

## New chemistry of bis[1,2]dithiolo[1,4]thiazines and bis[1,2]dithiopyrroles

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Dedicated to Prof. Charles W. Rees on the occasion of his 75<sup>th</sup> birthday

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### Abstract

The new long-chain or branched-chain *N*-alkyl bisdithiolothiazines **2a,b**, **3a,c**, and **4a,c** have been prepared by the appropriate one-pot reaction of the corresponding *N*-alkyldiisopropylamines and disulfur dichloride. The bisdithiopyrroles **5a-f** were obtained by thermal sulfur extrusion from their corresponding bisdithiolothiazines or by an alternative and faster method consisting of *S*-oxidation by dimethyldioxirane and SO extrusion. The cycloadditions of a bisdithiolothiazine ketothione and benzyne or *p*-tolylsulfonylacetylene were studied and the new cycloadducts **7** and **9** (*Z*+*E*) were characterized.

**Keywords:** *S,N*-Heterocycles, bisdithiolothiazine, bisdithiopyrrole, 1,3-dipolar cycloaddition, 1,2-dithiolane, benzodithiolane

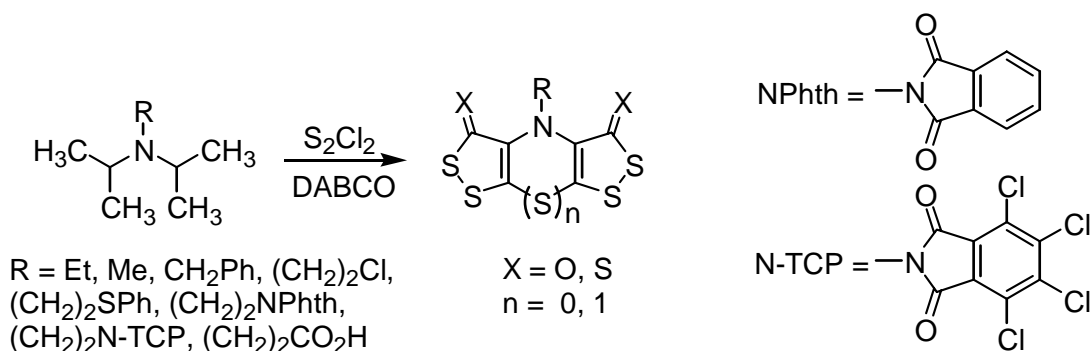
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### Introduction

Although many sulfur-containing heterocycles have been known from the early times of organic chemistry, it has not been until recently that some of these compounds have found their most important applications. The discovery of superconducting tetrathiafulvalene charge-transfer complexes<sup>1</sup> and molecular switches,<sup>2</sup> thiazole and thiadiazole liquid crystals<sup>3</sup> and thiophene nonlinear optical materials<sup>4</sup> has stimulated the search for new materials based on sulfur heterocycles. On the other hand, the study of many bioactive compounds, as for example Oltipraz [5-(2-pyrazinyl)-4-methyl-1,2-dithiole-3-thione],<sup>5</sup> and other natural and synthetic 1,2-dithiolethiones,<sup>6</sup> has drawn attention to the role of polysulfur heterocycles in the field of pharmaceutical chemistry. The development of new general methods for the synthesis of sulfur heterocycles has thus become an issue of intense research. In this context we have discovered

that *N*-ethyldiisopropylamine (Hünig's base), and other tertiary amines containing isopropyl groups, react under mild conditions with disulfur dichloride to give bis[1,2]dithiolo[1,4]-thiazines<sup>7</sup> and bis[1,2]dithiopyrroles.<sup>8</sup>

By means of this new reaction we have prepared some examples of these heterocyclic systems (Scheme 1), constituting a very short and convenient preparative method in some instances starting from all commercial reagents. These heterocycles, containing the 1,2-dithiole-3-thione moiety could be further functionalized by its cycloaddition with different dienophiles and 1,3-dipolar reagents. In order to assess the generality of the reaction, we now report some new aspects of the chemistry of these novel heterocycles.



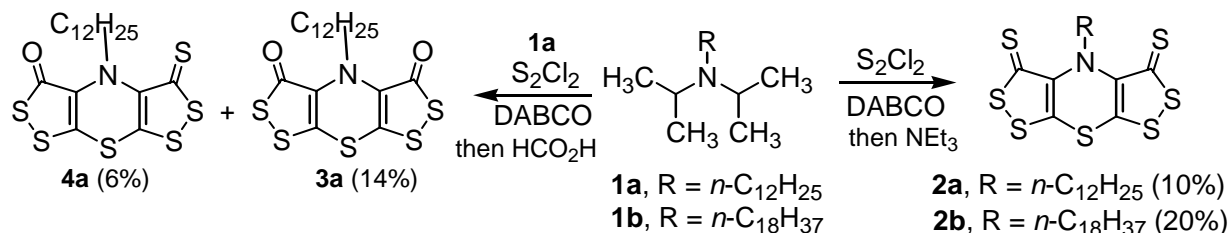
**Scheme 1**

## Results and Discussion

### Synthesis of new bis[1,2]dithiolo[1,4]-thiazines

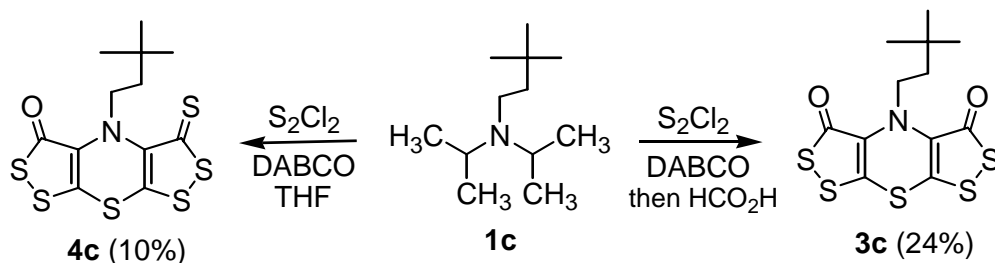
We were interested in analyzing the scope of the reaction between amines and  $\text{S}_2\text{Cl}_2$ , and especially in studying its use for the preparation of dithiothiazines containing apolar groups that could induce intermolecular interactions leading to ordered supramolecular structures. Amphiphilic molecules containing electronically delocalized polysulfur heterocycles and long hydrocarbon chains have been often used to build self-assembled molecular layers, usually referred as Langmuir-Blodgett films.<sup>9</sup> We therefore studied the reactions of *N*-alkyldiisopropylamines, bearing linear or branched alkyl chains, and disulfur dichloride, in order to obtain new bis[1,2]dithiolo[1,4]thiazines substituted with hydrocarbon chains. In this way, *N*-lauryldiisopropylamine **1a** (1 equiv) reacted with  $\text{S}_2\text{Cl}_2$  (10 equiv), DABCO (8 equiv) for three days and then with triethylamine (13 equiv) for two hours at room temperature to give *N*-laurylbis[1,2]dithiolo[1,4]thiazine-3,5-dithione **2a**, as black crystals with metallic luster (10%), which was characterized by spectroscopy (Scheme 2). By addition of formic acid (20 equiv) in place of triethylamine and refluxing for 2 hours, the *N*-laurylbis[1,2]dithiolo[1,4]thiazine-3,5-dione **3a** (14%) was obtained, together with the 3-oxo-5-thione derivative **4a** (6%). Similarly, by reaction of *N*-stearyldiisopropylamine **1b** (1 equiv),  $\text{S}_2\text{Cl}_2$  (10 equiv), and DABCO (8 equiv) for

three days and then triethylamine (13 equiv) for two hours at room temperature, we obtained *N*-stearyl[bis[1,2]dithiolo[1,4]thiazine-3,5-dithione **2b** (20%) as a black solid scarcely soluble in common solvents (Scheme 2).



### Scheme 2

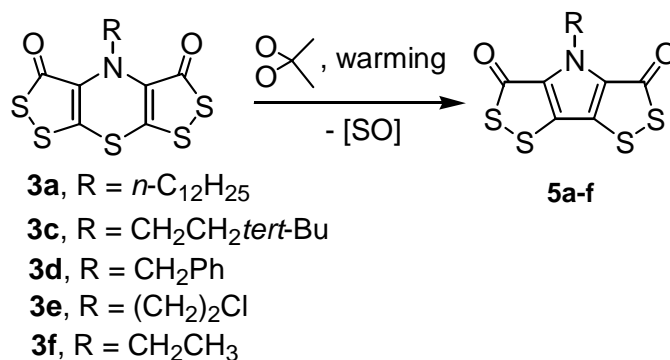
Looking for some derivatives with better solubility in organic solvents, we performed the reaction of *N*-(3,3-dimethyl)butyldiisopropylamine **1c** (1 equiv) with S<sub>2</sub>Cl<sub>2</sub> (10 equiv), DABCO (10 equiv), and formic acid (10 equiv), following the explained methodology, obtaining *N*-(3,3-dimethyl)butylbis[1,2]dithiolo[1,4]thiazine-3,5-dione **3c**, as an orange solid (24%). The *N*-(3,3-dimethyl)butylbis[1,2]dithiolo[1,4]thiazine-3-oxo-5-thione **4c** (10%) was obtained by reaction of **1c** (1 equiv) with S<sub>2</sub>Cl<sub>2</sub> (10 equiv) and DABCO (10 equiv) in tetrahydrofuran.



### Scheme 3

We have previously shown that bisdithiolothiazines readily extrude sulfur, to give fused bisdithiopyrroles.<sup>8,10</sup> This reaction usually proceeds by simply refluxing a solution of the substrate in a high boiling point solvent, such as chlorobenzene, for a period ranging from several minutes to a few hours. Nevertheless, some particular cases, for different reasons, are reluctant to extrude sulfur. For example, the transformation of *N*-(2-chloroethyl)-substituted bisdithiolothiazine **3e** into the corresponding pyrrole was complete only after 7 days of refluxing a chlorobenzene solution of the starting material. This is probably due to an attractive interaction between the chlorine and the thiazine sulfur atoms that contributes to stabilize the structure conformation, as deduced from calculations using *ab initio* density functional theory methods<sup>11</sup> and the measured X-ray crystal diffraction Cl⋯S distance of 3.85 Å.<sup>12</sup> On the other hand, the *N*-unsubstituted parent bisdithiolothiazine **3g** did not extrude sulfur at all, even after long periods of heating in refluxing chlorobenzene.<sup>13</sup> We then envisaged a new method for sulfur extrusion that could work

with the more reluctant cases. Thiazines have been reported to react with mild oxidizing reagents to give the corresponding thiazine oxides and dioxides.<sup>14</sup> The electron-withdrawing effect of oxygen atoms on sulfur makes SO and SO<sub>2</sub> much better leaving groups than S, making sulfur extrusion a much easier process. Hence, we treated *N*-laurylbisdithiolothiazine **3a** with 1 equivalent of dimethyldioxirane in benzene, followed by reflux until all the starting material had disappeared, as monitored by tlc. After the work-up, the only isolable product was the bisdithiopyrrole **5a**. We tried different amounts of the oxidizing reagent and reaction times, and the best results were obtained with 1.4 equivalents of DMD and refluxing the reaction mixture for 25 minutes. In these conditions, the pyrrole **5a** was obtained, after chromatography, in moderate yield (38%). This relatively low yield is probably due to some oxidation of the sulfur atoms on the dithiole ring, followed by decomposition. Though, if a smaller amount of DMD is used, some starting material remains unreacted and the yield decreases; on the other hand, if the amount of DMD is increased, the yield also drops, due to over-oxidation. We applied this reaction to **3c** as well as to other substrates. The best results are summarized in **Table 1**, along with the experimental or bibliographic results from thermal sulfur extrusion. Remarkably, the reaction of *N*-(2-chloroethyl)-substituted dithiolothiazine **3e** (entry 4) was performed in only 1 h, in contrast with the 7 days reaction time in thermal conditions, though some starting material was recovered along with the desulfuration product.



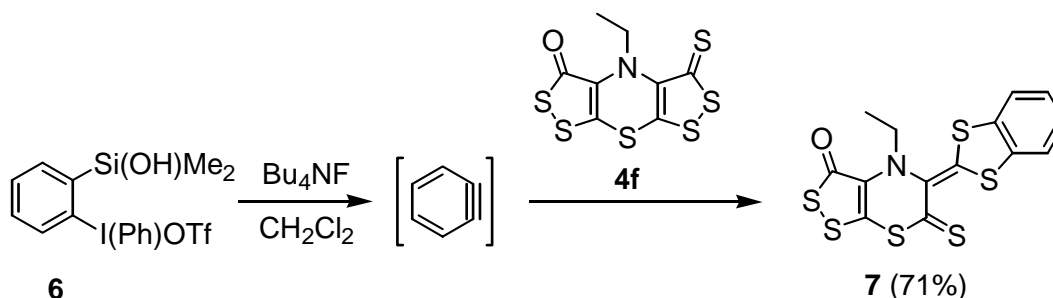
#### Scheme 4

**Table 1.** Sulfur extrusion of thiazines **3a-g**

Entry	R	No equiv DMD	Reaction time (min)	Yield	Thermal reaction solvent/time (Yield)
1	C <sub>12</sub> H <sub>25</sub>	2.4	15	46	Toluene/10 h (85%)
2	CH <sub>2</sub> CH <sub>2</sub> C(CH <sub>3</sub> ) <sub>3</sub>	1.5	25	50	Toluene/8 h (quant.)
3	CH <sub>2</sub> Ph	1.4	25	44	Xylene/7 h (92%) <sup>15</sup>
4	CH <sub>2</sub> CH <sub>2</sub> Cl	2.4	60	37 <sup>a</sup>	Xylene/7 days (99%) <sup>12</sup>
5	CH <sub>2</sub> CH <sub>3</sub>	1.5	20	51	Xylene/3 h (quant.) <sup>10</sup>

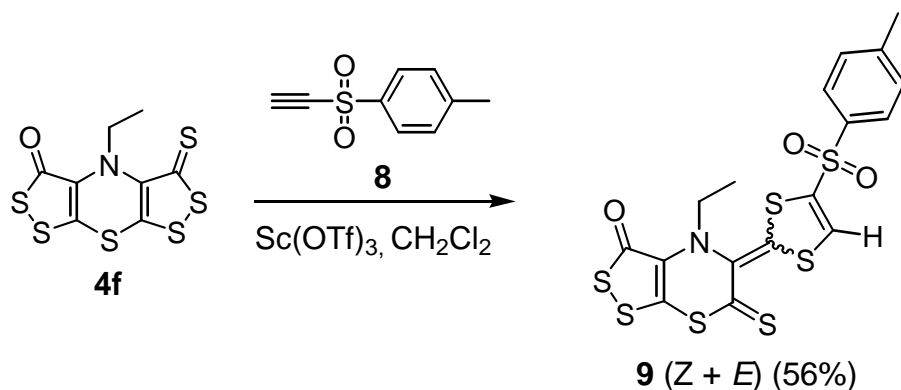
<sup>a</sup>A 32% of starting material **3e** was also recovered.

We have shown that bisdithiopyrroles that contain one or two exocyclic sulfur atoms are able to undergo 1,3-dipolar cycloadditions with dimethyl acetylenedicarboxylate, yielding complex polycyclic 1,3-dithioles.<sup>8</sup> Bisdithiolothiazine ketothiones should also react with activated triple bonds to give new polycyclic systems. With this in mind, we essayed the reaction of dithiolothiazine ketothione **4f** with benzyne. In the first experiment, we used the classic conditions to generate benzyne from anthranilic acid<sup>16</sup> in the presence of dithiolothiazine **4f**. Unfortunately, this produced the total decomposition of **4f**. Other methods for the *in situ* synthesis of benzyne, such as oxidation of 1-aminobenzotriazol with different oxidizing agents: lead tetraacetate,<sup>17</sup> *N*-iodosuccinimide<sup>18</sup> or BAIB, or the treatment of *o*-trimethylsilylphenyl triflate with cesium fluoride and catalytic palladium tetrakis(triphenyl)phosphine, led to the decomposition of **4f**. Nevertheless, the Kitamura's method,<sup>19</sup> starting from the *ortho*-hydroxydimethylsilyl-substituted hypervalent iodine salt **6**, provided a very mild and convenient method to generate benzyne in the presence of **4f**, from which the immediate formation of a cycloaddition product was observed by tlc. Work up and purification by column chromatography provided the benzodithiolane derivative **7** as a red solid (71%) characterized by spectroscopy. (Scheme 5).



### Scheme 5

The acetylene group behaves as a good dipolarophile when it is activated by a sulfone group. Therefore we submitted dithiolothiazine **4f** to reaction with excess of ethynyl *p*-tolyl sulfone **8** in dichloromethane, in the presence of scandium triflate [Sc(OTf)<sub>3</sub>], which is a good catalyst for cycloadditions. After work-up and column chromatography of reaction residue we separated the new dithiolane derivative **9** as a red solid, mixture of geometric isomers (56%), which was characterized by spectroscopy (Scheme 6). The <sup>1</sup>H-NMR spectrum of **9** showed two distinct signals corresponding to the 1,3-dithiole proton ( $\delta$  7.9 and 7.7) and two groups of two double quartets partially superimposed at  $\delta$  3.5 and 3.2, corresponding to the diastereotopic methylene group placed on the nitrogen which is part of the asymmetric folded thiazine ring, that undergoes restricted inversion at room temperature.



### Scheme 6

## Conclusions

We have extended the previous methodology in the direct conversion of *N*-alkyldiisopropylamines into *N*-alkylbisdithiolothiazines in one pot to the synthesis of the long chain or branched alkyl derivatives, which were hitherto unknown, and developed an alternative way to the preparation of *N*-alkylbisdithiopyrroles by selective *S*-oxidation of the thiazine sulfur with dimethyldioxirane and thermal extrusion of SO from the sulfoxide. In addition, we have studied the cycloaddition of a bisdithiolothiazine ketothione with benzyne and discovered that only the benzyne prepared by the mildest Kitamura's method was suitable for the cycloaddition on our substrate. We have also studied the catalyzed cycloaddition of acetylene activated by a sulfone group on the same substrate and obtained a new dithiolane derivative as the *Z* + *E* mixture of isomers. This, and the benzodithiolane obtained in the latter cycloaddition, are compounds that combine electron acceptors and donor in the same molecule, and can be useful as organic materials.

## Experimental Section

**General Procedures.** Bis[1,2]dithiolo[1,4]thiazine dithiones **3d-g** and **4h** were prepared as described.<sup>10,12,15</sup> *N*-lauryldiisopropylamine and *N*-stearyldiisopropylamine were prepared following known methods.<sup>20</sup> Acyl chlorides, diisopropylamine, and disulfur dichloride, were purchased from Aldrich and used without further purification. Aromatic and chlorinated solvents were distilled from phosphorus pentoxide, triethylamine was distilled from calcium hydride. Melting points were not corrected. CH<sub>2</sub> and CH groups were identified by DEPT experiments on representative examples. MPLC (medium pressure liquid chromatography) was carried out on a Gilson apparatus, with silica gel Merck C60 (< 230 mesh). Flash chromatography was carried

out following the method proposed by Still and co-workers,<sup>21</sup> with silica gel Merck C60 (230-400 mesh). Petroleum ether refers to the fraction bp 40-60 °C.

**Synthesis of bis[1,2]dithiolo[3,4-*b*:4',3'-*e*][1,4]thiazine-3,5-dithiones.** Disulfur dichloride (3.0 mL, 37.5 mmol) was added dropwise under a nitrogen atmosphere to a solution of *N*-lauryldiisopropylamine (1.0 g, 3.71 mmol) or *N*-stearyldiisopropylamine (1.3 g, 3.71 mmol) and 1,4-diazabicyclo[2.2.2]octane (DABCO, 3.32 g, 29.6 mmol) in chloroform (100 mL) at -40 °C. The mixture was stirred under dry nitrogen for 15 min at -40 °C and then for 3 days at room temperature. It was then cooled at 0 °C and triethylamine (6.7 mL, 48.1 mmol) was added dropwise. After the addition, stirring was kept for 2 h at room temperature, the reaction mixture was filtered through Celite, and the solvent was removed in the rotary evaporator. The resulting solid was purified by MPLC (petroleum ether to CH<sub>2</sub>Cl<sub>2</sub>) to give **1c** and **1d** respectively.

**4-Laurylbis[1,2]dithiolo[3,4-*b*:4',3'-*e*][1,4]thiazine-3,5-dithione (2a).** black prisms with metallic luster (178 mg, 10%), mp 147-149 °C (CH<sub>2</sub>Cl<sub>2</sub>-petroleum ether). <sup>1</sup>H-NMR (CDCl<sub>3</sub>, 400 MHz) δ 4.09 (t, *J* = 7.9 Hz, 2H, CH<sub>2</sub>), 1.74 (q, *J* = 7.9 Hz, 2H, CH<sub>2</sub>), 1.37 (q, *J* = 7.9 Hz, 2H, CH<sub>2</sub>), 1.25 (m, 16H, 8 × CH<sub>2</sub>), 0.88 (t, *J* = 7.0 Hz, 3H, CH<sub>3</sub>); <sup>13</sup>C-NMR (CDCl<sub>3</sub>, 100 MHz) δ 201.94 (C=S), 155.38 and 149.07 (2 × sp<sup>2</sup> tertiary C), 47.97, 31.84, 29.56, 29.50, 29.41, 29.26, 26.77, and 22.62 (8 × CH<sub>2</sub>, DEPT), and 14.06 (CH<sub>3</sub>, DEPT); IR (KBr, cm<sup>-1</sup>) ν 2920, 2848, 1551, 1434, 1308 (C=S), 1063; MS (EI) *m/z* 479 (M<sup>+</sup>, 12), 447 (M - 32, 100), 414 (25), 280 (20), 100 (25), 64 (82), 43 (78). Anal. Calcd for C<sub>18</sub>H<sub>25</sub>NS<sub>7</sub>: C, 45.05; H, 5.25; N, 2.92. Found: C, 44.95; H, 5.32; N, 2.80.

**4-Stearylbis[1,2]dithiolo[3,4-*b*:4',3'-*e*][1,4]thiazine-3,5-dithione (2b).** black solid with metallic luster (418 mg, 20%), mp 134-135 °C (CH<sub>2</sub>Cl<sub>2</sub>-petroleum ether). <sup>1</sup>H-NMR (CDCl<sub>3</sub>, 400 MHz) δ 4.10 (t, *J* = 7.9 Hz, 2H, CH<sub>2</sub>), 1.74 (q, *J* = 7.9 Hz, 2H, CH<sub>2</sub>), 1.36 (q, *J* = 7.9 Hz, 2H, CH<sub>2</sub>), 1.26 (m, 28H, 14 × CH<sub>2</sub>), 0.88 (t, *J* = 7.0 Hz, 3H, CH<sub>3</sub>); <sup>13</sup>C-NMR (C<sub>5</sub>D<sub>5</sub>N, 50 MHz) δ 203.75 (C=S), 162.15 and 149.64 (2 × sp<sup>2</sup> tertiary C), 48.42, 32.01, 29.96, 29.88, 29.81, 29.76, 29.73, 29.62, 29.54, 29.50, 27.15, and 22.83 (12 × CH<sub>2</sub>, DEPT), 14.18 (CH<sub>3</sub>, DEPT); IR (KBr, cm<sup>-1</sup>) ν 2919, 2847, 1451, 1310 (C=S), 1065; MS (FAB) *m/z* 564 (M<sup>+</sup> + 1, 2), 532 (M<sup>+</sup> - 31, 4), 500 (M<sup>+</sup> - 63, 3), 312 (7), 280 (3), 248 (4), 216 (4), 192 (3). Anal. Calcd for C<sub>24</sub>H<sub>37</sub>NS<sub>7</sub>: C, 51.11; H, 6.61; N, 2.48. Found: C, 51.42; H, 6.57; N, 2.38.

**Synthesis of bis[1,2]dithiolo[3,4-*b*:4',3'-*e*][1,4]thiazine-3,5-diones.** Disulfur dichloride (3.0 mL, 37.5 mmol) was added dropwise under a nitrogen atmosphere to a solution of *N*-lauryldiisopropylamine (1.0 g, 3.71 mmol) or *N*-(3,3-dimethylbutyl)diisopropylamine (686 mg, 3.71 mmol) and 1,4-diazabicyclo[2.2.2]octane (DABCO, 3.32 g, 29.6 mmol) in 1,2-dichloroethane (100 mL) at -40 °C. The mixture was stirred under dry nitrogen for 15 min at -40 °C and then for 3 days at room temperature. It was then cooled at 0 °C and formic acid (2.8 mL, 74.2 mmol) was added and the mixture heated under reflux for 2 hours. Then the reaction mixture was filtered through Celite and the solvent was removed in the rotary evaporator. The resulting solid was purified by MPLC (petroleum ether to CH<sub>2</sub>Cl<sub>2</sub>) to give **3a**, **4a**, and **3c** respectively.

**4-Laurylbis[1,2]dithiolo[3,4-*b*:4',3'-*e*][1,4]thiazine-3,5-dione (3a).** red solid (232 mg, 14%), mp 106-107 °C (CH<sub>2</sub>Cl<sub>2</sub>-petroleum ether). <sup>1</sup>H-NMR (CDCl<sub>3</sub>, 400 MHz) δ 3.77 (t, *J* = 7.5 Hz, 2H, CH<sub>2</sub>), 1.67 (q, *J* = 7.5 Hz, 2H, CH<sub>2</sub>), 1.43 (q, *J* = 7.5 Hz, 2H, CH<sub>2</sub>), 1.30 (m, 16H, 8 × CH<sub>2</sub>), 0.88 (t, *J* = 7.1 Hz, 3H, CH<sub>3</sub>); <sup>13</sup>C-NMR (CDCl<sub>3</sub>, 100 MHz) δ 181.95 (C=O), 145.58 and 137.39 (2 × sp<sup>2</sup> tertiary C), 46.79, 31.84, 29.68, 29.56, 29.45, 29.26, 26.56, and 22.62 (8 × CH<sub>2</sub>, DEPT), 14.07 (CH<sub>3</sub>, DEPT); IR (KBr, cm<sup>-1</sup>) ν 2919, 2848, 1631(C=O), 1556, 1512, 1043, 1024; MS (EI) *m/z* 447 (M<sup>+</sup>, 15), 415 (M – 32, 7), 354 (3), 279 (100), 43 (82). Anal. Calcd for C<sub>18</sub>H<sub>25</sub>NO<sub>2</sub>S<sub>5</sub>: C, 48.29; H, 5.63; N, 3.13. Found: C, 48.38; H, 5.73; N, 3.15.

**3-Oxo-4-laurylbis[1,2]dithiolo[3,4-*b*:4',3'-*e*][1,4]thiazine-5-thione (4a).** red solid (103 mg, 6%), mp 129-130 °C (CH<sub>2</sub>Cl<sub>2</sub>-petroleum ether). <sup>1</sup>H-NMR (CDCl<sub>3</sub>, 400 MHz) δ 3.94 (t, *J* = 7.5 Hz, 2H, CH<sub>2</sub>), 1.71 (q, *J* = 7.5 Hz, 2H, CH<sub>2</sub>), 1.38 (q, *J* = 7.5 Hz, 2H, CH<sub>2</sub>), 1.25 (m, 16H, 8 × CH<sub>2</sub>), 0.88 (t, *J* = 7.0 Hz, 3H, CH<sub>3</sub>); <sup>13</sup>C-NMR (CDCl<sub>3</sub>, 100 MHz) δ 201.49 (C=S), 182.23 (C=O), 154.70, 148.66, 147.41 and 137.98 (4 × sp<sup>2</sup> tertiary C), 47.54, 31.91, 29.63, 29.55, 29.42, 29.33, 26.75, and 22.69 (8 × CH<sub>2</sub>, DEPT), 14.13 (CH<sub>3</sub>, DEPT); IR (KBr, cm<sup>-1</sup>) ν 2919, 2851, 1628(C=O), 1533, 1467, 1287 (C=S), 1082, 1014; MS (EI) *m/z* 463 (M<sup>+</sup>, 16), 431 (M – 32, 14), 398 (19), 370 (19), 338 (10), 308 (28), 295 (32), 43 (84). Anal. Calcd for C<sub>18</sub>H<sub>25</sub>NOS<sub>6</sub>: C, 46.61; H, 5.43; N, 3.02. Found: C, 46.59; H, 5.49; N, 2.97.

**4-(3,3-Dimethylbutyl)bis[1,2]dithiolo[3,4-*b*:4',3'-*e*][1,4]thiazine-3,5-dione (3c).** orange solid (323 mg, 24%), mp 182-183 °C (CH<sub>2</sub>Cl<sub>2</sub>-petroleum ether). <sup>1</sup>H-NMR (CDCl<sub>3</sub>, 400 MHz) δ 3.79 (t, *J* = 8.7 Hz, 2H, CH<sub>2</sub>), 1.65 (t, *J* = 8.7 Hz, 2H, CH<sub>2</sub>), 0.92 (s, 9H, 3 × CH<sub>3</sub>); <sup>13</sup>C-NMR (CDCl<sub>3</sub>, 100 MHz) δ 181.98 (C=O), 145.99 and 137.10 (2 × sp<sup>2</sup> tertiary C), 43.89 and 43.02 (2 × CH<sub>2</sub>, DEPT), 29.85 (quaternary C), 29.35 (3 × CH<sub>3</sub>, DEPT); IR (KBr, cm<sup>-1</sup>) ν 2947, 2908, 1633 (C=O), 1545, 1513, 1078, 1035; MS (EI) *m/z* 365 (M<sup>+</sup> + 2, 23), 363 (M<sup>+</sup>, 78), 331 (M – 32, 3), 292 (41), 281 (52), 279 (100), 251 (29), 57(100), 43 (92); HRMS, M<sup>+</sup> = 362.9558 C<sub>12</sub>H<sub>13</sub>NO<sub>2</sub>S<sub>5</sub> requires 362.9550. Anal. Calcd for C<sub>12</sub>H<sub>13</sub>NO<sub>2</sub>S<sub>5</sub>: C, 39.64; H, 3.60; N, 3.85. Found: C, 39.78; H, 3.66; N, 3.78.

**3-Oxo-4-(3,3-dimethylbutyl)bis[1,2]dithiolo[3,4-*b*:4',3'-*e*][1,4]thiazine-5-thione (4c).** Disulfur dichloride (3.0 mL, 37.5 mmol) was added dropwise under a nitrogen atmosphere to a solution of *N*-(3,3-dimethylbutyl)diisopropylamine (686 mg, 3.71 mmol) and 1,4-diazabicyclo[2.2.2]octane (DABCO, 3.32 g, 29.6 mmol) in tetrahydrofuran (100 mL) at –40 °C. The mixture was stirred under dry nitrogen for 15 min at –40 °C and then for 3 days at room temperature. Then the reaction mixture was filtered through Celite and the solvent was removed in the rotary evaporator. The resulting solid was purified by MPLC (cyclohexane to CH<sub>2</sub>Cl<sub>2</sub>) to give **4c**, red solid (141 mg, 10%), mp 138-139 °C (CH<sub>2</sub>Cl<sub>2</sub>-cyclohexane). <sup>1</sup>H-NMR (CDCl<sub>3</sub>, 400 MHz) δ 3.97 (t, *J* = 8.6 Hz, 2H, CH<sub>2</sub>), 1.67 (t, *J* = 8.6 Hz, 2H, CH<sub>2</sub>), 0.90 (s, 9H, 3 × CH<sub>3</sub>); <sup>13</sup>C-NMR (CDCl<sub>3</sub>, 100 MHz) δ 201.57 (C=S), 182.27 (C=O), 155.06, 148.25, 147.73 and 137.77 (4 × sp<sup>2</sup> tertiary C), 44.46 and 42.73 (2 × CH<sub>2</sub>, DEPT), 29.95 (quaternary C), 29.39 (3 × CH<sub>3</sub>, DEPT); IR (KBr, cm<sup>-1</sup>) ν 2959, 1631 (C=O), 1530, 1464, 1274 (C=S), 1103, 1068; MS (EI) *m/z* 381 (M<sup>+</sup> + 2, 16), 379 (M<sup>+</sup>, 66), 363 (M – 16, 51), 346 (M – 33, 7), 308 (77), 295 (44), 279 (100), 262 (32). Anal.



Calcd for  $C_{12}H_{13}NOS_6 + C_6H_{12}$  (cyclohexane): C, 46.61; H, 5.43; N, 3.02. Found: C, 46.16; H, 5.10; N, 2.89.

**General procedure for the DMD oxidation of bisdithiolothiazines.** The indicated amount (Table 1) of dimethyldioxirane (DMD, 0.09 M in acetone)<sup>22</sup> was added to a solution of 4-alkyl-bis[1,2]dithiolo[3,4-*b*:4',3'-*e*][1,4]thiazine-3,5-dione (0.1 mmol) in benzene (2 mL) at  $-60\text{ }^\circ\text{C}$ , and the resulting solution was left to reach  $-30\text{ }^\circ\text{C}$  and stirred for 1 h. Then the solution was evaporated at reduced pressure below  $0\text{ }^\circ\text{C}$ . Then the residue was dissolved in benzene (5 mL) and refluxed for the indicated period of time. The solvent was removed in the rotary evaporator, and the resulting residue was purified by flash chromatography (dichloromethane-petroleum ether).

**4-Laurylbis[1,2]dithiolo[4,3-*b*:3',4'-*d*]pyrrole-3,5-dione (5a).** red solid (37 mg, 85%), mp  $89-90\text{ }^\circ\text{C}$  ( $\text{CH}_2\text{Cl}_2$ -petroleum ether).  $^1\text{H-NMR}$  ( $\text{CDCl}_3$ , 400 MHz)  $\delta$  4.52 (t,  $J = 7.5\text{ Hz}$ , 2H,  $\text{CH}_2$ ), 1.77 (q,  $J = 7.5\text{ Hz}$ , 2H,  $\text{CH}_2$ ), 1.24 (m, 18H,  $9 \times \text{CH}_2$ ), 0.88 (t,  $J = 7.1\text{ Hz}$ , 3H,  $\text{CH}_3$ );  $^{13}\text{C-NMR}$  ( $\text{CDCl}_3$ , 100 MHz)  $\delta$  181.48 (C=O), 135.32 and 130.03 ( $4 \times \text{sp}^2$  tertiary C), 44.55, 31.92, 29.65, 29.58, 29.49, 29.38, 29.20, 29.01, 26.54, 25.78, and 22.67 ( $11 \times \text{CH}_2$ , DEPT), 14.10 ( $\text{CH}_3$ , DEPT); IR (KBr,  $\text{cm}^{-1}$ )  $\nu$  2923, 2849, 1671 and 1650 (C=O), 1458, 1430, 1347, 1205, 1078; MS (EI)  $m/z$  417 ( $\text{M}^+ + 2$ , 24), 416 ( $\text{M}^+ + 1$ , 27), 415 ( $\text{M}^+$ , 100), 387 (11), 354 (28), 260 (41), 247 (56); HRMS,  $\text{M}^+ = 415.0798$   $\text{C}_{18}\text{H}_{25}\text{NO}_2\text{S}_4$  requires 415.0768.

**4-(3,3-Dimethylbutyl)bis[1,2]dithiolo[4,3-*b*:3',4'-*d*]pyrrole-3,5-dione (5c).** orange solid (34 mg, 100%), mp  $203-204\text{ }^\circ\text{C}$  ( $\text{CH}_2\text{Cl}_2$ -petroleum ether).  $^1\text{H-NMR}$  ( $\text{CDCl}_3$ , 400 MHz)  $\delta$  4.55 (t,  $J = 8.7\text{ Hz}$ , 2H,  $\text{CH}_2$ ), 1.65 (t,  $J = 8.7\text{ Hz}$ , 2H,  $\text{CH}_2$ ), 0.97 (s, 9H,  $3 \times \text{CH}_3$ );  $^{13}\text{C-NMR}$  ( $\text{CDCl}_3$ , 100 MHz)  $\delta$  181.13 (C=O), 135.31 and 129.91 ( $2 \times \text{sp}^2$  tertiary C), 45.24 and 41.58 ( $2 \times \text{CH}_2$ , DEPT), 29.90 (quaternary C), 29.21 ( $3 \times \text{CH}_3$ , DEPT); IR (KBr,  $\text{cm}^{-1}$ )  $\nu$  2957, 2924, 2865, 1686, 1662, and 1647 (C=O), 1429, 1353, 1263, 1196, 1092; MS (EI)  $m/z$  333 ( $\text{M}^+ + 2$ , 19), 332 ( $\text{M}^+ + 1$ , 18), 331 ( $\text{M}^+$ , 100), 274 (16), 260 (49), 247 (73), 57(42); HRMS,  $\text{M}^+ = 330.9831$   $\text{C}_{12}\text{H}_{13}\text{NO}_2\text{S}_4$  requires 330.9829.

**Cycloaddition of bisdithiolothiazine 4f with benzyne: synthesis of (7).** Tetrabutylammonium fluoride (0.232 mL, 0.232 mmol, 1.0 M in THF) was added dropwise to a chilled ( $0^\circ\text{C}$ ) stirred solution of 4-ethyl-3-oxo-bis[1,2]dithiolo[3,4-*b*:4',3'-*e*][1,4]thiazine-5-thione **4f** (30 mg, 0.093 mmol) and [2-(hydroxydimethylsilyl)phenyl](phenyl)iodonium triflate<sup>19</sup> **6** (117 mg, 0.232 mmol) in dichloromethane (2 mL). Then the mixture was stirred for 30 min at room temperature. Water (10 mL) was added on the mixture and extracted with dichloromethane ( $3 \times 10\text{ mL}$ ). The combined extracts were dried ( $\text{Na}_2\text{SO}_4$ ) and evaporated under reduced pressure. Fast column chromatography of the residue ( $\text{SiO}_2$ , petroleum ether-dichloromethane 9:1) gave benzodithiolane **7** as a red solid (26 mg, 70%), mp.  $72-73\text{ }^\circ\text{C}$  (petroleum ether-dichloromethane).  $^1\text{H-NMR}$  ( $\text{CDCl}_3$ , 400 MHz)  $\delta$  7.68-7.65 (m, 2H,  $2 \times \text{CH}$ , Ar), 7.45-7.43 (m, 2H,  $2 \times \text{CH}$ , Ar), 3.56 (double quartet, six signals,  $J = 14.0\text{ Hz}$ ,  $J = 7.0\text{ Hz}$ , 1 H,  $\frac{1}{2}\text{CH}_2$ ), 3.35 (double quartet, six signals,  $J = 14.0\text{ Hz}$ ,  $J = 7.0\text{ Hz}$ , 1 H,  $\frac{1}{2}\text{CH}_2$ ), 1.25 (t,  $J = 7.0\text{ Hz}$ , 3H,  $\text{CH}_3$ );  $^{13}\text{C-NMR}$  ( $\text{CDCl}_3$ , 100 MHz)  $\delta$  192.23 (C=S), 185.14 (C=O), 165.38, 153.96, 137.54, 134.78, 132.52, and 131.84 (6

$\times$   $sp^2$  tertiary + aromatic C), 127.57, 127.31, 123.87, and 122.08 ( $4 \times$  CH, Ar), 48.18 ( $CH_2$ ), 13.48 ( $CH_3$ ); IR (KBr  $cm^{-1}$ )  $\nu$  1646 (C=O), 1635, 1398, 1337, 1308, 1290 (C=S), 1262, 1105, 1044. MS (EI)  $m/z$  399 ( $M^+$ , 40), 370 ( $M - 29$ , 100), 208 (45), 178 (30), 108 (25), 69 (25); HRMS,  $M^+ = 398.9006$   $C_{14}H_9NOS_6$  requires 398.9008. Anal. Calcd for  $C_{14}H_9NOS_6$ : C, 42.08; H, 2.27; N, 3.51. Found: C, 41.79; H, 2.44; N, 3.12.

**Cycloaddition of bisdithiolothiazine 4h and ethynyl *p*-tolyl sulfone 8 synthesis of 9.** Ethynyl *p*-tolyl sulfone **8** (39 mg, 0.22 mmol) and scandium triflate (22 mg, 0.045 mmol) were added to a stirred solution of 4-ethyl-3-oxo-bis[1,2]dithiolo[3,4-b:4',3'-e][1,4]thiazine **4f** (58 mg, 0.180 mmol) in  $CH_2Cl_2$  (15 mL) and the mixture was stirred for 1 day at room temperature. Then the solvent was evaporated at reduced pressure. Fast column chromatography of the the resulting residue (SiO<sub>2</sub> petroleum ether to  $CH_2Cl_2$ /petroleum ether 7:3) gave **9** (51 mg, 56%) as a red solid, mp 85-87 °C ( $CH_2Cl_2$ -petroleum ether). <sup>1</sup>H-NMR ( $CDCl_3$ , 400 MHz)  $\delta$  7.90 (s, 1H, CH), 7.87 (d,  $J = 8.4$  Hz, 2H,  $2 \times$  CH, Ar), 7.86 (d,  $J = 8.4$  Hz, 2H,  $2 \times$  CH, Ar), 7.69 (s, 1H, CH), 7.39 (d,  $J = 8.4$  Hz, 2H,  $2 \times$  CH, Ar), 7.38 (d,  $J = 8.4$  Hz, 2H,  $2 \times$  CH, Ar), 3.57 (six signals, double quartet,  $J = 7.2$  Hz, 1H,  $\frac{1}{2}CH_2$ ), 3.49 (six signals, double quartet,  $J = 7.2$  Hz, 1H,  $\frac{1}{2}CH_2$ ), 3.20 (six signals, double quartet,  $J = 7.2$  Hz, 1H,  $\frac{1}{2}CH_2$ ), 3.17 (six signals, double quartet,  $J = 7.2$  Hz, 1H,  $\frac{1}{2}CH_2$ ), 2.45 (s, 3H,  $CH_3$ ), 2.44 (s, 3H,  $CH_3$ ), 1.18 (t,  $J = 7.2$  Hz, 6H,  $2 \times$   $CH_3$ ); <sup>13</sup>C-NMR ( $CDCl_3$ , 100 MHz)  $\delta$  193.39 (C=S), 192.25 (C=S), 184.74 (C=O), 184.45 (C=O), 167.73, 164.27, 153.26, 152.38, 146.04, 145.88, 141.09, 139.79, 136.23, 132.15, 131.32, and 130.86 ( $12 \times$   $sp^2$  tertiary C + CH dithiole), 130.48 and 130.43 ( $2 \times$  CH, Ar), 128.76 ( $sp^2$  tertiary C), 128.05 and 127.99 ( $2 \times$  CH, Ar), 47.94 and 47.52 ( $2 \times$   $CH_2$ ), 23.70, 22.96, 14.07, and 13.40 ( $4 \times$   $CH_3$ ); IR (KBr,  $cm^{-1}$ )  $\nu$  2959, 2924, 2846, 1674 (C=O), 1526, 1417, 1336 and 1305 ( $SO_2$ ), 1153 (S=O), 1087, 575; MS (EI)  $m/z$  505 ( $M^+ + 2$ , 6), 503 ( $M^+$ , 17), 476 (33), 475 (22), 474 ( $M^+ - 29$ , 100), 414 (2), 370 (2), 312 (5); HRMS,  $M^+ = 502.8930$   $C_{17}H_{13}NO_3S_7$  requires 502.8940. Anal. Calcd for  $C_{17}H_{13}NO_3S_7$ : C, 40.53; H, 2.60; N, 2.78. Found: C, 40.62; H, 2.72; N, 2.77.

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