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Preparation and structure determination of 28-membered and 42-membered cyclic molecules linked with two or three disulfide bonds

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Preparation and structure determination of 28-membered and 42-membered cyclic molecules linked with two or three disulfide bonds

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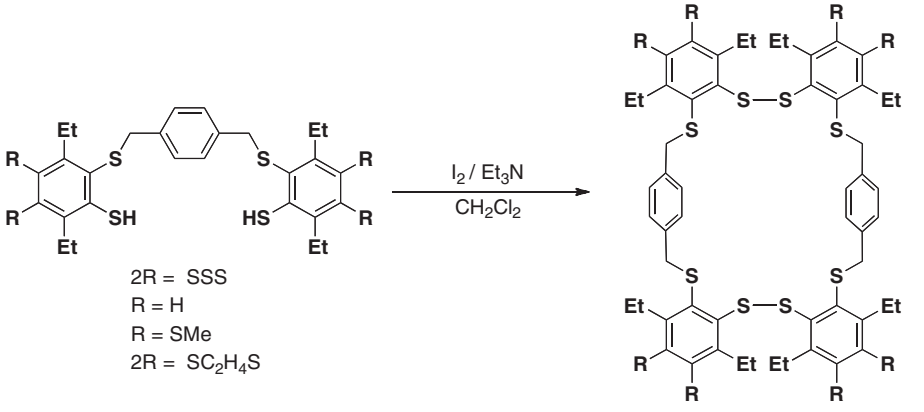
4,7-Diethylbenzo[1,2,3]trithioles (**1a**–**1c**), 4,8-diethylbenzo[1,2-*d*:4,5-*d′*]bis[1,2,3]trithiole (**1d**), and 6, 10-diethyl[1,2,3]trithiolo[*h*]benzopentathiepin (**1d′**) were treated with sodium borohydride and 0.5 equiv. of *p*-xylylene dibromide to produce bridged molecules **2a**–**2d** with two thiol groups. On oxidation of **2a** with iodine in the presence of triethylamine, 28-membered macrocycle **3a**, linked with two disulfide bonds, was obtained *via* a dimeric cyclization reaction, instead of a monomeric 14-membered macrocycle. Compounds **2b**–**2d** were similarly treated with iodine and triethylamine to give 28-membered macrocycles **3b**–**3d**. In the case of the reaction of **2c**, a trimeric reaction occurred to produce 42-membered macrocycle **4** together with **3c**. The structures of the cyclic molecules were determined by NMR and mass spectrometry, which was further supported by X-ray crystallographic analysis.



Keywords: macrocycle; disulfide; thiacrown; benzotrithiole and oxidation

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1. Introduction

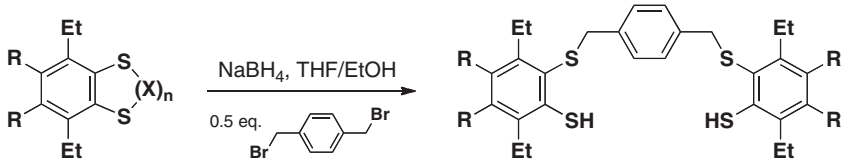
Thiacrown ethers and thiacalixarenes have been attracted much attention because of their molecular-recognition properties, inclusion of metal atoms, and functionalities of complexes produced (*1–4*). In addition, thiacrown ethers and thiacalixarenes show high affinity for heavy metals such as mercury, silver, platinum, gold, and so on. So, these compounds have potential utility to remove highly toxic metal ions or to recover important metals from industrially contaminated water. In thiacrown ether ring systems, introducing one or more unsaturated linkages is effective to control their structure, cavity size, and a number of metal atoms inserted, which could affect their character as functional materials (*5*). *Cis* and *trans* bond systems, in particular, can dramatically change the conformation and functionality of the molecule. In addition, while thiacrown ethers and related compounds have been prepared from many types of substrates, the disulfide linkage could be one of the useful key systems for construction of the desired molecules (*6*).

On the other hand, there are many reports with respect to the preparation, structure determination, biological activity, and electrochemical properties of benzo-annelated cyclic polysulfides (*7*). In related studies, we recently described optical and electrochemical properties of thianthrenes and phthalocyanines fused with one through four trithiole rings (*8*,*9*) and related molecules (*10*). To prepare the macrocyclic compounds with sulfur functional groups, 5,6-bis(methylthio)-4,7-diethylbenzo[1,2,3]trithiole (**1a**), 5,6-ethylenedithio-4,7-diethylbenzo[1,2,3]trithiole (**1b**), 4,7-diethylbenzo[1,2,3]trithiole 2-oxide (**1c**), 4,8-diethylbenzo[1,2-*d*:4,5-*d*′]bis[1,2,3]trithiole (**1d**), and 6,10-diethyl[1,2,3]trithiolo[*h*]benzopentathiepin (**1d**′) were reacted with sodium borohydride and *p*-xylylene dibromide, and the dithiol derivatives **2a**–**2d**, produced by these reactions, were then oxidized with iodine in the presence of triethylamine. This process gave 28-membered cyclic molecule **3a**–**3d** with two disulfide bonds *via* dimeric cyclization reactions. In addition, **2c** afforded the 42-membered macrocyclic molecule **4** by an oxidative trimerization reaction. This paper describes the preparation and structure determination of macrocyclic molecules **3a**–**3d** and **4** connected by *p*-xylylendithio linkers and disulfide bonds.

2. Results and discussion

To prepare sulfur containing macrocyclic molecules, **1d** with two trithiole rings (*11*) was initially treated with 1 equiv. of sodium borohydride and *p*-xylylene dibromide in the presence of potassium carbonate in THF/methanol. However, an insoluble yellow material was immediately produced in this reaction and hence we could not analyze the product. This insoluble material could be produced by a random oligomerization reaction of the reactants. To simplify the reaction system and to avoid the oligomerization reaction, **1a** was utilized as a substrate with only 0.5 equiv. of *p*-xylylene dibromide (Scheme 1). We previously reported that when 6,10-dimethoxy[1,2,3]trithiolo[*h*]benzopentathiepin was treated with sodium borohydride and then methyl iodide, 6,9-dimethoxybenzopentathiepin, with one methylthio and one thiol group, was obtained as a major product (*11a*). Consequently, using a similar procedure, **1a** was reduced with sodium borohydride and then treated with 0.5 equiv. of *p*-xylylene dibromide to give dithiol derivative **2a**, bridged by a xylylenedithio group, in 55% yield as a stable colorless powder (Scheme 1). Compound **2a** is soluble in chloroform, dichloromethane, and THF.

In the ^{1}H NMR spectrum of **2a**, there are two triplet and two quartet signals for the ethyl groups, two singlet peaks for the two different methylthio groups, and two singlet signals for the CH_2 and aromatic *p*-xylylene protons. In addition, one singlet peak for two thiol groups was observed at $\delta = 6.31$ ppm. The IR spectrum showed the absorption of the thiol group at 2474 cm^{-1}. Compound **2a** is stable and oxidation of the thiol groups with oxygen did not proceed under air.



1a: X = S, n = 1, R = SMe
1b: X = S, n = 1, 2R = SC_2H_4S
1c: X = SO, n = 1, R = H
1d: X = S, n = 1, 2R = SSS
1d': X = S, n = 3, 2R = SSS

2a: 55%
2b: 80%
2c: 63%
2d: 74% (from **1d**)
2d: 76% (from **1d'**)

Scheme 1. Preparation of dithiol derivatives **2a**–**2d**.

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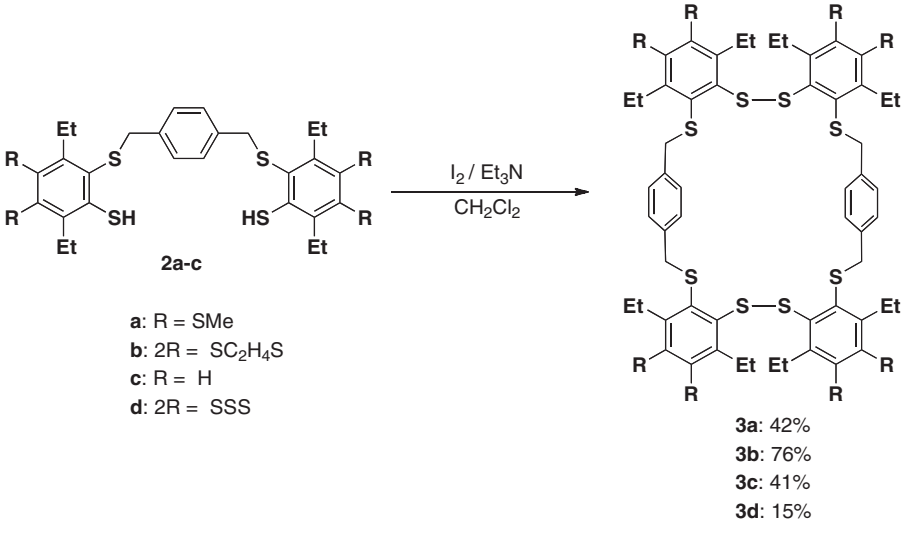
Since **2a** was obtained in moderate yield, **1b**–**1d** were similarly treated with sodium borohydride and then *p*-xylylene dibromide to produce the corresponding dithiol derivatives **2b**–**2d**, respectively (**2b**: 80%, **2c**: 63%, and **2d**: 74% from **1d** and 76% from **1d**′). Compounds **2b**–**2d** are stable and soluble in chloroform, dichloromethane, and THF. ^{1}H NMR spectra of these products showed the anticipated signals for the ethyl, thiol, and xylylene groups. In addition, a multiplet signal for the ethylenedithio groups was observed in the spectrum of **2b**, and the spectrum of **2c** showed the aromatic protons as an AB quartet. It also appears that the chemical shifts of the singlet signal of the thiol groups were affected by the substituents next to the two ethyl groups; **2a**: $\delta = 6.31$ ppm, **2b**: $\delta = 6.16$ ppm, **2c**: $\delta = 5.88$ ppm, and **2d**: $\delta = 6.00$ ppm.

It was expected that two dithiol groups on the benzene rings of **2a**–**2d** could be oxidized to produce the disulfide bond. If the oxidative bond formation proceeds exclusively via an intramolecular reaction between the two thiol groups, **2a**–**2d** would produce 14-membered ring macrocycles. To avoid intermolecular oligomerization of **2a**–**2d**, dilute reaction conditions and a mild oxidizing reagent were utilized for the disulfide formation. Thus, a dichloromethane solution of **2a** was slowly dropped into a dichloromethane solution of triethylamine together with a dichloromethane solution of iodine and the reaction mixture was stirred for 12 h at room temperature (Scheme 2). With this procedure, intermolecularly dimerized **3a** with two disulfide bonds was surprisingly obtained in 42% yield as a colorless and powdery material after purification with column chromatography and gel permeation chromatography (GPC). Compound **3a** is stable under ambient conditions (room temperature and under 1 atm of air) and easily soluble in chloroform, dichloromethane, and THF.

In the ^{1}H NMR spectrum of **3a**, we could observe two triplet and two quartet signals for the ethyl groups, two singlet peaks for the methylthio groups, and two singlet peaks for the xylylene group as expected (*vida supra*). In addition, the signal of the thiol group disappeared in the spectrum. Interestingly, one ethyl group of **3a** appeared at $\delta = 0.61$ (t) and 2.86 (q) ppm, which is at a higher magnetic field than that of **2a**: $\delta = 1.10$ (t) and 3.13 (q) ppm, suggesting that the ethyl groups of **3a** are magnetically shielded by aromatic rings which is clearly a function of the conformation adopted by the product. Meanwhile, two singlet signals for the xylylene protons were observed at $\delta = 4.12$ (SCH_2) and 7.57 (ArH) ppm, which are at lower magnetic field than that of **2a**: $\delta = 3.90$ (SCH_2) and 7.07 (ArH) ppm. Fast atom bombardment mass spectrometry (FABMS) measurement showed a signal at $m/z = 1360.13$ [M^+], which corresponds to the molecular ion peak of a dimerized macrocycle. Therefore, the structure of compound **3a** is a dimerized 28-membered ring system instead of a monomeric 14-membered structure. The 14-membered macrocycle was not obtained under the reaction conditions.

Compounds **2b**–**2d** were also oxidized by a similar method as described above to produce **3b**–**3d** (**3b**: 76%, **3c**: 41%, and **3d**: 15%), after purification with column chromatography and

GPC. Compound **3d** was unstable compared with **3a**–**3c** and easily produced an insoluble yellow material. In the ^{1}H NMR spectra of **3b**–**3d**, signals for one of the ethyl groups were observed at higher magnetic fields than those of **2b**–**2d**. Furthermore, singlet peaks for the xylylene group of **3b**–**3d** appeared at similar chemical shifts as those observed for **3a**. These results suggested that the structures of **3b**–**3d** are similar to those of **3a**. In addition, the molecular ion peak of **3c** was observed by FABMS measurement: $m/z = 992.28$ [M$^+$], suggesting that **3c** is a 28-membered ring system.



Scheme 2. Preparation of 28-membered macrocycles **3a**–**3d**.

Compound **3c** produced thin needle crystals after recrystallization and its X-ray crystallographic analysis was performed to determine the structure (*12*). However, we could not obtain a satisfactory final *R* factor, and bond lengths and angles of the one of the ethyl groups show unusual values. Nevertheless, we could verify the molecular structure and the results showed the dimerized 28-membered ring system of **3c** as described above, even though the structure refinement was not sufficient. Unfortunately, the results could not be improved by using other crystals. In the molecule, the two benzene rings of the xylylene groups are shown to be parallel to each other and separated by a distance of 7.7 Å. The distance between the two disulfide bonds is 8.6 Å. In addition, the molecular structure showed that one ethyl group exists above the adjacent benzene ring, which gives rise to the higher magnetic field shift observed for one of the ethyl groups in the ^{1}H NMR spectrum of **3c**.

On the other hand, it appeared that **2c** afforded an additional cyclized product **4** as a colorless powder in 10% yield together with **3c**, after GPC purification. The results of GPC analysis suggested that the molecular weight of this compound is larger than that of **3c**. In the ^{1}H NMR spectrum of **4**, we can observe two triplet signals ($\delta = 0.99$ and 1.09 ppm) and two quartet signals for the ethyl groups ($\delta = 2.57$ and 2.79 ppm), two singlet peaks for the xylylene group ($\delta = 3.81$ and 7.05 ppm), and AB quartet for the benzene rings. The signal of the thiol group was not observed in the spectrum and the chemical shifts of the xylylene group appeared at slightly higher magnetic fields than those of **3c**. Finally, the molecular ion peak of **3c** was obtained with an FABMS measurement: $m/z = 1488.46$ [M$^+$], which suggests that **4** is a trimerized 42-membered macrocyclic molecule (Figure 1). On the other hand, we could not obtain 42-membered macrocyclic molecules by the oxidation of **2a**, **2b**, and **2d**.

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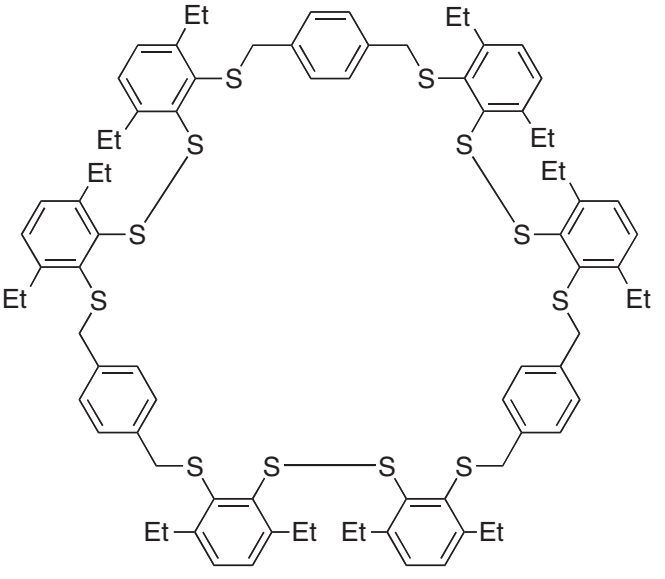

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Figure 1. The structure of 28-membered macrocycle **4**.

To determine the electrochemical properties of the macrocycles, reduction potentials of **3b** and **3c** were measured by cyclic voltammetry using $Ag/AgNO_3$ as a reference electrode (solvent: CH_2Cl_2, scan rate: 200 mV/s). Both compounds **3b** and **3c** showed one quasi-reversible reduction potential; **3b**: $E_{1/2} = -1.22$ V and **3c**: $E_{1/2} = -1.22$ V. These potentials are similar to the value for bis(2,5-diethylphenyl) disulfide: $E_{1/2} = -1.22$ V. On the other hand, to measure the oxidation potential of **3c**, when the cyclic voltammetry was scanned from 0 to 2.0 V, the value of the current was gradually increased after about 1.05 V but no peak potential was observed in the voltammogram.

As a preliminary experiment, we treated **3c** with excess amounts of silver trifluoroacetate in the NMR tube (solvent: $CDCl_3$/acetone-d_6). The signals of **3c** were broadened and changed to new signals in the spectrum, suggesting that the silver complex of **3c** was produced in the solution. However, the signals in the spectrum become complex in several hours.

3. Conclusion

Cyclic polysulfides **1a**–**1d′** were treated with sodium borohydride and 0.5 equiv. of *p*-xylylene dibromide to produce bridged molecules **2a**–**2d** with two thiol groups. Oxidative dimerization of **2a** proceeded on treatment with iodine in the presence of triethylamine, which gave a 28-membered macrocycle **3a** linked with two disulfide bonds. Similar reactions of **2b** and **2d** with iodine produced dimeric macrocycles **3b** and **3d**, respectively, while **2c** afforded 28-membered macrocycle **3c** and 42-membered macrocycle **4** under the reaction conditions. Although **2a**–**2d** did not produce 14-membered macrocycles by oxidative intramolecular cyclization, these molecules can be utilized as the building unit for 28-membered and 42-membered macrocycles. The structures of the molecules were determined with NMR, FABMS, and X-ray crystallographic analysis. The chemical shifts of the ethyl and xylylene groups were different for the 28-membered and 42-membered macrocycles.

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4. Experimental

4.1. *General*

NMR spectra were measured on Bruker DRX-400 and AVANCE-500 III spectrometers. IR spectra were recorded using a JASCO FT-7300 spectrometer. Mass spectra were obtained using a JEOL JMS-700 mass spectrometer. Elemental analyses were performed using a Yanako MT5 analyzer. A JAI LC-908 model was used for GPC. A Hokuto Denko Co. Model HAB-151 apparatus was employed for measuring oxidation potentials.

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4.2. *Redox potentials*

All measurements were performed by cyclic voltammetry using $Ag/AgNO_3$ (0.01 mol/l) as a reference electrode, glassy carbon as a working electrode, and Pt as a counter-electrode (scan rate: 200 mV/s). A solution of n-Bu_4NClO_4 in CH_2Cl_2 (0.1 mol/l) was used as an electrolyte. The oxidation potential of ferrocene was observed at $E_{1/2} = 0.09$ V by the apparatus without any correction.

4.3. *5,6-Bis(methylthio)-4,7-diethylbenzotrithiole (***1a***) (13), 5,6-ethylenedithio-4,7-diethylbenzotrithiole (***1b***) (8), 4,7-diethylbenzotrithiole 2-oxide (***1c***) (14), 4,8-diethylbenzo[1,2-d:4,5-d′]bis[1,2,3]trithiole (***1d***) (11b), and 6,10-diethyl[1,2,3]-trithiolo[h]benzopentathiepin (***1d′***) (10b)*

Compounds **1a**–**1d′** were prepared by methods described previously.

4.4. *Preparation of dithiol* **2a**

Compound **1a** (321 mg, 1.0 mmol, in 50 ml of THF and 5 ml of EtOH) was treated with $NaBH_4$ (1.2 equiv.) for 30 min and then *p*-xylylene dibromine (0.5 equiv.) was added to the solution. The mixture was stirred at room temperature for 12 h. After treatment with aqueous HCl, the solvent was evaporated and the aqueous solution was extracted with CH_2Cl_2. The extract was dried over $MgSO_4$ and the solvent was evaporated. The product was purified by column chromatography (silica gel, CCl_4) to produce **2a** in 55% yield; colorless crystals; m.p. 178°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.10 (t, $J = 7.4$ Hz, 6H, CH_3), 1.25 (t, $J = 7.4$ Hz, 6H, CH_3), 2.35 (s, 6H, SCH_3), 2.45 (s, 6H, SCH_3), 3.13 (q, $J = 7.4$ Hz, 4H, CH_2), 3.19 (q, $J = 7.5$ Hz, 4H, CH_2), 3.90 (s, 4H, SCH_2), 6.31 (s, 2H, SH), 7.07 (s, 4H, ArH); ^{13}C NMR (101 MHz, $CDCl_3$) δ 12.3, 14.5, 32.3, 32.4, 39.7, 129.2, 129.3, 134.9, 136.0, 137.1, 140.9, 143.00, 143.0321.7, 32.1, 141.7, 142.1, 142.7; IR (KBr) 2474 cm^{-1} (SH); MS (*m*/*z*) 682 (M^+); Anal. Calcd for $C_{32}H_{42}S_8$: C, 56.26; H, 6.20%. Found: C, 56.59; H, 6.12%.

4.5. *Preparation of dithiol* **2b**

Yield: 80%; yellow crystals; m.p. 158.5°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.08 (t, $J = 7.5$ Hz, 6H, CH_3), 1.21 (t, $J = 7.5$ Hz, 6H, CH_3), 2.99 (q, $J = 7.5$ Hz, 4H, CH_2), 3.01 (q, $J = 7.5$ Hz, 4H, CH_2), 3.13–3.24 (m, 8H, CH_2), 3.89 (s, 4H, SCH_2), 6.16 (s, 2H, SH), 7.06 (s, 4H, ArH). Anal. Calcd for $C_{32}H_{38}S_8$: C, 56.59; H, 5.64%. Found: C, 56.12; H, 5.68%.

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4.6. *Preparation of dithiol* 2c

Yield: 63%; colorless crystals; m.p. 81–82°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.09 (t, $J = 7.4$ Hz, 6H, CH_3), 1.27 (t, $J = 7.4$ Hz, 6H, CH_3), 2.66 (q, $J = 7.4$ Hz, 4H, CH_2), 2.69 (q, $J = 7.4$ Hz, 4H, CH_2), 3.87 (s, 4H, SCH_2), 5.88 (s, 2H, SH), 7.02 (s, 4H, ArH), 6.92, 7.07 (ABq, J = 7.9 Hz, 4H, ArH); ^{13}C NMR (126 MHz, $CDCl_3$) δ 13.6, 15.8, 29.1, 29.2, 39.3, 124.9, 128.8, 129.0, 129.8, 136.4, 138.8, 140.3, 147.6; MS (*m*/*z*) 498 (M^+); Anal. Calcd for $C_{28}H_{34}S_4$: C, 67.42; H, 6.87%. Found: C, 67.09; H, 6.85%.

4.7. *Preparation of dithiol* 2d

Method A: Compound **1d′** (1295 mg, 3.35 mmol, in 300 ml of THF and 300 ml of EtOH) was treated with $NaBH_4$ (127 mg, 3.35 mmol) for 30 min and *p*-xylylene dibromine (442 mg, 1.7 mmol) was added to the solution. The mixture was stirred at room temperature for 12 h. After treatment with aqueous HCl, the solvent was evaporated and the aqueous solution was extracted with CH_2Cl_2. The extract was dried over $MgSO_4$ and the solvent was evaporated. Then the product was purified by column chromatography (silica gel, *n*-hexane to *n*-hexane:$CHCl_3 = 2:1$) to produce **2d** in 76% yield (871 mg).

Method B: Compound **1d** (447 mg, 1.39 mmol, in 100 ml of THF and 100 ml of EtOH) was similarly treated with $NaBH_4$ and *p*-xylylene dibromide to produce **2d** in 74% yield (351 mg); yellow powder; m.p. 135–138°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.07 (t, $J = 7.5$ Hz, 6H, CH_3), 1.32 (t, $J = 7.5$ Hz, 6H, CH_3), 2.78 (q, $J = 7.5$ Hz, 4H, CH_2), 2.86 (q, $J = 7.5$ Hz, 4H, CH_2), 3.88 (s, 4H, SCH_2), 6.00 (s, 2H, SH), 7.06 (s, 4H, ArH); ^{13}C NMR (101 MHz, $CDCl_3$) δ 12.3, 14.5, 32.3, 32.4, 39.7, 129.2, 129.3, 134.9, 136.0, 137.1, 140.9, 143.00, 143.03. Anal. Calcd for $C_{28}H_{30}S_{10}$: C, 48.94; H, 4.40%. Found: C, 48.88; H, 4.22%.

4.8. *Cyclization of* 2a

A solution of **2a** (137 mg, 0.2 mmol in 100 ml of CH_2Cl_2) was slowly dropped to a solution of Et_3N (0.56 ml, 0.4 mmol in 100 ml of CH_2Cl_2) together with a solution of I_2 (51 mg, 0.2 mmol in 100 ml of CH_2Cl_2). The reaction mixture was stirred for 12 h at room temperature. After treatment with aqueous $NaHSO_3$, the solution was dried over $MgSO_4$ and the solvent was evaporated. Then the product was purified by column chromatography (silica gel, *n*-hexane to *n*-hexane:$CHCl_3 = 1:1$) and GPC to produce **3a** in 42% yield; **3a**: colorless powder; m.p. 204°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.61 (t, $J = 7.3$ Hz, 12H, CH_3), 1.27 (t, $J = 7.3$ Hz, 12H, CH_3), 2.38 (s, 12H, SCH_3), 2.46 (s, 12H, SCH_3), 2.86 (q, $J = 7.3$ Hz, 8H, CH_2), 3.52 (q, $J = 7.3$ Hz, 8H, CH_2), 4.12 (s, 8H, SCH_2), 7.57 (s, 8H, ArH); ^{13}C NMR (101 MHz, $CDCl_3$) δ 15.5, 16.6, 21.7, 22.0, 29.0, 30.0, 42.4, 129.7, 136.2, 142.2, 143.8, 144.8, 145.8, 151.7, 153.6; FABMS $m/z = 1360.13$ [M^+]. Anal. Calcd for $C_{64}H_{80}S_{16}$: C, 56.85; H, 6.36%. Found: C, 56.59; H, 6.12%.

4.9. *Cyclization of* 2b

3b: 76%; colorless crystals; m.p. 169–170°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.71 (t, $J = 7.3$ Hz, 12H, CH_3), 1.23 (t, $J = 7.3$ Hz, 12H, CH_3), 2.71 (q, $J = 7.3$ Hz, 8H, CH_2), 3.14–3.24 (m, 16H, CH_2), 3.33 (q, $J = 7.3$ Hz, 8H, CH_2), 4.07 (s, 8H, SCH_2), 7.52 (s, 8H, ArH); ^{13}C NMR (101 MHz, $CDCl_3$) δ 14.0, 14.9, 26.8, 27.4, 30.6, 30.9, 42.5, 129.6, 134.6, 135.6, 136.3, 137.5, 140.8, 145.6, 146.9. Anal. Calcd for $C_{64}H_{72}S_{16}$: C, 56.76; H, 5.36%. Found: C, 56.66; H, 5.42%.

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4.10. *Cyclization of* 2c

To a solution of **2c** (85.3 mg, 17 mmol, in 100 ml of $CHCl_3$) was added Et_3N (0.1 ml, 0.72 mmol) and I_2 (107 mg, 0.42 mmol). The mixture was stirred for 110 h. After treatment with aqueous $NaHSO_3$, the solvent was evaporated, and the aqueous solution was extracted with $CHCl_3$. The extract was dried with $MgSO_4$ and the solvent was evaporated. Then the product was purified by column chromatography (silica gel, *n*-hexane:$CHCl_3$) and GPC to produce **3c** in 41% (34.8 mg) and **4** in 10% (8.2 mg); **3c**: colorless powder; m.p. 206°C (decomp.); ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.84 (t, $J = 7.5$ Hz, 12H, CH_3), 1.24 (t, $J = 7.5$ Hz, 12H, CH_3), 2.42 (q, $J = 7.5$ Hz, 8H, CH_2), 3.00 (q, $J = 7.5$ Hz, 8H, CH_2), 4.03 (s, 8H, SCH_2), 7.07, 7.19 (ABq, $J = 7.9$ Hz, 4H, ArH), 7.39 (s, 8H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 15.6, 16.2, 28.6, 29.1, 42.1, 129.3, 129.5, 130.1, 136.5, 140.3, 143.3, 147.2, 148.0; FABMS $m/z = 992.28$ [M^+]. Anal. Calcd for $C_{48}H_{64}S_8$: C, 67.69; H, 6.49%. Found: C, 67.37; H, 6.48%; **4**: ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.99 (t, $J = 7.5$ Hz, 18H, CH_3), 1.09 (t, $J = 7.5$ Hz, 18H, CH_3), 2.57 (q, $J = 7.5$ Hz, 12H, CH_2), 2.79 (q, $J = 7.5$ Hz, 12H, CH_2), 3.81 (s, 12H, SCH_2), 7.05 (s, 12H), 7.07, 7.12 (ABq, $J = 8.0$ Hz, 6H, ArH); ^{13}C NMR (126 MHz, $CDCl_3$) δ 15.3, 15.9, 28.5, 28.8, 42.0, 129.0, 129.2, 130.1, 136.4, 140.0, 142.3, 147.4, 147.8; FABMS $m/z = 1488.46$ [M^+].

4.11. *Cyclization of* 2d

15%; yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.84 (t, $J = 7.3$ Hz, 12H, CH_3), 1.24 (t, $J = 7.3$ Hz, 12H, CH_3), 2.59 (q, $J = 7.4$ Hz, 8H, CH_2), 3.13 (q, $J = 7.3$ Hz, 8H, CH_2), 4.00 (s, 8H, SCH_2), 7.38 (s, 8H, ArH).

4.12. *Reaction of* 3c *with* CF_3COOAg

Compound **3c** was reacted with CF_3COOAg in the NMR tube by using $CDCl_3$/acetone-d_6; ^{1}H NMR (500 MHz, $CDCl_3$/acetone-d_6) δ 1.08 (brs, 12H, CH_3), 1.24 (t, $J = 7.1$ Hz, 12H, CH_3), 2.53 (brs, 8H, CH_2), 2.96 (brs, 8H, CH_2), 4.13 (br, 8H, SCH_2), 6.99 (brs, 8H), 7.40, 7.52 (ABq, $J = 7.9$ Hz, 4H, ArH).

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