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Thiazolo[4,5-*d*]thiazole—a new domain for potential optoelectronic application

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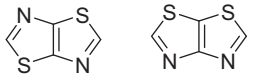
ABSTRACT

A novel heterocyclic moiety based on thiazolo[4,5-*d*]thiazole was prepared via a six-step synthesis from butane-2,3-dione. This thiazolothiazole compound was further derivatized to afford either neutral conjugated condensation products or analogous *N*-alkyl salts. The obtained derivatives represent dipolar structures expressed as A-π-D (push–pull compounds) as well as quadrupolar D-π-A-π-D structures. Both types of compound show intramolecular charge transfer and therefore could be suitable for nonlinear optical applications.

The search for new organic molecules with possible applications in optoelectronics is of considerable interest.[1] From the appropriate candidates, aromatic heterocycles provide strong potential advantages for several electro-optic and nonlinear-optic applications due to their suitable electronic structures and chemical, photochemical, and thermal stability.[2]

In continuation of our research in the field of new thiazole-based heterocycles with optical nonlinearities, we have studied the thiazolothiazole structural motif as an aromatic system with π-deficient acceptor capacity. Two isomeric thiazolothiazoles are possible, namely thiazolo[5,4-*d*]thiazole (**1a**) and thiazolo[4,5-*d*]thiazole (**1b**).



1a **1b**

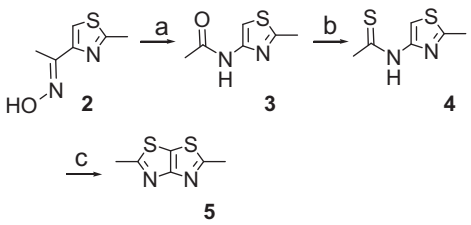
Compound **1a** and its substituted derivatives are functional materials used in the field of organic semiconductors.[3] Recent research showed that the thiazolothiazole system is a promising candidate as a core unit for high performance semiconductors.[4] Unlike more common derivatives of compound **1a** which have found practical optoelectronical applications, there is little known on the synthesis and properties of isomer **1b**.

Although several cyclic thiocarbamates with structures comprising the thiazolo[4,5-*d*]thiazole skeleton have been prepared,[5,6] only few fully aromatic derivatives of **1b** have been synthesized. One such example is 2,5-dichlorothiazolo[4,5-*d*]thiazole which was prepared by high temperature synthesis.[7] Starting from chloral amides some *p*-substituted 2,5-diphenylthiazolo[4,5-*d*]thiazoles were synthesized recently.[8]

In this Letter we report a six-step synthesis of 2,5-dimethylthiazolo[4,5-*d*]thiazole **5**, the product of its methylation, 2,3,5-trimethyl thiazolothiazolium iodide **8**, and some of their condensation products of the structural type A-π-D with a thiazolothiazole core or a 3-methylthiazolothiazolium core as an acceptor, a dimethylamino donor and an ethene or styrene linker.

Quantum chemical calculations[9] show isomer **1a** to be more stable by about 3 kJ/mol than **1b**. The *C*2h symmetry with a center of symmetry is the reason for the zero dipole moment of **1a**, while the dipole moment of isomer **1b** with C_{2v} symmetry equals 2.5×10^{-30} C.m. This electronic structure brings nonlinearity to molecule **1b** and its derivatives. The synthetic route to the target molecule is outlined in Scheme 1.

Starting oxime **2** was prepared by a known three-step synthesis from butane-2,3-dione.[10] The Beckmann rearrangement under the described conditions[11] was shown to be impractical due to the



Scheme 1. Reagents and conditions: (a) PCl_5, 1,4-dioxane, rt, 4 h, 73%; (b) Lawesson's reagent, THF, MW, 100 °C, 10 min, 88%; (c) $K_3[Fe(CN)_6]$, $NaOH/H_2O$/EtOH, rt, 82%.

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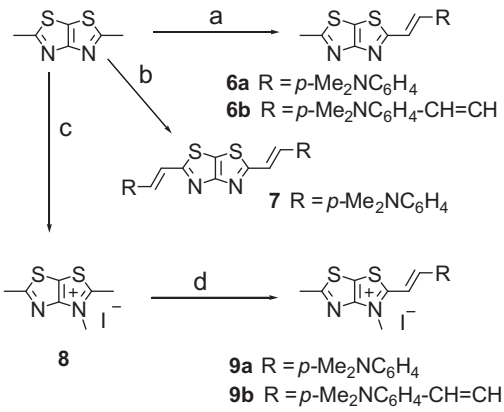

Scheme 2. Reagents and conditions: (a) RCHO, KOH, DMSO, rt, 2 h, **6a** (94%), **6b** (37%); (b) RCHO, NaH, THF, reflux, 2 h, 56%; (c) MeI, MeOH, MW, 100 °C, 15 min, 97%; (d) RCHO, MeOH, MW, 100 °C, 20 min, **9a** (66%), **9b** (75%).

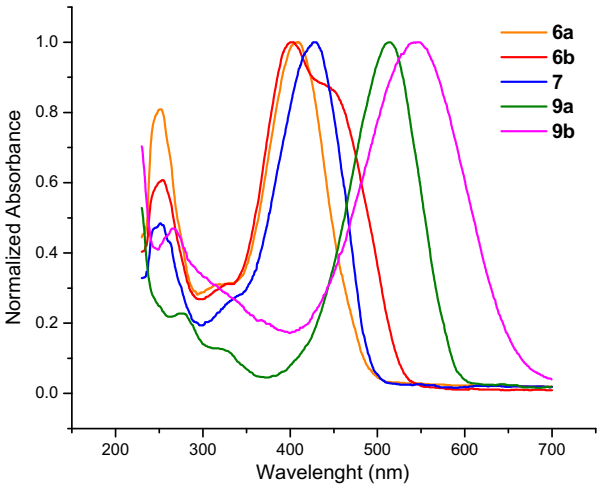

Figure 1. Normalized absorption spectra of the prepared conjugated thiazolo[4,5-*d*]thiazole derivatives.

reaction time 14 days, so we investigated other conditions. Neither a change of catalyst nor an elevated temperature satisfied the requirements. However, variation of the solvent led to a substantial decrease of the reaction time when cyclic ethers were used. 1,4-Dioxane was preferred over THF as the latter partially reacts with PCl_5 to form hard to separate chlorinated by-products. Amide **3** was converted into thioamide **4** using Lawesson's reagent under microwave conditions (100 °C, 3 bar, 10 min) and finally thiazolothiazole **5** was obtained in 82% yield via Jacobsen cyclization using aqueous potassium ferricyanide as the oxidant.[12] The total yield of **5** obtained by the sequence in Scheme 1 was 53%; when calculated from butane-2,3-dione the overall yield was 15%. The structure of the new heterocyclic system in **5** was confirmed by its ^{1}H NMR spectrum, when only one signal was evident (2.83 ppm for methyl groups) and especially by its ^{13}C NMR spectrum, where three different signals for aromatic carbons were observed (two small ones at 120.6 and 170.0 ppm for ring junction carbons and one more intense signal at 168.3 ppm typical for position 2 in a thiazole ring).

The potential of compound **5** to form conjugated systems suitable for nonlinear optical materials was demonstrated by further derivatization (Scheme 2). Due to the acidic character of the methyl groups this compound undergoes Knoevenagel-type reaction with aromatic aldehydes. Thus, the reaction with *p*-dimethylaminobenzaldehyde in DMSO catalyzed by KOH afforded product **6a** in 94% yield,[13] and with *p*-dimethylamino-cinnamyl aldehyde gave **6b** in 37% yield. Dimethylthiazolothiazole **5** reacted under these reaction conditions only on one side and the products represent a dipolar structure of type A-π-D. In order to prepare thiazolothiazoles derivatized on both sides, it was necessary to use a more powerful solvent and stronger base. Thus, **7** was synthesized from the same starting materials as **6a**, but using THF and 2 equiv of NaH instead of DMSO/KOH led to completion of the reaction. The condensation product **7** is considered as a type D-π-A-π-D structure; these are typical substances used for two-photon absorbance materials.

The acidity of the methyl group in **5** was enhanced by quaternization of the skeletal nitrogen forming a thiazolium salt. Methylation of **5** with iodomethane under microwave conditions (100 °C, 5 bar, 15 min) afforded almost quantitatively, 2,3,5-trimethyl thiazolothiazolium iodide **8**. This salt reacted with the aldehydes mentioned above and conjugated salts **9a** and **9b** were obtained in 66%[14] and 75% yields, respectively (Scheme 2). The structures of all the salts were confirmed by spectral methods.

The neutral compounds **6a** and **6b** with A-π-D architecture represent dipolar structures with intramolecular charge transfer (ICT) from the periphery D to heterocycle A. This fact results in an intense absorption band in the UV–vis spectra measured in $CHCl_3$. The position of the long wavelength maxima in **6a** and **6b** is very similar (about 400 nm), compound **6b** shows a higher extinction coefficient than **6a**.

The corresponding charge transfer from the dimethylamino group to the heterocycle is more effective in the thiazolothiazolium salts **9a** and **9b**. This effect results in an intense long wavelength band in the region above 500 nm (in methanol). The two double bonds in conjugated linker **9b** result in a bathochromic shift of the long wave band in comparison with the one double bond in **9a**. The absorption spectra shown in Figure 1 were measured in $CHCl_3$ for neutral compounds and in MeOH for the salts with the following parameters: λ_{max}/nm (log ε): **6a** 408 (4.30), **6b** 400 (4.48), **7** 428 (4.27), **9a** 514 (4.64), **9b** 546 (4.53).

Another type of structure with quadrupolar D-π-A-π-D is represented by compound **7**. The dipolar and/or quadrupolar structures of the prepared compounds together with the stable heterocyclic core make these products potential nonlinear optical (NLO) materials.

In summary, a new route to thiazolo[4,5-*d*]thiazole derivatives with alkyl substituents, based on Jacobsen cyclization has been developed. The products can be further derivatized by condensation reaction forming dipolar or quadrupolar conjugated molecules which are applicable as NLO materials.

Acknowledgment

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12. Compound **5**. To the stirred solution of $K_3[Fe(CN)_6]$ (20 mmol) in H_2O (25 mL), a suspension of **4** (0.861 g, 5 mmol) in 10% NaOH (18 mL) and EtOH (20 mL) was added dropwise, then the mixture stirred for 45 min at rt. The product was extracted with $CHCl_3$ (5×30 mL), the combined organic layer dried over Na_2SO_4, the solvent removed by evaporation and the crude product purified by column chromatography (silica gel, hexane/AcOEt 1:1) to give 0.697 g (82%) white solid, mp 100–101 °C. ^{1}H NMR (300 MHz, $CDCl_3$): 2.83 (s, 6H). ^{13}C NMR (75 MHz, $CDCl_3$): 170.0, 168.3, 120.6, 20.5. IR (ATR): 2919, 1508, 1405, 1377, 1368, 1167, 1128, 1119, 1073, 993 cm^{-1}. UV–vis (MeOH): λ_{max}/nm (log ε): 222 (4.30), 266 (3,86). HRMS: calcd for $C_6H_7N_2S_2$ $[M+H]^+$ 171.0045, found 171.0050.
13. Compound **6a**. To a solution of **5** (0.192 g, 0.7 mmol) and 4-dimethylaminobenzaldehyde (0.157 g, 1.05 mmol) in DMSO (3 mL) three drops of 50% KOH were added. The mixture was stirred for 3 h at rt, the precipitated solid filtered, washed with a small amount of cold MeOH and dried to give 0.201 g (94%) of **6a** as an orange solid mp 224–227 °C. ^{1}H NMR ((300 MHz, $CDCl_3$): 7.45 (d, J = 8.0 Hz, 2H), 7.41 (d, J = 16.2 Hz, 1H), 7.12 (d, J = 16.2 Hz, 1H), 6.70 (d, J = 8.0 Hz, 2H), 3.02 (s, 6H), 2.84 (s, 3H). IR (ATR): 3027, 2976, 2908, 2804, 1595, 1525, 1363, 1226, 1165, 945, 803 cm^{-1}. HRMS: calcd for $C_{15}H_{16}N_3S_2$ $[M+H]^+$ 302.0786, found 302.0798.
14. Compound **9a**. A solution of **8** (0.15 g, 0.48 mmol) and 4-dimethylaminobenzaldehyde (0.13 g, 0.906 mmol) in MeOH (2 mL) capped in a 5 mL vial was irradiated in a microwave reactor to 100 °C for 15 min with stirring. After cooling to rt the resulting dark solid was filtered, washed with cold MeOH, cold acetone and dried to give 0.14 g (66%) of **9a**, mp 229–230 °C. ^{1}H NMR (300 MHz, DMSO-d_6): 7.95 (d, J = 15.6 Hz, 1H), 7.84 (d, J = 8.7 Hz, 2H), 7.42 (d, J = 15.6 Hz, 1H), 6.81 (d, J = 8.7 Hz, 2H), 4.19 (s, 3H), 3.08 (s, 6H), 2.86 (s, 3H). ^{13}C NMR (75 MHz, DMSO-d_6): 175.0, 171.4, 155.4, 152.9, 145.9, 132.0, 121.6, 118.6, 111.9, 107.2, 39.8, 36.4, 20.2. IR (ATR): 2902, 1567, 1531, 1505, 1450, 1374, 1279, 1154, 941, 810, 794 cm^{-1}. HRMS: calcd for $C_{16}H_{18}N_3S_2^+$ $[M]^+$ 316.0937, found 316.0940.