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Suggested citation referring to the original publication:
European journal of organic chemistry 2021 (2020) 3, pp. 499 - 511
DOI https://doi.org/10.1002/ejoc.202001418
ISSN 1434-193X, 1099-0690

Journal article | Version of record

Secondary publication archived on the Publication Server of the University of Potsdam:
Zweitveröffentlichungen der Universität Potsdam : Mathematisch-Naturwissenschaftliche Reihe 1381
ISSN: 1866-8372
https://nbn-resolving.org/urn:nbn:de:kobv:517-opus4-566241
DOI: https://doi.org/10.25932/publishup-56624

EurJOC
European Journal of Organic Chemistry

Full Papers
doi.org/10.1002/ejoc.202001418

Chemistry Europe
European Chemical Societies Publishing

Sulfur Tuning of [1,3]-Dioxolo[4.5-*f*]benzodioxole (DBD) Fluorescent Dyes

Pablo Wessig,*[a] Leonard John,[a] Eric Sperlich,[a] and Alexandra Kelling[a]

Dedicated to Professor Bernd Giese on the occasion of his 80th birthday.

The replacement of oxygen by sulfur atoms of [1,3]-dioxolo[4.5-*f*]benzodioxole (DBD) fluorescent dyes is an efficient way to adjust the photophysical properties (sulfur tuning). While previously developed S^4-DBD dyes exhibit considerably red-shifted absorption and emission wavelength, the heavy atom effect of four sulfur atoms cause low fluorescence quantum yields and short fluorescence lifetimes. Herein, we demonstrate that the replacement of less than four sulfur atoms (S^1-DBD, 1,2-S^2-DBD, and 1,4-S^2-DBD dyes) permits a fine-tuning of the photophysical properties. In some cases, a similar influence on the wavelength without the detrimental effect on the quantum yields and lifetimes is observed. Furthermore, the synthetic accessibility of S^1- and S^2-DBD dyes is improved, compared with S^4-DBD dyes. For coupling with biomolecules a series of reactive derivatives of the new dyes were developed (azides, OSu esters, alkynes, maleimides).

Introduction

Fluorescent dyes nowadays are indispensable tools especially in biosciences, medicine but also in many other areas.[1] Above all, the usage of these dyes in fluorescence microscopy[2] including fluorescence lifetime imaging microscopy (FLIM)[3] and several techniques summarized as super resolution microscopy[4] is vastly superior to classic optical microscopy. This is mainly due to the much higher sensitivity of fluorescence compared with other kinds of signal generation. The selection of a suitable dye for a certain application depends on a series of physical and chemical properties. The most important criteria are the absorption and emission wavelength (λ_{abs}, λ_{em}). Long-wave absorption and emission are desirable in most cases, because the penetration depth (*e.g.* in biological tissue) increases with increasing wavelength. A large STOKES shift (*i.e.* the difference between λ_{abs} and λ_{em}) is important for STED microscopy[4a] and to minimize self-quenching. A long fluorescence lifetime τ_F is advantageous for FLIM because it enhances the signal-to-noise ratio regarding the undesirable natural background fluorescence. The signal-to-noise ratio of fluorescence microscopy is mainly influenced by the brightness of the dye, which is defined by the product of fluorescence quantum yield Φ_F and molar attenuation coefficient ε. In addition to these photophysical parameters the bleaching stability (*i.e.* the chemical stability against extensive irradiation) and the synthetic accessibility are important criteria. Hardly any dye is exhibiting ideal values for all photophysical parameters. Therefore, there is a continued need for new fluorescent dyes or improvement of existing dye classes.

Some years ago we developed a new class of dyes, which are based on the [1,3]-dioxolo[4.5-*f*]benzodioxole skeleton bearing electron withdrawing groups (EWG) in positions 4,8 and named them DBD dyes (Figure 1).[5a,b] The outstanding features of these dyes are very large STOKES shifts, long fluorescence lifetimes and high bleaching stability. Meanwhile, we developed numerous applications such as probes for sensing lipophilic environment,[5c] conformational changes of proteins,[5d,e] detecting carbohydrate-lectin interactions,[5f] *ds*DNA,[5o] and alkaline cations.[5g,h] Furthermore, fluorescence lifetime based assays[5i,j] and FRET pairs[5k–n] were developed. In addition to those application-oriented developments we always were interested in fundamental research to improve the photophysical properties of DBD dyes. Looking at the structure of DBD dyes there are basically three ways to influence their photophysical properties: varying the EWGs ("EWG tuning"),

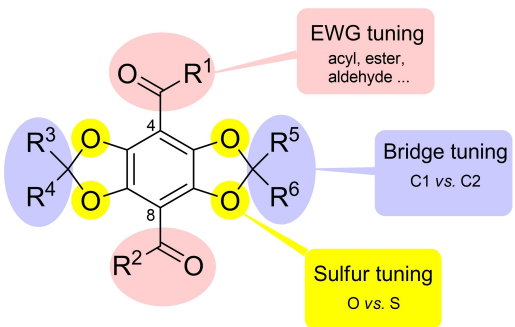

Figure 1. Structure of DBD dyes and adjusting screws for influencing the photophysical properties.

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Supporting information for this article is available on the WWW under https://doi.org/10.1002/ejoc.202001418

changing the length of the bridge between the ring hetero atoms ("bridge tuning"), and replacing the DBD core oxygen by sulfur atoms ("sulfur tuning") (Figure 1). Recently, we demonstrated that absorption and emission wavelength of DBD dyes can be efficiently influenced (λ_{em} = 480–610 nm) by EWG tuning.[6]

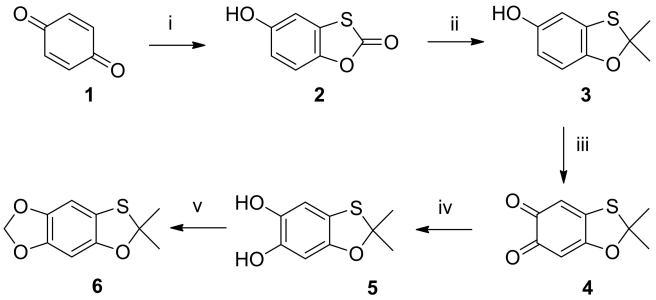
With the aim to further shift absorption and emission to longer wavelength we tackled the "sulfur tuning" and first examined the maximum of replacing all four oxygen by sulfur atoms (S_4-DBD dyes, see Figure 2).[7] Despite a considerable red-shift of absorption and emission this approach also revealed some disadvantages: An enhanced spin-orbit coupling (heavy atom effect) of the sulfur atoms increases the efficiency of intersystem crossing (ISC) to the triplet state. This causes a significant lowering of the fluorescence quantum yields and lifetimes.[7b] Moreover, the quite efficient synthesis of S_4-DBD dyes mandatorily requires the use of extremely malodorous *tert*-butylthiol.[7a] It should be noted that very recently an alternative route has been published.[7d] Therefore we hypothesized that the replacement of already less than four sulfur atoms could satisfactorily improve the spectroscopic and synthetic issues.

Herein we describe the synthesis and properties of S_1-, 1,2-S_2- and 1,4-S_2-DBD dyes (Figure 2) as well as the influence of bridge tuning.

Results and Discussion

S_1-DBD dyes

The parent heterocycle [1,3]dioxolo[4,5-*f*][1,3]benzoxathiole ("S_1-DBD", Figure 2) was mentioned only once in the literature[8] (besides two patents without synthetic details), but the synthetic route specified there is unsuitable for our purposes. After numerous unsuccessful attempts we identified the long-established reaction of 1,4-benzoquinone **1** with thiourea as method of choice on the way to S_1-DBD dyes.[9] Saponification of the resulting thiocarbonate **2** and protection as acetonide gave compound **3** in good yields. The introduction of the third oxygen atom took place by oxidation of **3** to quinone **4** using Frémy's salt ($K_2[ON(SO_3)_2]$).[10] After reduction to catechol **5** (which was used without further purification) and bridging using $BrClCH_2$ we obtained the target compound **6** (Scheme 1).



Scheme 1. Synthesis of compound **6**. i thiourea, HOAc, 100 °C, 1 h, 82 %. ii 1. NaOH, 2. 2,2-dimethoxypropane, cat. PPTSA, 66 %. iii $K_2[ON(SO_3)_2]$), 86 %. iv PtO_2/H_2. v $BrClCH_2$, K_2CO_3, 77 %, 2 steps.

Next, we pursued the introduction of different EWGs. For this purpose **6** was first lithiated (*n*-BuLi, TMEDA, *n*-hexane), followed by treatment with electrophiles (DMF, N-methoxy-N-methyl butanamide, ethyl chloroformate). Besides the desired 4,8-disubstituted compounds **9** we always obtained the mono-substituted compounds **7** and **8** as by-products (Scheme 2).

The unequivocal distinction between **7** and **8** was possible based on the X-ray structure analysis of **7a** and **7b** (see below).

1,2-S_2-DBD dyes

More than 30 years ago Klar and co-workers reported on the surprisingly smooth reaction of various catechol ethers with disulfur dichloride giving dibenzo[*c*,*g*][1,2,5,6]tetrathiocines.[11] Since then, this method was mentioned only three times.[12] En route to 1,2-S_2-DBD dyes we successfully applied the method to 1,2-benzodioxole **10** and 2,3-dihydro-1,4-benzodioxine **13**. The resulting tetrathiocines **11** and **14** could readily be reduced to the dithiols **12** and **15**. Due to its performance we used this approach to explore the influence of the bridge length on the photophysical properties ("bridge tuning", *cf.* Figure 1). Accordingly, four parent compounds **16**–**19** were prepared (Scheme 3).

Once again, the introduction of formyl groups provided mixtures of mono- and disubstituted products. Best results were achieved with two five-membered rings (**16**), while the reactants with six-membered heterocyclic rings (**17**–**19**) gave consistently worse results (Scheme 4). The reason could be a partial deprotonation of the ethylene bridge.

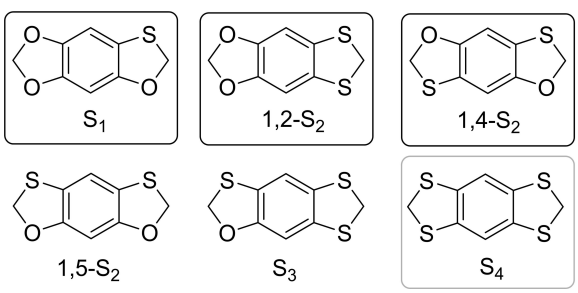
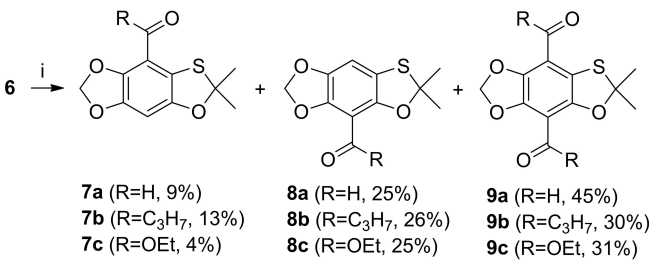
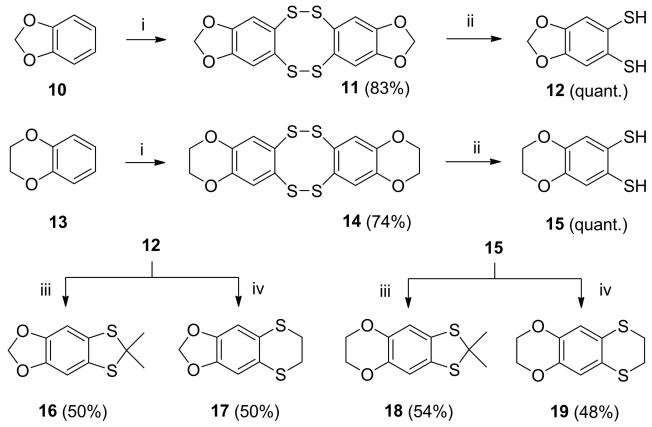


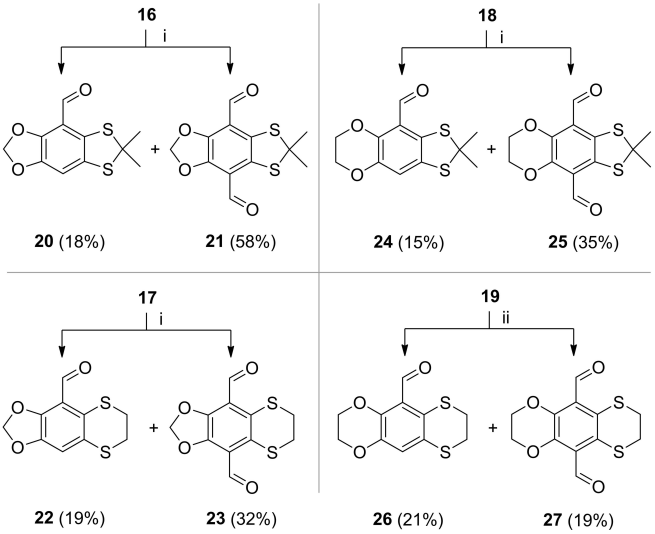
Figure 2. Structure of S_n-DBD dye parent compounds.



Scheme 2. Synthesis of compounds **7**–**9**. i 1. *n*-BuLi, TMEDA, *n*-hexane, 2. DMF (**a**) or N-methoxy-N-methyl butanamide (**b**) or ethyl chloroformate (**c**).



Scheme 3. Synthesis of compounds **16–19**. i S_2Cl_2, HOAc, r.t. 12 h. ii $NaBH_4$, DMF, 100 °C, 2 h. iii acetone, DCM, BF_3Et_2O (cat.), iv $BrCH_2CH_2Br$, K_2CO_3, DMF, 90 °C, 3 h.

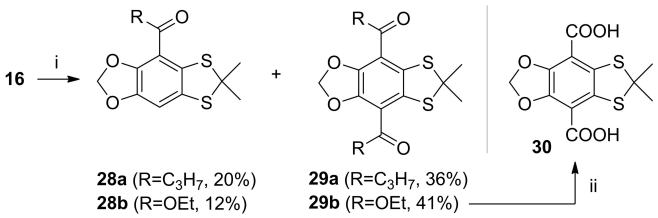


Scheme 4. Synthesis of 1,2-S_2-DBD aldehydes. i *n*-BuLi, TMEDA, *n*-hexane, r.t. ii *n*-BuLi, TMEDA, *n*-hexane, −10 °C.

It should be noted that the replacement of five- by six-membered heterocycles does not cause significant improvement of the photophysical properties (*vide infra*). As the yields of these compounds are also rather low, we focused our efforts on 1,2-S_2-DBD dyes bearing a dioxole and a dithiole ring. Accordingly, the ketones **28a**, **29a** and the esters **28b**, **29b** were prepared. Moreover, **29b** could be quantitatively saponified to the dicarboxylic acid **30** (Scheme 5).

1,4-S_2-DBD dyes

The preparation of 1,4-S_2-DBD dyes turned out to be difficult. After numerous attempts we identified the Pd-catalyzed intramolecular oxidative C–H-sulfuration[15] as a viable route. For this purpose we used compound **3**, an intermediate of S_1-DBD dyes (*cf.* Scheme 1). First, **3** was converted into thiocarbamate **31**



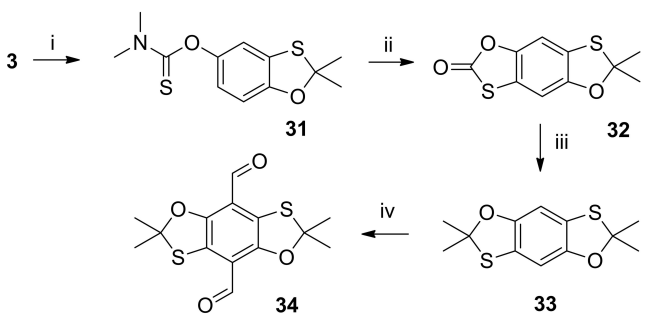
Scheme 5. Synthesis of 1,2-S_2-DBD dyes **28–30**. i 1. *n*-BuLi, TMEDA, *n*-hexane, 2. N-methyl-N-methoxy butanamide (**a**) or ethyl chloroformate (**b**). ii NaOH, ACN/H_2O (1:1), 60 °C, 4 h, quant.

followed by treatment with $Pd(OAc)_2$ in the presence of benzoquinone. Unfortunately, the yields of the desired thiocarbonate **32** were rather low (23%). The next steps, comprising of replacement of the thiocarbonate by an acetonide (**33**) and introduction of the formyl groups (**34**) proceeded disappointingly poor (Scheme 6). In summary, 1,4-S_2-DBD dyes are significantly worse accessible than 1,2-S_2-DBD dyes.

Reactive S_1-DBD and 1,2-S_2-DBD dyes for bioconjugation

Most biological and biochemical applications of fluorescent dyes require functional groups for coupling with biomolecules. Because dialdehydes **9a** and **21** exhibit the best synthetic accessibility we prepared a collection of bioreactive S_1-DBD and 1,2-S_2-DBD dyes with these chromophores. The synthesis of 1,2-S_2-DBD dyes started with dithiol **12**. The acetalization with pivaloyl protected 5-hydroxypentan-2-one gave compound **35a** and, after deprotection, the alcohol **35b**. Formyl groups were introduced in the usual way giving dialdehyde **36**. After several unsuccessful attempts we identified a previously developed cyclohexanone derivative[5m] as suitable building block for reactive S_1-DBD dyes. Using catechol **5** (Scheme 1) we prepared silyl-protected spirane **43**. After installation of the formyl groups and deprotection we obtained the alcohol **44b**.

These two compounds **36** and **44b** were used as platform to synthesize propargyl carbonates **37**, **45** (for CuAAc with azides[14]), OSu esters **39**, **47** (for reaction with amines), the azide



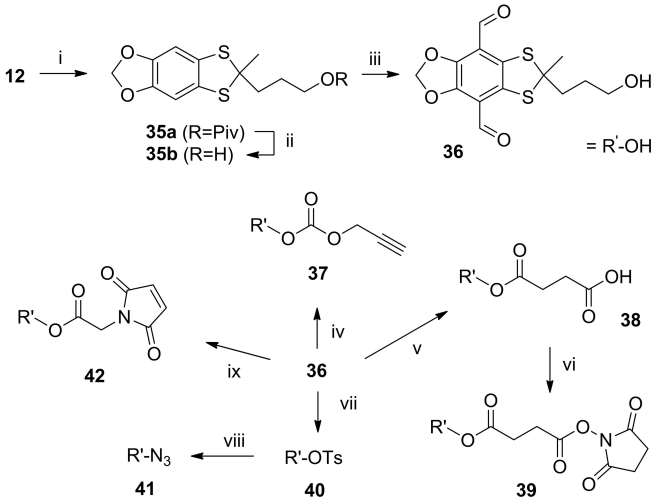
Scheme 6. Synthesis of 1,4-S_2-DBD dialdehyde **34**. i dimethylthiocarbamoyl chloride, N,N-diisopropylethylamine, 75%. ii $Pd(OAc)_2$, TsOH, benzoquinone, HOAc, toluene, 23%. iii 1. NaOH, 2. acetone, PPTSA, 21%. iv 1. *n*-BuLi, TMEDA, *n*-hexane, 0 °C, 2. DMF, 27%.

41 (for CuAAc with alkynes[14]), and maleimides **42**, **48** (for reaction with thiols, *e.g.* cystein, Scheme 7 and Scheme 8).

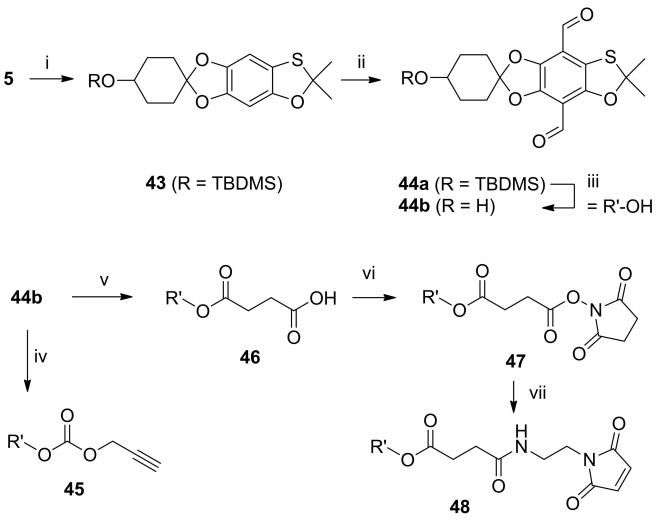
Structure of S_n-DBD dyes

For the three compounds **7a**, **7b** and **21**, X-ray structure analyses were performed. The arrangement of the molecules of **7a**, **7b** and **21** in the solid is very similar. In all three compounds, parallel stacking interactions between the aromatic molecules are formed (see Supporting information for illustrations). In addition, the molecules arrange themselves in such a way that the S atoms of different molecules come very close to each other (Figure 3).

In compounds **7a** and **7b** this leads to the formation of dimers in which the S···S distance is shorter than the sum of the van der Waals radii, in **21** the distance is much larger. The reason for this arrangement are weak C–H···O-hydrogen bridges between the molecules with H···O distances ranging from 2.57 Å to 2.69 Å which are typical for these bonds.[16] All three X-ray structures exhibit a striking feature with respect to the conformation of the acyl groups. The oxygen atoms of the acyl groups in *o*-position to sulfur are always directed towards sulfur atoms despite the considerable larger van der Waals radius of S compared to O (1.80 Å *vs.* 1.52 Å). The distances of both atoms are much shorter than the sum of the van der Waals radii (r_{SO} =



Scheme 7. Syntheses of reactive S_2-DBD dyes **37**–**42**. i 4-oxopentyl 2,2-dimethylpropanoate, $BF_3 \cdot Et_2O$ (cat.), DCM, 12 h, r.t., 55%. ii LiOH, MeOH, 12 h, r.t., 83%. iii *n*-BuLi, TMEDA, *n*-hexane 0 °C, 1 h, 35% (+21% monoaldehyde). iv propargyl chloroformate, DMAP, pyridine,12 h, r.t., 89%. v succinic anhydride, pyridine, DMAP, 62%. vi N-Hydroxysuccinimide, EDC, DCM, 16 h, r.t., 87%. vii TsCl, DMAP, pyridine, 12 h, r.t., 50%. viii NaN_3, DMF, 14 h, r.t., >99%. ix (2,5-dioxo-2,5-dihydro-1H-pyrrol-1-yl)acetyl chloride,[13] DIPEA, DCM/DMF, 5 h, r.t., 62%.



Scheme 8. Syntheses of reactive S_1-DBD dyes **45**–**48**. i *tert*-butyl[(4,4-dimethoxycyclohexyl)oxy]dimethylsilane,[5m] PPTSA, toluene, 2 h, rfx., 53% (2 steps from **4**). ii *n*-BuLi, TMEDA, *n*-hexane 0 °C, 1 h, 35% (+35% monoaldehydes). iii HF, ACN, quant. iv propargyl chloroformate, DMAP, pyridine,12 h, r.t., 88%. v succinic anhydride, pyridine, DMAP, r.t., 14 h, 64%. vi N-Hydroxysuccinimide, EDC, DCM, 12 h, r.t., 85%. vii N-(2-aminoethyl)-maleimide-trifluoroacetate, DIPEA, DMF, r.t., 15 h, 65%.

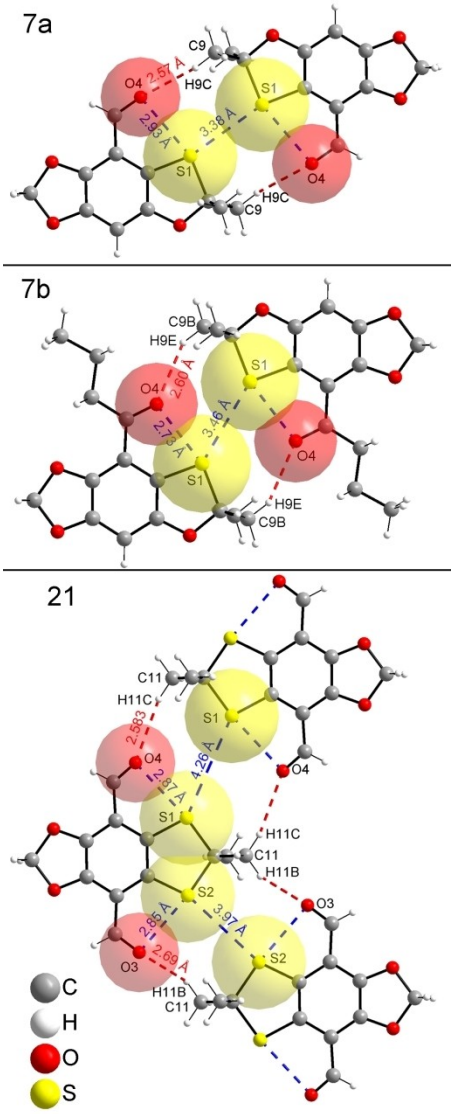


Figure 3. X-ray structures of **7a, b** and **21** with selected bond lengths.

3.32 Å[17]), which suggests the presence of chalcogen bridges. In the three compounds the S···O distances vary from 2.73 Å to 2.92 Å, the C–S···O angles from 157° to 164° and the S···O=C angles from 93° to 101°. The values correspond very well with already published distances and angles for such sigma-hole interactions between intramolecular S···O atoms.[18] Further illustrations of the crystal structure and the intermolecular interactions are shown in the Supporting Information.

To find out the reason for the preferred conformation of the acyl groups we performed DFT calculations (M06-2X-D3[19]/def2-TZVP[20]) with 1,4-S_2-DBD dialdehyde (analogous to compound **34**, without methyl groups). Considering conformations **A**, **B**, **C** we found that **A** with both formyl oxygen atoms directed to sulfur atoms is by far the most stable conformation. The other two conformers **B**, **C** are less stable by 4.2 kcal/mol and 8.0 kcal/mol respectively (Figure 4). Bearing in mind the +M effect of ring heteroatoms and the −M effect of formyl groups each conformer can be expressed as three mesomers (**A-1**,**2**,**3**, **B-1**,**2**,**3**, **C-1**,**2**,**3**). This assumption is supported by inspecting the bond orders obtained from a Natural Bond Orbital (NBO) analysis.[21] In Figure 4 the Wiberg bond indices (totals by atoms) are depicted in the formulae of **A-1**, **B-1**, **C-1**. The indices of those ring heteroatoms to which a formyl oxygen atom is directed are significantly increased indicating a partial double bond to the aromatic ring (for details see the SI). The origin of the pronounced preference of sulfur over oxygen as donor atoms should be the higher Lewis basicity of thioethers compared with ethers. Additionally, there are presumably stronger Coulomb forces (dashed lines in Figure 4) between S and O due to larger vdW radius of S.

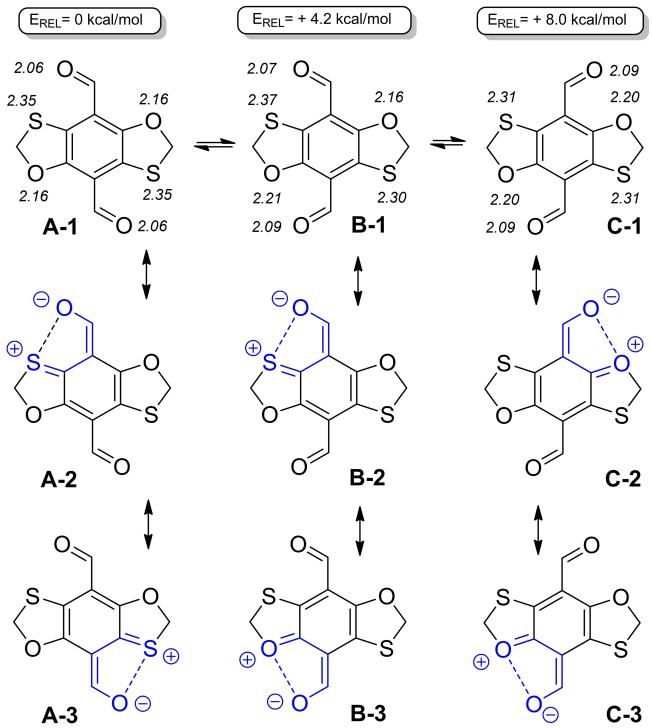


Figure 4. Mesomeric structures, conformers, and Wiberg bond indices (totals by atoms) of 1,4-S_2-DBD dyes.

Photophysical properties of S_n-DBD dyes

The photophysical properties of selected S_n-DBD dyes and, for comparison, of O_4-DBD dialdehyde[6] are summarized in Table 1 (for complete data see the SI). First, we compare the dialdehydes of S_1-DBD (**9a**), 1,2-S_2-DBD (**21**), and 1,4-S_2-DBD (**34**). The introduction of one sulfur atom results in a significant red-shift of absorption (25 nm) and emission (9 nm) without reduction of fluorescence lifetime τ_F and quantum yield Φ_F. This effect is increased by a second S atom in *o*-position (**21**), though entailed with clear reduction of τ_F, Φ_F. Surprisingly, the latter effect is not observed with 1,4-S_2-DBD dialdehyde **34**. Perhaps the spatial proximity of the sulfur atoms in 1,2-DBD dyes cause a stronger spin-orbit coupling and consequently an increase of the intersystem crossing to the triplet state than in 1,4-S_2-DBD dyes.[7b] The data of **21**, **23**, **25**, **27** illustrate the influence of bridge tuning. In all cases the replacement of one-atom bridge by two-atom bridge leads to worse photophysical properties (blue shift of λ_{abs}, λ_{em}, decreased values for τ_F and Φ_F). Nevertheless, the extremely high Stokes Shift (193 nm) of **23** is remarkable. The properties of 1,2-S_2-DBD ketones (**29a**) and esters (**29b**) are in the expected range.

Table 1. Photophysical data of O_4-DBD dialdehyde and selected S_x-DBD dyes.[a]

No.	λ_{abs}[b,c]	λ_{em}[c]	$\Delta\lambda$[c]	$\Delta\tilde{\nu}$[d]	τ_F[e]	Φ_F	ε[b,f]
[g]	475	609	134	4.63	17.7	0.32	1.78
9a	500	618	118	3.82	17.9	0.43	4.22
21	505	637	133	4.10	9.8	0.21	4.76
23	437	630	193	7.01	4.0	0.10	2.15
25	493	595	102	3.48	9.1	0.21	3.72
27	420	588	168	6.80	3.7	0.07	1.42
29a	459	590	131	4.84	9,6	0.23	4.91
29b	413	525	112	5.17	8.4	0.30	3.44
34	520	620	100	3.10	16.8	0.52	4.08

[a] solvent: actonitrile. [b] λ_{abs} and ε refer to the long-wave absorption. [c] λ_{abs}, λ_{em}, $\Delta\lambda$ in nm. [d] $\Delta\nu$ in $10^3 \cdot cm^{-1}$ [e] τ_F in ns. [f] ε in $10^3 \cdot M^{-1} cm^{-1}$. [g] O_4-DBD dialdehyde.[6]

Conclusion

A red-shift of absorption and emission wavelength as much as possible without significant reduction of fluorescence lifetime and quantum yields is the most important criterion for evaluating the influence of structural alterations of DBD dyes. Nevertheless, the synthetic accessibility and possibilities for functionalization are also very important. Based on the photophysical criterion the 1,4-S_2-DBD dyes would be the optimal solution (*e.g.* **34**), but the syntheses to these compounds currently proceed with very low yields. On the other hand, there is an efficient route to 1,2-S_2-DBD dyes with tetrathiocines as key intermediates. Moreover, we demonstrated that a variety of reactive compounds for bioconjugation (**37**–**42**) are easily accessible.

The "bridge tuning", *i.e.* the replacement of the heterocyclic five-membered by a six-membered ring is an interesting variation of DBD dyes, but does not improve the photophysical properties.

In summary, a considerable improvement of DBD dyes, both photophysically and synthetically, could be achieved by "sulfur-tuning".[22]

Experimental Section

General information: See the Supporting Information

5-Hydroxybenzo[*d*][1,3]oxathiol-2-one (2): 1,4-Benzoquinone (10.90 g, 100.0 mmol, 1.0 equiv.) was dissolved in 80 mL glacial acetic acid and added dropwise to a solution of thiourea (9.21 g, 121.0 mmol, 1.2 equiv.) in 100 mL 2 M HCl at room temperature. The reaction mixture was treated with 10 mL HCl (conc.) and stirred for 1 h while a white precipitate was formed. The reaction was heated for 1 h at 95 °C and cooled with an ice bath. The white precipitate was filtered of, washed with H_2O and purified by silica gel column chromatography (PE:EE 5:1) yielding **2** (13.9 g, 82.7 mmol, 82%) as a white solid, m.p. 158 °C. R_f (PE:EE/10:1): 0.33. ^{1}H-NMR (400 MHz, DMSO-d^6): 9.77 (s, 1 H), 7.25 (d, ^3J = 8.8 Hz, 1 H), 7.11 (s, 1 H), 6.76 (d, ^3J = 8.8 Hz, 1 H) ppm. ^{13}C-NMR (101 MHz, DMSO-d^6): 169.4, 154.9, 140.7, 123.1, 114.6, 112.5, 109.5 ppm. IR (ATR, cm^{-1}): 3324, 1694, 1587, 1459, 1286, 1207, 1096, 1042, 857. HRMS: calcd. for $C_7H_4O_3S_1$ 167.9881 [M]$^+$, found 167.9886.

2,2-Dimethylbenzo[*d*][1,3]oxathiol-5-ol (3): NaOH (0.71 mg, 17.84 mmol, 3.0 equiv.) was added to a mixture of **2** (1.00 g, 5.95 mmol, 1.0 equiv.) in 40 mL H_2O/MeOH (1:1) and stirred for 2 h at 60 °C under a nitrogen atmosphere. The reaction was acidified with 1 M HCl to pH = 2 and extracted with ethyl acetate (2×). The solvent was removed under reduced pressure and the remaining white solid dissolved in acetone (0.80 mL, 6.0 mmol, 1.1 equiv.), 80 mL anhydrous toluene and a catalytic amount of *p*-toluenesulfonic acid. The mixture was refluxed in a DEAN-STARK apparatus for 20 h, cooled to room temperature, washed with saturated $NaHCO_3$ solution and dried with $MgSO_4$. After the solvent was removed under reduced pressure, the crude product was purified by flash silica gel column chromatography (PE:EE 10:1) to afford 3 (740 mg, 4.61 mmol, 69%) as a colourless oil. R_f (PE:EE/5:1): 0.53. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.63 (s, 1 H), 6.61 (s, 1 H), 1.82 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 150.6, 149.4, 128.1, 112.0, 110.8, 109.9, 98.1, 30.2. IR (ATR, cm^{-1}): 3381, 2973, 1474, 1367, 1327, 1215, 1173, 1117. HRMS (EI): calcd. for $C_9H_{10}O_2S_1$ 182.0396 [M]$^+$, found 182.0399.

2,2-Dimethylbenzo[*d*][1,3]oxathiole-5,6-dione (4): FREMYs salt (740 mg, 4.06 mmol, 1.0 equiv.) was added to a solution of KH_2PO_4 (718 mg, 5.28 mmol, 1.3 equiv.) in 40 mL H_2O at 0 °C. Alcohol **3** (740 mg, 4.06 mmol, 1.0 equiv.) was dissolved in 10 mL MeOH and added dropwise over a period of 10 min to the solution. The mixture was stirred for 2 h at room temperature while the solution turned into a red suspension which was filtered off. The solid was washed several times with DCM and water. The phases of the filtrate were separated and the water phase was extracted with DCM (2×). The combined organic layers were washed with brine and dried with $MgSO_4$. After removing the solvent in vacuo, the crude product was purified by flash silica gel column chromatography (DCM:MeOH 50:1) to yield **4** (680 mg, 15.34 mmol, 86%) as a red solid, m.p. 210 °C. R_f (PE:EE/3:1): 0.23. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm) 6.40 (s, 1 H), 6.00 (s, 1 H), 1.92 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm) 177.7, 175.8, 167.6, 153.8, 117.4, 102.9, 102.8, 31.0. IR (ATR, cm^{-1}): 3061, 1659, 1639, 1558, 1365, 1247, 1162, 1026, 838. HRMS (EI): calcd. for $C_9H_8O_3S_1$ 196.0194 [M]$^+$, found 196.0195.

6,6-Dimethyl-[1,3]dioxolo[4′,5′:4,5]benzo[1,2-*d*][1,3]oxathiole (6): Quinone **4** (650 mg, 3.31 mmol, 1.0 equiv.) was dissolved in 40 mL anhydrous THF with a spatula-tip of PtO_2. The atmosphere was flushed three times with hydrogen and stirred under hydrogen [$p(H_2)$ = 1 atm] at room temperature till complete conversion monitored by TLC (2 h). During the hydrogenation the colour of the solution turned from red to colourless. The solvent was reduced to 10% and the atmosphere flushed with nitrogen. 20 mL dry DMF, anhydrous K_2CO_3 (2.29 g, 16.56 mmol, 5.0 equiv.) and CH_2BrCl (0.30 mL, 3.98 mmol, 1.2 equiv.) were added to the residue and stirred for 3 h at 90 °C and further 14 h at room temperature. The reaction mixture was acidified with 2 M HCl and extracted with ethyl acetate (2×). The combined organic layers were washed with brine, dried with $MgSO_4$ and concentrated under reduced pressure. Purification of the crude product by flash silica gel column chromatography (PE:EE 10:1) gave **6** (537 mg, 2.55 mmol, 77%) as a colourless oil. R_f (PE:EE/20:1): 0.45. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.59 (s, 1 H), 6.41 (s, 1 H), 5.87 (s, 2 H), 1.81 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 149.1, 145.8, 142.5, 116.9, 102.9, 101.4, 98.5, 94.8, 30.2. IR (ATR, cm^{-1}): 2969, 2886, 1494, 1464, 1379, 1278, 1128, 1036. HRMS (EI): calcd. for $C_{10}H_{10}O_3S_1$ 210.0351 [M]$^+$, found: 210.0346.

6,6-Dimethyl-[1,3]dioxolo[4′,5′:4,5]benzo[1,2-*d*][1,3]oxathiole-4,8-dicarbaldehyde (9a): *n*-BuLi (2.5 M in hexane, 0.40 mL, 1.00 mmol, 2.1 equiv.) was given to a mixture of compound **6** (100 mg, 0.48 mmol, 1.0 equiv.) and dry TMEDA (0.14 mL, 0.95 mmol, 2.0 equiv.) in 6 mL anhydrous hexane and stirred for 1 h at 0 °C. Dry DMF (0.10 mL, 1.19 mmol, 2.5 equiv.) was added and stirred for 1 h at 0 °C. The reaction mixture was quenched with 1 M HCl. After phase separation the water layer was extracted with ethyl acetate (2×). The combined organic layers were washed with brine, dried with $MgSO_4$, evaporated and purified with flash silica gel column chromatography (PE:EE 5:1) to afford **9a** (54 mg, 0.22 mmol, 45%) as a red solid, m.p. 188 °C. R_f (PE:EE/ 5:1): 0.20. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.18 (s, 2 H), 6.20 (s, 2 H), 1.86 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 186.3, 185.5, 151.0, 145.6, 145.4, 118.7, 116.0, 110.1, 104.4, 100.8, 30.7. IR (ATR, cm^{-1}): 2962, 2908, 1664, 1438, 1408, 1258, 1057, 1018, 925. HRMS (EI): calcd. for $C_{12}H_{10}O_5S_1$ 266.0249 [M]$^+$, found: 266.0253.

Additionally **7a** was isolated in 9% and **8a** with a yield of 25%, both as a yellow solid.

6,6-Dimethyl-[1,3]dioxolo[4′,5′:4,5]benzo[1,2-*d*][1,3]oxathiole-8-carbaldehyde (7a): M.p. 132 °C, R_f (PE:EE/5:1) 0.55. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.16 (s, 1 H), 6.59 (s, 1 H), 6.04 (s, 2 H), 1.80 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 185.8, 150.0, 146.2, 145.1, 117.3, 113.5, 102.8, 99.4, 98.6, 30.5. IR (ATR, cm^{-1}): 3086, 2974, 2901,

2849, 1676, 1459, 1378, 1346, 1290, 1215, 1153, 1053. HRMS (EI): calcd. for $C_{11}H_{10}O_4S_1$ 238.0300 $[M]^+$, found: 238.0293.

6,6-Dimethyl-[1,3]dioxolo[4′,5′:4,5]benzo[1,2-*d*][1,3]oxathiole-4-carbaldehyde (8a): M.p. 135 °C, R_f (PE:EE/5:1): 0.38. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.14 (s, 1 H), 6.79 (s, 1 H), 6.05 (s, 2 H), 1.88 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 186.5, 150.1, 146.1, 143.2, 118.2, 108.2, 108.1, 103.1, 100.6, 30.4. IR (ATR, cm^{-1}): 3081, 2974, 2924, 2868, 1682, 1617, 1453, 1366, 1273, 1170, 1067, 1031. HRMS (EI): calcd. for $C_{11}H_{10}O_4S_1$ 238.0300 $[M]^+$, found: 238.0305.

1,1′-(6,6-Dimethyl-[1,3]dioxolo[4′,5′:4,5]benzo[1,2-*d*][1,3]oxathiole-4,8-diyl)bis(butan-1-one) (9b): Compound **6** (100 mg, 0.48 mmol, 1.0 equiv.) was dissolved with TMEDA (0.15 mL, 0.95 mmol, 2.0 equiv.) in 3 mL dry *n*-hexane and cooled to 0 °C. After adding *n*-BuLi (2.5 M in hexane, 0.40 mL, 1.00 mmol, 2.1 equiv.) the mixture was stirred for 1 h at 0 °C. N-methoxy-N-methyl butanamide (156 mg, 1.19 mmol, 2.5 equiv.) was added and stirred for another hour at 0 °C. The mixture was quenched with 1 M HCl. The phases were separated and the water layer extracted with ethyl acetate (2×20 mL). The combined organic layers were dried with $MgSO_4$ and concentrated in vacuo. After purification by flash silica gel column chromatography (PE:EE 10:1) compound **9b** (50 mg, 0.14 mmol, 30%) was isolated as an orange solid, m.p. 146 °C. R_f (PE:EE/10:1): 0.35. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.11 (s, 2 H), 2.91 (m, 4 H), 1.80 (s, 6 H), 1.76–1.62 (m, 4 H), 0.96 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 198.5, 196.9, 147.8, 144.9, 142.9, 120.8, 115.8, 112.1, 102.7, 97.6, 46.0, 45.0, 30.4, 17.6, 17.2, 14.0, 13.9. IR (ATR, cm^{-1}): 2960, 2930, 2872, 1687, 1662, 1427, 1365, 1261, 1077. HRMS (EI): calcd. for $C_{18}H_{22}O_5S_1$ 350.1188 $[M]^+$, found: 280.1185.

Additionally **7b** was isolated in 13% and **8b** in 26%.

1-(6,6-Dimethyl-[1,3]dioxolo[4′,5′:4,5]benzo[1,2-*d*][1,3]oxathiol-8-yl)butan-1-one (7b): M.p. 147 °C, R_f (PE:EE/10:1): 0.63. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.56 (s, 1 H), 6.02 (s, 2 H), 2.93 (t, ^3J = 7.3 Hz, 2 H), 1.77 (s, 6 H), 1.76–1.70 (m, 2 H), 0.98 (s, 3 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 197.2, 149.9, 146.1, 142.6, 119.4, 114.6, 103.0, 101.9, 98.2, 96.9, 44.8, 31.1, 30.4, 17.3, 14.0. IR (ATR, cm^{-1}): 2955, 2929, 1676, 1613, 1445, 1365, 1270, 1231, 1165, 1045, 958. HRMS (EI): calcd. for $C_{14}H_{16}O_4S_1$ 280.0769 $[M]^+$, found 280.0764.

1-(6,6-Dimethyl-[1,3]dioxolo[4′,5′:4,5]benzo[1,2-*d*][1,3]oxathiol-4-yl)butan-1-one (8b): M.p. 147 °C, R_f (PE:EE/10:1): 0.48. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.71 (s, 1 H), 5.99 (s, 2 H), 2.87 (t, ^3J = 7.3 Hz, 2 H), 1.86 (s, 6 H), 1.73–1.68 (m, 2 H), 0.97 (s, 3 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 198.4, 147.3, 145.0, 143.0, 118.5, 110.2, 106.0, 102.3, 99.3, 45.9, 30.3, 17.7, 14.0. IR (ATR, cm^{-1}): 2957, 2931, 2870, 1677, 1613, 1443, 1365, 1275, 1230, 1176, 1048. HRMS (EI): calcd. for $C_{14}H_{16}O_4S_1$ 280.0769 $[M]^+$, found: 280.0766.

Diethyl 6,6-dimethyl-[1,3]dioxolo[4′,5′:4,5]benzo[1,2-*d*][1,3]oxathiole-4,8-dicarboxylate (9c): To a solution of compound **6** (140 mg, 0.66 mmol, 11.0 equiv.) and TMEDA (0.21 mL, 1.33 mmol, 2.0 equiv.) in dry hexane (5 mL) *n*-BuLi (2.5 M in hexane, 0.56 mL, 1.40 mmol, 2.1 equiv.) was given and stirred for 1 h at 0 °C. Then ethyl chloroformate (0.18 mL, 1.66 mmol, 2.5 equiv.) was added and stirred again for 1 h at 0 °C. The reaction was quenched with saturated NH_4Cl-solution and extracted with ethyl acetate (3× 30 mL). The combined organic layers were washed with brine, dried with $MgSO_4$, evaporated and purified by flash silica gel column chromatography (PE:EE 10:1) to yield **9c** (73 mg, 0.21 mmol, 30%) as a yellowish oil. R_f (PE:EE/10:1): 0.30. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.11 (s, 2 H), 4.43–4.36 (m, 4 H), 1.83 (s, 6 H), 1.39–1.36 (m, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 163.9, 162.6, 148.3, 146.1, 143.2, 121.9, 109.9, 104.9, 103.1, 98.0, 62.1, 61.6, 30.5, 14.4, 14.3. IR (ATR, cm^{-1}): 2962, 2931, 1769, 1720, 1434, 1368, 1261, 1174, 1070, 1022 cm^{-1}. HRMS (EI): calcd. for $C_{16}H_{18}O_7S_1$ 354.0773 $[M]^+$, found: 354.0765.

Compound **7c** was additionally added in a yield of 4% as well as **8c** in 25%.

Ethyl 6,6-dimethyl-[1,3]dioxolo[4′,5′:4,5]benzo[1,2-*d*][1,3]oxathiole-8-carboxylate (7c): R_f (PE:EE/10:1): 0.45. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.55 (s, 1 H), 6.02 (s, 2 H), 4.40 (q, ^3J = 7.2 Hz, 2 H), 1.80 (s, 6 H), 1.40 (t, ^3J = 7.1 Hz, 3 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 164.3, 149.4, 146.5, 143.2, 120.3, 102.3, 98.1, 97.2, 65.3, 61.7, 30.4, 14.5. IR (ATR, cm^{-1}): 2925, 2833, 1652, 1593, 1368, 1243, 1172, 1050, 934. HRMS (EI): calcd. for $C_{13}H_{14}O_5S_1$ 282.0562 $[M]^+$, found: 282.0564.

Ethyl 6,6-dimethyl-[1,3]dioxolo[4′,5′:4,5]benzo[1,2-*d*][1,3]oxathiole-4-carboxylate (8c): R_f (PE:EE/10:1): 0.68. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.73 (s, 1 H), 6.00 (s, 2 H), 4.39 (q, ^3J = 7.1 Hz, 2 H), 1.86 (s, 6 H), 1.37 (s, 3 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 166.4, 149.2, 146.3, 142.5, 115.9, 101.4, 98.0, 94.8, 69.4, 64.9, 30.5, 30.2, 14.3. IR (ATR, cm^{-1}): 2956, 2928, 2871, 1764, 1464, 1367, 1243, 1172, 1117, 1050. HRMS (EI): calcd. for $C_{13}H_{14}O_5S_1$ 282.0562 $[M]^+$, found: 282.0569.

[1,3]Dioxolo[8,9][1,2,5,6]benzotetrathiocino[3,4-*f*][1,3]benzodioxole (11): In a 100 mL flask disulfur dichloride (1.4 mL, 17.6 mmol, 1.0 equiv.) was added to a solution of 1,3-benzodioxole (2 mL, 17.60 mmol, 1.0 equiv.) in 40 mL glacial acetic acid and stirred for 18 h at room temperature. The yellow solid was collected by filtration, washed with diethyl ether (100 mL) and dried in vacuo to yield **11** (2.69 g, 7.30 mmol, 84%) as a yellow solid which was used without further purification in the next step, m.p. 107–107.5 °C. R_f (DCM:MeOH/50:1): 0.60. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 7.24 (s, 4 H), 5.97 (s, 4 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 148.6, 131.9, 111.2, 101.6. IR (ATR, cm^{-1}): 2882, 1498, 1456, 1230, 1032, 923. HRMS (EI): calcd. for $C_{14}H_8O_4S_4$ 367.9305 $[M]^+$, found: 367.9307.

Benzo[*d*][1,3]dioxole-5,6-dithiol (12): Compound **11** (3.30 g, 8.96 mmol, 1.0 equiv.) was suspended in 60 mL dry DMF. After adding $NaBH_4$ (1.69 g, 44.78 mmol, 5.0 equiv.) the solution was heated for 2 h at 100 °C. The light brown solution was cooled with an ice bath, quenched with 50 mL water and extracted with DCM (1×20 mL). The organic phase was put aside and not further used. The water layer was acidified with 1 M HCl to pH = 2 and extracted with DCM (2×30 mL). The solvent of the combined organic layers was removed. Toluene (2×50 mL) was given to the crude product and removed in vacuo to remove DMF and water residues. Compound **12** (3.34 g, 8.96 mmol, quant.) was isolated as a light greenish oil and used without further purification in the next step. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.87 (s, 2 H), 5.93 (s, 2 H), 3.69 (s, 2 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 147.2, 123.1, 111.7, 101.6. IR (ATR, cm^{-1}) = 2893, 2785, 2539, 1499, 1458, 1227, 1032, 925. HRMS (EI): calcd. for $C_7H_6O_2S_2$ 185.9809 $[M]^+$, found: 185.9812.

2,3,10,11-Tetrahydro[1,4]dioxino[2′,3′:8,9][1,2,5,6]benzotetrathio-cino[3,4-*g*][1,4]benzodioxine (14): 1,4-Benzodioxan (2.0 mL, 15.86 mmol, 1.0 equiv.) and disulfur dichloride (1.27 mL, 15.86 mmol, 1.0 equiv.) were added to 40 mL glacial acetic acid and stirred for 24 h at room temperature. The precipitate was filtered of, washed with 100 mL diethyl ether and dried in vacuo. 2.45 g (6.18 mmol, 78%) of **14** were isolated as a beige solid and used without further purification in the next step, m.p. 189–190. R_f (DCM:MeOH 50:1): 0.65. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 7.26 (s, 4 H), 4.24 (s, 8 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 144.1, 125.3, 117.9, 64.5. IR (ATR, cm^{-1}): 2980, 2921, 2882, 1560, 1466, 1295, 1275, 1250, 1062, 893. HRMS (EI): calcd. for $C_{16}H_{12}O_4S_4$ 395.9618 $[M]^+$, found: 395.9621.

2,3-Dihydrobenzo[*b*][1,4]dioxine-6,7-dithiol (15): 14 (1.00 g, 2.52 mmol, 1.0 equiv.) was suspended in dry DMF (15 mL) and $NaBH_4$ (0.48 g, 12.6 mmol, 5.0 equiv.) was added. The mixture was heated for 2 h at 100 °C while the colour of the solution turned from brownish to yellow. The reaction was cooled to 0 °C with an

ice bath and quenched with 20 mL water and 20 mL DCM was added. The organic phase was put apart and wasn't used further. The water layer was acidified with 1 M HCl (pH = 2) and extracted with DCM (2×30 mL). The combined organic layers were concentrated in vacuo. The residue was dissolved in dry toluene and concentrated again under reduced pressure to yield **15** (1.01 g, 2.52 mmol, quant.) without further purification as a colourless oil and used without further purification in the next step. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.18 (s, 2 H), 3.47 (s, 2 H), 3.46 (s, 4 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 142.6, 122.7, 119.9, 64.2. IR (ATR, cm^{-1}): 2930, 2890, 2538, 1487, 1325, 1190, 1058, 865 cm^{-1}. HRMS (E): calcd. for $C_8H_8O_2S_2$ 199.9966 $[M]^+$, found: 199.9962.

6,6-Dimethyl-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*d*][1,3]dioxole (16): The Dithiol **12** (2.0 g, 10.74 mmol, 1.0 equiv.) and acetone (1.20 mL, 16.1 mmol, 1.5 equiv.) were dissolved in 100 mL dry DCM. Boron trifluoride etherate complex (48%-solution, 4.25 ml, 16.1 mmol, 1.5 equiv.) was added and stirred over night at room temperature. The reaction was quenched with saturated $NaHCO_3$ solution (20 mL). After phase separation the water layer was extracted with DCM (2×30 mL)). The combined organic layer were washed with brine and dried with $MgSO_4$. The solvent was removed in vacuo and the crude product purified by flash silica gel column chromatography (PE:EE, 10:1) to yield **16** (1.33 g, 5.88 mmol, 50%) as a white solid, m.p. 72–73 °C. R_f (PE:EE/10:1): 0.60, ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.70 (s, 2 H), 5.91 (s, 2 H), 1.88 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 146.3, 129.8, 104.2, 101.5, 66.4, 31.1. IR (ATR, cm^{-1}): 2959, 2921, 2855, 1502, 1455, 1255, 1148, 1034. HRMS (EI): calcd. for $C_{10}H_{10}O_2S_2$ 226.0122 $[M]^+$, found: 226.0119.

6,7-Dihydro-[1,4]dithiino[2′,3′:4,5]benzo[1,2-*d*][1,3]dioxole (17): **12** (1.00 g, 5.37 mmol, 1.0 equiv.), 1,2-dibromoethane (0.97 mL, 11.28 mmol, 2.1 equiv.) and dry K_2CO_3 (2.23 g, 16.11 mmol, 3.0 equiv.) were dissolved in dry DMF. The mixture was stirred for 3 h at 90 °C and 12 h at room temperature. The black solution was acidified (pH = 4) with 1 M HCl and extracted with diethyl ether (3× 50 mL). The combined organic layers were washed with brine and concentrated in vacuo. Purification by flash silica gel column chromatography (PE:EE 10:1) gave **17** (0.57 g, 2.69 mmol, 50%) as a white solid, m.p. 101–103 °C. R_f (PE:EA/10:1): 0.43. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.73 (s, 2 H), 5.90 (s, 2 H), 3.17 (s, 4 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 146.3, 125.3, 109.6, 101.3, 30.5. IR (ATR, cm^{-1}): 2965, 2922, 2892, 1496, 1461, 1223, 1032, 929. HRMS (EI): calcd. for $C_9H_8O_2S_2$ 211.9966 $[M]^+$, found: 211.9967.

2,2-Dimethyl-6,7-dihydro-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*b*][1,4]-dioxine (18): Dithiol **15** (1.54 g, 7.69 mmol, 1.0 equiv.) was dissolved in 50 mL dry DCM. Acetone (0.85 mL, 11.5 mmol, 1.5 equiv.) and BF_3*OEt_2-Komplex (48%-solution, 2.97 mL, 11.53 mmol, 1.5 equiv.) were added and stirred for 14 h at room temperature. The mixture was quenched by adding saturated $NaHCO_3$ solution (20 mL) to the reaction. The phases were separated and the water layer extracted with DCM (2×30 mL). The combined organic layers were dried over $MgSO_4$ and concentrated in vacuo. Purification of the crude by flash silica gel column chromatography (PE:EE 20:1) gave **18** (1.00 g, 4.16 mmol, 54%) as a white solid, m.p. 92–93 °C. R_f (PE:EA/10:1): 0.65. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.72 (s, 2 H), 4.20 (s, 4 H), 1.88 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 141.9, 130.5, 111.9, 111.6, 66.0, 64.5, 31.3. IR (ATR, cm^{-1}): 2961, 2855, 1624, 1558, 1340, 1285, 1131, 1024. HRMS (EI): calcd. for $C_{11}H_{12}O_2S_2$ $[M]^+$ 240.0279, found: 240.0282

2,3,7,8-Tetrahydro-[1,4]dithiino[2′,3′:4,5]benzo[1,2-*b*][1,4]dioxine (19): Compound **15** (1.00 g, 2.52 mmol, 1.0 equiv.), dry K_2CO_3 (2.07 g, 14.98 mmol, 5.0 equiv.) and 1,2-dibromoethane (0.90 mL, 10.49 mmol, 2.1 equiv.) were dissolved in 50 mL dry DMF. The suspension was stirred for 3 h at 90 °C and further 16 h at room temperature. The dark gray solution was cooled with an ice bath and acidified (pH = 2) with 2 M HCl. Ethyl acetate was added and the phases were separated. The water layer was extracted with ethyl acetate (2×30 mL) and the combined organic layers washed with brine, dried with $MgSO_4$, concentrated under reduced pressure and purified by flash silica gel column chromatography (PE:EE 10:1) yielding **19** (540 mg, 1.21 mmol, 48%) as a white solid, m.p. 121 °C. R_f (PE:EE/5:1): 0.35. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.76 (s, 2 H), 4.21 (s, 4 H), 3.19 (s, 4 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 142.0, 124.3, 117.5, 64.5, 29.9. IR (ATR, cm^{-1}): 2959, 2885, 1484, 1453, 1358, 1253, 1233, 1030. HRMS (EI): calcd. for $C_{10}H_{10}O_2S_2$ 226.0112 $[M]^+$, found: 226.0113.

6,6-Dimethyl-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*d*][1,3]dioxole-4,8-dicarbaldehyde (21): *n*-BuLi (2.5 M in hexane, 0.19 mL, 0.46 mmol, 2.1 equiv.) was given to a solution of **16** (50 mg, 0.22 mmol, 1.0 equiv.) and TMEDA (0.07 mL, 0.44 mmol, 2.0 equiv.) in dry hexane at room temperature and stirred for 1 h. Anhydrous DMF (0.04 mL, 0.55 mmol, 2.5 equiv.) was given to the reaction mixture and stirred for another 30 min. The reaction was quenched with 1 M HCl. After phase separation the water layer was extracted with ethyl acetate (2×20 mL). The combined organic layers were washed with brine, dried with $MgSO_4$ and concentrated under reduced pressure. Purification of the residue by flash silica gel column chromatography (PE:EE 3:1) gave **21** (36 mg, 0.13 mmol, 58%) as a red solid, m.p. 230 °C (decomp.). R_f (PE:EE/3:1): 0.33. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.26 (s, 2 H), 6.27 (s, 2 H), 1.86 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 185.7, 149.8, 132.2, 117.2, 104.6, 64.9, 32.2. IR (ATR, cm^{-1}): 2970, 2924, 2881, 1669, 1450, 1390, 1251, 1215, 1103, 1024. HRMS (EI): calcd. for $C_{12}H_{10}0_4S_2$ 282.0008 $[M]^+$, found: 282.0007.

Additionally **20** was isolated as a yellow solid with a yield of 18%.

6,6-Dimethyl-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*d*][1,3]dioxole-4-carbaldehyde (20): M.p. 128 °C, R_f (PE:EE/3:1): 0.51. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.18 (s, 1 H), 6.90 (s, 1 H), 6.09 (s, 2 H), 1.87 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 185.8, 146.6, 131.6, 115.5, 108.7, 103.1, 65.5, 31.6. IR (ATR, cm^{-1}): 2956, 2925, 2857, 1672, 1456, 1378, 1251, 1097, 1045. HRMS (EI): calcd. for $C_{11}H_{10}O_3S_2$ 254.0071 $[M]^+$, found: 254.0074.

6,7-Dihydro-[1,4]dithiino[2′,3′:4,5]benzo[1,2-*d*][1,3]dioxole-4,9-dicarbaldehyde (23): A mixture of **17** (70 mg, 0.33 mmol, 1.0 equiv.) and TMEDA (0.1 mL, 0.69 mmol, 2.1 equiv.) in 10 mL dry hexane was cooled to 0 °C and treated with *n*-BuLi (1.6 M in hexane, 0.52 mL, 0.82 mmol, 2.5 equiv.). After 1 h dry DMF (0.07 mL, 0.82 mmol, 2.5 equiv.) was added at 0 °C to the mixture and stirred for a further hour at 0 °C. 1 M HCl (5 mL) was added, phases separated and the water-layer extracted with ethyl acetate (2× 10 mL). The combined organic layers were dried with $MgSO_4$, concentrated in vacuo and purified by flash silica gel column chromatography to yield **23** (28 mg, 0.11 mmol, 32%) as an orange solid, m.p. 231 °C. R_f (PE:EE/3:1): 0.18. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.51 (s, 2 H), 6.27 (s, 2 H), 3.25 (s, 4 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 187.8, 148.8, 131.7, 121.0, 104.5, 31.9. IR (ATR, cm^{-1}): 2920, 1676, 1566, 1443, 1388, 1271, 1190, 1019. HRMS (EI): calcd. for $C_{11}H_8O_4S_2$ 267.9864 $[M]^+$, found: 267.9863.

Additionally **22** was isolated in a yield of 19% as a yellow solid.

6,7-Dihydro-[1,4]dithiino[2′,3′:4,5]benzo[1,2-*d*][1,3]dioxole-4-carbaldehyde (22): M.p. 126 °C. R_f (PE:EE/3:1): 0.43. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.36 (s, 1 H), 6.89 (s, 1 H), 6.06 (s, 2 H), 3.23–3.12 (m, 4 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 187.4, 149.1, 146.4, 128.3, 126.9, 118.2, 114.0, 102.9, 30.6, 30.4. IR (ATR, cm^{-1}): 2901, 1676, 1593, 1450, 1223, 1203, 1054, 922. HRMS (EI): calcd. for $C_{10}H_8O_3S_2$ 239.9915 $[M]^+$, found: 239.9913.

2,2-Dimethyl-6,7-dihydro-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*b*][1,4]dioxine-4,9-dicarbaldehyde (25): A suspension of **18** (100 mg, 0.42 mmol, 1.0 equiv.) and TMEDA (0.13 mL, 0.83 mmol, 2.0 equiv.) in dry hexane was treated with n-BuLi (2.5 M in hexane, 0.35 mL, 0.87 mmol, 2.1 equiv.) at room temperature and stirred for 1 h. Dry DMF (0.08 mL, 1.04 mmol, 2.5 equiv.) was given to the reaction and stirred again for 1 h at room temperature. The reaction was quenched with 1 M HCl and the phases separated. The water layer was extracted three times with ethyl acetate and the combined organic layers dried over $MgSO_4$. The solvent was removed in vacuo and the crude product purified by flash silca gel column chromatography (PE:EE 3:1) to yield **25** (43 mg,0.15 mmol, 35%) as a red solid, m.p. 192 °C. R_f (PE:EE/3:1): 0.25, ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.64 (s, 2 H), 4.43 (s, 4 H), 1.82 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 187.9, 144.1, 134.7, 122.4, 64.6, 63.0, 32.6. IR (ATR, cm^{-1}): 2957, 2925, 2879, 1663, 1569, 1429, 1366, 1294, 1224, 1097. HRMS (EI): calcd. for $C_{13}H_{12}O_4S_2$ 296.0177 $[M]^+$, found: 296.0172.

Additionally **24** was isolated as a yellow solid in a yield of 15%.

2,2-Dimethyl-6,7-dihydro-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*b*][1,4]dioxine-4-carbaldehyde (24): M.p. 130–132 °C. R_f (PE:EE/3:1): 0.52. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.40 (s, 1 H), 6.95 (s, 1 H), 4.36–4.27 (m, 4 H), 1.85 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 187.8, 145.0, 141.3, 131.7, 120.4, 117.0, 64.8, 64.5, 64.2, 31.9. IR (ATR, cm^{-1}): 2957, 2922, 2870, 1664, 1559, 1439, 1294, 1213, 1064. HRMS (EI): calcd. for $C_{12}H_{12}O_3S_2$ 268.0228 $[M]^+$, found: 268.0231.

2,3,7,8-Tetrahydro-[1,4]dithiino[2′,3′:4,5]benzo[1,2-*b*][1,4]dioxine-5,10-dicarbaldehyde (27): **19** (100 mg, 0.44 mmol, 1.0 equiv.) was suspended in a mixture of TMEDA, dry hexane (20 mL) and dry THF (2 mL). *n*-BuLi (2.5 M in hexane, 0.38 mL, 0.93 mmol, 2.1 equiv.) was added and stirred for 1 h at 0 °C. Anhydrous DMF (0.1 mL, 1.1 mmol, 2.5 equiv.) was added and stirred for further 30 min. The reaction was quenched with 1 M HCl (10 mL) and the phases were separated. The water layer was extracted with ethyl acetate (2× 20 mL). The combined organic layers were dried over $MgSO_4$, concentrated in vacuo and purified by flash silica gel column chromatography (PE:EE 5:1) to yield **27** (24 mg,0.08 mmol, 19%) as a red solid, m.p. 235 (decomp.). R_f (PE:EE/1:1): 0.42. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.47 (s, 2 H), 4.40 (s, 4 H), 3.20 (s, 4 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 189.0, 143.7, 129.5, 126.4, 64.5, 29.8. IR (ATR, cm^{-1}): 2924, 2875, 1670, 1560, 1466, 1377, 1289, 1248, 1063. HRMS (EI): calcd. for $C_{12}H_{10}O_4S_2$ 282.0021 $[M]^+$, found: 282.0015.

Additionally **26** was isolated as a yellow solid with a yield of 21%.

2,3,7,8-Tetrahydro-[1,4]dithiino[2′,3′:4,5]benzo[1,2-*b*][1,4]dioxine-5-carbaldehyde (26): M.p. 129 °C. R_f (PE:EE/1:1): 0.6., ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.42 (s, 1 H), 6.91 (s, 1 H), 4.34–4.32 (m, 2 H), 4.28–4.25 (m, 2 H), 3.28–3.25 (m, 2 H), 3.13–3.10 (m, 2 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 188.9, 145.8, 140.7, 128.6, 124.0, 123.2, 122.4, 64.8, 64.1 29.4, 29.2. IR (ATR, cm^{-1}): 2925, 2879, 1641, 1560, 1466, 1377, 1289, 1248, 1063. HRMS (EI): calcd. for $C_{11}H_{10}O_3S_2$ 254.0066 $[M]^+$, found: 254.0069.

1,1′-(6,6-Dimethyl-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*d*][1,3]dioxole-4,8-diyl)bis(butan-1-one) (29a): A mixture of **16** (100 mg, 0.44 mmol, 1.0 equiv.) and TMEDA (0.14 mL, 0.88 mmol, 2.0 equiv.) in dry hexane (4 mL) was stirred at room temperature and *n*-BuLi (2.5 M in hexane, 0.37 mL, 0.93 mmol, 2.1 equiv.) was added. The solution was stirred for 1 h at room temperature till N-methoxy-N-methyl butanamide (145 mg, 1.10 mmol, 2.5 equiv.) was added and stirred for further 2 h at the same temperature. 1 M HCl (10 mL) was added and the phases were separated. The water-layer was extracted with ethylacetate (2×20 mL) and the combined organic layers dried over $MgSO_4$, evaporated and purified by flash silica gel column chromatography to yield **29a** (45 mg, 0.16 mmol, 36%) as an orange solid, m.p. 145 °C. R_f (PE:EE/10:1): 0.40. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.19 (s, 2 H), 2.95 (t, ^3J = 7.1 Hz, 4 H), 1.73 (s, 10 H, CH_2), 0.97 (t, ^3J = 7.4 Hz, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 197.8, 146.7, 133.7, 118.3, 102.5, 60.2, 45.3, 31.4, 17.4, 13.9. IR (ATR, cm^{-1}): 2960, 2872, 1666, 1423, 1389, 1253, 1218, 1150, 1046, 967. HRMS (EI): calcd. for $C_{18}H_{22}O_4S_2$ 366.0960 $[M]^+$, found: 366.0961.

Furthermore **28a** was isolated as a yellow solid in a yield of 20%.

1-(6,6-Dimethyl-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*d*][1,3]dioxol-4-yl)butan-1-one (28a): M.p. 92 °C. R_f (PE:EE/10:1): 0.63. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.86 (s, 1 H), 6.05 (s, 2H), 2.93 (t, ^3J = 7.3 Hz, 2 H), 1.82 (s, 6 H), 1.73 (q, ^3J = 7.3 Hz, 2 H), 0.97 (t, ^3J = 7.4 Hz, 3 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 197.5, 146.8, 146.2, 132.0, 131.5, 116.7, 107.5, 102.1, 63.3, 44.9, 31.4, 17.4, 13.9. IR (ATR, cm^{-1}): 2954, 2926, 2868, 1659, 1588, 1443, 1391, 1239, 1210, 1034. HRMS (EI): calcd. for $C_{14}H_{16}O_3S_2$ 296.0541 $[M]^+$, found: 296.0543.

Diethyl 6,6-dimethyl-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*d*][1,3]dioxole-4,8-dicarboxylate (29b): To a suspension of compound **16** (150 mg, 0.66 mmol, 1.0 equiv.) and TMEDA (0.20 mL, 1.33 mmol, 2.0 equiv.) in dry hexane (10 mL), *n*-BuLi (0.90 mL, 1.6 M in hexane, 1.39 mmol, 2.1 equiv.) was added at room temperature. The mixture was stirred for 1 h and ethyl chloroformate (0.16 mL, 1.66 mmol, 2.5 equiv.) was added. After 1 h the reaction was quenched with 1 M HCl (10 mL) and the phases were separated. The water layer was extracted with ethyl acetate (2×20 mL), dried over $MgSO_4$ and concentrated in vacuo. The residue was purified by flash silica gel column chromatography (PE:EA 10:1) to yield **29b** (100 mg, 0.27 mmol, 41%) as a yellow solid, m.p. 141–143 °C. R_f (PE:EE/10:1): 0.38, ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.15 (s, 2 H), 4.41 (q, ^3J = 7.1 Hz, 4 H), 1.82 (s, 6 H), 1.40 (t, ^3J = 7.1 Hz, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 164.2, 147.6, 133.5, 111.9, 103.2, 62.2, 61.3, 31.4, 14.4. IR (ATR, cm^{-1}): 2959, 2926, 1768, 1701, 1433, 1367, 1244, 1148, 1027, 952. HRMS (EI): calcd. for $C_{16}H_{18}O_6S_2$ 370.0554 $[M]^+$, found: 370.0059.

Additionally **28b** was isolated as a light-yellow solid in a yield of 12%.

Ethyl 6,6-dimethyl-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*d*][1,3]dioxole-4-carboxylate (28b): M.p. 68 °C. R_f (PE:EE/10:1): 0.50. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.84 (s, 1 H), 6.05 (s, 2 H), 4.42–4.27 (q, ^3J = 7.1 Hz, 2 H), 1.86 (s, 6 H), 1.40 (s, 3 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 164.5, 147.3, 146.7, 130.6, 117.5, 107.2, 102.5, 63.7, 61.9, 31.4, 14.5. IR (ATR, cm^{-1}): 2958, 2923, 2854, 1769, 1451, 1258, 1105, 1025, 797. HRMS (EI): calcd. for $C_{13}H_{14}O_4S_2$ 298.0334 $[M]^+$, found: 298.0338.

6,6-Dimethyl-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*d*][1,3]dioxole-4,8-dicarboxylic acid (30): Ester **29b** (30 mg, 0.08 mmol, 1.0 equiv.) has been dissolved with NaOH (130 mg, 3.2 mmol, 40 equiv.) in a mixture of 8 mL ACN/H_2O (1:1) and stirred at 60 °C for 4 h. The mixture was treated with 20 mL water and extracted with ethyl acetate (10 mL). The water layer was acidified (pH = 2) with 1 M HCl and extracted with ethyl acetate (2×20 mL), dried over $MgSO_4$ and evaporated. Compound **30** (25 mg, 0.08 mmol, quant.) was isolated as a yellow solid, m.p. 235 °C (decomp.). R_f (DCM:MeOH/10:1): 0.30. ^{1}H-NMR (400 MHz, DMSO-d^6, ppm): 6.17 (s, 2 H,), 1.73 (s, 6 H). ^{13}C-NMR (101 MHz, DMSO-d^6, ppm): 164.9, 147.2, 131.7, 111.8, 103.1, 60.6, 30.8. IR (ATR, cm^{-1}): 3414, 2917, 1866, 1688, 1438, 1265, 1249, 1069, 1017. HRMS (EI): calcd. for $C_{12}H_{10}O_6S_2$ 313.9919 $[M]^+$, found: 313.9914.

O-(2,2-Dimethylbenzo[*d*][1,3]oxathiol-5-yl) dimethylcarbamothioate (31): Compound **3** (1.30 g, 7.13 mmol, 1.0 equiv.), N,N-diisopropylethylamine (1.82 mL, 10.70 mmol, 1.5 equiv.) and dimethylthiocarbamoyl chloride (1.32 g, 10.70 mmol, 1.5 eq) were dissolved in 8 mL dry DMF and stirred for 18 h at room temperature. Water (20 mL) and ethyl acetate (20 mL) was added and the

phases separated. The water layer was extracted twice (20 mL) and the combined organic layers dried over $MgSO_4$. The solvent was removed in vacuo and the residue purified by flash silica gel column chromatography (PE:EE 5:1) to yield **31** (1.44 g, 5.35 mmol, 75%) as a colourless oil which was used without further purification in the next step. R_f (PE:EE/3:1): 0.70. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.80 (m, 1 H), 6.75–6.72 (m, 1 H), 6.64–6.62 (m, 1 H), 3.44 (s, 3 H), 3.30 (s, 3 H), 1.84 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 188.1, 152.9, 148.7, 127.8, 119.6, 116.9, 110.7, 110.2, 98.6, 43.4, 38.8, 30.6, 30.3. IR (ATR, cm^{-1}): 3341, 2975, 2936, 1532, 1468, 1393, 1285, 1172, 1194, 1117, 956, 851. HRMS (EI): calcd. for $C_{12}H_{15}O_2N_1S_2$ 269.0539 $[M]^+$, found: 269.0543.

6,6-Dimethylbenzo[1,2-*d*:4,5-*d*′]bis([1,3]oxathiole)-2-one (32): **31** (200 mg, 0.74 mmol, 1.0 equiv.), benzoquinone (88 mg, 0.82 mmol, 1.1 equiv.), $Pd(OAc)_2$ (9 mg, 0.04 mmol, 0.05 equiv.) and *p*-toluenesulfonic acid (14 mg, 0.07 mmol, 0.1 equiv.) were dissolved in 4 mL glacial acetic acid and 4 mL dry toluene. The suspension was heated for 18 h at 120 °C. All volatile compounds were removed in vacuo. The crude was purified by flash silica gel column chromatography (PE:EE 5:1) to yield **32** (40 mg, 0.17 mmol, 23%) as a white solid which was used without further purification in the next step. 108–110 °C. R_f (PE:EE/5:1): 0.68. ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 7.04 (s, 1 H), 6.78 (s, 1 H), 1.85 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 169.1, 152.6, 142.9, 125.4, 118.9, 106.4, 104.1, 99.2, 30.4. IR (ATR, cm^{-1}): 3382, 2957, 2923, 2852, 1751, 1451, 1370, 1261, 1090, 1032. HRMS (EI): calcd. for $C_{10}H_8O_3S_2$ 239.9915 $[M]^+$, found: 239.9920.

2,2,6,6-Tetramethylbenzo[1,2-*d*:4,5-*d*′]bis([1,3]oxathiole) (33): **32** (70 mg, 0.29 mmol, 1.0 equiv.) and NaOH (117 mg, 2.91 mmol, 10.0 equiv.) has been dissolved in a mixture of 20 mL MeOH/H_2O (1:1) and stirred for 2 h at 60 °C. The colourless solution was acidified with 1 M HCl and extracted with ethyl acetate (2×20 mL). The combined organic layers were evaporated and dissolved in 40 mL dry toluene, a spatula-tip of PPTSA and 2,2-dimethoxypropane (15 µL, 0.1 mmol, 0.4 equiv.). The mixture was distilled (1 mL/min) with a LIEBIG condenser while every 15 minutes 2,2-dimethoxypropane (15 µL, 0.1 mmol, 0.4 equiv.) and 15 mL dry toluene have been added. After 2 h the mixture was washed with saturated $NaHCO_3$ solution. The water layer was extracted with ethyl acetate (2×20 mL) and the combined organic layers dried over $MgSO_4$, evaporated and purified by flash silica gel column chromatography (PE:EA 20:1) to yield **33** (15 mg, 0.06 mmol, 21%) as a white solid, m.p. 137–138 °C. R_f (PE:EE/20:1): 0.47. ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 6.56 (s, 2 H), 1.81 (s, 12 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 150.1, 129.1, 125.6, 105.0, 98.4, 30.3. IR (ATR, cm^{-1}): 2959, 2923, 2853, 1463, 1367, 1281, 1175, 1104, 956. HRMS (EI): calcd. for $C_{12}H_{14}O_2S_2$ 254.0435 $[M]^+$, found: 254.0431.

2,2,6,6-Tetramethylbenzo[1,2-*d*:4,5-*d*′]bis([1,3]oxathiole)-4,8-dicarbaldehyde (34): *n*-BuLi (60 µL, 2.5 M in hexane, 0.12 mmol, 2.1 equiv.) was added to a solution of **33** (15 mg, 0.06 mmol, 1.0 equiv.) and TMEDA (20 µL, 0.12 mmol, 2.1 equiv.) in 5 mL dry hexane at room temperature and stirred for 1 h. Dry DMF (12 µL, 0.15 mmol, 2.5 equiv.) was added and stirred for further 30 min. The reaction was quenched with 1 M HCl and the two phases were separated. The water layer was extracted with ethyl acetate (2× 20 mL). The combined organic layers were washed with brine, dried over $MgSO_4$ and concentrated under reduced pressure. Purification by flash silica gel column chromatography (PE:EE 10:1) gave **34** (5 mg, 0.02 mmol, 27%) as a red solid, m.p. 210 °C. R_f (PE:EE/5:1) 0.55. ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 10.28 (s, 2 H), 1.89 (s, 12 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 187.5, 153.4, 124.6, 117.4, 100.7, 30.9, 29.9. IR (ATR, cm^{-1}): 2938, 2866, 1696, 1651, 1528, 1432, 1358, 1302, 1280, 1119, 1074, 1014. HRMS (EI): calcd. for $C_{14}H_{14}O_4S_2$ 310.0334 $[M]^+$, found: 310.0339.

3-(6-Methyl-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*d*][1,3]dioxol-6-yl) propyl pivalate (35a): Boron trifluoride etherate complex (48% solution, 6.80 mL, 25.8 mmol, 1.5 equiv.) was given to a solution of compound **12** (3.20 g, 17.2 mmol, 1.0 equiv.) and 4-oxopentyl 2,2-dimethylpropanoate (4.80 g, 25.8 mmol, 1.5 equiv.) in dry DCM and stirred for 20 h at room temperature. The mixture was quenched with saturated $NaHCO_3$ solution. After phase separation the water-layer was extracted with DCM (2×20 mL). The combined organic layers were washed with brine, dried with $MgSO_4$ and concentrated in vacuo. The product was purified by flash silica gel column chromatography (PE:EE 10:1) to yield **35a** (3.3 g, 9.3 mmol, 55%) as a colourless oil. R_f (PE:EE/10:1): 0.43. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.67 (s, 2 H), 5.91 (s, 2 H), 4.07 (t, ^3J = 6.3 Hz, 2 H), 2.08 (s, 2 H), 1.85 (s, 5 H, CH_2), 1.18 (s, 9 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 178.6, 146.3, 129.6, 104.1, 101.6, 70.2, 63.9, 39.9, 38.9, 28.9, 27.3, 25.9. IR (ATR, cm^{-1}): 2986, 2935, 2830, 1722, 1659, 1592, 1369, 1280, 1191, 1123, 1040, 956. HRMS (EI): calcd. for $C_{17}H_{22}O_4S_2$ 354.0960 $[M]^+$, found: 354.0956.

3-(6-Methyl-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*d*][1,3]dioxol-6-yl) propan-1-ol (35b): **35a** (3.60 g, 10.16 mmol, 1.0 equiv.) was suspended with lithium hydroxide monohydrate (1.28 g, 30.47 mmol, 3.0 equiv.) in 100 mL MeOH and stirred for 18 h at room temperature. The solvent was removed and the crude product solved in 50 mL 1 M HCl. The mixture was extracted with ethyl acetate (2×) and the combined organic layer washed with brine, dried with $MgSO_4$, evaporated and purified with flash silica gel column chromatography (PE:EE 2:1) to yield **35b** (2.53 g, 9.4 mmol, 92%) as a colourless oil. R_f (PE:EE/3:1): 0.18. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.67 (s, 2 H), 5.90 (s, 2 H), 3.65 (t, ^3J = 6.4 Hz, 2 H), 2.19–2.08 (m, 2 H), 1.85 (s, 3 H), 1.77 (s, 2 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 146.2, 129.4, 104.1, 101.5, 70.4, 62.6, 39.8, 29.7, 29.1. IR (ATR, cm^{-1}): 2959, 2916, 1728, 1500, 1462, 1241, 1095, 1034, 934. HRMS (EI): calcd. for $C_{12}H_{14}O_3S_2$ 270.0384 $[M]^+$, found: 270.0382.

6-(3-Hydroxypropyl)-6-methyl-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*d*][1,3]dioxole-4,8-dicarbaldehyde (36): **35b** (100 mg, 0.37 mmol, 1.0 equiv.) and TMEDA (0.12 mL, 0.78 mmol, 2.1 equiv.) were dissolved in 5 mL dry hexane and cooled to 0 °C. *n*-BuLi (1.6 M in hexane, 0.81 mL, 1.29 mmol, 3.5 equiv.) was added and stirred for 1 h at 0 °C. At the same temperature anhydrous DMF (0.07 mL, 0.92 mmol, 2.5 equiv.) was added. After 1 h the reaction mixture was quenched with 1 M HCl (10 mL). After phase separation the water layer was extracted with ethyl acetate (2×). The combined organic layers were dried with $MgSO_4$ and concentrated under reduced pressure. Purification of the residue by flash silica gel column chromatography (PE:EE 1:1) gave **36** (42 mg, 0.13 mmol, 35%) as a red oil. R_f (PE:EE/1:1): 0.25. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.24 (s, 2 H), 6.26 (s, 2 H), 3.65 (t, ^3J = 6.3 Hz, 2 H), 2.05 (s, 2 H), 1.85 (s, 5 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 185.6, 149.7, 132.2, 117.1, 104.6, 69.1, 62.6, 40.7, 31.1, 29.5. IR (ATR, cm^{-1}): 3357, 2951, 2928, 2856, 2865, 1677, 1440, 1378, 1254, 1036. HRMS (EI): calcd. for $C_{14}H_{14}O_5S_2$ 326.0283 $[M]^+$, found: 326.0281.

The monoaldehyde was additionally isolated as a yellow solid in a yield of 21%:

6-(3-Hydroxypropyl)-6-methyl-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*d*][1,3]dioxole-4-carbaldehyde: R_f (PE:EA/1:1): 0.45. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.18 (s, 1 H), 6.86 (s, 1 H), 6.09 (s, 2 H), 3.68 (t, ^3J = 6.3 Hz, 2 H), 2.16–2.11 (m, 2 H), 1.87 (s, 3 H), 1.82 (s, 2 H). ^{13}C NMR (101 MHz, $CDCl_3$, ppm): 185.7, 149.6, 146.5, 131.2, 129.8, 115.1, 108.5, 103.1, 69.6, 62.6, 40.3, 30.2, 29.6. IR (ATR, cm^{-1}): 3357, 2925, 2859, 1676, 1444, 1378, 1250, 1045. HRMS (EI): calcd. for $C_{13}H_{14}O_4S_2$ 298.0334 $[M]^+$, found: 298.0329.

3-(4,8-Diformyl-6-methyl-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*d*][1,3]-dioxol-6-yl)propyl prop-2-yn-1-yl carbonate (37): To a solution of **36** (40 mg, 0.12 mmol, 1.0 equiv.) and dry pyridine (9 μL, 0.12 mmol, 1.0 equiv.) in 5 mL anhydrous DCM, propargyl chloroformate (12 μL, 0.12 mmol, 1.5 equiv.) was added and stirred at 0 °C. After complete conversion of the reaction, monitored by TLC (5 h), the solvent was removed. The crude product was purified by flash silica gel column chromatography (PE:EE 3:1) to yield **37** (45 mg, 0.11 mmol, 89 %) as a red oil. R_f (PE:EE/1:1): 0.70. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.25 (s, 2 H), 6.27 (s, 2 H), 4.71 (d, ^3J = 2.4 Hz, 2 H), 4.18 (t, ^3J = 6.3 Hz, 2 H), 2.52 (s, 1 H, CH), 2.11–2.01 (m, 2 H), 1.97–1.89 (m, 2 H), 1.86 (s, 3 H) ^{13}C-NMR (500 MHz, $CDCl_3$, ppm): 185.5, 154.6, 149.8, 132.1, 117.2, 104.6, 101.8, 68.6, 68.2, 55.4, 54.0, 40.9, 30.9, 25.6. IR (ATR, cm^{-1}): 3275, 2949, 2924, 2854, 1749, 1676, 1448, 1388, 1244, 1100, 1027, 865. HRMS (EI): calcd. for $C_{18}H_{16}O_7S_2$ 408.0337 [M]$^+$, found: 408.0334.

3-(((3-(4,8-Diformyl-6-methyl-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*d*][1,3]dioxol-6-yl)propoxy)carbonyl)oxy)propanoic acid (38): **36** (100 mg, 0.31 mmol, 1.0 equiv.), succinic anhydride (306 mg, 3.06 mmol, 10.0 equiv.), anhydrous pyridine (0.12 mL, 1.53 mmol. 5.0 equiv.) and a spatula-tip of DMAP were dissolved in 5 mL dry DCM and stirred for 18 h at room temperature. The reaction was quenched with H_2O. After phase separation the organic layer was washed with 1 M HCl (2×), dried with $MgSO_4$ and concentrated under reduced pressure. Purification with flash silica gel column chromatography (DCM: MeOH 25:1) afforded **38** (80 mg, 0.19 mmol, 62 %) as a red oil. R_f (PE:EA/1:1): 0.10. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.27 (m, 2 H), 6.26 (s, 2 H), 4.12–4.07 (m, 2 H), 2.63 (dd, ^3J = 12.1, 4.2 Hz, 4 H), 2.08–1.99 (m, 2 H), 1.89–1.82 (m, 5 H, CH_2). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 185.6, 172.2, 149.8, 131.9, 117.0, 104.6, 68.7, 64.4, 40.9, 31.0, 29.0, 25.6. IR (ATR, cm^{-1}): 3343, 2959, 2920, 2859, 1726, 1446, 1389, 1245, 1159, 1028. HRMS (EI): calcd. for $C_{18}H_{18}O_8S_2$ 426.0443 [M]$^+$, found: 426.0440.

2,5-Dioxopyrrolidin-1-yl 3-(((3-(4,8-diformyl-6-methyl-[1,3]dithiolo-[4′,5′:4,5]benzo[1,2-d][1,3]dioxol-6-yl)propoxy)carbonyl)oxy)-propanoate (39): Compound 38 (33 mg, 0.08 mmol, 1.0 equiv.) was dissolved with EDC (21 μL, 0.12 mmol, 1.5 equiv.) and N-hydroxysuccinimide (14 mg, 0.12 mmol, 1.5 equiv.) in 3 mL anhydrous DCM and stirred for 18 h. The mixture was washed with brine (2×), saturated $NaHCO_3$-solution and dried over $MgSO_4$. After purification with silica gel column chromatography (PE:EE 1:1) **39** (35 mg, 0.67, 87 %) was isolated as a red oil. R_f (PE:EE 1:1): 0.20. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.24 (s, 2H), 6.27 (s, 2H), 4.13 (t, ^3J = 6.2 Hz, 2 H), 2.93 (t, ^3J = 6.9 Hz, 2 H), 2.85 (s, 4 H), 2.72 (t, ^3J = 6.9 Hz, 2 H), 2.06–2.01 (m, 2 H), 1.91–1.84 (m, 5 H, CH_2). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 185.6, 171.0, 169.1, 167.8, 149.8, 132.0, 117.1, 104.6, 68.7, 64.7, 40.9, 30.9, 28.9, 26.5, 25.7, 25.5. IR (ATR, cm^{-1}): 2952, 2920, 2861, 1732, 1677, 1448, 1390, 1252, 1202, 1058, 1027, 863. HRMS (EI): calcd. for $C_{22}H_{21}O_{10}N_1S_2$ 523.0601 [M]$^+$, found: 523.0603.

3-(4,8-Diformyl-6-methyl-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*d*][1,3]-dioxol-6-yl)propyl 4-methylbenzenesulfonate (40): Alcohol **36** (40 mg, 0.13 mmol, 1.0 equiv.) was solved with pyridine (0.02 mL, 0.19 mmol, 1.5 eq), *p*-TsCl (28 mg, 0.15 mmol, 1.2 equiv.) and a spatula-tip of DMAP in 5 mL dry DCM and stirred for 20 h at room temperature. The mixture was quenched with 10 mL water and extracted with DCM (2×). The combined organic layers were washed with Brine, dried with $MgSO_4$, evaporated and purified by flash silica gel column chromatography (PE:EE 3:1) to yield **36** (29 mg, 0.06 mmol, 50 %) as a red oil which was used without further purification in the next step. R_f (PE:EE/1:1): 0.55. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.23 (s, 2 H), 7.75 (d, ^3J = 8.2 Hz, 2 H), 7.34 (d, ^3J = 8.1 Hz, 2 H), 6.27 (s, 2 H), 4.02 (s, 2 H), 2.44 (s, 3 H), 2.30 (s, 5 H), 2.25 (s, 2 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 185.5, 149.9, 145.4, 143.6, 130.0, 128.6, 125.9, 104.6, 68.3, 53.6, 40.5, 31.0, 21.4. IR (ATR, cm^{-1}) 3412, 2925, 2872, 1680, 1455, 1392, 1331, 1208, 1107, 1008. HRMS (EI): calcd. for $C_{21}H_{20}O_7S_3$ 480.0371 [M]$^+$, found: 480.0368.

6-(3-Azidopropyl)-6-methyl-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*d*][1,3]-dioxole-4,8-dicarbaldehyde (41): Compound **40** (20 mg, 0.04 mmol, 1.0 equiv.) was dissolved in 5 mL dry DMF. After NaN_3 (4 mg, 0.06 mmol, 1.5 equiv.) was added the reaction was stirred over night at room temperature. The solvent was removed in vacuo and the resulting residue solved in DCM. The organic layers were washed with H_2O and brine (2×), dried over $MgSO_4$ and concentrated under reduced pressure. After purification with flash silica gel column chromatography (PE:EE 5:1) **41** (14 mg, 0.04 mmol, quant.) was obtained as a red solid, m.p. 90–91 °C. R_f (PE:EE/3:1): 0.45. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.26 (s, 2 H) 6.27 (s, 2 H), 3.31 (t, ^3J = 6.7 Hz, 2 H), 2.07–2.03 (m, 2 H), 1.87–1.82 (m, 5 H), 1.25 (s, 2 H). ^{13}C-NMR (500 MHz, $CDCl_3$, ppm): 185.5, 149.9, 132.0, 117.1, 104.6, 68.7, 51.4, 41.6, 31.1, 25.9. IR (ATR, cm^{-1}): 2959, 2918, 2847, 2094, 1690, 1447, 1386, 1243, 1100, 1028. HRMS (EI): calcd. for $C_{14}H_{13}O_4N_3S_2$ 351.0347 [M]$^+$, found: 351.0344.

3-(4,8-Diformyl-6-methyl-[1,3]dithiolo[4′,5′:4,5]benzo[1,2-*d*][1,3]-dioxol-6-yl)propyl 2-(2,5-dioxo-2,5-dihydro-1H-pyrrol-1-yl)acetate (42): Oxalyl chloride (55 μL, 0.64 mmol, 5.0 equiv.) was added to a stirred solution of 2-(2,5-dioxo-2,5-dihydro-1H-pyrrol-1-yl)acetic acid (20 mg, 0.13 mmol, 1.0 equiv.) in 5 mL dry DCM at room temperature. After 12 h all volatile compounds have been removed. The residue was dissolved in 5 mL dry DCM and added to a solution of alcohol **36** (34 mg, 0.10 mmol, 1.0 equiv.), DIPEA (35 μL, 0.21 mmol, 2.0 equiv.) and two drops of DMF in 10 mL dry DCM. After 5 h the mixture was diluted with water (10 mL) and the phases were separated. The water layer was extracted with DCM (2×30 mL) and the combined organic layers washed (2×50 mL) with saturated $NaHCO_3$-solution, dried over $MgSO_4$ and concentrated in vacuo. After purification by flash silica gel column chromatography **42** (30 mg, 0.06 mmol, 62 %) was isolated as a red oil. R_f (PE:EE/1:1): 0.48. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.27 (s, 2 H), 6.80 (s, 2 H), 6.28 (s, 2 H), 4.26 (s, 2 H), 4.15 (t, ^3J = 6.2 Hz, 2 H), 2.04–2.00 (m, 2 H), 1.87 (s, 5 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm) δ = 185.5, 169.9, 167.2, 149.8, 134.7, 132.0, 117.1, 104.6, 68.7, 65.4, 40.8, 38.8, 31.3, 25.5. IR (ATR, cm^{-1}): 2956, 2929, 2856, 1471, 1101, 1066, 1047, 867. HRMS (EI): calcd. for $C_{20}H_{17}O_8S_1$ 463.0396 [M]$^+$, found: 463.0395.

***Tert*-butyl((6′,6′-dimethylspiro[cyclohexane-1,2′-[1,3]dioxolo-[4′,5′:4,5]benzo[1,2-*d*][1,3]oxathiol]-4-yl)oxy)dimethylsilane (43)**: Compound **4** (400 mg, 2.04 mmol, 1.0 equiv.) and PtO_2 (5 mg, 0.02 mmol, 0.01 equiv.) were dissolved in 40 mL dry THF. The atmosphere was flushed with hydrogen (3×) and the reaction stirred under hydrogen [$p(H_2)$ = 1 atm] at room temperature till complete conversion followed by TLC. The colour of the solution turned from red to colourless. The solvent was removed under reduced pressure. The crude, *tert*-butyl[(4,4-dimethoxycyclohexyl) oxy]dimethylsilane (123 mg, 0.45 mmol, 0.2 equiv.) and PPTSA (15 mg, 0.02 mmol, 0.05 equiv.) were dissolved in 40 mL dry toluene. The flask was equipped with a LIEBIG condenser and the mixture heated till the solvent was distilled (1 mL/min). Every 15 minutes *tert*-butyl[(4,4-dimethoxycyclohexyl)oxy]dimethylsilane (123 mg, 0.45 mmol, 0.2 equiv.) and 15 mL dry toluene were added. After 2 h the mixture was cooled to room temperature and washed with saturated $NaHCO_3$-solution. The water-layer was extracted with ethyl acetate (2×20 mL) and the combined organic layers were dried over $MgSO_4$, evaporated and purified by flash silica gel column chromatography (PE:EE 20:1) to yield **43** (440 mg, 1.08 mmol, 53 %) as a colourless oil. Rf (PE:EE/10:1): 0.82. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 6.51 (s, 1 H), 6.33 (s, 1 H), 3.93 (s, 1 H), 1.81 (s, 8 H), 0.90 (s, 9 H), 0.06 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 148.6, 145.6, 142.5, 129.2, 119.0, 115.7, 102.7, 94.3, 68.1, 66.5, 31.2, 30.5, 30.2, 26.0, 18.2, −4.7. IR (ATR, cm^{-1}): 2952, 2929, 2924, 2854,

1749, 1676, 1448, 1388, 1244, 1100, 1027, 865. HRMS (EI): calcd. for $C_{21}H_{32}O_4S_1Si_1$ 408.1791 $[M]^+$, found: 408.1798.

4-((*Tert*-butyldimethylsilyl)oxy)-6′,6′-dimethylspiro[cyclohexane-1,2′-[1,3]dioxolo[4′,5′:4,5]benzo[1,2-*d*][1,3]oxathiole]-4′,8′-dicarbaldehyde (44a): *n*-BuLi (0.41 mL, 2.5 M in hexane, 1.03 mmol, 2.1 equiv.) was added to a mixture of TMEDA (0.15 mL, 0.98 mmol, 2.0 equiv.) and **43** (200 mg, 0.49 mmol, 1.0 equiv.) dissolved in 8 mL dry hexane. The reaction was stirred for 1 h at room temperature. Dry DMF (0.10 mL, 1.22 mmol, 2.5 equiv.) was added and stirred for further 30 minutes. The reaction was quenched with saturated NH_4Cl-solution and the phases were separated. The water layer was extracted with ethyl acetate (2×20 mL) and the combined organic layers washed with brine, dried over $MgSO_4$ and evaporated. After purification by flash silica gel column chromatography (PE:EE 10:1) 44a (80 mg, 0.17 mmol, 35%) was isolated as a red oil. R_f (PE:EE/10:1): 0.35. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.23 (s, 1 H), 10.18 (s, 1 H), 3.96 (s, 1 H), 1.96–1.79 (m, 14 H), 0.91 (s, 9 H), 0.08 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 186.3, 186.0, 150.0, 145.9, 123.9, 116.0, 110.4, 100.2, 66.3, 31.2, 31.0, 30.9, 30.8, 25.9, 18.2, −4.7. IR (ATR, cm^{-1}): 2952, 2929, 2855, 1680, 1458, 1375, 1265, 1089, 1055, 1020. HRMS (EI): calcd. for $C_{23}H_{32}O_6S_1Si_1$ 464.1689 $[M]^+$, found: 464.1683.

Additionally 20% of [1,3]dioxolo[4′,5′:4,5]benzo[1,2-d][1,3]oxathiole]-8′-carbaldehyde and 15% of 4-((*tert*-butyldimethylsilyl)oxy)-6′,6′-dimethylspiro[cyclohexane-1,2′-[1,3]dioxolo[4′,5′:4,5]benzo[1,2-d][1,3]oxathiole]-4′-carbaldehyde were collected:

4-((*Tert*-butyldimethylsilyl)oxy)-6′,6′-dimethylspiro[cyclohexane-1,2′-[1,3]dioxolo[4′,5′:4,5]benzo[1,2-d][1,3]oxathiole]-8′-carbaldehyde: R_f (PE:EE/10:1): 0.42. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.19 (s, 1 H), 6.52 (s, 1 H), 3.96 (s, 1 H), 1.80 (s, 14 H), 0.88 (s, 9 H), 0.06 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 186.3, 149.4, 146.0, 145.6, 121.6, 113.5, 99.5, 98.2, 66.11, 31.2, 30.5, 29.9, 27.3, 25.8, 18.4, −4.7. IR (ATR, cm^{-1}): 2951, 2929, 2855, 1679, 1462, 1375, 1278, 1096, 1053, 1017. HRMS (EI): calcd. for $C_{22}H_{32}O_5S_1Si_1$ 436.1740 $[M]^+$, found: 436.1733.

4-((*Tert*-butyldimethylsilyl)oxy)-6′,6′-dimethylspiro[cyclohexane-1,2′-[1,3]dioxolo[4′,5′:4,5]benzo[1,2-*d*][1,3]oxathiole]-4′-carbaldehyde: R_f (PE:EA 10:1): 0.55. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.13 (s, 1 H), 6.70 (s, 1 H), 3.91 (s, 1 H), 1.91–1.82 (m, 14 H), 0.90 (s, 9 H), 0.07 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 185.5, 143.0, 141.9, 138.7, 121.5, 116.9, 108.0, 100.2, 94.8, 31.3, 31.0, 30.7, 30.4, 25.9, 18.2, −4.7. IR (ATR, cm^{-1}): 2952, 2929, 2856, 1717, 1468, 1376, 1292, 1251, 1101, 1006. HRMS (EI): calcd. for $C_{22}H_{32}O_5S_1Si_1$ 436.1740 $[M]^+$, found: 436.1735.

4-Hydroxy-6′,6′-dimethylspiro[cyclohexane-1,2′-[1,3]dioxolo-[4′,5′:4,5]benzo[1,2-*d*][1,3]oxathiole]-4′,8′-dicarbaldehyde (44b): **44a** (100 mg, 0.22 mmol, 1.0 equiv.) and HF (10 mL, 0.23 mmol, 1.1 equiv.) were dissolved in a mixture of 4 mL ACN/THF (3:1) and stirred for 14 h at room temperature. The reaction was quenched with saturated $NaHCO_3$-solution. The red solution was extracted with DCM (3×20 mL) and the combined organic layers dried over $MgSO_4$ and concentrated in vacuo. Purification by flash silica gel column chromatography (PE:EE 1:1) gave **44b** (75 mg, 0.22 mmol, quant.) as a red solid, m.p. 156–157 °C. R_f (PE:EE/1:1): 0.18. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.23 (s, 1 H), 10.18 (s, 1 H), 3.98 (s, 1 H), 2.05–1.99 (m, 6 H), 1.87–1.82 (m, 8 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 186.4, 185.9, 150.3, 145.7, 145.6, 123.3, 117.2, 116.1, 110.4, 100.3, 66.8, 31.6, 31.0, 30.8. IR (ATR, cm^{-1}): 3428, 2932, 2862, 1676, 1456, 1369, 1261, 1136, 1087, 1013. HRMS (EI): calcd. for $C_{17}H_{18}O_6S_1$ 350.0824 $[M]^+$, found: 350.0826.

4′,8′-Diformyl-6′,6′-dimethylspiro[cyclohexane-1,2′-[1,3]dioxolo-[4′,5′:4,5]benzo[1,2-*d*][1,3]oxathiol]-4-yl ethynyl carbonate (45): Alcohol **44b** (25 mg, 0.07 mmol, 1.0 equiv.), dry pyridine (18 µL, 0.14 mmol, 2.0 equiv.) and propargyl chloroformate (20 mL, 0.14 mmol, 2.0 equiv.) were dissolved in 5 mL dry DCM at 0 °C and stirred for 16 h while the reaction reached room temperature. All volatile compounds were removed in vacuo. The crude was purified by flash silica gel column chromatography (PE:EE 3:1) to yield **45** (27 mg, 0.06 mmol, 88%) as a red oil. R_f (PE:EE/3:1): 0.52. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.21 (s, 1 H), 10.18 (s, 1 H), 4.97–4.86 (m, 1 H), 4.74 (s, 2 H), 2.55 (t, ^4J = 2.4 Hz, 1 H), 2.22–1.97 (m, 8 H), 1.87 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 186.2, 185.7, 154.0, 145.4, 145.3, 122.5, 117.6, 116.1, 110.4, 100.4, 77.0, 75.9, 73.3, 72.8, 55.4, 31.0, 30.8, 30.7, 27.5, 27.3. IR (ATR, cm^{-1}): 2924, 2853, 1745, 1676, 1456, 1374, 1250, 1216, 1085. HRMS (EI): calcd. for $C_{21}H_{20}O_8S_1$ 432.0873 $[M]^+$, found: 432.0878.

4-((4′,8′-Diformyl-6′,6′-dimethylspiro[cyclohexane-1,2′-[1,3]dioxolo-[4′,5′:4,5]benzo[1,2-*d*][1,3]oxathiol]-4-yl)oxy)-4-oxobutanoic acid (46): A suspension of **44b** (100 mg, 0.29 mmol, 1.0 equiv.), succinic anhydride (285 mg, 2.85 mmol, 10.0 equiv.), dry pyridine (0.12 mL, 1.43 mmol, 5.0 equiv.) and a spatula-tip of DMAP in 10 mL dry DCM was stirred for 14 h at room temperature. Water (10 mL) was added and the phases were separated. The organic layer was washed with saturated $NaHCO_3$-solution (2×20 mL), 1 M HCl (2×20 mL), dried over $MgSO_4$ and concentrated under reduced pressure. Purification via flash silica gel column chromatography gave **46** (81 mg, 0.18 mmol, 64%) as a red oil. R_f (PE:EE/1:1): 0.15. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.22 (s, 1 H), 10.17 (s, 1 H), 5.01 (s, 1 H), 2.66 (t, ^3J = 6.0 Hz, 4 H), 2.22–1.95 (m, 8 H), 1.85 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 186.4, 186.3, 185.7, 171.8, 150.4, 145.5, 145.3, 123.0, 117.5, 116.1, 110.4, 100.4, 69.3, 68.7, 31.3, 30.8, 29.4, 27.5, 27.3. IR (ATR, cm^{-1}): 3362, 2967, 2866, 1710, 1678, 1266, 1206, 1170, 1085, 1010, 730. HRMS (EI): calcd. for $C_{21}H_{22}O_9S_1$ 450.0985 $[M]^+$, found: 450.0982.

4′,8′-Diformyl-6′,6′-dimethylspiro[cyclohexane-1,2′-[1,3]dioxolo-[4′,5′:4,5]benzo[1,2-*d*][1,3]oxathiol]-4-yl (2,5-dioxopyrrolidin-1-yl) succinate (47): **46** (50 mg, 0.11 mmol, 1.0 equiv.), EDC (30 mL, 0.17 mmol, 1.5 equiv.) and N-hydroxysuccinimide (20 mg, 0.17 mmol, 1.5 equiv.) was dissolved in 5 mL dry DCM and stirred for 16 h at room temperature. DCM (10 mL) was added and the organic mixture was washed with brine (2×20 mL), saturated $NaHCO_3$-solution (1×20 mL), Brine (1×20 mL) and dried over $MgSO_4$. Purification by flash silica gel column chromatography obtained **47** (52 mg, 0.09 mmol, 85%) as a red solid, m.p. 164–165. R_f (PE:EE/1:1): 0.43. ^{1}H-NMR (400 MHz, $CDCl_3$, ppm): 10.24 (s, 2 H), 10.18 (s, 1 H), 5.04 (s, 1 H), 3.00–2.76 (m, 8 H), 2.10–1.88 (m, 8 H), 1.86 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 186.2, 185.9, 170.4, 169.0, 167.8, 150.4, 145.5, 145.4, 122.7, 117.5, 116.0, 110.4, 100.4, 69.9, 69.3, 31.5, 30.7, 29.8, 29.1, 27.5, 26.5, 25.8. IR (ATR, cm^{-1}): 2923, 2852, 1726, 1675, 1457, 1372, 1268, 1203, 1084. HRMS (EI): calcd. for $C_{25}H_{25}O_{11}N_1S_1$ 547.1148 $[M]^+$, found: 547.1152.

4′,8′-Diformyl-6′,6′-dimethylspiro[cyclohexane-1,2′-[1,3]dioxolo-[4′,5′:4,5]benzo[1,2-*d*][1,3]oxathiol]-4-yl 4-((2-(2,5-dioxo-2,5-dihydro-1H-pyrrol-1-yl)ethyl)amino)-4-oxobutanoate (48): Compound **47** (50 mg, 0.09 mmol, 1.0 equiv.), DIPEA (32 µL, 0.18 mmol, 2.0 equiv.) and (2,5-dioxo-2,5-dihydro-1H-pyrrol-1-yl)ethan-1-aminio trifluoroacetate (35 mg, 0.14 mmol, 1.5 equiv.) were dissolved in 5 mL dry DMF and stirred for 14 h at room temperature. All volatile compounds were removed in vacuo and the residue purified by flash silica gel column chromatography (DCM:MeOH 50:1) to yield **48** (34 mg, 0.06 mmol, 65%) as a red solid, m.p. 92 °C. R_f (DCM:MeOH/25:1): 0.20. ^{1}H-NMR (300 MHz, $CDCl_3$, ppm): 10.22 (s, 1 H), 10.18 (s, 1 H), 6.73–6.71 (m, 2 H), 4.14 (q, ^3J = 7.1 Hz, 1H), 3.50–3.33 (m, 4 H), 2.66–2.43 (m, 4 H), 2.24–1.93 (m, 8 H), 1.87 (s, 6 H). ^{13}C-NMR (101 MHz, $CDCl_3$, ppm): 186.3, 185.8, 173.1, 172.4, 171.8, 171.0, 150.4, 145.5, 145.4, 134.4, 134.3, 122.8, 117.5, 116.1, 110.4, 100.4, 60.8, 51.9, 39.6, 38.3, 36.0, 34.9, 30.8, 29.8, 27.5, 14.3. IR (ATR, cm^{-1}): 2926, 2854, 1702, 1438, 1369, 1265, 1203, 1084. HRMS (ESI): calcd. for $C_{27}H_{29}N_2O_{10}S_1$ 573.1543 $[M+H]^+$, found: 573.1537.

Acknowledgements

Open access funding enabled and organized by Projekt DEAL.

Conflict of Interest

The authors declare no conflict of interest.

Keywords: Fluorescent dyes · Heterocycles · Photophysics · Stokes shift · Sulfur

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[22] Patent application has been made for S_1-DBD and S_2-DBD dyes: appl. number 102020114139.4.

Manuscript received: October 27, 2020
Revised manuscript received: November 27, 2020
Accepted manuscript online: December 5, 2020