Contents lists available at ScienceDirect

Journal of Molecular Structure

journal homepage: www.elsevier.com/locate/molstruc

Synthesis, single crystal structure and photo-luminescent property of bipolar compounds containing 1,3,4-oxadiazole and carbazolyl units

Jie Han*, Yong-Heng Wei

Department of Chemistry, Nankai University, Tianjin 300071, PR China

ARTICLE INFO

Article history: Received 19 October 2009 Received in revised form 31 December 2009 Accepted 7 January 2010 Available online 14 January 2010

Keywords: 1,3,4-Oxadiazole Carbazole Bipolar charge transport Synthesis

ABSTRACT

Two bipolar molecules **1a** and **1b**, which incorporate both electron-transporting oxadiazole and holetransporting carbazolyl or *N*,*N*⁻dimethylphenyl moieties within the conjugation system, were synthesized and characterized by ¹H NMR, ¹³C NMR, elemental analysis and mass spectrometry. The molecular structure of compound **1a** was further confirmed by single X-ray crystallography. The solutions of both compounds in CH₂Cl₂ individually displayed two absorption bands with λ_{max} values at 376–378 nm and emitted with λ_{max} values at 478–479 nm and quantum yields of 0.61–0.63. The cyclic voltammograms results showed that the carbazole-containing compound **1a** has better hole injection ability than the *N*,*N*-dimethylphenyl end-capped **1b**.

© 2010 Elsevier B.V. All rights reserved.

1. Introduction

Ever since Tang and Van Slyke reported the first electroluminescent devices using organic compounds as emitters [1], development of organic light-emitting diodes (OLEDs) has been an active subject of academic and industrial research due to the potential use in displays [2,3]. To achieve high luminescence efficiency, the electron and hole currents in OLEDs should be balanced. To date, several ways have been successfully adopted to improve the carrier injection capability [4]. Generally, the most common method is to dope electron- and hole-transport materials, which results many layers in an OLED and make it sophisticated to make a device [5]. In order to avoid this drawback, another strategy – to incorporate the electron- and hole-transport moieties within a single molecule, was first suggested by Murray et al. who reported the first example of bipolar charge transport molecule N-(p-tolylamino)phenyl)-N'-(1,2-dimethylpropyl)-1,4,5,-8-naphthalenetetracarboxylic diimide (TAND) in 1996 [6]. From then on, there's an increasing interest in research in this field, because such materials covalently combining two kinds of functional subunits may reduce the layers in OLED [7-11], and also avoid the problem of phase separation occasionally encountered in using doping strategy [12].

Among many kinds of organic electron-transporting materials, 2,5-diaryl-1,3,4-oxadiazole derivatives have been intensively studied in fields of organic light-emitting diodes [13,14] and

E-mail address: hanjie@nankai.edu.cn (J. Han).

liquid crystals [15] due to their good thermal stability, high photoluminescence quantum yield and the electron-deficient nature of the oxadiazole moiety. In contrast, the triphenylamine derivatives have been proved to be excellent hole-transporting materials, which have shown a wide range of practical applications [16-18]. On base of the electronic nature of the 1,3,4-oxadiazole and triphenylamine units, it is possible to develop new bipolar charge organic compounds by rational combination of these two structural motifs, and an authoritative review was published by Hughes and Bryce in 2005 [19]. In recent years, there has been a growing interest in the development of 1,3,4-oxadiazole- and triphenylamine-containing compounds due to the potential application in OLEDs. Although quite a lot of low molecular weight organic molecules [20–24] and various organic complexes [25–29] of such kind of compounds have been reported in literature, the single X-ray crystal structures of the bipolar charge compounds are scarce [30,31], which makes it difficult to study the structure-property relations of this class of materials. Herein, we report the synthesis, single crystal structure and photophysical property of new bipolar molecules containing N,N'-dimethylphenyl and/or carbazolyl end-capped 2,5-diaryl-1,3,4-oxadiazole derivatives 1a and 1b, and the synthetic route as well as the reaction conditions is depicted in Scheme 1. In these compounds, the carbazolyl or *N*,*N*'-dimethylphenyl and 1,3,4-oxadiazole moieties connected with phenyl and ethynyl groups serve as hole- and electron-transporting functionalities, respectively, which are typical for the bipolar molecules. In addition, the whole compounds form a donor- π -acceptor system, which may also be used as molecular wire.





^{*} Corresponding author. Tel.: +86 22 2350 9933.

^{0022-2860/\$ -} see front matter © 2010 Elsevier B.V. All rights reserved. doi:10.1016/j.molstruc.2010.01.016



Scheme 1. Reagents and conditions: (1) 2-methyl-3-butyn-2-ol, Cul, Pd(PPh₃)₂Cl₂, PPh₃, triethylamine, tetrahydrofuran, r.t., 7 h; (2) sodium hydroxide, toluene, reflux, 2 h; (3) 9-(4-bromophenyl)carbazole, Cul, Pd(PPh₃)₂Cl₂, PPh₃, triethylamine, tetrahydrofuran, reflux 6 h; (4) Cul, Pd(PPh₃)₂Cl₂, PPh₃, triethylamine, tetrahydrofuran, 4-iodo-*N*,*N*⁻ dimethylaniline, reflux, 6 h.

2. Result and discussion

2.1. Synthesis and characterization

The starting material 2-(4-iodophenyl)-5-(4-N,N'-dimethylphenyl)-1,3,4-oxadiazole (**i**) was prepared according to the method reported by us [32]. 9-(4-Bromophenyl)carbazole was prepared according to the literature procedures [33]. All of the other chemicals were used as purchased from Aldrich. Tetrahydrofuran and triethylamine were dried over sodium metal and distilled under a N₂ atmosphere prior to use.

According to the standard Sonogashira coupling reaction procedures [34], the starting compound (i) reacted with 2-methyl-3-butyn-2-ol to afford the crude compound (ii), which was directly used in the following reaction without purification. The key intermediate compound (iii), namely 2-(4-ethynylphenyl)-5-(4-*N*,*N*'dimethylphenyl)-1,3,4-oxadiazole, was synthesized by refluxing the crude compound (ii) with sodium hydroxide in toluene. The final products **1a** and **1b** were prepared in good yields according to the similar procedure to that of compound (ii). The structures and purifications of **1a** and **1b** were characterized fully by ¹H NMR, ¹³C NMR, MS, HRMS and elemental analysis, the molecular structure of **1a** was further confirmed by the single X-ray crystallography.

2.2. X-ray crystal structure of compound 1a [35]

In order to investigate the relationship between the structures and spectroscopic and electrochemical behaviors of the target compounds, attempts were made to grow single crystals suitable for X-ray diffraction studies on the final molecules, and yellow plate-like crystals **1a** suitable for single crystal X-ray diffraction were obtained by slow evaporation of its CH₂Cl₂ solution at room temperature. The X-ray molecular structure with atomic number of **1a** is shown in Fig. 1. The dihedral angles between the oxadiazole ring and the benzene rings i and ii are 5.46°and 5.73°, respectively, while the angle between the benzene rings iii and iv is 12.89°. In particular a planar trigonal geometry is observed around the N amino atom, N1, as reported in other compounds bearing dialkylamino or diphenylamino groups [36]. The five-membered ring N1–C1–C6–C7–C12 is inclined by 63.83° to the benzene ring iii, due to steric repulsion form the phenyl iv and the phenyl groups in the carbazolyl moiety, which makes the overall molecule of **1a** to adopt a bent T-shape.

2.3. UV-vis absorption and photoluminescence spectra

The UV-vis absorption and photoluminescence spectra of compounds 1a and 1b in dichloromethane are depicted in Fig. 2, and the photophysical data are summarized in Table 1. Similar absorption pattern were observed in 1a and 1b, they both displayed a weak absorption band at λ_{max} = 284–287 nm and a strong absorption band at λ_{max} = 376–378 nm, which were corresponded to the π - π * transitions of the conjugated aromatic rings [37]. As seen in Fig. 2, both **1a** and **1b** were emissive at $\lambda_{max} = 478-479$ nm with emission quantum yields of 61% and 63%, respectively. From the maximum λ_{abs} , λ_{em} and the emission quantum yields of **1a** and **1b**, we can see that the terminal *N*,*N*-dimethylphenyl and carbazolyl groups influence the photophysical properties of 1a and 1b slightly. Notably, the Stokes shifts (102 nm for 1a and 101 nm for **1b**) are much larger than the analogous 1,3,4-oxadiazole-based compounds in literatures [38], which may be explained by a "push-pull effect" created by the strong electron-donating N,Ndimethylphenyl/carbazolyl groups and the electron-accepting oxadiazole moiety [39].

2.4. Electrochemical property

The cyclic voltammograms (CVs) of compounds **1a** and **1b** were shown in Fig. 3. The resulting data were also summarized in Table 2. As seen in Fig. 3, both **1a** and **1b** exhibited two



Fig. 1. Single crystal structure of 1a. Ellipsoids are drawn at 30% probability level.



Fig. 2. Normalized UV/vis absorption and emission spectra of 1a and 1b in CH_2Cl_2 at 298 K (concentration = 5×10^{-6} mol dm⁻³).

Table 1

Photophysical data for 1a and 1b in CH_2Cl_2 at 298 K (concentration = 5×10^{-6} mol $dm^{-3}).$

| Compound | $\lambda_{abs}/nm \ (\epsilon/dm^3 \ mol^{-1} \ cm^{-1})$ | $\lambda_{\rm em}/\rm nm$ | Φ |
|----------|---|---------------------------|--------|
| 1a | 287 (8230), 376 (31,200) | 478 | 0.61 |
| 1b | 284 (7150), 378 (31,600) | 479 | 0.63 |



Fig. 3. Cyclic voltammograms for **1a** and **1b** in DMF with 0.1 M TBAPF₆ as supporting electrolyte at scanning rate of 100 mV/s.

Table 2 Electrochemical data for compounds 1a and 1b.

| Compound | $E_{1/2red}^{3}$ | $E_{1/2red}^2$ | $E_{1/2red}^{1}$ | $E_{1/2 \text{ox}}^{1}$ | $E_{1/2 \text{ox}}^2$ |
|----------|------------------|----------------|------------------|-------------------------|-----------------------|
| 1a | -1.99 | -1.77 | -0.93 | 0.62 | 0.86 |
| 1b | - | -1.80 | -0.93 | 0.68 | 0.90 |

irreversible anodic oxidation couples, which could be attributed to the sequential removal of electrons from the dimethylamino or arylamine moieties at the molecular end, respectively. These results suggested that the oxadiazole derivatives containing the *N*,*N*-dimethylphenyl moieties underwent a stepwise oxidation process, and the second irreversible oxidation step may be due to the generation of either stable or electro-inactive ionic species [34]. Since the oxidation process is closely related with the removal of electrons (or the injection of the holes) from the HOMO of the compounds, the lower oxidation potentials for **1a** suggest a better hole injection ability than **1b**. When swept cathodically, two or three quasi-reversible reduction peaks were observed for **1a** and **1b**, respectively. These reduction waves might be associated with both the triple bonds and the oxadiazole ring [38]. The presence of the carbazolyl group on the molecular end made the electrochemical reduction much easier due to the delocalization of π -electrons in the carbazole ring system, so we could conclude that the carbazole-containing compound **1a** may be used to match the levels of the hole injection and/or transport layers more closely than **1b**.

3. Experimental

3.1. General

The nuclear magnetic resonance (NMR) spectra were recorded on a Bruker AVANCE 300 MHz DRX FT-NMR spectrometer using CDCl₃ as solvent and tetramethylsilane (TMS) as internal standard. Electron impact (EI) and high-resolution mass spectra (HRMS) were recorded by a Finnigan MAT 95 mass spectrometer. Elemental analyses were obtained on Yanaco CHN CORDER MT-3 elemental analyzer. UV/vis absorption spectra were measured using a Cary300 absorption spectrometer. Luminescence was measured using a VARIAN spectrometer. Cyclic voltammetric experiments were performed on an LK 2005 electrochemical analyzer at room temperature in nitrogen-purged DMF with 0.1 M TBAPF₆ as supporting electrolyte at scanning rate of 100 mV/s. The working electrode was a platinum disk, the assistant electrode was Ag/AgCl, and a saturated calomel electrode was used as reference electrode, calibrated against a Fc/Fc⁺ couple [40]. The onset potential was determined from the intersection of two tangents drawn at the rising and background current of the cyclic voltammogram.

3.2. Synthesis of the intermediate compound iii

A mixture of compound i (452 mg, 1 mmol), 2-methyl-3-butyn-2-ol (101 mg, 1.2 mmol), *bis*-(triphenylphosphine) palladium(II) chloride (0.01 mmol, 7 mg) and copper(I) iodide (0.01 mmol, 2 mg) in a solution of dry THF (20 mL) and triethyl amine (5 mL) was stirred at room temperature under nitrogen for 12 h. The reaction mixture was evaporated in vacuo and the solid residue was dissolved with CH₂Cl₂ (50 mL). The resultant solution was washed sequentially with aqueous sodium cyanide and brine, and dried over anhydrous MgSO₄, then the solution was filtered and the solvent was removed in vacuo to afford crude solid that was used directly to prepare the intermediate compound iii. To a methanolic solution (50 mL) of the as-formed compound ii was added sodium hydroxide (40 mg, 1 mmol). The reaction mixture was refluxed for 4 h and the solvent was removed by rotary evaporation. The solid residue was dissolved in CH₂Cl₂ (50 mL) and the solution was washed with distilled water and brine and dried over anhydrous MgSO₄. The crude solid was obtained by evaporation of solution, and then purified by flash column chromatography on silica gel (eluent: dichloromethane-ethyl acetate, 25: 1 v/v). The total yield of the two-step reaction was 78%. ¹H NMR (CDCl₃, 300 MHz): δ 8.07 (d, J = 8.57 Hz, 2H), 7.98 (d, J = 9.06 Hz, 2H), 7.62 (d, *J* = 8.57 Hz, 2H), 6.76 (d, *J* = 9.06 Hz, 2H), 3.24 (s, 1H), 3.07 (s, 6H) ppm; MS-EI (*m/z*, *I*%): 289 ([M]⁺ 86.47); HRMS-EI (*m/z*): 289.1215 (M⁺, requies 289.1215). ¹³C NMR (CDCl₃, 75 MHz): 165.65, 163.04, 152.57, 132.79, 128.52, 126.63, 125.08, 124.60, 111.72, 110.82, 93.04, 79.88, 40.19 ppm.

3.3. Synthesis of 2-(4-N,N'-dimethylphenyl)-5-{4-[-(2-(4-N,N'-dimethylamino)phenyl)ethynyl]Phenyl} -1,3,4-oxadiazole **1a**

A mixture of compound **iii** (0.5 mmol), *N*,*N*'-dimethyl-4-iodoaniline (0.5 mmol), CuI (10 mg), Pd(PPh₃)₂Cl₂ (20 mg) were dissolved in THF (10 ml) and TEA (10 ml). The solution was stirred at room temperature for 2 h and then heated to reflux for an additional 6 h. The mixture was evaporated to dryness, then the residual yellow solid was dissolved in DCM and column chromatographed (DCM: acetate = 25:1) to yield yellow solid (98 mg, 48%). mp 244–245 °C. ¹H NMR (CDCl₃, 300 MHz): δ 8.06 (d, *J* = 8.64 Hz, 2H), 7.98 (d, *J* = 9.08 Hz, 2H), 7.61 (d, *J* = 8.64 Hz, 2H), 7.98 (d, *J* = 9.08 Hz, 2H), 6.67 (d, *J* = 8.96 Hz, 2H), 3.07 (s, 6H), 3.01 (s, 6H) ppm; MS-EI (*m*/*z*, *I*%): 408 (M⁺, 100); HRMS-EI (*m*/*z*): 408.1950 (M⁺, requires 408.1950). ¹³C NMR (CDCl₃, 75 MHz): 165.45, 163.44, 152.54, 150.52, 133.07, 131.79, 128.50, 127.40, 126.64, 123.03, 111.95, 111.76, 111.08, 109.54, 93.94, 87.24, 40.31, 40.23 ppm. C₂₆H₂₄N₄O (408.50): calcd C, 76.45; H, 5.92; N, 13.72; found: C, 76.74; H, 5.66; N, 13.69.

Compound **1b** was prepared according to the similar procedures as **1a**.

2-(4-*N*,*N*⁻dimethylphenyl)-5-{4-[-(9-phenylcarbazole)ethynyl]phenyl}-1,3,4-oxadiazole **1b**: Yellow solid; 275 mg, yield 52%; mp 278–280 °C. ¹H NMR (CDCl₃, 300 MHz) δ: 8.15 (m, 4H), 8.00 (d, *J* = 9.08 Hz, 2H), 7.79 (d, *J* = 8.48 Hz, 2H), 7.72 (d, *J* = 8.52 Hz, 2H), 7.61 (d, *J* = 8.48 Hz, 2H), 7.44 (m, 4H), 7.31 (m, 4H), 6.78 (d, *J* = 9.08 Hz, 2H), 3.08 (s, 6H); MS-EI (*m*/*z*, *I*%): 530 (M⁺, 100); HRMS-EI (*m*/*z*): 530.2107 (M⁺, requires 530.2107). ¹³C NMR (CDCl₃, 75 MHz): δ 165.66, 163.14, 152.64, 140.68, 138.17, 133.40, 132.34, 128.57, 127.05, 126.79, 126.24, 126.11, 124.17, 123.77, 121.88, 120.54, 120.45, 111.79, 110.92, 109.89, 91.45, 89.80, 40.24 ppm. C₃₆H₂₆N₄O (530.63): calcd C, 81.49; H, 4.94; N, 10.56; found: C, 81.31; H, 5.06; N, 10.35.

Acknowledgements

This work was supported by a grant from the National Natural Science Foundation of China (No. 20772064) and the Open Project of State Key Laboratory of Supramolecular Structure and Materials (SKLSSM200908). The authors thank Dr. Nianyong Zhu for the single X-ray crystallographic measurements.

References

- [1] C.W. Tang, S.A. Vanslyke, Appl. Phys. Lett. 51 (1987) 913.
- [2] J.G.C. Veinot, T.J. Marks, Acc. Chem. Res. 38 (2005) 632.
- [3] J.C. Li, S.C. Blackstock, G.J. Szulczewski, J. Phys. Chem. B 110 (2006) 17493.
- [4] S. Oyston, C.S. Wang, G. Hughes, A.S. Batsanov, I.F. Perepichka, M.R. Bryce, J.H. Ahn, C. Pearson, M.C. Petty, J. Mater. Chem. 15 (2005) 194.
- [5] Y. Shirota, J. Mater. Chem. 10 (2000) 1.
- [6] B.J. Murray, J.E. Kaeding, W.T. Gruenbaum, P.M. Borsenberger, Jpn. J. Appl. Phys. 35 (1996) 5384.
- [7] Z.H. Li, M.S. Wong, H. Fukutani, Y. Tao, Org. Lett. 8 (2006) 4271.
- [8] H. Tsuji, C. Mitsui, Y. Sato, E. Nakamura, Adv. Mater. 21 (2009) 3776.
- [9] M. Guan, Z.Q. Bian, Y.F. Zhou, F.Y. Li, C.H. Huang, Chem. Commun. (2003) 2708.

- [10] L.-H. Chan, H.-C. Yuh, C.-T. Chen, Adv. Mater. 13 (2001) 1637.
- [11] L.-B. Li, S.-J. Ji, Y. Liu, Chin. J. Chem. 26 (2008) 595.
- [12] R. Pudzich, J. Salbeck, Synth. Met. 138 (2003) 21.
- [13] A.P. Kulkarni, C.J. Tonzola, A. Babel, S.A. Jenekhe, Chem. Mater. 16 (2004) 4556.
- [14] G. Hughes, M. Bryce, J. Mater. Chem. 15 (2005) 94.
- [15] (a) J. Han, X.-Y. Chang, L.-R. Zhu, Y.-M. Wang, J.-B. Meng, S.-W. Lai, S.S.-Y. Chui, Liq. Cryst. 35 (2008) 1379;
 (b) J. Han, X.-Y. Chang, Y.-M. Wang, J.-B. Meng, J. Mol. Struct. 937 (2009) 122;
- (c) J. Han, F.-Y. Zhang, Z. Chen, J.-Y. Wang, L.-R. Zhu, M.-L. Pang, J.-B. Meng, Liq. Cryst. 35 (2008) 1359.
- [16] S. Liu, X. Jiang, H. Ma, M.S. Liu, A.K.Y. Jen, Macromolecules 33 (2000) 3514.
- [17] Q. Tong, S. Lai, M. Chan, K. Lai, J. Tang, H. Kwong, C. Lee, S. Lee, Chem. Mater. 19 (2007) 5851.
- [18] K. Zhang, Y. Tao, C. Yang, H. You, Y. Zou, J. Qin, D. Ma, Chem. Mater. 20 (2008) 7324.
- [19] G. Hughes, M.R. Bryce, J. Mater. Chem. 15 (2005) 94.
- [20] Y. Tao, Q. Wang, C. Yang, K. Zhang, Q. Wang, T. Zou, J. Qin, D. Ma, J. Mater. Chem. 18 (2008) 4091.
- [21] N.-J. Xiang, Y. Xu, L.M. Leung, M.-L. Gong, Chem. J. Chinese U. 28 (2007) 2316.
 [22] K.-T. Wong, S.-Y. Ku, Y.-M. Cheng, X.-Y. Lin, Y.-Y. Hung, S.-C. Pu, P.-T. Chou, G.-
- H. Lee, S.-M. Peng, J. Org. Chem. 71 (2006) 456. [23] N.J. Xiang, T.H. Lee, M.L. Gong, K.L. Tong, S.K. So, L.M. Leung, Synth. Met. 156
- (2006) 270.
 [24] K.T. Kamtekar, C. Wang, S. Bettington, A.S. Batsanov, I.F. Perepichka, M.R. Bryce, J.H. Ahn, M. Rabinal, M.C. Petty, J. Mater. Chem. 16 (2006) 3823.
- [25] C.K.M. Chan, C.-H. Tao, H.-L. Tam, N. Zhu, V.W.-W. Yam, K.-W. Cheah, Inorg. Chem. 48 (2009) 2855.
- [26] H. Tang, H. Tang, Z. Zhang, J. Yuan, C. Cong, K. Zhang, Synth. Met. 159 (2009) 72.
- [27] Z. Xu, Y. Li, X. Ma, X. Gao, H. Tian, Tetrahedron 64 (2008) 1860.
- [28] N.-J. Xiang, T.H. Lee, L.M. Leung, S.K. So, J.-X. SHI, M.-L. Gong, Chem. J. Chinese U. 27 (2006) 808.
- [29] Z. He, W.-Y. Wong, X. Yu, H.-S. Kwok, Z. Lin, Inorg. Chem. 45 (2006) 10922.
- [30] H. Yu, Y. Huang, W. Zhang, T. Matsuura, J. Meng, J. Mol. Struct. 642 (2002) 53.
- [31] C.C. Chiang, H.-C. Chun, C.-S. Lee, M.-K. Leung, K.-R. Lin, K.-H. Hsieh, Chem. Mater. 20 (2008) 540.
- [32] J. Han, S.S.-Y. Chui, C.M. Che, Chem. Asian J. 1 (2006) 814.
- [33] F. Bellina, C. Calandri, S. Cauteruccio, R. Rossi, Eur. J. Org. Chem. (2007) 2147.
- [34] C. Wang, L. Pålsson, A.S. Batsanov, M.R. Bryce, J. Am. Chem. Soc. 128 (2006) 3789.
- [35] Crystal data for **1a**: $C_{36}H_{26}N_4O$, $M_r = 530.61$, Orthorhombic, P n a 2_1 . Crystal size: $0.4 \times 0.25 \times 0.2$ mm³, a = 10.841(2) Å, b = 10.504(2) Å, c = 28.378(5) Å, $\alpha = 90^\circ$, $\beta = 90^\circ$, $\gamma = 90^\circ$, V = 3231.5(10) Å³, Z = 4, T = 301(2) K, $\rho_{calcd} = 1.091$ g cm⁻³, $\mu_{Mo} = 0.067$ mm⁻¹, F(000) = 1112, total number of unique reflections 2539 ($R_{int} = 0.0502$). Numbers of parameters = 310, $R_1 = 0.0997$ and $wR_2 = 0.2683$. Crystallographic data (excluding structure factors) for **1a** have been deposited with the Cambridge Crystallographic Data Center as supplementary publication nos. CCDC: 602983. Copies of the data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (fax: (+44) 1223–336–033; e-mail: deposit@ccdc.cam.ac.uk).
- [36] A. Carella, A. Castaldo, R. Centore, A. Fort, A. Sirigu, A. Tuzi, J. Chem. Soc., Perkin Trans. 2 (2002) 1791.
- [37] T. Hadizad, J. Zhang, Z.Y. Wang, T.C. Gorjanc, C. Py, Org. Lett. 7 (2005) 795.
- [38] G. Hughes, D. Kreher, C. Wang, A.S. Batsanov, M.R. Bryce, Org. Biomol. Chem. 2 (2004) 3363.
- [39] M. Tachibana, S. Tanaka, Y. Yamashita, K. Yoshizawa, J. Phys. Chem. B 106 (2002) 3549.
- [40] C.J. Tonzola, M.M. Alam, W. Kaminsky, S.A. Jenekhe, J. Am. Chem. Soc. 125 (2003) 13548.