodic 48 49 electrocatalytic reaction (Ellis et al., 2016). Clearly, in a new system (like the aqueous DSSC), the possibility to simultaneously study several of these experimental factors at 50 51 the same time, bypassing the traditional one-factor-at-a-time (OFAT) process, would permit to effectively drive research towards well-defined paths supported by a solid 52 mathematical/statistical justification. In this respect, despite being scarcely adopted by 53 54 the energy-related research community (Gianotti et al., 2014; Miccoli et al., 2016), multivariate chemometrics, such as design of experiments (DoE) (Kennard et al., 1969), 55 would represent a key-enabling method. 56

57 In this work, we propose a DoE for the simultaneous investigation of the characteristics of photoanode, electrolyte and photoanode/electrolyte interface of 58 aqueous DSSCs. A simple experimental matrix based on 20 photoelectrochemical cells 59 60 enables to comprehensively weight each of the experimental factors involved, and to 61 easily identify the best conditions to maximize sunlight conversion efficiency. Amongst the powerful and intriguing aspects of the adopted approach, the ability to find two 62 performance maximization strategies must be mentioned, which is the fundamental 63 achievement of this work. 64

2. Experimental

Sodium iodide (NaI), iodine (I₂), chenodeoxycholic acid (CDCA), ethanol, acetone, 67 tert-butanol (t-BuOH) and acetonitrile (ACN) were purchased from Sigma-Aldrich. 68 Deionized water (DI-H₂O, 18 MΩ cm⁻¹ at 25 °C) was obtained by Direct-Q 3 UV Water 69 Purification System (Millipore). Sensitizing dye 2-[{4-[4-(2,2-diphenylethenyl)phenyl]-70 1,2,3,3a,4,8b-hexahydrocyclopento[b]indole-7-yl}methylidene]-cyanoacetic 71 acid 72 (D131) was purchased from Inabata Europe S.A. FTO-glass plates (sheet resistance 7 Ω 73 sq⁻¹, purchased from Solaronix) were cut into 2 cm \times 1.5 cm sheets and used as substrates for the fabrication of both photoanodes and counter electrodes. 74

75 FTO covered glasses were rinsed in mixed acetone/ethanol in an ultrasonic bath for 10 min; solvent traces were removed by flash evaporation at 450 °C on a hotplate. Front 76 electrodes were prepared by depositing a single layer of porous TiO₂ on top of the 77 78 conductive substrate by means of a manual screen printer with a 43T mesh frame. After deposition of the paste (18NR-T, Dyesol) and 20 min rest to let it bed thoroughly, the 79 TiO₂ layer was dried at 80 °C for 20 min; finally, it was sintered increasing the 80 81 temperature up to 480 °C in 45 min. The fabricated photoanodes had a thickness of ≈ 6 μ m and active area of 0.25 cm². They were finally reactivated by heating at 450 °C for 82 20 min and, subsequently, soaked into a D131 dye solution (0.50 mM in t-BuOH:ACN 83 84 1:1); CDCA was added to the dye solution as coadsorbent (its concentration represents 85 one of the factors investigated in this work). Dipping in dye solutions was carried out at 22 °C for 5 h under dark conditions and shaking in a Buchi Syncore platform equipped 86 with a cooling plate. After dye loading, photoanodes were washed in acetone to remove 87 residual dye not specifically adsorbed onto the TiO₂ layer. 88

As regards the preparation of counter electrodes, FTO conductive glasses were platinized by spreading a H_2PtCl_6 5.0 mM solution on the plate surface and heating up to 400 °C.

Photoanodes were faced to the counter electrodes exploiting Surlyn[®] thermoplastic 92 frames (internal area 0.6 cm \times 0.6 cm) as spacers (60 μ m thick), taking care of the 93 overlapping of the active areas. All of these components were assembled by hot 94 pressing (20 s) at 110 °C. The electrolyte solution (consisting of NaI and I₂ dissolved in 95 water) was injected by vacuum backfilling process through a hole in the Surlyn[®] frame, 96 97 which was then sealed by a commercial epoxy glue. The amounts of NaI and I₂ 98 represent relevant factors in the aqueous DSSC field, thus they are investigated in this work. 99

Photovoltaic performances were evaluated recording three consecutive J-V curves 100 on a Keithley 2420 Source Measure Unit. Cells were irradiated under simulated 1 sun 101 light intensity (100 mW cm⁻², AM 1.5G) after calibration by silicon diode, as it is 102 103 typically done in the DSSC framework (Bella et al., 2017; Fan et al., 2017; Liu et al., 2017; Maçaira et al., 2017; Mengal et al., 2017). Electrochemical impedance 104 spectroscopy (EIS) data were recorded using a potentiostat (CH Instruments Inc., Model 105 106 680) in the frequency range between 10 kHz and 0.1 Hz. The amplitude of the AC signal was 10 mV. Spectra were recorded under dark conditions at applied DC 107 potentials equal to the previously measured V_{oc} values under 1 sun (Buraidah et al., 108 2017; Mohan et al., 2017; Paušová et al., 2017; Subramanian et al., 2017; Vekariya et 109 110 al., 2017).

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112 **3. Results and Discussion**

An experimental design was compiled to simultaneously investigate the effect of two 113 114 key parameters, such as the concentration of the redox mediator and the ratio between the co-adsorbent CDCA and the dye-sensitizer in the photoanode dipping solution, of an 115 aqueous DSSC. As regards the electrolyte, two variables were identified: concentrations 116 117 of I_2 (x_2 , from 10 to 30 mM) and NaI (x_3 , from 1.0 to 5.0 M), respectively. The CDCA/Dye molar ratio (x_1) was the third variable, which ranged from 18 to 50. Such an 118 experimental domain was chosen accordingly to preliminary tests useful to identify the 119 120 most appropriate conditions to enable proper operation of lab-scale aqueous DSSCs (Bella et al., 2016). In order to carry out a multivariate experimental design, the 121 software MODDE (version 11.0.2.2309, Umetrics) was chosen. A two-level full 122 123 factorial DoE was planned and the list of experiments is summarized in Table 1, together with the measured responses of short-circuit current density (J_{sc}) , open-circuit 124 125 potential (V_{oc}), fill factor (FF) and power conversion efficiency (PCE) (Abdul Rani et al., 2014; Park et al., 2015). These experiments represent the most statistically 126 significant points of the investigated experimental domain as a whole, and design the 127 128 cubic geometry shown in Fig. A.1 in Appendix A.

129

Table 1. DoE model matrix consisting of 20 experiments, useful to investigate the three selected experimental variables (x_1 , x_2 and x_3). The measured responses for J_{sc} , V_{oc} , FF

and PCE are also shown.

Exp.	CDCA:Dye ratio [x1]	[Iodine] (<i>x</i> ₂ , mM)	[Iodide] (x3, M)	$J_{\rm sc}$ (mA cm ⁻²)	V _{oc} (mV)	FF (%)	PCE (%)
N1	18:1	10	1.0	1.48	564	54.7	0.46
N2	50:1	10	1.0	2.21	607	54.7	0.73
N3	18:1	30	1.0	0.92	476	54.9	0.24
N4	50:1	30	1.0	1.71	540	59.5	0.55
N5	18:1	10	5.0	3.55	528	56.0	1.05
N6	50:1	10	5.0	1.73	532	44.2	0.41
N7	18:1	30	5.0	2.67	450	58.3	0.70
N8	50:1	30	5.0	2.27	465	45.6	0.48

N9	34:1	20	3.0	0.70	425	53.4	0.17
N10	34:1	20	3.0	1.35	453	56.9	0.35
N11	18:1	10	1.0	1.56	549	55.6	0.48
N12	50:1	10	1.0	2.57	613	57.1	0.90
N13	18:1	30	1.0	1.08	494	57.3	0.30
N14	50:1	30	1.0	1.88	557	59.7	0.63
N15	18:1	10	5.0	3.47	502	56.1	0.98
N16	50:1	10	5.0	1.72	534	44.0	0.42
N17	18:1	30	5.0	2.82	434	58.2	0.71
N18	50:1	30	5.0	2.58	474	44.6	0.55
N19	34:1	20	3.0	1.12	463	56.2	0.29
N20	34:1	20	3.0	1.44	468	57.8	0.39

The model was fitted with the obtained experimental responses listed in **Table 1** and the summary of fit plot, i.e. a bar graph showing the values of the R^2 , Q^2 and reproducibility parameters, is shown in **Fig. A.2 in Appendix A**. By the analysis of the data, it is evidenced that the resulting regression model provides a significant description of the relationship between the independent variables and the responses, which means an optimal analysis of the investigated photoelectrochemical system, as

also shown in **Fig. A.3 in Appendix A**.

141 To figure out the most significant within all of the variables under study, a coefficients plot for the selected response was elaborated as shown in Fig. 1. We noticed 142 that the increase in the concentration of I_2 and NaI negatively affected the V_{oc} , while the 143 opposite effect was obtained by raising CDCA concentration. On the contrary, J_{sc} 144 values increased upon NaI addition, unless when also CDCA was added in high 145 146 amounts. Overall, the PCE substantially increased at increasing amounts of NaI, while decreased upon increasing the concentration of I₂. The worst situation is highlighted by 147 the interaction coefficient $x_1 \times x_3$, i.e. when concentration levels of CDCA and NaI are 148 149 kept both at the highest level. Fig. 1 truly helps in identify the most relevant 150 experimental factors affecting each of the photovoltaic parameters measured by J-V

151 analysis.

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Fig. 1. *Coefficient plot* for the DoE. Each plot displays the coefficients, when changing
from level 0 to a higher level, for the selected response (i.e., the photovoltaic
parameters).

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Contour plots (isoresponse graphs) are shown in Fig. 2 (for J_{sc} , V_{oc} and PCE) and in 158 Fig. A.4 in Appendix A (for FF). They graphically show the relevance of each factor in 159 influencing the measured response. In particular, highest values of V_{oc} were obtained at 160 low concentrations of NaI and I2 ad high amount of CDCA. This was due to the 161 inhibition of electron $-I_2$ and electron $-I_3^-$ recombination processes usually observed in 162 I₂-rich electrolytes (Mathew et al., 2013); moreover, it is known from Nernst equation 163 that an increase in NaI concentration reduces the working potential value (Fabregat-164 165 Santiago et al., 2005).



Fig. 2. *Contour plots* of the fitted DoE considering J_{sc} , V_{oc} and PCE as response; their values are written onto the contour lines. Values range from low (blue) to high (red) values.

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As regards J_{sc} , in the presence of medium-low CDCA:Dye ratios the maximum 173 current density values were achieved at high NaI content, with a rather little effect given 174 by the selected concentration of I_2 . Conversely, at high CDCA:Dye ratios, J_{sc} trend 175 showed two maxima: i) at low [NaI] and [I₂], and ii) at high [NaI] and [I₂] values, 176 177 respectively. Also PCE values showed a peculiar trend, with high values obtained in the 178 presence of low I₂ and high NaI contents at medium-low CDCA:Dye ratios, while the 179 best PCE values resulted at high CDCA levels in the presence of low concentrations of 180 iodine species. This performance trend is basically related to the amount of dye molecules anchored at the surface of the TiO₂ electrode. Actually, at low dye loading 181 (high ratio CDCA:Dye), little amounts of iodide ions are sufficient for the regeneration 182 183 of the oxidized sensitizer molecules; conversely, at low CDCA:Dye ratios, increased 184 iodide concentration is required to enable the efficient reduction of Dye⁺ species.

Contour plots clearly show the advantages of the DoE approach in the rapid and 185 186 effective characterisation of an electrochemical power source, highlighting that device performance can be maximized by different combinations of the same experimental 187 parameters. Fig. 3 shows the J-V and Nyquist plots of N5 and N12, which are the two 188 189 best cells of the experimental matrix detailed in Table 1. Clearly, even if the two cells provided similar PCE values (1.05% and 0.90%, respectively), their figure of merits are 190 rather different. Indeed, cell N5 shows high J_{sc} , low V_{oc} , recombination resistance (R_{ct} = 191 192 82.5 Ω) and redox couple diffusion resistance ($R_d = 23.3 \Omega$) as expected for DSSCs based on liquid electrolytes containing high amount of iodine species; conversely, the 193

194 lower redox mediator content in cell N12 leads to lower J_{sc} , higher V_{oc} , R_{ct} (154 Ω) and 195 R_d (44.4 Ω).

In our opinion, the experimental conditions adopted for cell N12 are preferable than those of cell N5, since the use of lower amounts of dye and redox mediator would lower the final cost of the solar cell, without affecting the overall sunlight conversion efficiency.

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Fig. 3. (A) *J–V* curves and (B) corresponding Nyquist plots of aqueous DSSCs (N5 and N12 of Table 1) measured under 1 sun irradiation (AM 1.5G). Inset of B) represents the equivalent circuit used to fit experimental data.

205

206 **4.** Conclusions

A multivariate study of photoelectrode sensitization, electrolyte formulation and
interface phenomena in aqueous DSSCs has been proposed in this work. The proposed

approach enlightened that the concurrent evaluation of several experimental factors

210 affecting the overall performance is fundamental to support the researchers in finding

the optimal operating conditions of any new energy device with solid mathematical and

statistical bases (Ccorahua et al., 2017; D'Angelo et al., 2017; Feng et al., 2017; Miao et

al., 2017; Zhu et al., 2017). The lab-scale aqueous DSSCs, that were assembled based

- on the optimised parameters resulting for chemometrics, provided a reproducible $\approx 1\%$
- sunlight conversion efficiency without the addition of additives, and can therefore be
- used as a solid benchmark for future studies aimed at boosting its performance.
- 217

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- 221

222 **References**

Abdul Rani, R., Zoolfakar, A.S., Subbiah, J., Ou, J.Z., Kalantar-Zadeh, K., 2014.
Highly ordered anodized Nb₂O₅ nanochannels for dye-sensitized solar cells.
Electrochem. Commun. 40, 20-23.

Bella, F., Gerbaldi, C., Barolo, C., Grätzel, M., 2015. Aqueous dye-sensitized solar
cells. Chem. Soc. Rev. 44, 3431-3473.

Bella, F., Galliano, S., Falco, M., Viscardi, G., Barolo, C., Grätzel, M., Gerbaldi, C.,
2016. Unveiling iodine-based electrolytes chemistry in aqueous dye-sensitized solar
cells. Chem. Sci. 7, 4880-4890.

Bella, F., Popovic, J., Lamberti, A., Tresso, E., Gerbaldi, C., Maier, J., 2017. Interfacial
effects in solid-liquid electrolytes for improved stability and performance of dyesensitized solar cells. ACS Appl. Mater. Interfaces 9, 37797-37803.

Bella, F., Verna, A., Gerbaldi, C., 2018. Patterning dye-sensitized solar cell
photoanodes through a polymeric approach: A perspective. Mater. Sci. Semicond.
Process. 73, 92-98.

Buraidah, M.H., Shah, S., Teo, L.P., Chowdhury, F.I., Careem, M.A., Albinsson, I.,
Mellander, B.-E., Arof, A.K., 2017. High efficient dye sensitized solar cells using
phthaloylchitosan based gel polymer electrolytes. Electrochim. Acta 245, 846-853.

Ccorahua, R., Troncoso, O.P., Rodriguez, S., Lopez, D., Torres, F.G., 2017. Hydrazine
treatment improves conductivity of bacterial cellulose/graphene nanocomposites
obtained by a novel processing method. Carbohydr. Polym. 171, 68-76.

- Click, K.A., Schockman, B.M., Dilenschneider, J.T., McCulloch, W.D., Garrett, B.R.,
 Yu, Y., He, M., Curtze, A.E., Wu, Y., 2017. Bilayer dye protected aqueous
 photocathodes for tandem dye-sensitized solar cells. J. Phys. Chem. C 121, 8787-8795.
- D'Angelo, A.J., Panzer, M.J., 2017. Enhanced lithium ion transport in poly(ethylene
 glycol) diacrylate-supported solvate ionogel electrolytes via chemically cross-linked
 ethylene oxide pathways. J. Phys. Chem. B 121, 890-895.
- Daeneke, T., Uemura, Y., Duffy, N.W., Mozer, A.J., Koumura, N., Bach, U., Spiccia,
 L., 2012. Aqueous dye-sensitized solar cell electrolytes based on the ferricyanideferrocyanide redox couple. Adv. Mater. 24, 1222-1225.
- Dong, C., Xiang, W., Huang, F., Fu, D., Huang, W., Bach, U., Cheng, Y.B., Li, X.,
 Spiccia, L., 2014. Controlling interfacial recombination in aqueous dye-sensitized solar
 cells by octadecyltrichlorosilane surface treatment. Angew. Chem. Int. Ed. 53, 69336937.
- Ellis, H., Jiang, R., Ye, S., Hagfeldt, A., Boschloo, G., 2016. Development of high
 efficiency 100% aqueous cobalt electrolyte dye-sensitised solar cells. Phys. Chem.
 Chem. Phys. 18, 8419-8427.
- Fabregat-Santiago, F., Bisquert, J., Garcia-Belmonte, G., Boschloo, G., Hagfeldt, A.,
 2005. Influence of electrolyte in transport and recombination in dye-sensitized solar
 cells studied by impedance spectroscopy. Sol. Energy Mater. Sol. Cells 87, 117-131.
- Fan, K., Yu, J., Ho, W., 2017. Improving photoanodes to obtain highly efficient dyesensitized solar cells: A brief review. Mater. Horiz. 4, 319-344.
- Feng, X., Yang, Z., Chmely, S., Wang, Q., Wang, S., Xie, Y., 2017. Lignin-coated
 cellulose nanocrystal filled methacrylate composites prepared via 3D stereolithography
 printing: Mechanical reinforcement and thermal stabilization. Carbohydr. Polym. 169,
 272-281.
- Galliano, S., Bella, F., Gerbaldi, C., Falco, M., Viscardi, G., Grätzel, M., Barolo, C.,
 2017. Photoanode/electrolyte interface stability in aqueous dye-sensitized solar cells.
 Energy Tech. 5, 300-311.
- 271 Gianotti, V., Favaro, G., Bonandini, L., Palin, L., Croce, G., Boccaleri, E., Artuso, E.,
- 272 Van Beek, W., Barolo, C., Milanesio, M., 2014. Rationalization of dye uptake on titania
- slides for dye-sensitized solar cells by a combined chemometric and structural approach.
 ChemSusChem 7, 3039-3052.

- Imperiyka, M., Ahmad, A., Hanifah, S.A., Bella, F., 2014. A UV-prepared linear
 polymer electrolyte membrane for dye-sensitized solar cells. Physica B 450, 151-154.
- Kennard, R.W., Stone, L.A., 1969. Computer aided design of experiments.
 Technometrics 11, 137-148.
- Leandri, V., Ellis, H., Gabrielsson, E., Sun, L., Boschloo, G., Hagfeldt, A., 2014. An
 organic hydrophilic dye for water-based dye-sensitized solar cells. Phys. Chem. Chem.
 Phys. 16, 19964-19971.
- Li, C.T., Lin, R.Y.Y., Lin, J.T., 2017. Sensitizers for aqueous-based solar cells. Chem.
 Asian J. 12, 486-496.
- Lin, R.Y.Y., Wu, F.L., Li, C.T., Chen, P.Y., Ho, K.C., Lin, J.T., 2015. Highperformance aqueous/organic dye-sensitized solar cells based on sensitizers containing triethylene oxide methyl ether. ChemSusChem 8, 2503-2513.
- Liu, X., Gao, L., Yue, G., Zheng, H., Zhang, W, 2017. Efficient dye-sensitized solar
 cells incorporating hybrid counter electrode of CuMnSnS₄ microsperes/carbon
 nanotubes. Sol. Energy 158, 952-959.
- Maçaira, J., Andrade, L., Mendes, A., 2017. Highly efficient SiO₂/TiO₂ composite
 photoelectrodes for dye-sensitized solar cells. Sol. Energy 158, 905-916.
- Mathew, A., Anand, V., Rao, G.M., Munichandraiah, N., 2013. Effect of iodine
 concentration on the photovoltaic properties of dye sensitized solar cells for various
 I₂/LiI ratios. Electrochim. Acta 87, 92-96.
- McConnell, I., Li, G., Brudvig, G.W., 2010. Energy conversion in natural and artificial
 photosynthesis. Chem. Biol. 17, 434-447.
- Mengal, N., Arbab, A.A., Sahito, I.A., Memon, A.A., Sun, K.C., Jeong, S.H., 2017. An
 electrocatalytic active lyocell fabric cathode based on cationically functionalized and
 charcoal decorated graphite composite for quasi-solid state dye sensitized solar cell. Sol.
 Energy 155, 110-120.
- 301 Miao, L., Shi, B., Stanislaw, N., Mu, C., Qi, K., 2017. Facile synthesis of hierarchical
- ZnO microstructures with enhanced photocatalytic activity. Mater. Sci. Poland 35, 45 49.
- Miccoli, B., Cauda, V., Bonanno, A., Sanginario, A., Bejtka, K., Bella, F., Fontana, M.,
 Demarchi, D., 2016. One-dimensional ZnO/gold junction for simultaneous and versatile
 multisensing measurements. Sci. Rep. 6, art. no. 29763.
- Mohan, K., Dolui, S., Nath, B.C., Bora, A., Sharma, S., Dolui, S.K., 2017. A highly stable and efficient quasi solid state dye sensitized solar cell based on polymethyl methacrylate (PMMA)/carbon black (CB) polymer gel electrolyte with improved open airquit voltage. Electrochim. Acta 247, 216, 228
- 310 circuit voltage. Electrochim. Acta 247, 216-228.

Park, K.H., Dhayal, M., 2015. Simultaneous growth of rutile TiO₂ as 1D/3D
nanorod/nanoflower on FTO in one-step process enhances electrochemical response of
photoanode in DSSC. Electrochem. Commun. 49, 47-50.

Paušová, Š., Kment, S., Zlámal, M., Baudys, M., Hubicka, Z., Krýsa, J., 2017.
Transparent nanotubular TiO₂ photoanodes grown directly on FTO substrates.
Molecules 22, art. no. 775.

- Subramanian, S.C., Velayudhan, M.M., Narayanapillai, M., 2017. Oxa-bridged donoracceptor systems containing triazine core for dye sensitized solar cell application.
 Chemist 90, 23-31.
- Vekariya, R.L., Vaghasiya, J.V., Dhar, A., 2017. Coumarin based sensitizers with orthohalides substituted phenylene spacer for dye sensitized solar cells. Org. Electron. 48,
 291-297.
- Xiang, W., Huang, F., Cheng, Y.B., Bach, U., Spiccia, L., 2013. Aqueous dyesensitized solar cell electrolytes based on the cobalt(II)/(III) tris(bipyridine) redox couple. Energy Environ. Sci. 6, 121-127.
- Yang, C.C., Yu, Y.H., Van Der Linden, B., Wu, J.C.S., Mul, G., 2010. Artificial
 photosynthesis over crystalline TiO₂-based catalysts: fact or fiction? J. Am. Chem. Soc.
 132, 8398-8406.
- Yang, W., Söderberg, M., Eriksson, A.I.K., Boschloo, G., 2015. Efficient aqueous dyesensitized solar cell electrolytes based on a TEMPO/TEMPO⁺ redox couple. RSC Adv.
 5, 26706-26709.
- Zhu, J., Maza, W.A., Morris, A.J., 2017. Light-harvesting and energy transfer in
 ruthenium(II)-polypyridyl doped zirconium(IV) metal-organic frameworks: a look
 toward solar cell applications. J. Photochem. Photobiol., A 344, 64-77.