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Fluorescent dyes with large Stokes shifts based on benzo[1,2-d:4,5-d']bis([1,3]dithiole) ("S^4-DBD dyes")

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Abstract: We report on a further development of [1,3]-dioxolo[4.5-f]benzodioxole (DBD) fluorescent dyes by replacement of the four oxygen atoms of the heterocyclic core by sulfur atoms. This variation causes striking changes of the photophysical properties. Whereas absorption and emission significantly shifted to longer wavelength, the fluorescence lifetimes and quantum yields are diminished compared to DBD dyes. The latter effect is presumably caused by an enhanced intersystem crossing to the triplet state due to the sulfur atoms. Especially the very large Stokes shifts of the S^4-DBD dyes ranging from 3000 cm^{-1} to 7400 cm^{-1} (67 nm to 191 nm) should be emphasized. By analogy with DBD dyes a broad variation of absorption and emission wavelength is possible by introducing different electron withdrawing substituents. Moreover, some derivatives for coupling with biomolecules were developed.

Introduction

The detection of luminescence is one of the most sensitive techniques for monitoring molecular events. Above all, countless applications in biology, biochemistry, and medicine have contributed to the popularity of this method.[1,2] Depending on the luminescence lifetime a distinction is made between the long-lived phosphorescence and the rather short-lived fluorescence. Besides inorganic materials (*e.g.* quantum dots) and luminescent metal ions (mainly lanthanides), small fluorescent organic molecules are utilized in luminescence applications. The suitability of a fluorescent dye for a specific application is influenced by an array of physical and chemical properties. Here the absorption maxima and emission wavelength (λ_{EX}, λ_{EM}), the fluorescence quantum yield (Φ_F), the molar attenuation coefficient (ε), the fluorescence lifetime (τ_F), the bleaching stability and two combinations of these properties, the Stokes shift ($\Delta\lambda = \lambda_{EM} - \lambda_{EX}$) and the brightness ($\varepsilon\Phi_F$) are of particular importance. A large Stokes shift minimizes self-quenching and scattered light in the context of biological imaging. Furthermore, fluorescent dyes possessing large Stokes shifts play an important role in super-resolution microscopy (*e.g.* STED).[3] There is no fluorescent dye exhibiting ideal properties in all these categories. Therefore, there is still a great need for new fluorescent dyes.

Some years ago, we discovered a new class of fluorescent dyes based on [1,3]-dioxolo[4.5-*f*]benzodioxole, which are called DBD dyes.[4] The outstanding features of these dyes are large Stokes shifts $\Delta\lambda$ (> 100 nm), long fluorescence lifetimes τ_F (> 20ns) and a large bleaching stability. Meanwhile, we developed numerous different applications, *e.g.* fluorescent probes for lipophilic environment in proteins[5a-d], biological membranes[5e], and *ds*DNA[5f]. Moreover, DBD dyes were used in various FRET pairs as acceptor[6a] or donor[6b-d].

A powerful and versatile class of fluorescent dyes is distinguished by a broad adaptability of physical and chemical properties to a specific application. This is mainly achieved by structural variation of the dye. Recently we demonstrated that absorption and emission wavelength of DBD dyes **1** can be varied over a broad spectral range by different electron withdrawing groups (R^1CO, R^2CO) in positions 4 and 8 of the aromatic core (Fig. 1).[4c] Another option for structural variation is the replacement of all oxygen atoms of the DBD core by sulfur atoms. From this we expect a distinct red-shift of absorption and emission wavelength. Herein we describe synthesis and properties of a new class of fluorescent dyes based on benzo[1,2-d:4,5-d']bis([1,3]dithiole). By analogy with DBD dyes we call these dyes S^4-DBD dyes **2** (Fig. 1).

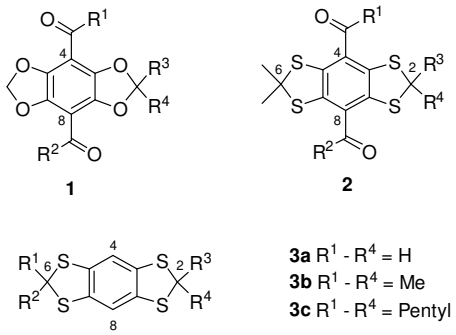


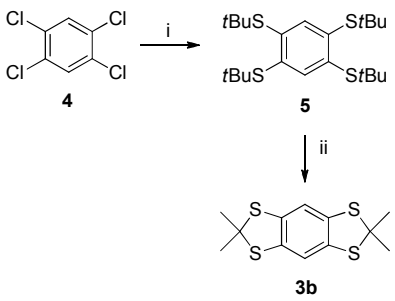
Figure 1. Structure of DBD dyes **1**, S^4-DBD dyes **2** and parent scaffold **3**

Results and Discussion

Synthesis of S^4-DBD dyes

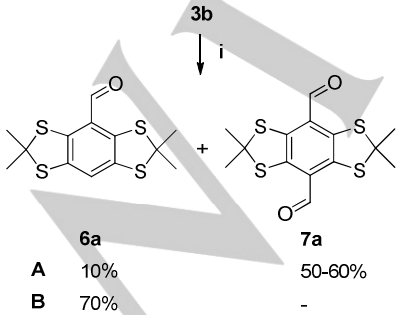
Benzo[1,2-d:4,5-d']bis([1,3]dithioles) (hereinafter S^4-DBD) were first mentioned in 1969 by Klemm and Geiger, whereby atoms 2 and 6 (*cf.* **3** in Fig. 1) were sp^2 hybridized and part of a C-C double bond.[7] Only nearly a quarter of a century later the parent compound **3a** was prepared by reduction of the corresponding

2,6-bisdithione,[8] obtained from the tetrathiol.[9] Bearing in mind the well known C-H acidity of thioacetals we hypothesized that 2,2,6,6-tetrasubstituted derivatives such as **3b** should be more suitable for functionalization of position 4 and 8. Compound **3b** was first mentioned in the patent literature. Already in 1982 Odorisio et al. reported on the preparation of S^4-DBD compounds by reductive dealkylation of 1,2,4,5-tetrakis-(ethylthio)benzene and acid-catalyzed reaction of the resulting 1,2,4,5-tetramercaptobenzene with aldehydes and ketones.[10] An improved two-step synthesis avoiding the isolation of 1,2,4,5-tetramercaptobenzene, which is sensitive to oxidation, was developed by Rawal and co-workers in 2002 and is summarized in Scheme 1.[11]



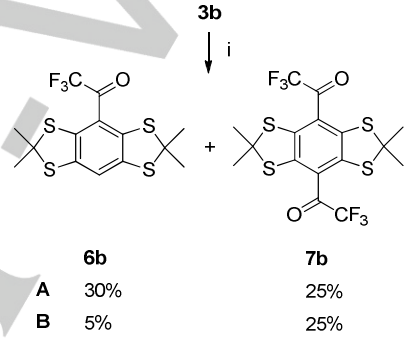
Scheme 1. Synthesis of compound **3b**. i *tert.*-BuSH, Na, DMF, 55-70%, ii HBF_4-Et_2O, acetone, toluene, rfx., 85%.

Starting with the commercially available 1,2,4,5-tetrachloro-benzene **4** 1,2,4,5-tetrakis(*tert.*-butylsulfanyl)benzene **5** is prepared with good yields by reaction with sodium *tert.*-butyl-thiolate. Simultaneous removal of *tert.*-butyl groups and acetalization with acetone afforded the target compound **3b**.
To introduce the electron-withdrawing groups in 4 and 8 position we first investigated the synthesis of monoaldehyde **6a** and dialdehyde **7a**. The latter is formed in good yields using 4 eq. *n*-BuLi in TMEDA/hexane and subsequent treatment with DMF by analogy with the previously published procedure for oxygen DBD dyes.[4c] In this case the monoaldehyde **6a** is only formed in traces (method A). The use of 4 eq. *tert.*-BuLi instead of *n*-BuLi gives similar yields.



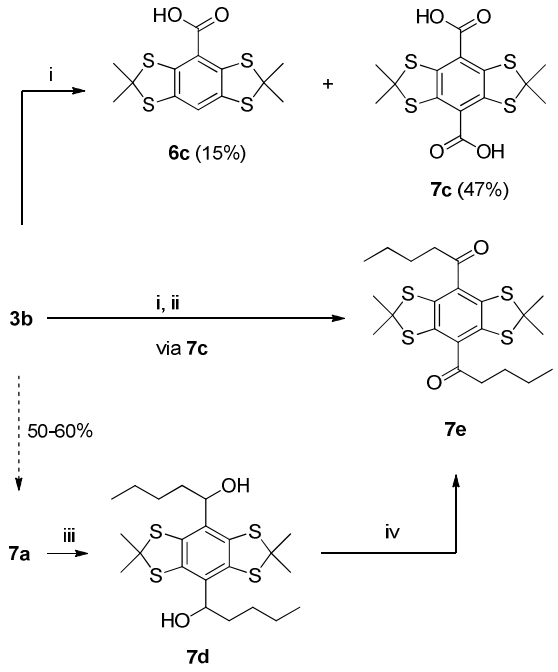
Scheme 2. Synthesis of aldehydes **6a**, **7a**. i method **A**: 1. 4 eq. *n*-BuLi, *n*-hexane, TMEDA, r.t., 3h or 4 eq. *tert.*-BuLi, *n*-hexane, TMEDA, r.t., 1h; 2. DMF. method **B**: 1. 2 eq. *n*-BuLi, Et_2O, r.t., 2 h, rfx.; 2. DMF.

The selective preparation of **6a** succeeded using 2.2 eq. *n*-BuLi in diethylether. Obviously, the presumably extremely basic dilithiated **3b** (vide infra) is only formed in hexane but immediately destroyed in ether (Scheme 2).
Next we attempted to prepare 4,8-diacyl derivatives in a similar manner. Unfortunately, the reaction of dilithiated **3b** with various Weinreb amides, acyl chlorides, and N,N-dimethylacetamide gave only traces of the target compounds together with small amounts of monoacyl derivatives. Obviously, the acylation reagents are rather deprotonated than attacked by a nucleophile due to the strong basicity of dilithiated **3b**. Furthermore, it is known that Weinreb amides can undergo an O-N bond cleavage if treated with strong bases.[12] This hypothesis is corroborated by the reaction with trifluoroacetic acid derivatives. Thus **3b** provided after lithiation both with N-methoxy-N-methyl-trifluoroacetamide and N,N-dimethyl-trifluoroacetamide 25% of the corresponding diketone **7b** besides varying amounts of monoketone **6b** (Scheme 3).

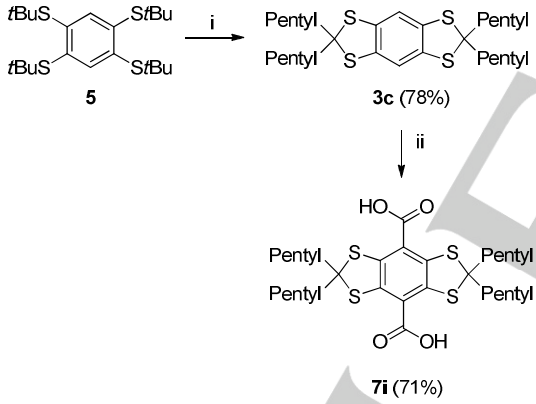


Scheme 3. Synthesis of trifluoromethylketones **6b**, **7b**. i: 1) 4 eq. *n*-BuLi, TMEDA, *n*-hexane, r.t., 3h; 2) method **A**: 4.5 eq. N-methoxy-N-methyl-trifluoroacetamide. method **B**: 4.5 eq. N,N-dimethyl-trifluoroacetamide.

Because a single-stage introduction of the acyl groups is seemingly difficult we investigated multistep routes. Thus, treatment of dilithiated **3b** with CO_2 afforded the dicarboxylic acid **7c** together with small amounts of monocarboxylic acid **6c**. Unfortunately, this compound is slightly soluble in any solvents and difficult to purify. Nevertheless, the 4,8-dipentanoyl-S^4-DBD dye **7e** was obtained from **7c** by reaction with *n*-BuLi, albeit with an unsatisfactory yield of 26%. We achieved significantly better results by treating the dialdehyde **7a** with *n*-BuLi to give the diol **7d**, followed by oxidation with Dess-Martin periodinane[13] (Scheme 4).
To circumvent the solubility problems of **7c** we investigate the synthesis of 2,2,6,6-tetrapentylsubstituted **3c** by acetalization of **5** with 6-undecanone. The corresponding dicarboxylic acid **7i** was prepared analogously to **7c** but in much better yields (Scheme 5). Compound **7i** is also much easier to purify as it is more soluble in most organic solvents in comparison to **7c**.
Treatment of dilithiated **3b** with ethyl chloroformate afforded diester **7f** apart from low quantities of monoester **6f**. The dinitrile **7h** was accessible from dialdehyde **7a** via dioxime **7g** in good yields (Scheme 6).



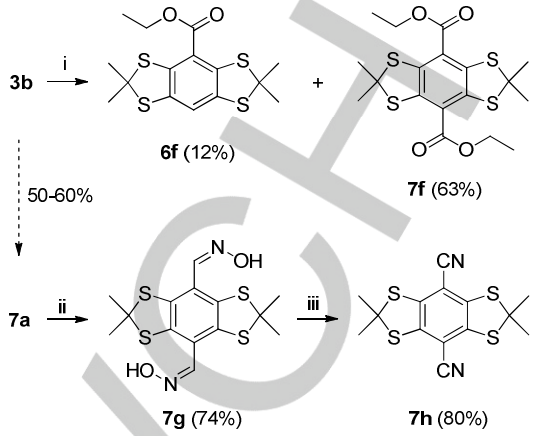
Scheme 4. Synthesis of acids **6c**, **7c** and 4,8-dipentanoyl-S^4-DBD dye **7e**. i 1) 4 eq. *n*-BuLi, TMEDA, *n*-hexane, r.t., 3h; 2) CO_2, -20°C. ii 8 eq. *n*-BuLi, *n*-hexane, 40°C, 26%. iii 4 eq. *n*-BuLi, neat TMEDA, r.t. 56%. iv Dess-Martin periodinane, DCM, 86%.



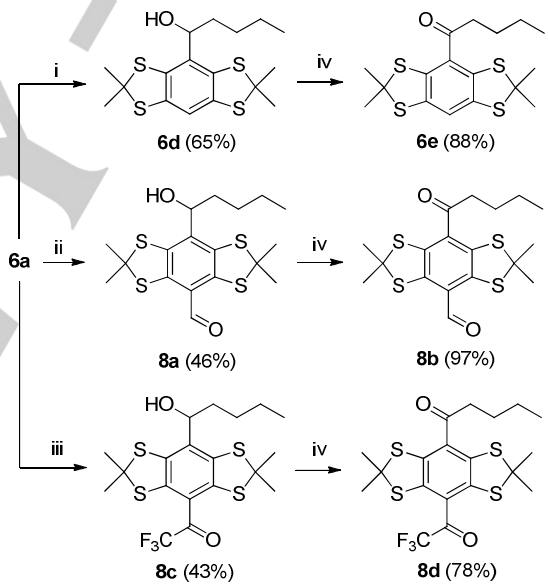
Scheme 5. Synthesis of carboxylic acid **7i**. i HBF_4-Et_2O, 6-undecanone, toluene, 3 h, rfx. ii 1) 3 eq. *tert*..-BuLi, TMEDA, *n*-hexane, r.t., 1h; 2) CO_2, -20°C.

Next we were interested in 4,8-asymmetrically disubstituted S^4-DBD dyes **8** (including monosubstituted compounds), because such dyes facilitate spectroscopic fine-tuning. In this context, we defined monoaldehyde **6a** as key intermediate due to its good accessibility (*cf.* Scheme 2, method **B**). By analogy with the preparation of diketone **7e** we obtained monoketone **6e** by oxidation of alcohol **6d**. Treatment of **6a** with an excess *n*-BuLi, followed by reaction either with DMF or the Weinreb amide of trifluoroacetic acid gave the alcohols **8a** or **8c**, which were subsequently oxidized to asymmetrical S^4-DBD dyes **8b,d** (Scheme 7).

For applications of fluorescent dyes, above all in the field of the biosciences, the presence of functional groups capable for coupling with biomolecules (*e.g.* peptides, proteins, lipids, nucleic acids) is indispensable.



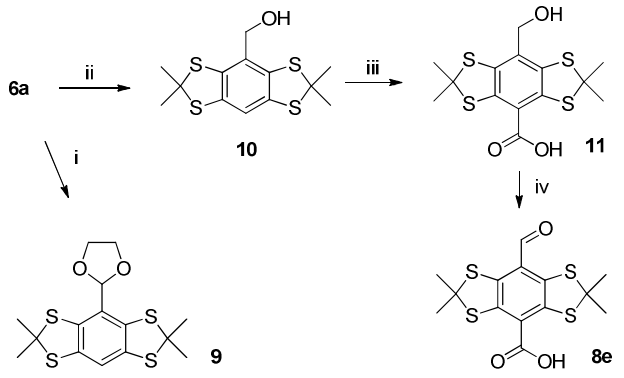
Scheme 6. Synthesis of esters **6e**, **7e** and dinitrile **7h**. i 1) 4 eq. *n*-BuLi, TMEDA, *n*-hexane, 3h, r.t.; 2) 6 eq. ethyl chloroformate, -70°C. ii 3 eq. NH_2OH, MeOH, 3 h, rfx. iii DMSO, Ac_2O.



Scheme 7. Synthesis of **6d,e** and **8a-d**. i 4 eq. *n*-BuLi, THF, r.t., 10 min. ii 1) 4 eq. *n*-BuLi, TMEDA, r.t., 3h; 2) 5 eq. DMF. iii 1) 4 eq. *n*-BuLi, TMEDA, r.t., 3h; 2) 4.5 eq. N-methoxy-N-methyl-trifluoroacetamide. iv Dess-Martin periodinane, DCM.

Based on our previous publications on DBD dyes two strategies have been proven to be successful: A) functionalization of one of the acyl groups in 4,8 position or B) functionalization of one of the acetal moieties. First we pursued the approach A. Starting again with monoaldehyde **6a** we protected the aldehyde group as dioxolane **9**. Although compound **9** was obtained with excellent yield it turned out to be extremely sensitive towards traces of acids and consecutive reactions with **9** failed. Instead of protection we now reduced the aldehyde to the primary alcohol **10** with nearly quantitative yield. The subsequent lithiation and carboxylation to acid **11** and oxidation to formyl-

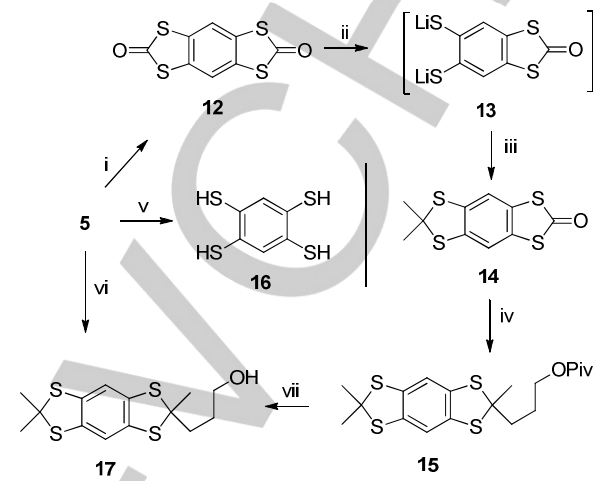
acid **8a** were successful but the yield for these two steps was unacceptably low (15%, Scheme 8).



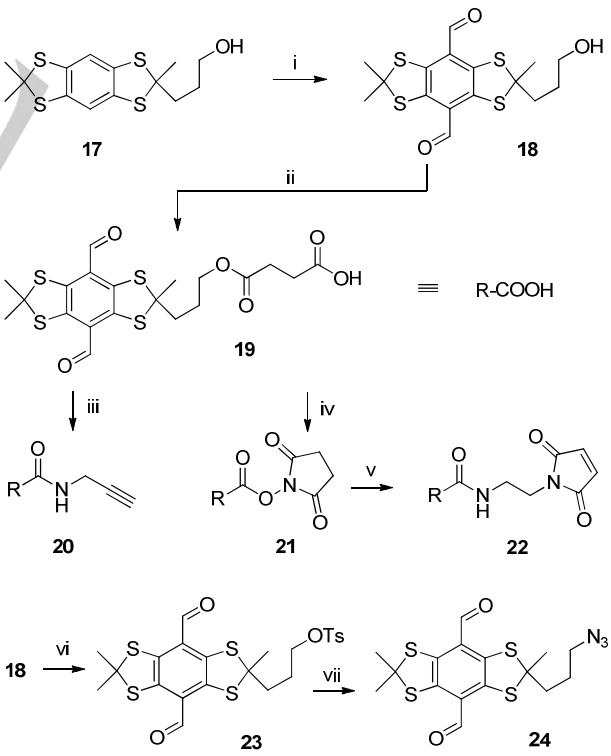
Scheme 8. Synthesis of **9**-**11** and **8e**. i 1.1eq. ethylene glycol, cat. TsOH, toluene, rfx, 3 h, 99%. ii $NaBH_4$, THF, 0°C, 30 min, 99%. iii 1. 3eq. *n*-BuLi, TMEDA, *n*-hexane, r.t., 3 h; 2. CO_2, 25%. iv $(COCl)_2$, DMSO, Et_3N, DCM, -78°C, 61%.

Therefore we discarded approach A and focused on approach B – the functionalization of one of the acetal moieties. First we were looking for a way to selectively introduce two different acetals. Already thirty years ago, the preparation of bis-dithiocarbonate **12** and the selective opening of one of the dithiolane rings upon treatment with alcoholates were described.[14] We applied this procedure to compound **5** and performed the abovementioned ring opening with LiOMe giving the intermediate **13**. Compound **14** was obtained after treatment with acetone in the presence of HBF_4 and BF_3. Repeating these steps with **25**[15] which was synthesized in one step from commercially available 5-hydroxy-pentan-2-one, afforded unsymmetrically substituted S^4-DBD compound **15**. Unfortunately, none of the three steps proceeded with significantly more than 50% yield. Alternatively, we investigated the direct route via the benzene-1,2,4,5-tetrathiol **16**.[16] This compound could be obtained from **5** and should be directly used due to its high oxidation sensitivity. It should be noted that **16** has been prepared for the first time by this way. **15** could be obtained from **16** directly only with erratic yields, probably due the oxygen-sensitive nature of **16**. So we studied the direct synthesis of **17** by preparing **16** in situ. Deprotection of **5** with HBF_4-Et_2O under inert conditions was followed by addition BF_3-Et_2O and successive treatment with **25** and acetone. **15** was afforded as an inseparable mixture with **3b**. Therefore the raw product was subjected to NaOH/MeOH to saponify the ester. The resulting polarity difference facilitated the separation of the desired alcohol **17** and the by-product **3b**. The overall yield from **5** was 30-34% and consequently this route should be preferred (Scheme 9).

The syntheses of bioreactive S^4-DBD dyes should be exemplarily demonstrated with S^4-DBD dialdehyde chromophore due to its outstanding photophysical properties (*vide infra*). First, alcohol **17** was converted to dialdehyde **18** by treatment with an excess *n*-BuLi followed by reaction with DMF. The subsequent reaction of **18** with succinic anhydride afforded carboxylic acid **19**, which was used for the preparation of three bioreactive S^4-DBD dyes: N-propargyl-amide **20** (for CuAAC with azides), N-hydroxy-succinimide ester **21** (reactive towards NH_2 groups), and maleimide **22** (reactive towards thiol groups). Furthermore the azide **24** was prepared from **18** via the tosylate **23** (Scheme 10).



Scheme 9. Synthesis of **17**. i 1. Na, pyridin, rfx. 3 h; 2. $COCl_2$, 55%. ii 2 eq. LiOMe, THF, 1 h. iii 4 eq. HBF_4/Et_2O, acetone, rfx., 4 h, 46%. iv 1. 2 eq. LiOMe, THF, 1h; 2. 3.5 eq. HBF_4/Et_2O, 2 eq. BF_3/Et_2O, 5-pivaloyloxy-pentan-2-one **25**, rfx, 4 h, 55%. v HBF_4/Et_2O, toluene, rfx., 1 d, 60%. vi 1. 2 eq. HBF_4/Et_2O, toluene, rfx, 3 h; 2. 2 eq. BF_3/Et_2O, 1eq. 25, r.t., 2h; 3. 1.5 eq. acetone, r.t., 2h, 4. NaOH, MeOH, rfx, 3 h, 30-34%. vii NaOH, MeOH, rfx, 3 h, 89%.



Scheme 10. Syntheses of bioreactive S^4-DBD dyes **19**-**22**, **24**. i 1. 6 eq. *n*-BuLi, TMEDA, r.t. 2 h; 2.7 eq. DMF, r.t. 1 h, 38%. ii 5 eq. succinic anhydride, 10 eq. pyridine, cat. DMAP, r.t., 16 h, 87% iii 4 eq. propargylamine, 1.5 eq. DCC, cat. N-hydroxysuccinimide (HOSu), DCM, r.t., 5h, 74%. iv 1.1eq. HOSu, 1.1 eq. DCC, cat. DMAP, DCM, r.t., 16h, 83%. v 21, 1.5 eq. N-(2-

aminoethyl)maleimide trifluoroacetate **32**, 2 eq. DIPEA, DCM, r.t., 16h, 85%. vi 2eq. TsCl, 4eq. pyridine, cat. DMAP, DCM, rfx., 3 h, 64%. vii 2 eq. NaN_3, DMF, r.t., 16h, 92%.

The X-ray crystal structure of **7a** is depicted in fig. 2. The most striking difference between this structure and the previously published structure of DBD dyes[4a] lies in the strongly folded dithiole rings, whereas the dioxole rings in DBD dyes are virtually planar. The angle between the π-plane (green) and the parallel planes defined by the sulfur atoms and the acetal C-atom (red) amounts to about 31°.

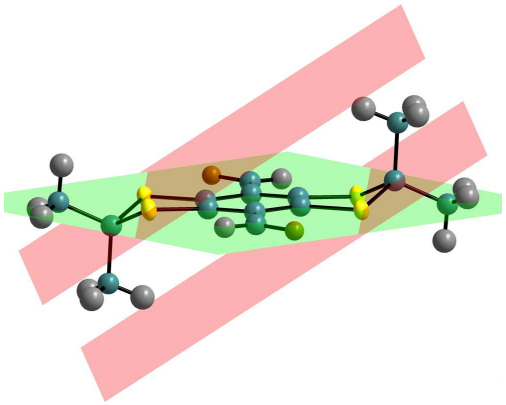


Figure 2. X-ray crystal structure of **7a** (π-plane: green, S-C-S planes: red).

Consequently, two of the four methyl groups are nearly perpendicular on the π-plane (angles between the normal of the π-plane and Me-C bonds are only 4.9°). However, the activation barrier of the ring flip should be very low based on NMR (only one signal for the methyl groups at 1.93 ppm) and molecular modeling (E_A = 1.6 kcal/mol, see the SI).

Photophysical properties of S^4-DBD dyes

The photophysical properties of S^4-DBD dyes in ethanol are summarized in table 1 (for other solvents see the SI). The absorption wavelength of compounds **6** with one electron withdrawing group range from 390 to 444 nm and the corresponding emission wavelength from 469 to 606 nm. If a second acceptor is introduced (**7**, **8**) both absorption and emission wavelength are considerably red-shifted. A special behavior is observed with carboxylic acids **7c**, **7i**, and **8e**. In these cases the absorption wavelength shows a remarkable concentration dependency, which is exemplarily depicted in fig. 3 for compound **8e**. Similar phenomena are known for other carboxylic acids[18] and arise from intermolecular hydrogen bonds between carboxyl groups.

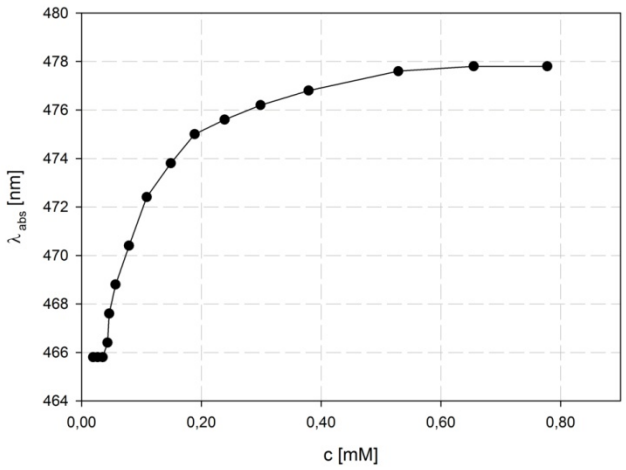


Figure 3. Concentration dependency of absorption wavelength of λ_{abs} of **8e**.

Table 1. Photophysical data of S^4-DBD dyes **6**-**8** (in EtOH)

	R^1	R^2	λ_{ABS} [nm]	λ_{EM} [nm]	$\Delta\lambda$ [nm]	$\Delta\tilde{\nu}$ [10^3 cm^{-1}]	τ_F [ns]	Φ_F [%]	ε [10^3 $M^{-1}cm^{-1}$]
6a	CHO	-	444	606	162	6.02	2.2	4.5	5.39
6b	$COCF_3$	-	442	616	174	6.39	2.8	1.1	1.21
6c	COOH	-	390	469	79	4.32	<1	0.4	3.27
6e	COBu	-	405	556	151	6.71	1.5	3.5	3.16
6f	COOEt	-	396	482	86	4.51	<1	1.1	3.69
7a	CHO	-	526	665	139	3.97	3.4	8.4	1.58
7c	COOH	-	421[a]	537	116	5.13	2.6	3.0	4.73
7e	COBu	-	421	612	191	7.41	3.5	6.2	3.01
7f	COOEt	-	430	550	120	5.07	2.9	13.7	4.64
7h	CN	-	443	510	67	2.97	1.3	0.9	4.11
7i	COOH	-	429[b]	531	102	4.48	3.3	7.2	4.79
8b	COBu	CHO	463	639	176	5.95	3.0	7.5	4.60
8e	COOH	CHO	476[c]	632	156	5.19	2.8	2.6	2.11

[a] c = 1.3 mM; [b] c = 1.7 mM; [c] c = 0.24 mM (absorption wavelength of **7c**, **7i**, and **8e** depends on concentration).

A series of dyes exhibits red emission above 600 nm. Especially to be emphasized are the partly very large Stokes shifts $\Delta\tilde{\nu}$ reaching values of 4000 – 7400 cm^{-1}. Compared with their oxygen analogs the absorption maxima are almost always red-shifted by 20 nm on average (except **7e**, for details see the SI) with a maximum of 47 nm (**7a**). The shift of emission wavelength is even greater and reaches values of 20 – 30 nm. The fluorescence lifetimes τ_F of S^4-DBD dyes are significantly lower than those of DBD dyes and amount to 1 – 3 ns. The fluorescence quantum yields exhibit single-digit values (except **7f**), which is substantially below the values of DBD dyes. The reason for the lower τ_F and Φ_F values of S^4-DBD dyes could be an increased intersystem crossing (ISC) efficiency to give the triplet state. This process, which is caused by enhanced spin-orbit coupling with the sulfur atoms,[19] competes with the fluorescence. To prove this hypothesis a triplet-triplet annihilation / upconversion (TTA-UC) experiment was carried out with compound **7a** and 9,10-Diphenylanthracene (DPA) as annihilator.[20] The individual photophysical steps are represented by equations 1-5. After excitation at 540 nm (eq. 1) **7a** undergoes an ISC to the triplet state (eq. 2). Then the triplet energy is transferred to DPA (eq. 3). Between two triplet excited DPA molecules triplet-triplet annihilation takes place giving a ground state and a singlet excited DPA molecule (eq. 4). Finally, the DPA fluorescence of DPA at 410-430 nm is observed (eq. 5). It should be noted that a direct excitation of DPA at 540 nm can be ruled out so that the DPA fluorescence must originate from TTA-UC.

$$^1\mathbf{7a} + h\nu^1 \longrightarrow {}^1\mathbf{7a}^* \quad (1)$$

$$^1\mathbf{7a}^* \xrightarrow{ISC} {}^3\mathbf{7a} \quad (2)$$

$$^3\mathbf{7a} + {}^1DPA \longrightarrow {}^1\mathbf{7a} + {}^3DPA \quad (3)$$

$$2\,{}^3DPA \longrightarrow {}^1DPA + {}^1DPA^* \quad (4)$$

$$^1DPA^* \longrightarrow {}^1DPA + h\nu^2 \quad (5)$$

Fluorescent dyes with large Stokes shifts decrease the crosstalk between excitation and emission as well as the self-quenching due to back-scattering from biological tissues. Moreover, such dyes have particular significance in super-resolution microscopy (*e.g.* STED). Recently Hell and co-workers published a review about dyes with large Stokes shifts suitable for STED.[3] To evaluate the S^4-DBD dyes concerning the absorption and emission wavelength we compared them with 41 dyes (only one-component systems) from reference [3]. The results for the most outstanding dyes **6e**, **7a,e,f** and **8b** are depicted in figure 4 (the blue dashed curves mark different Stokes shifts $\Delta\tilde{\nu}$) and furnish evidence for the competitiveness of S^4-DBD dyes.

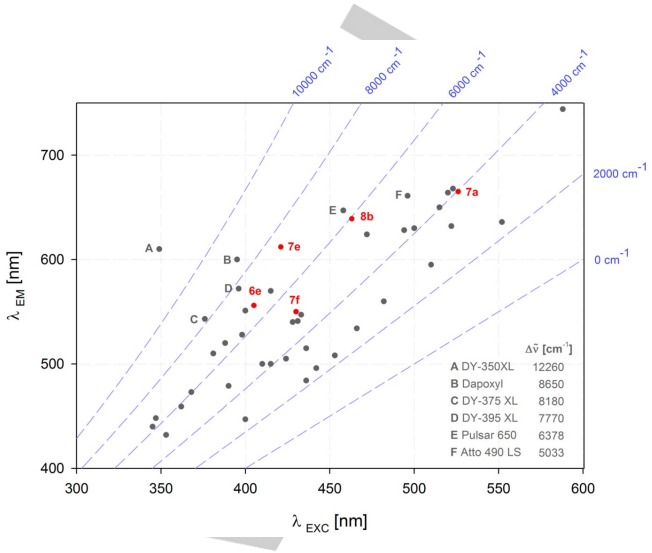


Figure 4. Comparison of 41 dyes from ref. [3] with some S^4-DBD dyes.

Conclusion

We have developed a new class of fluorescent dyes based on benzo[1,2-d:4,5-d']bis([1,3]dithiole) and called them S^4-DBD dyes.[17] Starting with the commercially available 1,2,4,5-tetrachlorobenzene **4** the parent heterocycle **3b** (bearing four methyl groups in positions 2 and 6) could be prepared in two steps and with good yields on a gram-scale level. Lithiation in positions 4 and 8, followed by reaction with various electrophilic reagents provides access to a broad range of fluorescent S^4-DBD dyes. Compared with the previously developed DBD dyes a considerable bathochromic shift of the absorption and emission wavelength is observed. However, the fluorescence lifetimes and quantum yields of S^4-DBD dyes are significantly lower. We assume that a slightly accelerated intersystem crossing to the triplet state, caused by enhanced spin-orbit coupling with the sulfur atoms is the reason for this phenomenon.[18] An outstanding feature of S^4-DBD dyes is that they posses very large Stokes shifts. They could therefore be predestined for super-resolution microscopy. Finally, a series of S^4-DBD dye derivatives were developed, which enable the coupling with biomolecules. Thus, carboxylic acid **19**, OSu-ester **21** (for amines), alkyne **20**, azide **24** (for CuACC), and maleimide **22** were synthesized. We are currently developing promising biochemical applications of S^4-DBD dyes.

Experimental Section

General Information. See the Supporting information

1,2,4,5-Tetrakis(tert.-butylthio)benzene (5). To an ice-cooled solution of dry DMF (600 mL) and 2-methylpropane-2-thiol (159 g, 1.76 mol, 5 eq.) in an 1 L Schlenk flask, were added small pieces of sodium (39.60 g, 1.72 mol, 4.9 eq.) after which the mixture was stirred overnight. To the brown-yellow suspension was added 1,2,4,5–tetrachlorobenzene **4** (76 g, 208 mmol) and the mixture was refluxed for 8 h. After cooling to room

temperature the reaction mixture was poured on ice. The precipitate was collected, washed thoroughly with water, methanol and small amounts of cold petrol ether and dried under reduced pressure to yield **5** (90.23 g, 60 %) as creamy-white powder. m.p.: 144 – 145 °C. R_f (PE:EE/15:1): 0.68; ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.35 (s, 36 H), 7.94 (s, 2 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 31.3, 48.1, 139.3, 144.7; HRMS (EI): calculated for $C_{22}H_{38}S_4$ $[M]^+$: 430.1856, found: 430.1853.

2,2,6,6-Tetramethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole) (3b). To a 250 mL flask containing a suspension of **5** (10 g, 23.21 mmol), acetone (13.7 mL, 185.71 mmol, 8 eq.) and toluene (100 mL) was added tetrafluoroboric acid diethyl ether complex (6.4 mL, 46.43 mmol, 2 eq.) and the mixture was refluxed for 3 h. After cooling to room temperature, the blackish mixture was washed with saturated $NaHCO_3$ solution and the aqueous phase was extracted with DCM twice. The combined organic layers were dried over $MgSO_4$ and the solvent was removed in vacuum. The crude yellow-brown product was purified by recrystallization from petrol ether to yield **3b** (5.60 g, 85 %) as a white solid. m.p.: 146 – 147 °C. R_f (PE:EE/15:1): 0.68; ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.89 (s, 12 H), 7.03 (s, 2 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 31.3, 65.7, 116.8, 135.7; HRMS (EI): calculated for $C_{12}H_{14}S_4$ $[M]^+$: 285.9978, found: 285.9976.

2,2,6,6-Tetrapentylbenzo[1,2-d:4,5-d']bis([1,3]dithiole) (3c). To 100 mL flask containing a suspension of **5** (4 g, 9.29 mmol), undecan-6-one (4.74 g, 27.86 mmol, 3 eq.) and toluene (50 mL) was added tetrafluoroboric acid diethyl ether complex (2.55 mL, 18.57 mmol, 2 eq.) and the mixture was refluxed for 3 h. After cooling to room temperature, the blackish mixture was washed with saturated $NaHCO_3$ solution and the aqueous layer was extracted with DCM 3 times. The combined organic layers were dried over $MgSO_4$ and the solvent was removed in vacuo. The crude product was purified by flash column chromatography (PE) to yield **3c** (3.71 g, 78 %) as colorless white crystals. m.p.: 72 – 76 °C. R_f (PE): 0.39; ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 0.79 – 0.99 (m, 12 H), 1.25 – 1.38 (m, 16 H), 1.40 – 1.55 (m, 8 H), 1.96 – 2.14 (m, 8 H), 6.94 (s, 2 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 14.0, 22.5, 25.7, 31.8, 41.0, 74.8, 116.0, 135.1; HRMS (EI): calculated for $C_{28}H_{46}S_4$ $[M]^+$: 510.2482, found: 510.2486. IR (cm^{-1}): 3340, 2955, 2923, 2858, 1452, 1381, 1363, 1248, 1164 1150.

2,2,6,6-Tetramethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4-carbaldehyde (6a). A 100 mL three-necked flask was charged with **3b** (1.5 g, 5.24) and dry Et_2O (50 mL). *n*-BuLi (1.6 M in pentane, 7.2 mL, 11.5 mmol, 2.2 eq.) was added and the mixture was gently refluxed for 2 h. After cooling to room temperature dry DMF (1.6 mL, 20.94 mmol, 4 eq.) was added and the reaction is stirred for 1 h at that temperature. To the white-beige slurry water was added and the color changes immediately to dark orange. The aqueous layer was extracted with DCM 3 times and the combined organic layers were dried over $MgSO_4$. After concentrated in vacuum, the crude product was purified by flash column chromatography (PE/EE) to yield **6a** (1.24 g, 70 %) as a yellow solid. m.p.: 148 °C. R_f (PE:EE/15:1): 0.38; ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.90 (s, 12 H), 7.19 (s, 1 H), 10.07 (s, 1 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 31.6, 65.8, 120.2, 137.8, 139.6, 188.6; HRMS (EI): calculated for $C_{13}H_{14}OS_4$ [M]+: 313.9928, found: 313.9938; IR (cm^{-1}): 2968, 2845, 1673, 1519, 1413, 1362, 1260, 1201, 947, 878.

2,2,6,6-Tetramethylbenzo[1,2-d:4,5-d']bis[1,3]dithiole-4,8-dicarbaldehyde (7a). A 50 mL three-necked flask was charged with 3b (1 g, 3.49 mmol), dry *n*-hexane (20 mL) and TMEDA (1 mL, 7.0 mmol, 2 eq.). To the suspension was added dropwise *n*-BuLi solution in pentane (8.2 mL, 14.0 mmol, 4 eq.). The mixture was stirred at room temperature for 3 h and cooled down to 0 °C. Dry DMF (1.2 mL, 15.7 mmol, 4.5 eq.) was added and the reaction was allowed to stir for 1 h at room temperature. To the white slurry was added water, which immediately turned to dark red. The aqueous layer was extracted with DCM 3 times and the combined organic layers were dried over $MgSO_4$. After concentration in vacuum, the crude product was refluxed in petrol ether ether for 10 min and cooled down to 0 °C. The precipitate was collected, washed thoroughly with petroleum ether and dissolved in a small amount of DCM. Precipitation with petroleum ether followed by drying in vacuum, yielded **7a** (620 mg, 52 %) as a blackish red solid. m.p.: >240 °C (decomposition). R_f (PE:EE/15:1): 0.29; ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.93 (s, 12 H), 10.19 (s, 2 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 31.9, 65.6, 126.9, 141.8, 188.8; HRMS (EI) calculated for $C_{14}H_{14}O_2S_4$ [M]+: 341.9877, found: 341.9882; IR (cm^{-1}): 3327, 2954, 2841, 1669, 1448, 1361, 1225, 1165, 1153, 856.

2,2,2-Trifluoro-1-(2,2,6,6-tetramethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4-yl)ethan-1-one (6b) and 1,1'-(2,2,6,6-tetramethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4,8-diyl)bis(2,2,2-trifluoroethan-1-one) (7b). A 50 mL three-necked flask was charged with **3b** (200 mg, 698 µmol), dry *n*-hexane (10 mL) and TMEDA (211 µl, 1.40 mmol, 2 eq.). To the suspension was added dropwise *n*-BuLi-solution in pentane (1.86 mL, 2.79 mmol, 4 eq.) and the mixture was stirred at room temperature for 3 h. Then the mixture was cooled to 0 °C and 2,2,2-trifluoro-N-methoxy-N-methylacetamide (338 µl, 2.79 mmol, 4.5 eq.) was added dropwise. The reaction was allowed to stir 1 h at room temperature and then water was added. The yellow slurry was acidified with 1 M hydrochloric which turned blood-red. The aqueous layer was extracted with DCM 3 times and the combined organic layers were dried over $MgSO_4$. After concentration in vacuum, the crude product was purified by flash column chromatography (PE:EE) to yield **7b** (82 mg, 25 %) as black-red solid. m.p.: 150 – 152 °C and **6b** (80 mg, 30 %) as a red-orange solid. m.p.: 93 – 97 °C.

7b R_f (PE:EE/5:1): 0.11. ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.91(s); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 30.6, 67.9, 113.7, 117.6, 125.8, 138.2, 183.3, 184.0; HRMS (EI) calculated for $C_{16}H_{12}F_6O_2S_4$ $[M]^+$: 477.9624, found: 477.9633; IR (cm^{-1}): 2940, 1704, 1455, 1368, 1218, 1157, 1054, 957, 833, 728.

6b R_f (PE:EE/5:1): 0.71.^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.89(s, 12 H), 7.21 (s, 1 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 30.8, 66.1, 113.6, 117.4, 119.6, 123.5, 136.5, 138.3, 183.6, 184.1; HRMS (EI) calculated for $C_{14}H_{13}F_3OS_4$ [M]+: 381.9801, found: 381.9811; IR (cm^{-1}): 2962, 2923, 1688, 1367, 1258, 1202, 1186, 1170, 1142, 989.

2,2,6,6-Tetramethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4-carboxylic acid (6c) and 2,2,6,6-tetramethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4,8-dicarboxylic acid (7c). A 50 mL three-necked flask was charged with **3b** (400 mg, 1.4 mmol), dry *n*-hexane (20 mL) and TMEDA (464 µl, 3.1 mmol, 2 eq.). To the suspension was added dropwise *n*-BuLi solution in pentane (3.72 mL, 5.6 mmol, 4 eq.). The mixture was stirred at room temperature for 3 h and cooled down to -20 °C. Dry CO_2-gas was bubbled through the mixture for 30 min and the mixture was allowed to reach room temperature. To the slurry was added water until a yellow solution was formed. The mixture was washed with DCM 3 times and the aqueous layer was acidified with concentrated hydrochloric acid. The precipitate was allowed to settle overnight in a refrigerator. The orange precipitate was collected, washed thoroughly with water and extracted extensively with DCM. This filtrate contains mostly **6c**. A second extraction with warm THF gives a filtrate with contains mostly **7c**. Both filtrates were separately concentrated in vacuum and separately purified by flash column chromatography (DCM:MeOH:TFA) to yield **7c** (246 mg, 47 %) as an orange solid. m.p.: >300 °C) and **6c** (68 mg, 15 %) as a greenish solid. m.p.: >288 °C (decomposition).

7c. R_f (DCM:MeOH:TFA/100:1:0.4): 0.19; ^{1}H-NMR (300 MHz, DMSO-d^6, ppm): 1.75 (s); ^{13}C-NMR (75 MHz, DMSO-d^6, ppm): 30.7, 60.7, 123.5, 138.9, 167.1; HRMS (EI) calculated for $C_{14}H_{14}O_4S_4$ $[M]^+$: 373.9775, found: 373.9784; IR (cm^{-1}): 2917, 1665, 1415, 1366, 1341, 1249, 1208, 1108, 814, 721.

6c. R_f (DCM:MeOH:TFA/100:1:0.4): 0.21; ^{1}H-NMR (300 MHz, DMSO-d^6, ppm): 1.79 (s, 12 H), 7.41 (s, 1 H); ^{13}C-NMR (75 MHz, DMSO-d^6, ppm):

31.0, 62.7, 119.0, 121.4, 136.0, 138.6, 166.7; HRMS (EI) calculated for $C_{13}H_{14}O_2S_4$ $[M]^+$: 329.9871, found: 39.9878; IR (cm^{-1}): 2957, 2919, 1663, 1419, 1365, 1253, 1148, 1084, 1021, 986.

1-(2,2,6,6-Tetramethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4-yl)pentan-1-ol (6d). A 50 mL three-necked flask was charged with **6a** (300 mg, 0.954 mmol) and dry THF (6 mL). *n*-BuLi-solution in pentane (827 µl, 1.24 mmol, 1.3 eq) was added dropwise and the resulting brown slurry was allowed to stir for 10 min at room temperature. Water was added and the aqueous layer was extracted with DCM 3 times. The combined organic layers were dried over $MgSO_4$ and concentrated in vacuum. The crude product was purified by flash column chromatography (DCM:MeOH) to yield **6d** (231 mg, 65 %) as a colourless viscous oil. R_f (PE:EE/15:1): 0.24 ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 0.90 (t, *J* = 7.0 Hz, 3 H), 1.22 – 1.53 (m, 4 H), 1.65 – 1.83 (m, 2 H), 1.85(s, 6 H), 1.89 (s, 6 H), 2.16 (br s, 1 H), 4.71 – 4.76 (m, 1 H), 7.00 (s, 1 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm):14.0, 22.4, 28.0, 29.4, 32.7, 33.9, 64.6, 74.8, 115.8, 133.4, 134.2, 137.0; HRMS (EI) calculated for $C_{17}H_{24}OS_4$ $[M]^+$: 372.0710, found: 372.0701; IR (cm^{-1}): 3341, 2956, 2925, 2861, 1453, 1384, 1365, 1167, 1150, 1033.

1-(2,2,6,6-Tetramethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4-yl)pentan-1-one (6e). In a 50 mL flask, **6d** (200 mg, 0.531 mmol) was dissolved in DCM (25 mL). Dess-Martin periodinane (DMP, 450 mg, 1.06 mmol, 2 eq.) was added and the mixture was stirred at room temperature for 30 min. To the reaction was added a solution of sodium thiosulfate and sodium hydrogen carbonate in water and the aqueous layer was extracted with DCM 3 times. The combined organic layer were dried over $MgSO_4$ and concentrated in vacuo. Purification by flash column chromatography (PE:EE) afforded **6e** (175 mg, 88 %) as yellow solid (81 – 83 °C). R_f(PE:EE/10:1): 0.55; ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 0.93 (t, *J* = 7.4 Hz, 3 H), 1.31 – 1.46 (m, 2 H), 1.65 – 1.77 (m, 2 H), 1.86 (s, 12 H), 2.93 (t, *J* = 7.3 Hz, 2 H), 7.15 (s, 1 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 13.9, 22.3, 26.6, 31.0, 41.9, 64.2, 118.7, 130.1, 136.5, 137.3, 201.8; HRMS (EI) calculated for $C_{17}H_{22}OS_4$ $[M]^+$: 370.0554, found: 370.0555; IR (cm^{-1}): 2952, 2923, 2864. 1659, 1449, 1361, 1256, 1196,1169, 1147.

1,1'-(2,2,6,6-Tetramethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4,8-diyl)bis(pentan-1-ol) (7d). A 50 mL three-necked flask was charged with **7a** (200 mg, 0.58 mmol) and dry TMEDA (10 mL). To the dark-red suspension was added dropwise *n*-BuLi solution in pentane (1.5 mL, 2.34 mmol, 4 eq.) and was stirred for 30 min at room temperature. Water was added and the aqueous layer was extracted with DCM 3 times. The combined organic layers were dried over $MgSO_4$ and concentrated in vacuum. The crude product was purified by flash column chromatography (DCM:MeOH) to yield the two diasteromers of **7d** (150 mg, 56 % %) as a beige solid. m.p.: 171 – 207 °C. R_f (DCM:MeOH/50:1): 0.6; 0.45). ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 0.90 (t, *J* = 7.0 Hz, 6 H), 1.25 – 1.42 (m, 6 H), 1.43 – 1.57 (m, 2 H), 1.69 – 1.95 (m, 16 H), 2.87 (br s, 2H), 4.68 – 4.73 (m, 1 H), 4.79 – 4.83 (m, 1 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 14.0, 22.5, 28.1, 30.7, 33.6, 34.0, 63.2, 63.7, 74.7, 74.8, 133.6, 134.7; HRMS (EI) calculated for $C_{22}H_{34}O_2S_4$ $[M]^+$: 458.1442, found: 458.1439; IR (cm^{-1}): 3340, 2955, 2923, 2858, 1452, 1381, 1363, 1248, 1164, 1150.

1,1'-(2,2,6,6-Tetramethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4,8-diyl)bis(pentan-1-one) (7e). **Method A**. A 50 mL three-necked flask was charged with **3b** (300 mg, 1.05 mmol), dry *n*-hexane (20 mL) and TMEDA ((316 µl, 2.1 mmol, 2 eq.). To the suspension was added dropwise *n*-BuLi solution in pentane (2.62 mL, 4.19 mmol, 4 eq.). The mixture was stirred at room temperature for 1 h and cooled down to -20 °C. Dry CO_2-Gas was bubbled through the mixture for 1.5 h and after that was stirred for 30 min at room temperature. To the slurry was added *n*-BuLi-solution in pentane (5.24 mL, 8.38 mmol, 8 eq.) and the resulting mixture was heated for 14 h at 45 °C. After cooling to room temperature, water was added, the aqueous layer was extracted with DCM 3 times and the combined organic layers were dried over $MgSO_4$. After concentration in vacuum, the crude product was purified by flash column chromatography (PE/EE) to yield **7e** (124 mg, 26 %) as a yellow-orange solid. **Method B**. In a 50 mL flask, **7d** (100 mg, 0.218 mmol) was dissolved in DCM (15 mL). DMP (240 mg, 0.567 mmol, 2.6 eq.) was added and the mixture was stirred at room temperature for 30 min. To the reaction was added a solution of sodium thiosulfate and sodium hydrogen carbonate in water and the aqueous layers was extracted with DCM 3 times. The combined organic layer were dried over $MgSO_4$ and concentrated in vacuum. Purification by flash column chromatography (PE/EE) afforded **7e** (85 mg, 86 %) as yellow-orange solid. m.p.: 85-90 °C; R_f (PE:EE/15:1): 0.47; ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 0.93 (t, *J* = 7.3 Hz, 6 H), 1.31 – 1.48 (m, 4 H), 1.63 – 1.76 (m, 4 H), 1.84 (s, 12 H), 2.90 (t, *J* = 7.3 Hz, 4 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 13.8, 22.3, 26.5, 30.7, 41.9, 63.9, 131.6, 136.9, 203.0; HRMS (EI) calculated for $C_{22}H_{30}O_2S_4$ $[M]^+$: 454.1129, found: 454.1115; IR (cm^{-1}): 2958, 1657, 1454, 1369, 1215, 1172, 1034, 991, 787, 708.

Ethyl 2,2,6,6-tetramethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4-carboxylate (6f) and Diethyl 2,2,6,6-tetramethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4,8-dicarboxylate (7f). A 50 mL three-necked flask was charged with **3b** (200 mg, 698 µmol), dry *n*-hexane (20 mL) and TMEDA (210 µl, 1.40 mmol, 2 eq.). To the suspension was added dropwise *n*-BuLi solution in pentane (1.86 mL, 2.79 mmol, 4 eq.). The mixture was stirred at room temperature for 3 h and cooled down to -70 °C. Ethyl chloroformate (400 µl, 4.19 mmol, 6 eq.) was added and the reaction was allowed to reach room temperature overnight. Water was added, the aqueous layer was extracted with DCM 3 times and the combined organic layers were dried over $MgSO_4$. After concentration in vacuum, the crude product was purified by flash column chromatography (PE:EE) to yield **7f** (189 mg, 63 %) as yellow solid. m.p.: 178 – 180 °C and **6f** (32 mg, 12 %) as a yellow-greenish waxy solid.

7f. R_f (PE:EE/15:1): 0.30. ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.45 (t, *J* = 7.2 Hz, 6 H), 1.80 (s, 12 H), 4.43 (q, *J* = 7.2 Hz, 4 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 14.2, 31.1, 61.0, 62.5, 122.7, 140.1, 165.9; HRMS (EI) calculated for $C_{18}H_{22}O_4S_4$ $[M]^+$: 430.0401, found: 430.0403; IR (cm^{-1}): 2975, 1693, 1449, 1343, 1241, 1218, 1095, 1013, 861, 784.

6f. R_f (PE:EE/15:1): 0.43. ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.44 (t, *J* = 7.2 Hz, 3 H), 1.85 (s, 12 H), 4.41 (q, *J* = 7.2 Hz, 2 H), 7.15 (s, 1 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 14.3, 31.3, 62.3, 63.1, 119.3, 120.5, 136.6, 139.4, 165.6; HRMS (EI) calculated for $C_{15}H_{18}O_2S_4$ $[M]^+$: 358.0190, found: 358.0180; IR (cm^{-1}): 2958, 1692, 1454, 1388, 1378, 1361, 1254, 1148, 1080, 1015.

1Z,1'Z)-2,2,6,6-Tetramethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4,8-dicarbaldehyde dioxime (7g). **7a** (200 mg, 0.58 mmol) was refluxed in a 100 mL flask with methanol (40 mL), sodium acetate trihydrate (238 mg, 175 mmol, 3 eq.) and hydroxylamine hydrochloride (122 mg, 175 mmol, 3 eq.) for 3 h. The mixture was cooled down to 0 °C and 40 mL water was added. The precipitate was collected and washed with water. After drying in vacuum, **7g** (161 mg, 74 %) was obtained as a yellow-orange solid. m.p.: 265-269 °C (turning brown) which was used in the next step without further purification. R_f (DCM): 0.42. ^{1}H-NMR (300 MHz, DMSO-d^6, ppm): 1.82 (s, 12 H), 8.06 (s, 2 H), 11.92(s, 2H); ^{13}C-NMR (75 MHz, DMSO-d^6, ppm): 30.8, 62.8, 121.7, 135.0, 145.6; HRMS (EI) calculated for $C_{14}H_{16}O_2N_2S_4$ $[M]^+$: 372.0095, found: 372.0087; IR (cm^{-1}): 3267, 2964, 1365, 1287, 1247, 1168, 1152, 976, 908, 688.

2,2,6,6-Tetramethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4,8-dicarbonitrile (7h). A 50 mL Schlenk flask was charged with **7g** (100 mg, 0.27 mmol), K_2CO_3 (223 mg, 1.61 mmol, 3 eq.) and dry DMSO (15 mL). After adding acetic anhydride (152 µm, 0.161 mmol, 3 eq.), the mixture was stirred for 3 h at 90 °C. 30 mL water was added and the mixture was cooled down to ca. 0 °C. The precipitate was collected, washed with water 3 times and dried in vacuo. The crude product was purified by flash column chromatography (PE/EE) to yield **7h** (72 mg, 80 %) as a yellow solid. m.p >300 °C. R_f (PE:EE/10:1): 0.37. ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.98 (s, 12 H); ^{13}C-NMR (151 MHz, $CDCl_3$, ppm): 31.8, 67.8, 103.3,

114.7, 141.1; HRMS (EI) calculated for $C_{14}H_{12}N_2S_4$ $[M]^+$: 335.9878, found: 335.9880; IR (cm^{-1}): 2981, 2222, 1451, 1439, 1368, 1237, 1166, 1153, 1109, 723.

2,2,6,6-Tetrapentylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4,8-dicarboxylic acid (7i). A 100 mL three-necked flask was charged with **3c** (1.35 g, 2.64 mmol), dry *n*-hexane (30 mL) and TMEDA (800 µl, 5.28 mmol, 2 eq.). To the solution was added dropwise *tert.*-BuLi solution in pentane (5.28 mL, 7.93 mmol, 3 eq.). The mixture was stirred at room temperature for 1 h and cooled down to -20 °C. Dry CO_2 gas was bubbled through the mixture for 30 min and the mixture was allowed to reach room temperature. To the slurry was added water and a yellow precipitate was formed. After acidification with concentrated hydrochloric acid, the mixture was extracted with DCM 8 times and concentrated in vacuo. The crude product was refluxed with toluene and filtered after cooling to 0 °C. The solid was washed with acetone until the filtrate became colourless. The filtrate was concentrated in vacuo and purified by flash column chromatography (DCM:MeOH:TFA) to yield **7i** (1.13 g, 71 %) as an dark-red solid. m.p.: >300 °C. R_f (DCM:MeOH:TFA/100:1:0.4): 0.19. ^{1}H-NMR (300 MHz, DMSO-d^6, ppm): 0.69 – 0.93 (br m, 12 H), 1.10 – 1.53 (br m, 24 H), 1.78 – 1.97 (br m, 8 H); ^{13}C-NMR (75 MHz, DMSO-d^6, ppm): 13.8, 21.9, 24.9, 31.2, 40.6, 69.2, 122.6, 138.7, 166.9; HRMS (EI) calculated for $C_{30}H_{46}O_4S_4$ $[M]^+$: 598.2279, found: 598.2276; IR (cm^{-1}): 2955, 2926, 2856, 2504, 1666, 1417, 1341 1254, 1202, 727.

8-(1-Hydroxypentyl)-2,2,6,6-tetramethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4-carbaldehyde (8a). In a 50 mL three-necked flask **6a** (220 mg, 0.7 mmol) was dissolved in dry TMEDA (10 mL), cooled to 0 °C and then *n*-BuLi solution in pentane (1.75 mL, 2.8 mmol, 4 eq.) was added dropwise. After stirring for 3 h at room temperature, dry DMF (270 µl, 3.5 mmol, 5 eq.) was added and the resulting slurry was stirred for another 30 min at room temperature. Water was added and the aqueous layer was extracted with DCM 3 times. The combined organic layer were dried over $MgSO_4$ and concentrated under reduced pressure. Purification by flash column chromatography (PE/EE) yields **8a** (129 mg, 46 %) as a yellow solid. m.p.: 145 - 147 °C. R_f (PE:EE/5:1): 0.39 ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 0.91 (t, J = 7.1 Hz, 3 H), 1.23 – 1.58 (m, 4 H), 1.68 – 2.01 (m, 14 H), 2.34 (br s, 1H), 4.75 – 4.82 (m, 1 H), 10.08 (s, 1 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm):13.9, 22.4, 27.9, 29.8, 32.8, 33.4, 64.3, 74.7, 124.8, 135.6, 138.4, 141.3, 188.6; HRMS (EI): calculated for $C_{18}H_{24}O_2S_4$ $[M]^+$: 400.0659, found: 400.0652. IR (cm^{-1}):3325, 2952, 2926, 2858, 1670, 1366, 1250, 1168, 1036, 1000.

2,2,6,6-Tetramethyl-8-pentanoylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4-carbaldehyde (8b). In a 50 mL flask, **8a** (113 mg, 0.282 mmol) was dissolved in DCM (25 mL). DMP (240 mg, 0.564 mmol, 2 eq.) was added and the mixture was stirred at room temperature for 10 min. To the reaction was added a solution of sodium thiosulfate and sodium hydrogen carbonate in water and the aqueous layer was extracted with DCM once. The combined organic layer were dried over $MgSO_4$ and concentrated in vacuo. Purification by flash column chromatography (PE:EE) afforded **8b** (109 mg, 97 %) as orange solid. m.p.: 108 - 109 °C. R_f (PE:EE/15:1): 0.48. ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 0.92 (t, J = 7.3 Hz, 3 H), 1.31 – 1.45 (m, 2 H), 1.63 – 1.75 (m, 2 H), 1.88 (s, 12 H), 2.92 (t, J = 7.3 Hz, 2 H), 10.12 (s, 1 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 13.8, 22.3, 26.4, 31.3, 41.9, 64.9, 125.7, 133.1, 136.7, 141.5, 188.6, 203.0; HRMS (EI) calculated for $C_{18}H_{22}O_2S_4$ $[M]^+$: 398.0503, found: 398.0499; IR (cm^{-1}):2952, 2926, 1672, 1657, 1367, 1352, 1221, 1167, 1151, 945.

2,2,2-Trifluoro-1-(8-(1-hydroxypentyl)-2,2,6,6-tetramethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4-yl)ethan-1-one (8c). In a 50 mL three-necked flask **3** (220 mg, 0.7 mmol) was dissolved in dry TMEDA (10 mL), cooled to 0 °C and then *n*-BuLi solution in pentane (1.75 mL, 2.8 mmol, 4 eq.) was added dropwise. After stirring for 3 h at room temperature, 2,2,2-trifluoro-N-methoxy-N-methylacetamide (364 µl, 3.15 mmol, 4.5 eq) was added and the resulting slurry was stirred for 1 h at room temperature. Water und 1M hydrochloric acid were added and the aqueous layer was extracted with DCM 3 times. The combined organic layer were dried over $MgSO_4$ and concentrated under reduced pressure. Purification by flash column chromatography (PE:EE) yields **8c** (141 mg, 43 %) as a orange solid. m.p.: 112 – 115 °C. R_f (PE:EE/5:1): 0.22. ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 0.91 (t, J = 7.1 Hz, 3 H), 1.26 – 1.58 (m, 4 H), 1.66 – 1.97 (m, 14 H), 2.42 (br s, 1 H), 4.68 – 4.79 (m, 1 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm):13.9, 22.4, 27.9, 29.2, 31.9, 33.5, 65.3, 74.8, 113.5, 117.4, 122.7, 135.9, 137.0, 137.4, 184.6 HRMS (EI): calculated for $C_{19}H_{23}F_3O_2S_4$ $[M]^+$: 468.0533, found: 468.0527.

1-(2,2,6,6-Tetramethyl-8-(2,2,2-trifluoroacetyl)benzo[1,2-d:4,5-d']bis([1,3]dithiole)-4-yl)pentan-1-one (8d). In a 50 mL flask, **8c** (73 mg, 0.156 mmol) was dissolved in DCM (10 mL). DMP (132 mg, 0.312 mmol, 2 eq.) was added and the mixture was stirred at room temperature for 1.5 h. To the reaction was added a solution of sodium thiosulfate and sodium hydrogen carbonate in water and the aqueous layer was extracted with DCM 3 times. The combined organic layer were washed with 1M hydrochloric acid, dried over $MgSO_4$ and concentrated in vacuo. Purification by flash column chromatography (DCM) afforded **8d** (57 mg, 78 %) as orange solid. m.p.: 65 – 67 °C. R_f (PE:EE/5:1): 0.58. ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 0.94 (t, J = 7.4 Hz, 3 H), 1.33 – 1.47 (m, 2 H), 1.64 – 1.77 (m, 2 H), 1.87 (s, 12 H), 2.94 (t, J = 7.25 Hz, 2 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 13.8, 22.3, 26.4, 30.5, 41.7, 65.7, 115.64 (q, J = 292 Hz), 124.7, 132.0, 136.7, 137.9, 184.2, 184.6, 202.1; HRMS (EI) calculated for $C_{19}H_{21}O_2F_3S_4$ $[M]^+$: 466.0371, found: 466.0383; IR (cm^{-1}):2953, 2922, 1699, 1657, 1227, 1199, 1171, 1078, 979.

8-Formyl-2,2,6,6-tetramethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4-carboxylic acid (8e). In a 50 mL three-necked flask, dry DMSO (80 µl, 1.12 mmol, 4.5 eq.) was dissolved in dry DCM (10 mL) followed by cooling to -78 °C. Oxalyl chloride (86 µl, 0.999 mmol, 4 eq.) was added dropwise and the mixture was stirred at that temperature for 30 min. To the reaction was added a solution of **11** (90 mg, 0.250 mmol) in dry DMSO (10 mL) and was allowed to stir additional 30 min at that temperature. Triethylamine (350 µl, 2.50 mmol, 10 eq.) was added and the mixture was stirred at room temperature for 30 min. 1M hydrochloric acid was added, the aqueous layer was extracted with ethyl acetate 3 times, the combined organic layers were dried over $MgSO_4$. Concentration under reduced pressure was followed by flash column chromatography (DCM:AcOH). **8e** (55 mg, 61 %) was obtained as a dark red solid. m.p. >300 °C. R_f (DCM:AcOH/50:1): 0.24; ^{1}H-NMR (300 MHz, DMSO-d^6, ppm): 1.82 (s, 12 H), 10.04 (s, 1 H); ^{13}C-NMR (75 MHz, DMSO-d^6, ppm): 32.0, 63.9, 126.7, 140.8, 141.2, 167.4, 190.0; HRMS (EI) calculated for $C_{14}H_{14}O_3S_4$ $[M]^+$: 357.9826, found: 357.9834; IR (cm^{-1}): 3384, 2921, 2855, 2255, 1847, 1556, 1216, 985.

(2,2,6,6-Tetramethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4-yl)methanol (10). **6a** (340 mg, 1.08 mmol) was dissolved in a 100 mL flask containing THF (20 mL) und cooled down with an ice-bath. $NaBH_4$ (82 mg, 2.16 mmol, 2 eq.) was dissolved in water (10 mL) and added dropwise to the solution which decolorized quickly. After stirring for 30 min at room temperature, 1M hydrochloric acid was carefully added until residue $NaBH_4$ was completely quenched. The mixture was extracted with DCM 3 times, the combined organic layer were dried over $MgSO_4$ and concentrated in vacuo, yielding **10** (339 mg, 99 %) as a white-yellow solid which was used without further purification. m.p.: 130°C. R_f (PE:EE/5:1): 0.37; ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.89 (s, 12 H), 4.56 (s, 2 H), 7.01 (s, 1 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 31.3, 65.1, 116.3, 129.4, 135.8, 136.5; HRMS (EI): calculated for $C_{13}H_{16}OS_4$ $[M]^+$: 316.0079, found: 316.0086; IR (cm^{-1}): 3451, 2860, 2958, 2916, 1403, 1364, 1149, 1123, 1041, 964.

8-(Hydroxymethyl)-2,2,6,6-tetramethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4-carboxylic acid (11). A 100 mL three-necked flask was charged with **10** (300 mg, 948 µmol) and dry TMEDA (20 mL). To the solution was added dropwise *n*-BuLi solution in pentane (2.53 mL, 3.79 mmol, 4 eq.). The mixture was stirred at room temperature for 1 h and cooled down to -20 °C. Dry CO_2-Gas was bubbled through the

mixture for 30 min and the mixture was allowed to reach room temperature. To the slurry was added water and cooled down to 0 °C. Concentrated hydrochloric acid was carefully added and the resulting orange precipitate was extracted with ethyl acetate. Drying over $MgSO_4$, removal of the solvent in vacuo, followed by flash column chromatography (DCM:AcOH), yielding **11** (109 mg, 25 %) as a yellow-orange solid. m.p.: >300 °C. R_f (DCM:AcOH/50:1): 0.19. ^{1}H-NMR (300 MHz, DMSO-d^6, ppm): 1.78 (s, 12 H), 4.33 (s, 2 H); ^{13}C-NMR (75 MHz, DMSO-d^6, ppm): 30.9, 61.7, 63.2, 132.9, 136.1, 139. 1, 166.8; HRMS (EI) calculated for $C_{14}H_{16}O_3S_4$ $[M]^+$: 359.9982, found: 359.9972; IR (cm^{-1}): 2958, 2915, 2852, 1702, 1670, 1365, 1261, 1230, 1157, 1152.

Benzo[1,2-d:4,5-d']bis([1,3]dithiole)-2,6-dione (12). In a 1 l three-necked flask **5** (30 g, 69.64 mmol) was suspended in dry pyridine (500 mL). After heating to 100 °C sodium (8.65 g, 376.06 mmol, 5.4 eq.) in pieces was added to the mixture which turned reddish. Heating was continued for 3 h after which the mixture was cooled down to -5 °C. 20 % phosgene solution in toluene (110 mL, 208.92 mmol, 3 eq.) was added very carefully over a dropping funnel and the resulting slurry was stirred for 30 min at that temperature. After the carefully addition of 100 mL ice-cold water the mixture was poured on 400 mL of ice water. The precipitate was collected and washed thoroughly with water and methanol. After recrystallization with toluene, **12** (9.87 g, 55 %) was obtained as beige needles. m.p.: >300 °C. IR (cm^{-1}):3004, 2970, 2947, 1738, 1634, 1432, 1366, 1229, 1217, 1206.

6,6-Dimethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-2-one (14). **12** (900 mg, 69.64 mmol) was suspended in dry THF (150 mL) in a 250 mL three-necked flask. Lithium methanolate in methanol (3.17 mL, 6.97 mmol, 2 eq.) was added dropwise after which the slurry completely turned to a brown solution. Continuous stirring for 1 h at room temperature is followed first by slow addition of tetrafluoroboric acid diethyl ether complex (1.05 mL, 7.66 mmol, 2.2 eq.), then boron trifluoride diethyl ether complex (946 µl, 7.66 mmol, 2.2 eq.) and finally acetone (1.54 mL, 20.90 mmol, 6 eq.). The mixture is stirred at room temperature for 30 min and under refluxed for 4 h. Saturated sodium hydrogen carbonate solution is added and the aqueous layer was extracted with DCM 3 times followed by drying over $MgSO_4$ and concentration in vacuum. Purification by flash column chromatography (PE:EE) yields **14** (433 mg, 46 %) as a reddish solid. m.p.: 152 – 154 °C. R_f (PE:EE/10:1): 0.5. ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.93 (s, 6 H), 7.30 (s, 2 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 31.3, 66.0, 116.5, 129.0, 138.6, 189.6; HRMS (EI) calculated for $C_{10}H_8OS_4$ $[M]^+$: 271.9453, found: 271.9449; IR (cm^{-1}): 2969, 1737, 1641, 1447, 1425, 1366, 1332, 1217, 1094, 855.

3-(2,6,6-Trimethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-2-yl)propyl pivalate (15). In a 100 mL three-necked flask **14** (200 mg, 0.734 mmol) was dissolved in dry THF (25 mL) and lithium methanolate in methanol (834 µl, 1.84 mmol, 2.5 eq.) was added dropwise. The solution turned cloudy and was stirred for 1 h at room temperature. Tetrafluoroboric acid diethyl ether complex (352 µl, 2.57 mmol, 3.5 eq.), then boron trifluoride diethyl ether complex (181 µl, 1.47 mmol, 2 eq.) and **25** (205 mg, 1.10 mmol, 1.5 eq.) were added. The mixture was allowed stir at room temperature for 16 h after which saturated sodium hydrogen carbonate solution was added and the aqueous layer was extracted with DCM 3 times. The combined organic layers were dried over $MgSO_4$ and concentrated under reduced pressure. Purification by flash column chromatography (PE:EE) yields **15** (166 mg, 55 %) as a white waxy solid. m.p.: 86 – 88 °C. R_f (PE:EE/15:1): 0.43. ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.19 (s, 9 H), 1.82 – 1.92 (m, 11 H), 2.05 – 2.18 (m, 2 H) 4.09 (t, J = 6.2 Hz, 2 H), 7.01 (s, 2 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 25.8, 27.2, 29.1, 31.2, 31.4, 38.8, 40.0, 63.7, 65.8, 69.5, 116.7, 135.3, 135.8, 178.4; HRMS (EI) calculated for $C_{19}H_{26}O_2S_4$ $[M]^+$: 414.0810, found: 414.0807.

Benzene-1,2,4,5-tetrathiol (16). **5** (3.5 g, 8.12 mmol) was refluxed with degassed toluene (60 mL) and tetrafluoroboric acid diethyl ether complex (2.23 mL, 16.25 mmol, 2 eq.) in a 250 mL Schlenk flask for 1 d. After cooling to room temperature, degassed 12% NaOH (30 mL) was added carefully and the organic layer was separated. The aqueous layer was washed quickly with DCM once and then acidified with concentrated hydrochloric acid. The white precipitated was collected, washed with water and dissolved in DCM. The insoluble residue was discarded. All steps were carried out as quickly as possible. After concentration and drying in vacuum, **16** (998 mg, 60 %) was obtained as a very oxygen sensitive white solid, which was directly used without further purification. m.p.: 119 - 123 °C. ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 3.70 (s, 4 H), 7.41 (s, 2 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 129.9, 132.8; HRMS (EI) calculated for $C_6H_6S_4$ $[M]^+$: 205.9352, found: 205,9344; IR (cm^{-1}): 2976, 2958, 2916, 1724, 1425, 1284, 1258, 1157, 1134, 1093.

3-(2,6,6-Trimethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-2-yl)propan-1-ol (17). In a 250 mL Schlenk flask 5 (10 g, 23.21 mmol) was refluxed with degassed toluene (150 mL) and tetrafluoroboric acid diethyl ether complex (6.37 mL, 46.43 mmol, 2 eq.) for 3 h. After cooling to room temperature, boron trifluoride diethyl ether complex (5.73 mL, 46.43 mmol, 2 eq.) was added followed by the addition of **25** (4.32 g, 23.21 mmol). The mixture was stirred at room temperature for 2h after which acetone (2.56 mL, 34.82 mmol, 1.5 eq.) was added and stirring at room temperature was continued for 2 h. Saturated sodium hydrogen carbonate solution was added and the aqueous layer was extracted with DCM 3 times. The combined organic layers were concentrated under reduced pressure after which the beige solid was refluxed with methanol (100 mL) and NaOH (7.58 g, 189.46 mmol, 8 eq.) for 3 h. After removal of the solvent in vacuum, water was added and the mixture was extracted with DCM 3 times. The combined organic layers were dried over $MgSO_4$ and concentrated under reduced pressure. Purification by flash column chromatography (PE:EE) yields **17** (2.50 g, 32 %) as a white solid. m.p.: 142 – 146 °C. R_f (PE:EE/1:1): 0.53. ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.72 – 1.93 (m, 11 H), 2.17 – 2.19 (m, 2 H), 3.65 (t, J = 6.3 Hz, 2 H), 6.99 (s, 2 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 29.4, 29.5, 31.2, 31.3, 39.9, 62.4, 65.7, 69.7, 116.5, 135.4, 135.6; HRMS (EI) calculated for $C_{14}H_{18}OS_4$ $[M]^+$: 330.0241, found: 330.0242; IR (cm^{-1}): 2379, 1964, 2921, 1448, 1422, 1363, 1256, 1091, 1065, 849.

2-(3-Hydroxypropyl)-2,6,6-trimethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4,8-dicarbaldehyde (18). A 50 mL three-necked flask was charged with **17** (230 mg, 0.696 mmol and dry TMEDA (10 mL). To the solution was added dropwise *n*-BuLi solution in pentane (2.32 mL, 5.57 mmol, 8 eq.). The mixture was stirred at room temperature for 2 h and cooled down to 0 °C. Dry DMF (535 µl, 6.96 mmol, 10 eq.) was added and the reaction was allowed to stir for 30 min at room temperature. Water was added after which a color change to dark red followed. The aqueous layer was extracted with DCM 3 times and the combined organic layers were dried over $MgSO_4$. After concentration in vacuum, the crude product was purified by flash column chromatography (PE:EE) yielding **18** (102 mg, 38 %) as a blackish red solid. m.p.: 170 – 172 °C. R_f (PE:EE/1:1): 0.39. ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.77 – 1.96 (m, 11 H), 2.11 – 2.22 (m, 2 H), 3.69 (t, J = 6.2 Hz, 2 H), 10.17 (s, 2 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 29.4, 30.5, 31.8, 31.9, 40.4, 62.3, 65.6, 69.7, 126.7, 141.7, 188.8; HRMS (EI) calculated for $C_{16}H_{18}O_3S_4$ $[M]^+$: 386.0139, found: 386.0129; IR (cm^{-1}): 3364, 2919, 2850, 1671, 1358, 1225, 1171, 1151, 1055, 856.

4-(3-(4,8-Diformyl-2,6,6-trimethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-2-yl)propoxy)-4-oxobutanoic acid (19). In a 25 mL Schlenk flask **18** (55 mg, 0.142 mmol), dry pyridine (115µl, 1.42 mmol, 10 eq.) and a spatula-tip of DMAP were dissolved in dry DCM (10 mL). Upon adding succinic anhydride (71 mg, 0.711 mmol, 5 eq.) the mixture was stirred at room temperature for 16 h. Water was added and the mixture was extracted twice with DCM. The combined organic layers were washed twice with saturated sodium hydrogen carbonate solution and than twice with 1 M hydrochloric acid and dried over $MgSO_4$. Concentration in vacuum yields **19** (60 mg, 87 %) as a blackish red solid, which was pure enough for further use. m.p.: 80 – 82 °C. R_f (DCM:MeOH:TFA/50:1:0.1): 0.19 ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.86 – 1.96 (m, 11 H), 2.04 – 2.18 (m, 2 H), 2.54 – 2.74 (m, 4 H), 4.03 – 4.22 (m, 2 H), 10.17 (s, 2 H); ^{13}C-NMR (75

MHz, $CDCl_3$, ppm): 25.6, 28.8, 30.5, 31.8, 31.8, 40.4, 64.1, 65.8, 69.3, 126.7, 141.5, 141.8, 172.0, 177.6, 188.7; HRMS (EI) calculated for $C_{20}H_{22}O_6S_4$ $[M]^+$: 486.0294, found: 486.0289; IR (cm^{-1}): 2959, 2923, 2851, 1731, 1711, 1674, 1358, 1227, 1166, 858.

3-(4,8-Diformyl-2,6,6-trimethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-2-yl)propyl 4-oxo-4-(prop-2-yn-1-ylamino)butanoate (20). In a 25 mL Schlenk flask **19** (35 mg, 0.072 mmol), propargylamine (20 µl, 0.316 mmol, 4.4 eq.) and a spatula-tip of N-hydroxysuccinimide were dissolved in dry DCM (10 mL). Upon adding DCC (22 mg, 0.108 mmol, 1.5 eq.) the mixture was stirred at room temperature for 5 h. The mixture was concentrated to half in a N_2 stream and cooled to ca -20 °C before filtering. The filter was washed with cold DCM and the filtrate was washed with 1 M hydrochloric acid, dried over $MgSO_4$ and concentrated in vacuum. Purification by flash column chromatography (DCM:MeOH) yields **20** (28 mg, 74 %) as a blackish red solid. m.p.: 57 – 59 °C. R_f (DCM:MeOH/50:1): 0.21; ^{1}H-NMR (500 MHz, $CDCl_3$, ppm): 1.88 - 198 (m, 11 H), 2.06 – 2.15 (m, 2 H), 2.24 (t, *J* = 2.5 Hz, 1 H), 2.50 (t, *J* = 6.6 Hz, 2 H), 2.68 (t, *J* = 6.6 Hz, 2 H), 4.05 (dd, *J* = 2.5 Hz, *J* = 2.2 Hz, 2 H), 4.12 (t, *J* = 6.3 Hz, 2 H), 4.71 (t, *J* = 2.2 Hz, 1 H), 10.19 (s, 2 H); ^{13}C-NMR (126 MHz, $CDCl_3$, ppm): 25.7, 29.3, 29.3, 30.7, 30.8, 31.8, 31.9, 40.5, 64.1, 65.8, 69.3, 71.6, 79.5, 126.7, 141.5, 141.9, 188.7; HRMS (EI) calculated for $C_{23}H_{25}O_5NS_4$ $[M]^+$: 523.0616, found: 523.0605; IR (cm^{-1}): 3003, 2970, 2950, 1738, 1672, 1448, 1366, 1229, 1217, 1172.

3-(4,8-Diformyl-2,6,6-trimethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-2-yl)propyl (2,5-dioxopyrrolidin-1-yl) succinate (21). In a 25 mL Schlenk flask **19** (55 mg, 0.142 mmol), N-hydroxysuccinimide (19 mg, 0.090 mmol, 1.1 eq.) and a spatula-tip of DMAP were dissolved in dry DCM (10 mL). Upon adding DCC (11 mg, 0.090 mmol, 1.1 eq.) the mixture was stirred at room temperature for 16 h. The mixture was concentrated to half in a N_2 stream and cooled to ca -20 °C before filtering. The filter was washed with cold DCM and the filtrate was concentrated in vacuum. Purification by flash column chromatography (PE:EE) yields **21** (40 mg, 83 %) as a blackish red solid. m.p.: 66 – 68 °C. R_f (PE:EE/1:1): 0.39. ^{1}H-NMR (500 MHz, $CDCl_3$, ppm): 1.90 - 195 (m, 11 H), 2.08 – 2.14 (m, 2 H), 2.74 (t, *J* = 6.9 Hz, 2 H), 2.85 (br s, 4 H), 2.94 (t, *J* = 6.9 Hz, 2 H), 4.16 (t, *J* = 6.3 Hz, 2 H), 10.18 (s, 2 H); ^{13}C-NMR (126 MHz, $CDCl_3$, ppm): 25.6, 25.6, 26.3, 28.8, 30.4, 31.8, 31.9, 40.5 64.4, 65.7, 69.3, 126.7, 141.6, 141.8, 167.6, 168.8, 170.7, 188.7; HRMS (EI) calculated for $C_{24}H_{25}O_8NS_4$ $[M]^+$: 583.0463, found: 583.0443; IR (cm^{-1}): 2926, 2853, 1737, 1675, 1362, 1229, 1205, 1175, 1090, 1070.

3-(4,8-Diformyl-2,6,6-trimethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-2-yl)propyl 4-((2-(2,5-dioxo-2,5-dihydro-1H-pyrrol-1-yl)ethyl)amino)-4-oxobutanoate (22). In a 25 mL Schlenk flask **19** (30 mg, 0.061 mmol) and N-hydroxysuccinimide (9 mg, 0.074 mmol, 1.2 eq.) were dissolved in dry DCM (8 mL). Upon adding EDCI (14 mg, 0.074 mmol, 1.2 eq.) the mixture was stirred at room temperature for 5 h (monitoring by TLC). To the mixture were added **32** (19 mg, 0.074 mmol, 1.2 eq.) and DIPEA (21 µl, 0.123 mmol, 2 eq.), followed by stirring at room temperature for 16 h. Saturated sodium hydrogen carbonate solution was added and the aqueous layer was extracted once with DCM. The combined organic layers were washed with 1 M hydrochloric acid, dried over $MgSO_4$ and concentrated in vacuum. Purification by flash column chromatography (DCM:MeOH) yields **22** (32 mg, 85 %) as blackish red solid. m.p.: 96 – 99 °C. R_f (DCM:MeOH/25:1): 0.30; ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.86 - 197 (m, 11 H), 2.07 – 2.17 (m, 2 H), 2.42 (t, *J* = 6.8 Hz, 2 H), 2.61 (t, *J* = 6.8 Hz, 2 H), 3.36 – 3.53 (m, 2 H), 3.63 – 3.74 (m, 2 H), 4.10 (t, *J* = 6.2 Hz, 2 H), 6.03 (br s, 1 H), 6.71 (s, 2 H), 10.18 (s, 2 H); ^{13}C-NMR (126 MHz, $CDCl_3$, ppm):25.7, 29.3, 30.7, 30.8, 31.8, 31.9, 37.6, 38.9, 40.4, 64.0, 65.8, 69.4, 126.7, 134.2, 141.5, 141.8, 170.8, 171.7, 172.8, 188.7; HRMS (EI) calculated for $C_{26}H_{28}O_7N_2S_4$ $[M]^+$: 608.0774, found: 608.0772; IR (cm^{-1}): 1705, 1673, 1535, 1438, 1406, 1361, 1227, 1171, 728, 696.

3-(4,8-Diformyl-2,6,6-trimethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-2-yl)propyl 4-methylbenzenesulfonate (23). In a 25 mL Schlenk flask **18** (100 mg, 0.259 mmol), pyridine (84 µl, 1.03 mmol, 4 eq.) and a spatula-tip of DMAP were dissolved in dry DCM (10 mL). Upon adding tosyl chloride (99 mg, 0.517 mmol, 2 eq.) the mixture was refluxed for 3 h. After cooling to room temperature water and 1 M hydrochloric acid were added to the mixture, following by extraction twice with DCM. The combined organic layers were washed with saturated sodium hydrogen carbonate solution twice, dried over $MgSO_4$ and concentrated in vacuum. Purification by flash column chromatography (PE:EE) yields **23** (89 mg, 64 %) as a blackish red solid. m.p.: 133 – 134 °C. R_f (PE:EE/2:1): 0.58; ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.80 – 1.97 (m, 11 H), 2.01 – 2.11 (m, 2 H), 2.45 (s, 3 H), 4.06 (t, *J* = 5.8 Hz, 2 H), 7.35 (d, *J* = 7.9 Hz, 2 H), 7.77 (d, *J* = 8.3 Hz, 2 H), 10.15 (s, 2 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 21.6, 25.8, 30.5, 31.8, 31.8, 40.1, 65.9, 68.9, 69.7, 126.7, 127.9, 129.9, 132.9, 141.3, 141.9, 144.9, 188.6; HRMS (EI) calculated for $C_{23}H_{24}O_5S_5$ $[M]^+$: 540.0227, found: 540.0238; IR (cm^{-1}): 2922, 1674, 1355, 1228, 1173,917, 858, 814, 733, 553.

2-(3-Azidopropyl)-2,6,6-trimethylbenzo[1,2-d:4,5-d']bis([1,3]dithiole)-4,8-dicarbaldehyde (24). In 50 mL flask **23** (40 mg, 0.74 mmol) and NaN_3 (7 mg, 0.111 mmol, 1.5 eq.) were dissolved in dry DMF (7 mL) and stirred at room temperature for 16 h. DCM was added and the mixture was washed twice with saturated sodium hydrogen carbonate solution, once with 1 M hydrochloric acid and dried over $MgSO_4$. After concentration vacuum **24** (28 mg, 92 %) was obtained as blackish red viscous oil. R_f (PE:EE/5:1): 0.36; ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.73 – 1.98 (m, 11 H), 2.05 – 2.18 (m, 2 H), 3.34 (t, *J* = 6.6 Hz, 2 H), 10.17 (s, 2 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 25.8, 30.4, 31.8, 41.1, 51.0, 65.8, 69.2, 126.7, 141.3, 141.9, 188.7; HRMS (EI) calculated for $C_{16}H_{17}O_2N_3S_4$ $[M]^+$: 411.0204, found: 411.0210; IR (cm^{-1}): 2958, 2933, 2851, 2093, 1675, 1358, 1228, 1172, 1151, 858.

4-Oxopentyl pivalate (25). In a 250 mL three-necked flask 5-hydroxypentan-2-one (10 g, 97.91 mmol) was dissolved in dry DCM (140 mL) and dry pyridine (20 mL, 2.45 mmol, 2.5 eq.). After addition of a spatula tip of DMAP, the mixture was cooled down to 0 °C. Pivaloyl chloride (24 mL, 195.8 mmol, 2 eq.) was added dropwise and the reaction was allowed to stir for 16 h at room temperature. Water was added to the mixture and the organic layer was washed twice with 20 % ammonia solution, twice with 1 M hydrochloric acid and dried over $MgSO_4$. Concentration in vacuo yields **25** (13.92 g, 80 %) as colorless to slightly yellow liquid which was directly used in the next step without further purification. R_f (PE:EE/15:1): 0.16; ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.14 (s, 9 H), 1.81 – 1.92 (m, 2 H), 2.11 (s, 3 H), 2.47 (t, *J* = 7.3 Hz, 2 H), 3.93 – 4.07 (m, 2 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 22.7, 27.1, 29.8, 38.61, 39.7, 63.3, 178.3, 207.5; HRMS (ESI): calculated for $C_{10}H_{19}O_3$ $[M+H^+]$: 187.1334; found: 187.1323.

tert.-Butyl (2-aminoethyl)carbamate (30). A 500 mL three-necked flask was charged with ethane-1,2-diamine (30 mL, 458.19 mmol, 10 eq.) and dry DCM (150 mL). Upon cooling with an ice bath, di-*tert.*-butyl dicarbonate (10 g, 45.82 mmol) in DCM (100 mL) was added dropwise. Stirring at room temperature for 16 h was followed by washing the organic layer with water 3 times. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. **30** (3.55g, 48 %) was obtained as colorless oil. ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.21 (s, 2 H), 1.41 (s, 9 H), 2.69 – 2.81 (m, 2 H), 3.03 – 3.24 (m, 2 H), 5.02 (br s, 1 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm):28.3, 41.8, 43.4, 79.1, 156.1.

***tert.*-Butyl (2-(2,5-dioxo-2,5-dihydro-1H-pyrrol-1-yl)ethyl)carbamate (31)**. In a 100 mL flask a mixture of maleic anhydride (1.60 g, 16.32 mmol), triethylamine (2.71 mL, 19.58 mmol, 1.2 eq.) and ethanol (40 mL) was cooled down to 0 °C. **30** (3.14 g, 19.58 mmol, 1.2 eq.) was added dropwise and stirring continued for 4 h. The solvent was removed in vacuum completely and acetic anhydride (45 mL) and sodium acetate (1.47 g, 17.95 mmol, 1.1 eq.) was added. The mixture was heated at 70 °C for 3 h before cooling with an ice bath. Saturated sodium hydrogen carbonate solution was carefully added, followed by stirring for 15 min, after which the mixture was extracted with DCM 3 times. The combined organic layer were washed with 1 M hydrochloric acid twice, dried over

$MgSO_4$ and concentrated in vacuum. Purification by flash column chromatography (PE:EE), yields **31** (3.36 g, 86 %) as a white solid. R_f (PE:EE/1:1): 0.50. ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 1.38 (s, 9 H), 2.23 – 2.37 (m, 2 H), 3.59 – 3.70 (m, 2 H), 4.82 (br s, 1 H), 6.70 (s, 2 H); ^{13}C-NMR (75 MHz, $CDCl_3$, ppm): 28.2, 37.9, 39.3, 79.4, 134.1, 170.8; HRMS (EI) calculated for $C_{11}H_{16}O_4N_2$ $[M]^+$: 240.1105, found: 240.1101.

N-(2-Aminoethyl)maleimide trifluoroacetate (32). An ice cooled 25 mL flask was charged with dry DCM (6 mL), **31** (300 mg, 1.25 mmol) and trifluoracetic acid (3 mL) and stirred for 1 h. The solvent was evaporated and traces of trifluoroacetic acid were removed by co-evaporation with toluene. The crude product was dissolved in methanol (5 mL) and precipitated with diethyl ether. The white needles were collected and dried in vacuum, yielding **32** (267 mg, 84 %) as white needle like crystals. ^{1}H-NMR (300 MHz, DMSO-d^6, ppm): 2.99 (t, J = 5.8 Hz, 2 H), 3.66 (t, J = 5.9 Hz, 2 H), 7.05 (s, 2 H), 8.04 (br s, 3 H); ^{13}C-NMR (75 MHz, DMSO-d^6, ppm): 35.0, 37.5, 134.8, 171.0.

Keywords: fluorescence dyes • sulfur • heterocycles • Stokes shift • photophysics

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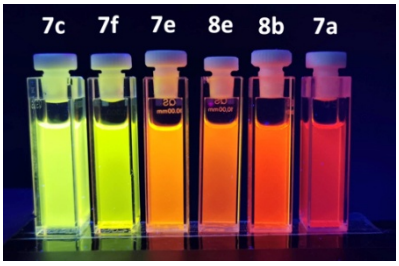

Replacing oxygen by sulfur atoms substantially changes the photophysical behavior of DBD dyes. While fluorescence quantum yields and lifetimes are decreased, absorption and emission wavelength markedly red-shifted. Especially to be emphasized the very large Stokes shifts. A series of S^4-DBD dyes with different electron withdrawing groups were prepared enabling a broad range of emission wavelength.

Key topic: fluorescence dyes