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Novel planar binuclear zinc phthalocyanine sensitizer for dye-sensitized solar cells: Synthesis and spectral, electrochemical, and photovoltaic properties



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HIGHLIGHTS

- APC and bi-NPC were designed for use in dyes-sensitized solar cells.
- Bi-NPC was synthesized based on Schiff base.
- Schiff base could form coplanar condition between mononuclear phthalocyanines.
- Bi-NPC shows the higher absorbance, the better red shift and performance.

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Introduction

As one of the most promising methods for future low cost power production from renewable energy sources, DSSCs have the outstanding advantage of high light-to-electricity conversion efficiencies and easy fabrication [1]. The absorption properties of dyes dictate the light-harvesting capacity of DSSCs, since the light absorption function is fulfilled by the dye and the electron and hole

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G R A P H I C A L A B S T R A C T



ABSTRACT

A planar binuclear zinc phthalocyanine was newly synthesized for use in dye-sensitized solar cells, based on Schiff base and asymmetric amino zinc phthalocyanine. The novel compounds were characterized using FTIR, UV–Vis, ¹H NMR, cyclic voltammetry and elemental analysis. From the reduction and oxidation behavior, it is proved that APC and bi-NPC have negative LUMO levels and positive HOMO levels, satisfying the energy gap rule, and can be employed as sensitizers for dye-sensitized solar cells (DSSCs) applications.

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transportation are fulfilled by the nanocrystalline metal oxide and electrolyte. As a kind of functional material, the dye should be soluble in solvents that are compatible with the TiO₂ and favorable for absorption of a nonaggregated monolayer on the surface [2]. Phthalocyanine is a special dye pigment consisting of $18-\pi$ electronics and has a similarity with biological molecules chlorophyll and hemoglobin [3,4]. Strong Q band light absorption properties at around 700 nm and excellent chemical stability make phthalocyanine become a better choice as sensitizer using in DSSCs. In addition, as the characteristic of color is bright and structure could be modified, phthalocyanine is widely used in different areas, such

as photographic printing [5], photovoltaic cells [6–8], liquid crystals [9,10], photodynamic therapy [11–14], light-emitting diodes [15,16] and chemical sensors [17,18]. Phthalocyanines have various central metals and extended π -conjugation system and have been tested several decades as sensitizers of wide-band gap oxide semiconductors, as increasingly high incident photon-to-electric current conversion yields are obtained [19–23]. However, poor solubility of macrocycle in organic solvent, strong tendency to aggregation on the film surface, lack directionality in the excited state and easy electron recombination between injected electron in TiO₂ conduction band and oxidized dye hinder the incident photon-to-electric current conversion yields [2].

This paper concerns phthalocyanines in which polar were attached to the periphery together with an additional group to enhance solubility in organic solvents and Schiff base connect two asymmetric mononuclear phthalocyanines. A new planar binuclear zinc phthalocyanine (9(10), 9'(10'), 16(17), 16'(17'), 23(24), 23'(24')-(β -naphthyloxy)-2(3), 2'(3')-(1,4-methanamide phenvl) zinc phthalocyanine (bi-NPC)), based on Schiff base and extended π -conjugation concept connecting two mononuclear unsymmetrical phthalocyanines, and asymmetric amino zinc phthalocyanine (9(10), 16(17), 23(24)-(β-naphthyloxy)-2(3)-(amido) Zinc Phthalocyanine (APC)) have been designed and synthesized for the dyesensitized solar cells (Fig. 1). APC has three β -naphthyloxy groups to enhance the solubility of phthalocyanine in common organic solvent, reduced the aggregation and turned the LUMO level of phthalocyanine. Bi-NPC is made of two unsymmetrical amino zinc phthalocyanines connected on Schiff base reaction. Formyl groups of 1, 4-phthalaldehyde and the amino of asymmetric mononuclear phthalocyanines form the Schiff base. Schiff base could provide a coplanar condition between two mononuclear phthalocyanines [24]. As reagents in organic synthesis and liquid crystal materials, Schiff base compounds and their metal complexes containing imine or methylene amine groups (-RC=N-) have important application in medicine, catalysis, analytical chemistry, corrosion and photo chromic. Compared with general method of ordinary mononuclear phthalocyanine by changing substituent to enhance conjugate system, C=N bond of Schiff base connecting two mononuclear phthalocyanines could extend conjugation between the two mononuclear unsymmetrical phthalocyanines. To a certain extent, it integrates and arranges the phthalocyanine molecules. B-naphthyloxy could increase the bi-NPC solubility in DMF, on the other hand reduce accumulation between the phthalocyanine molecules based on the space steric hindrance. The synthesis and spectral, electrochemical and photovoltaic properties of these phthalocyanines based sensitizers are investigated.

Experimental

4-Nitro-phthalonitrile, 1,4-phthalaladehyde, β -naphthol, 1,8diazabicyclo[5,4,0]-undec-7-ene (DBU), 1-pentanol, N,N-Dimethylformamide (DMF), tetrahydrofuran (THF), Na₂S·9H₂O, CHCl₃, HAC, anhydrous K₂CO₃, anhydrous MgSO₄, anhydrous SiO₂ were purchased commercially. DMF, THF and CHCl₃ were dried and distilled by accustomed methods before use. All other solvents and chemicals used in this work were analytical grade and used without further purification. Column chromatography was performed on silica gel (200–300).

Synthesis

4-(β -Naphthyloxy) phthalonitrile (1)

Phthalonitrile derivative was prepared by similar method reported in the literature [25,26]. 4-Nitro-phthalonitrile (1.732 g, 0.01 mol) and β -naphthol (1.442 g, 0.01 mol) were added successively with stirring to dry DMF (30 ml). After dissolution, anhydrous K₂CO₃ (2 g, 0.014 mol) was added and the reaction mixture was stirred at 60 °C. Further anhydrous K₂CO₃ (1 g, 7 mmol) was added portion-wise after 2 h. Stirring vigorously for 28 h under nitrogen. Then the reaction mass was poured into 200 ml of cold



Fig. 1. The molecular formula of APC and bi-NPC.

water and stirred for 15 min. The precipitate was filtered, washed several times with cold water until the filtrate became neutral, and crystallized from EtOH–water to give the product as a pink, crystalline powder. Yield: 1.497 g, 55.4%, m.p. 127–128 °C. Infrared spectrophotometer (IR) (KBr), υ (cm⁻¹): 3086 (H–Ar), 2236 (–C \equiv N), 1258 (Ar–O–Ar), 1589, 1572 (Ar C=C). Nuclear magnetic resonance (¹H NMR) (DMSO- d_6) δ , ppm: 7.66–6.98 (m, 10H, Ar-H). Elemental analysis (Anal. Calc.) for C₁₈H₁₀N₂O: C 79.99, H 3.73, N 10.36, O 5,92; Found C 80.11, H 3.83, N 10.17, O 5.84.

9(10), 16(17), 23(24)-(β-Naphthyloxy)-2(3)-(nitryl) zinc phthalocyanine (NPC) (2)

4-Nitro-phthalonitrile (0.173 g, 1 mmol), 4-(β-naphthyloxy) phthalonitrile (0.811 g, 3 mmol), Zn(CH₃COO)₂ (0.22 g, 1 mmol) and a catalytic amount of DBU in dry 1-pentanol (30 ml) were heated at 160 °C with stirring under nitrogen for 24 h. After cooling to room temperature, the reaction mixture was precipitated by adding methanol. The product was separated by filtration as a blue solid which was washed several times with methanol and ethanol to remove any unreacted precursor and then dried in vacuo. The solid material was subjected to silica gel column chromatography and eluted with THF: benzene = 1:10 (v/v), and bluish color band was collected. The solvent was removed under reduced pressure to get the desired product. Yield: 0.424 g, 40.5%, m.p. > 200 °C. IR (KBr), v (cm⁻¹): 3068 (H–Ar), 1535, 1343 (Ar–NO₂), 1603, 1578, 1456 (C=C), 1232, 1098, 757. ¹H NMR (DMSO-*d*₆) δ, ppm: 8.64– 6.95 (m, 33H, Ar-H). Anal. Calc. for C₆₂H₃₃N₉O₅Zn: C 70.99, H 3.15, N 12.02, O 7.63; found C 70.98, H 3.14, N 12.03, O 7.59.

9(10), 16(17), 23(24)-(β-Naphthyloxy)-2(3)-(amido) Zinc Phthalocyanine (APC) (3)

9(10), 16(17), 23(24)-(β -Naphthyloxy)-2(3)-(nitryl) Zinc Phthalocyanine (NPC) (0.314 g, 0.3 mmol) and Na₂S·9H₂O (0.216 g, 0.9 mmol) were dissolved in dry THF (30 ml). The reaction mixture was heated at 66 °C with stirring under nitrogen for 24 h. After cooling to room temperature, the product was separated by filtration as a blue liquid. The solvent was removed under reduced pressure to get the desired product. The solid material was subjected to chloroform column. Yield: 0.273 g, 89.4%, m.p. > 200 °C. IR (KBr), v (cm⁻¹): 3345, 1580 (Ar–NH₂). ¹H NMR (DMSO-*d*₆) δ , ppm: 7.62–6.87 (m, 33H, Ar–H), 3.43 (s, 2H, N–H). Anal. Calc. for C₆₂H₃₅N₉O₃₋Zn: C 73.08, H 3.44, N 12.38, O 4.71; found C 73.05, H 3.41, N 12.25, O 4.69.

9(10), 9'(10'), 16(17), 16'(17'), 23(24), 23'(24')-(β-Naphthyloxy)-2(3), 2'(3')-(1,4-methanamide phenyl) zinc phthalocyanine (bi-NPC) (4)

9(10), 16(17), 23(24)-(β-Naphthyloxy)-2(3)-(amido) Zinc Phthalocyanine (APC) (0.204 g, 0.2 mmol), 1,4-phthalaladehyde (0.013 g, 0.1 mmol) and anhydrous MgSO₄ (0.012 g, 0.1 mmol) were dissolved in dry THF (30 ml). Then added a catalytic amount of HAC and the reaction mixture was heated at 66 °C with stirring under nitrogen for 24 h. After cooling to room temperature, the product was separated by filtration as a blue liquid. The solvent was removed under reduced pressure to get the desired product. The solid material was subjected to Al₂O₃ gel column chromatography and eluted with THF: ethyl acetate = 6:1 (v/v). Then the product was washed several times with EtOH. Yield: 0.166 g, 77.8%, m.p. > 200 °C. IR (KBr), v (cm⁻¹): 1638 (C=N). ¹H NMR (DMSO-d₆) δ, ppm: 8.02–6.94 (m, 70H, Ar–H), 8.42 (s, 2H, C–H). Anal. Calc. for C₁₃₂H₇₂N₁₈O₆Zn₂: C 74.23, H 3.37, N 11.81, O 4.5; found C 74.18, H 3.25, N 11.78, O 4.47.

Characterization methods

The Fourier transform IR (FTIR) spectra of all the samples were measured using a Shimadzu 4800S spectrophotometer. The UV–Vis spectra of APC and bi-NPC were recorded with a Techcomp 2300 spectrophotometer. ¹H NMR spectra were recorded with a Varian Inova 400 MHz NMR system. Cyclic voltammetry measurements were performed on an electrochemical workstation (CHILK2005A, Tianjin Lanlike Chemistry electronic high-tech Co., Ltd., PR China). Cyclic voltammetry experiments were performed on 1×10^{-4} mol phthalocyanine dye solution in DMF at scan rate 100 mV/s using tetrabutylammonium perchlorate (0.1 mol/L) as supporting electrolyte. Cyclic voltammetry with a platinum wire was used as working electrode, the platinum as the counter film electrode, the calomel as the reference. Purge the solution with nitrogen for 1 h before the experiment.

Preparation dye-sensitized nanocrystalline TiO₂ thin films

TiO₂ photoelectrode (area: ca. 0.8 cm × 1.2 cm) was prepared by a similar method reported in the literature [27,28,31]. Nanocrystalline TiO₂ films of 6 μm thickness were deposited onto transparent conducting glass (which has been coated with a fluorine-doped stannic oxide layer, thickness of 4 mm, sheet resistance of 18–20 Ω). These films were dried at 150 °C for 20 min and then were gradually sintered at 500 °C for 20 min. The sensitizer was dissolved in ethanol at a concentration of 1×10^{-4} mol/L. The photoelectrode was dipped into the dye solution immediately after the high-temperature annealing and it was still hot (80 °C) and then kept at room temperature for 24 h so that the dye was adsorbed onto the TiO₂ films. After completion of the dye adsorption, the photoelectrode was withdrawn from the solution and washed thoroughly with ethanol to remove non-adsorbed dye under a stream of dry air or nitrogen.

Results and discussion

Design and synthesis

The synthesis of APC and bi-NPC were illustrated in the Scheme 1. 4-(β -Naphthyloxy) phthalonitrile **3** was prepared through the displacement reaction of 4-nitro-phthalonitrile **1** with β -naphthol **2** in DMF solution in a moderate yield. NPC was prepared through 4-(β -naphthyloxy) phthalonitrile **3** with 4-nitro-phthalonitrile **1** in 1-pentanol solution in the presence of DBU and metal salts. APC was prepared through NPC with Na₂S·9H₂O **4** in THF solution. Bi-NPC was prepared through APC with 1,4-phthalaldehyde **5** in THF solution and the presence of HAC.

UV-Vis measurements

Phthalocyanine has two characteristics of the absorption bands in UV-Vis area: B band and Q band. The B band (Soret band) were observed base on the transitions from the deeper π levels to the LUMO. The Q band observed was attributed to $\pi - \pi^*$ transitions from the highest occupied molecular orbital (HOMO) to the lowest unoccupied molecular orbital (LUMO) of the conjugated macrocycle. Fig 2 shows the electronic absorption spectrum of APC and bi-NPC in DMF solution. The absorption spectrum in solution shows the characteristic absorptions of bi-NPC are 351 (B band) and 680 (O band) nm and the characteristic absorptions of APC are 342 (B band) and 672 (Q band) nm. Analysis of UV-Vis spectra shows that no evidence of aggregation in solution as demonstrated by a sharp unperturbed phthalocyanine Q band. Compared with APC in equivalent environment, the bi-NPC shows the higher absorbance and the better red shift. Owing to Schiff base group in bi-NPC integrated the two mononuclear phthalocyanines, it makes the phthalocyanine possess superior arrangement. According to the Eq. (1), E_{0-0}



Scheme 1. (1) K₂CO₃, DMF; (2) DBU, 1-pentanol, Zn(CH₃COO)₂; (3) THF, Na₂S·9H₂O; (4)THF, HAC.



Fig. 2. UV–Vis absorption spectra of bi-NPC (log ε = 5.29) and APC (log ε = 5.09) in DMF.

energy of APC and bi-NPC estimated from absorption maximum are 1.845 eV and 1.823 eV, respectively.

$$E_{0-0} = \frac{1240}{\lambda_{\max}} \tag{1}$$

 λ_{max} is the absorption maximum.

Phthalocyanines are known to form aggregation, which is due to the strong coupling between the molecules that causes either a red shift or a blue shift in the absorption band of the aggregate



Fig. 3. Absorption spectral changes of APC (log ε = 5.09) in DMF at different concentrations.

[29]. Aggregation is usually depicted as a coplanar association of rings progressing from monomer to dimer and higher order complexes and affects the shape of the Q band. It is dependent on the concentration, nature of the solvent, nature of the substituents, complex metal ions and temperature. In this study, the aggregation behavior of APC (Fig. 3) and bi-NPC (Fig. 4) complexes were investigated in different concentration in DMF. As the concentration was increased, the intensity of absorption of the Q band also increased and there were no new bands due to the aggregated species [30]. It



Fig. 4. Absorption spectral changes of bi-NPC ($\log \varepsilon = 5.29$) in DMF at different concentrations.

is seen that the Beer–Lambert law were obeyed for APC and bi-NPC for concentrations ranging from 0.9×10^{-5} to 0.15×10^{-5} mol/L.

Electrochemical measurements

The reduction and oxidation behavior of metallophthalocvanine derivatives is due to the interaction between the phthalocvanine ring and the central metal. First-row transition metal phthalocvanines differ from those of the main-group metal phthalocyanines. due to the fact that metal 'd' orbitals may be positioned between the HOMO and LUMO of the phthalocyanine ligand [32]. To get an efficient charge separation, the HOMO and LUMO levels of APC and bi-NPC match with the conduction-band-edge energy level of the TiO₂ and the redox potential of electrolyte for efficient electron injection and APC and bi-NPC regeneration. Cyclic and differential pulse voltammetric techniques in DMF solvent were used to investigate the electrochemical behaviors of APC and bi-NPC. Half-wave potentials $(E_{1/2})$ $(E_{ox} - E_{red})/2$ by cyclic voltammetry or peak potentials by differential pulse voltammetry determine the oxidation potentials. The corresponding cyclic and differential pulse voltammograms were presented in Fig. 5. The first oxidation potentials $(E_{1/2(ox)})$ correspond to the HOMO level of phthalocyanine. Quasi-reversible oxidation of APC exhibition is 0.96 V and bi-NPC exhibits a quasi-reversible oxidation at 0.83 V. With respect to dye-sensitization of wide-band gap semiconductors, e.g. TiO₂, the first oxidation potentials of APC and bi-NPC, and the E_{0-0}



Fig. 5. Cyclic and differential pulse voltammograms of APC and bi-NPC in DMF.

transition energy, the energy levels of the LUMO is determined respectively to be -0.88 V vs SCE and -0.99 V vs SCE. The LUMO is calculated according to the following equation.

$$LUMO = HOMO = E_{0-0} \tag{2}$$

The energy level of the conduction band edge of TiO_2 is ca. -0.74 V vs SCE [33]. This makes electron injection from the excited state of APC or bi-NPC into the conduction band of TiO_2 thermodynamically feasible. The HOMO levels of APC and bi-NPC are more positive than the energy level of the redox couple I^-/I_3^- (0.2 V vs SCE) in the electrolyte, indicating more efficient phthalocyanines regeneration by electron transfer from I^- . Fig. 6 shows the schematic energy diagram of APC and bi-NPC dye sensitized TiO_2 electrodes. APC and bi-NPC have negative LUMO levels and positive HOMO levels, satisfying the energy gap rule. This means that the APC and bi-NPC could be employed as sensitizers for DSSCs applications [30]. Bi-NPC has stronger electron injection than APC.

Photovoltaic characterization

The *I–V* curve of dye-sensitized solar cells is measured in sun outside the laboratory, and monochromatic incident photon-toelectron conversion efficiency (*IPCE*) and total photoelectric conversion efficiency (η) are the main evaluation parameter of DSSCs performance. They could be calculated following Eqs. (3)–(5).

$$IPCE = 1240 \left(\frac{I_{ph}}{\lambda P_{in}}\right) \tag{3}$$

where λ is the wavelength, I_{ph} is the photocurrent of the incident radiation (mA/cm²) and Pin is the incident radioactive flux (W/m²).

$$\eta \ [\%] = \frac{J_{SC} \ [\text{mA cm}^{-2}] V_{OC}[V] \times ff}{I_0 \ [\text{WM}^{-2}]} \times 100\%$$
(4)

where I_0 is the photon flux (e.g. 1000 W m⁻² for 1.0 sun), J_{SC} is the short-circuit photocurrent density under irradiation, V_{OC} is the open-circuit voltage, and *ff* represents the fill factor. The fill factor is defined by the following equation.

$$ff = \frac{J_{PH(\max)}V_{PH(\max)}}{J_{SC}V_{OC}}$$
(5)

where $J_{PH(max)}$ and $V_{PH(max)}$ are the photocurrent and photovoltage for maximum power output; J_{SC} and V_{OC} are the short-circuit photocurrent density and open-circuit photovoltage. Fig. 7 shows the *I*–*V* curves of APC and bi-NPC. We have observed an overall efficiency 0.905% under 1 sun irradiation. Table 1 shows the photoelectric properties of APC and bi-NPC.



Fig. 6. Energy level diagram for APC and bi-NPC.



Fig. 7. Photocurrent density-voltage characteristics for DSSCs based on APC and bi-NPC

Table 1

The photoelectric properties of APC and bi-NPC.

DSSCs	$J_{\rm sc}~({\rm mA~cm^{-2}})$	$V_{\rm oc} ({ m V})$	ff
APC bi-NPC	2.19 2.56	0.53 0.57	0.55
DI-INI C	2.50	0.57	0.02

Conclusion and perspectives

In conclusion, we have designed two new zinc phthalocyanines, APC and bi-NPC, based on extended π -conjugation concept and Schiff base. Compared with mononuclear phthalocyanine in furthermore, the bi-NPC shows the higher absorbance and the better red shift. Owing to chemical integration of mononuclear phthalocyanines, it makes the phthalocyanine possess superior arrangement. From the absorption spectrum, the reduction and oxidation behavior, it is proved that APC and bi-NPC possess intensive absorption in the far-red/near-IR region, the excited electron can be easily injected into the TiO₂ conduction and the oxidized state of dyes can easily get reduced by taking electron form redox electrolyte. The two sensitizers are promising in the development of DSSCs. For the future, performance of phthalocyanine-based TiO₂ solar cells, some other substituents that are asymmetrically should be incorporated into the phthalocyanine macrocycle.

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References

- [1] B. ORegan, M. Grätzel, Nature 353 (1991) 737.
- [2] J.J. He, G. Benkö, F. Korodi, T. Polívka, R. Lomoth, B. Akermark, L.C. Sun, A. Hagfeldt, V. Sundström, J. Am. Chem. Soc. 124 (2002) 4992.
- [3] Y. Chiba, A. Islam, Y. Watanabe, R. Komiya, N. Koide, L. Han, Jpn. J. Appl. Phys. 45 (2006) 638.
- [4] A. Filyasova, I. Kudelina, A. Feofanov, J. Mol. Struct. 565 (2001) 173. [5] D. Ingram, J. Bennett, J. Chem. Phys. 22 (1954) 1136.
- [6] P. Patel, Google Patents, 2011.
- [7] M.G. Walter, A.B. Rudine, C.C. Wamser, J. Porphyrins Phthalocyanines 14 (2010) 759.
- [8] T.-M. Kim, H.-S. Shim, M.-S. Choi, H.J. Kim, J.-J. Kim, ACS Appl. Mater. Interfaces 6 (2014) 4286.
- [9] K. Chauhan, P. Sullivan, J. Yang, T. Jones, J. Phys. Chem. C 114 (2010) 3304.
- [10] M. Ince, M.V. Martínez-Díaz, J. Barberá, T. Torres, J. Mater. Chem. 21 (2011) 1531.
- [11] E. Venuti, R.G. Della Valle, I. Bilotti, A. Brillante, M. Cavallini, A. Calo, Y.H. Geerts, J. Phys. Chem. C 115 (2011) 12150.
- [12] R. Bonnett, Chem. Soc. Rev. 24 (1995) 19.
- [13] M. Van Leeuwen, University of East Anglia, 2013.
- [14] P. Agostinis, K. Berg, K.A. Cengel, T.H. Foster, A.W. Girotti, S.O. Gollnick, S.M. Hahn, M.R. Hamblin, A. Juzeniene, D. Kessel, CA: A Cancer J. Clin. 61 (2011) 250.
- [15] F.C. Rossetti, L.B. Lopes, A.R.H. Carollo, J.A. Thomazini, A.C. Tedesco, M.V.L.B. Bentley, J. Controlled Release 155 (2011) 400.
- [16] Y.J. Bae, N.J. Lee, T.H. Kim, H. Cho, C. Lee, L. Fleet, A. Hirohata, Nanoscale Res. Lett. 7 (2012) 1.
- [17] Z. Deng, Z. Lü, Y. Chen, Y. Yin, Y. Zou, J. Xiao, Y. Wang, Solid-State Electron. 89 (2013) 22 [18] M.L. Rodríguez-Méndez, C. Apetrei, C. Medina-Plaza, R. Muñoz, J.A. de Saja,
- Multisensor Syst. Chem. Anal.: Mater. Sensors 5 (2014) 139. [19] B. Wang, X. Zuo, Y. Wu, Z. Chen, C. He, W. Duan, Sens. Actuators B: Chem. 152
- (2011) 191.
- [20] L. Yang, L. Guo, Q. Chen, H. Sun, H. Yan, Q. Zeng, X. Zhang, X. Pan, S. Dai, J. Mol. Graph. Modell. 38 (2012) 82.
- [21] X. Zhang, L. Mao, D. Zhang, L. Zhang, J. Mol. Struct. 1022 (2012) 153.
- [22] L. Mao, Q. Tan, G. Xin, M. Han, X. Zhang, Chin. J. Org. Chem. 32 (2012) 2315.
- [23] D. Zhang, X. Zhang, L. Zhang, L. Mao, Bull. Kor. Chem. Soc. 33 (2012) 1225. [24] C.B. Kc, K. Stranius, P. D'Souza, N.K. Subbaiyan, H. Lemmetyinen, N.V. Tkachenko, F. D'Souza, J. Phys. Chem. C 117 (2013) 763.
- [25] E. Fourie, J.C. Swarts, I. Chambrier, M.J. Cook, J. Gen. Chem. 62 (1992) 2064.
- [26] S.S. Erdem, I.V. Nesterove, S.A. Soper, R.P. Hammer, J. Org. Chem. 74 (2009)
- 9280.
- [27] C.J. Barbe, F. Arendse, P. Comte, M. Jirousek, F. Lenzmann, V. Shklover, M. Gratzel, J. Am. Chem. Soc. 80 (1997) 3157.
- [28] M.K. Nazeeruddin, F. De Angelis, S. Fantacci, A. Selloni, G. Viscardi, P. Liska, S. Ito, T. Bessho, M. Gratzel, J. Am. Chem. Soc. 127 (2005) 16835.
- [29] Z.S. Wang, K. Hara, Y. Dan-oh, C. Kasada, A. Shinpo, S. Suga, H. Arakawa, H. Sugihara, J. Phys. Chem. B 109 (2005) 3907.
- [30] M. Özcesmeci, Í. Ozcesmeci, E. Hamurvudan, Polyhedron 29 (2010) 2710.
- [31] M. Kandaz, N.U. Yaraşir Meryem, A. Koca, O. Bekaroğlu, Polyhedron 21 (2002) 255
- [32] A Hagfeldt M Grätzel Chem Rev 95 (1995) 49
- [33] C.Y. Li, X.C. Yang, R.K. Chen, J.X. Pan, H.N. Tian, H.J. Zhu, X.N. Wang, A. Hagfeldt, L.C. Sun, Sol. Energy Mater. Sol. Cells 91 (2007) 1863.