Preparation and Reactions of Benzofurano-, Indolo-, and Benzothieno-3-sulfolenes

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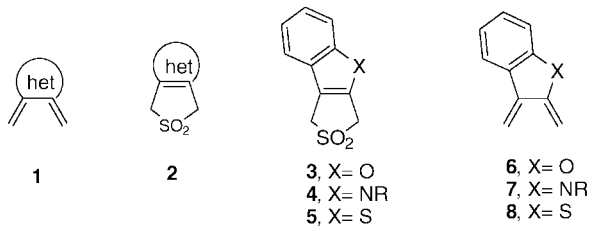
Benzofurano-, *N*-tosylindolo-, and benzothieno-3-sulfolenes have been prepared efficiently via their dihydro analogues. These fused 3-sulfolenes serve as ideal precursors for the corresponding heteroaromatic *o*-quinodimethanes. Derivatives of these 3-sulfolenes bearing bromo or alkyl group substitution from which substituted heteroaromatic *o*-quinodimethanes are generated have also been synthesized.

Introduction

The chemistry of heteroaromatic *o*-quinodimethanes (HAQD) **1** has drawn the increasing attention of organic chemists recently.[1] One general strategy toward the generation of these reactive intermediates involves SO_2 extrusion from heteroaromatic-fused 3-sulfolenes **2**.[2] The advantages of this strategy include the ease of preparation and handling of these stable fused-3-sulfolenes, the ease of derivatization of *o*-quinodimethanes, and the possibility of synthetic applications via inter- and intramolecular Diels−Alder reactions. To date, pyrrole-,[3] thiophene-,[4] furan-,[5] thiazole-,[6] isoxazole-,[7] pyrazole-,[8] oxazole-,[9] isothiazole-,[10] quinoxaline-,[11] pyrazine-,[12] pyridine-,[13] pyrimidine-,[14] pyrimidone-,[15] quinoline-,[16] quinolinone-,[17] and indole-fused[18] 3-sulfolenes have been synthesized. The extrusion of SO_2 from most of these molecules have been successful, and many of them can be utilized in the synthesis of interesting heterocyclic compounds. Since indole, benzofuran, and benzothiophene skeletons are frequently found in nature and in synthetic biologically active compounds, it is desirable to have convenient accesses to the preparation of derivatives of these heteroaromatics. The corresponding *o*-quinodimethanes, which are very reactive, appear to be useful candidates for this purpose. Therefore, we wished to explore the approaches toward the synthesis of benzofuran-, indole-, and benzothiophene-fused 3-sulfolenes **3**−**5** and to examine their ability as precursors of benzofurano-,[19] indolo-,[20] and benzothieno-*o*-quinodimethanes[21] **6**−**8**.



1 **2** **3**, X= O; **4**, X= NR; **5**, X= S **6**, X= O; **7**, X= NR; **8**, X= S

Furano-, pyrrolo-, and thieno-3-sulfolenes can be synthesized by a 1,4-dicarbonyl approach[3a] from compound **9**, or by a zincation/cyclization approach[3b,4a,5] from compound **10**. Since neither of these two routes is suitable for the synthesis of their benzo analogues **3**−**5**, different

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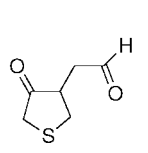
approaches needed to be developed. Toward this end, we considered it convenient to prepare the dihydrobenzoheterocycle-fused sulfolanes **11**−**13** as the key intermediates. Subsequent oxidative aromatization would give the final target molecules.



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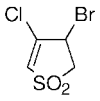

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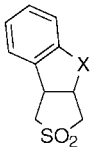
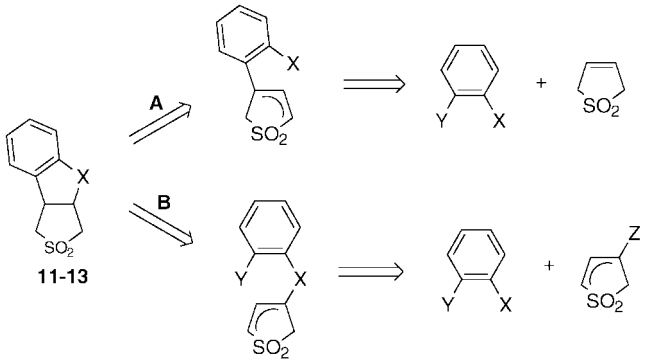


11, X= O
12, X= NR
13, X= S

Although molecules **11**−**13** can in principle be synthesized by a number of methods, two very efficient ways are shown in Scheme 1. These routes involve the construction of heterocycles on a preexisting five-membered, sulfone-containing molecule. In strategy A, the carbon−heteroatom (C−X) bond is formed first, and a cyclizative carbon−carbon (C−C) bond formation follows. Whereas in strategy B, the order of the formation of the two bonds is reversed.

Scheme 1

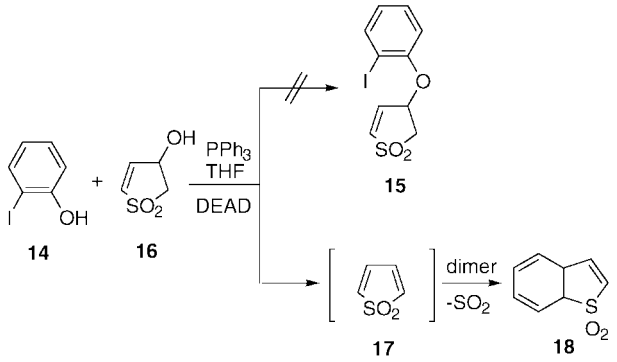


11-13

Synthesis of Dihydrobenzoheterocycle-Fused Sulfolanes 11−13. Attempts at preparing compound **11** by using strategy A via **15** commenced with the introduction of *o*-iodophenol **14** to a 2-sulfolene skeleton. Knowing that phenoxide ion can induce the dehydrobromination of 4-bromo-2-sulfolene and give thiophene dioxide **17** which dimerizes rapidly to produce compound **18**,[22] we tried carefully to avoid basic conditions and used Mitsunobu coupling conditions. Hence, 2-sulfolen-4-ol **16**[23] was treated with **14** and diethyl azodicarboxylate (DEAD) in the presence of PPh_3 (Scheme 2).[24] To our disappointment, the reaction only afforded compound **18** in 95% yield. No direct substitution product **15** was detected.

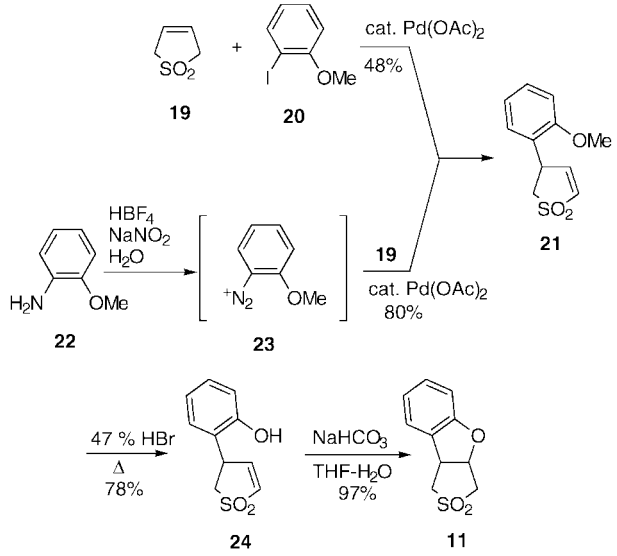
We then turned our efforts to strategy B for the preparation of **11**. When iodoanisole **20** was treated with **19** in the presence of 1.1 equiv of Et_3N and catalytic amount of $Pd(OAc)_2$ and Bu_4NBr,[25] the Pd-induced coupling reaction proceeded smoothly to give **21** in 48% yield (Scheme 3). Demethylation of **21** could be achieved readily in concentrated aqueous HBr under reflux where **24** was produced in 78% yield. Cyclization of **24** in saturated $NaHCO_3$ gave **11** in 97% yield. If compound **21** was demethylated and cyclized without the isolation of the intermediate **24**, the overall yield of **11** (53%) was appreciably lower. The yield of the preparation of compound **21** by Pd-induced coupling reaction could be

Scheme 2



14 **16** **15** **17** **18**

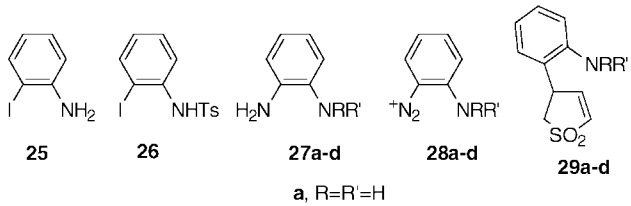
Scheme 3



19 **20** **21** **22** **23** **24** **11**

improved to 80% by using the diazonium salt **23**,[26] generated from *o*-anisidine **22**.

Since route B had been successful for the preparation of **11**, we attempted to apply the same strategy to the preparation of **12**. However, neither *o*-iodoaniline **25** nor *N*-tosyl-*o*-iodoaniline **26** gave the desired C−C bond formation product upon treatment with **19** under the same condition as that in Scheme 3, and only starting material was recovered. The reactions of the diazonium salts **28a**−**d**, generated from the amines **27a**−**d**, with **19** gave none of the desired products **29**.



25 **26** **27a-d** **28a-d** **29a-d**

a, R=R'=H
b, R=H, R'= Ts
c, R, R'= Phth
d, NRR'= NO_2

Therefore, the preparation of **12** via strategy A was examined. When 3,4-dibromosulfolane **30**[27] was treated with excess of **25** in refluxing MeOH, the desired secondary amine **31** was obtained in 61% yield (Scheme 4). We

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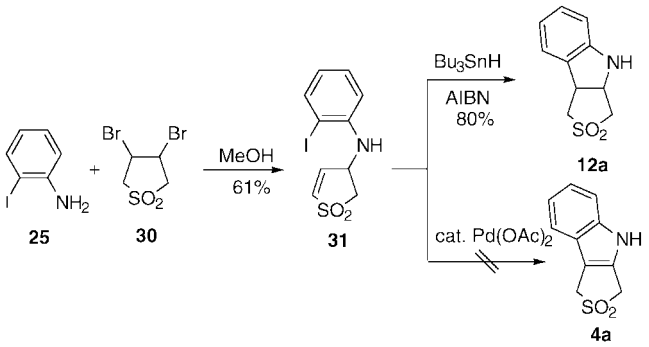
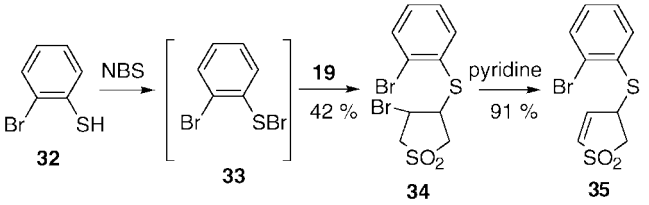
Scheme 4



Scheme 5



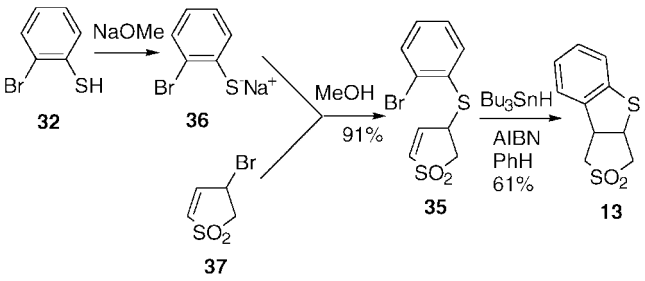
found that this reaction requires at least 8 equiv of the aniline **25**. If 3 or 4 equiv of **25** was used, the yield of **31** was substantially lower. This is consistent with the literature report that the reaction of aniline with **30** takes place via a sequence of elimination and conjugate addition.[22] Radical-initiated cyclization[28] proceeded smoothly when **31** was treated with Bu_3SnH and AIBN in refluxing benzene and **12a** (R = H) was obtained in 80% yield. Attempts of one-step conversion from **31** to the indolo-3-sulfolene (**4a**, R = H) via Pd induced C−C bond formation were not successful.

For the synthesis of (dihydrothieno)sulfolane **13**, attempts were made to prepare the intermediate **35**. A plausible method to prepare **35** involves a halosulfenylation−dehydrohalogenation reaction sequence.[29] When compound **19** was treated with the sulfenyl bromide **33** (generated in situ from 2-bromothiophenol **32** and NBS) at room temperature for 30 h, the addition reaction proceeded smoothly to give **34** in 42% yield. Dehydrobromination of **34** by treatment with pyridine gave **35** in 91% yield (Scheme 5).

An alternative and simple route for the preparation of **35** involves the direct substitution of 4-bromo-2-sulfolene **37**[22] with a sulfur nucleophile. When *o*-bromophenothiolate **36**, generated from **32** by treatment with NaOMe in MeOH, was reacted with **37**, the substituted product **35** was formed in 91% yield. Radical-initiated cyclization (Bu_3SnH, AIBN) of **35** in refluxing benzene yielded the desired product **13** (Scheme 6).

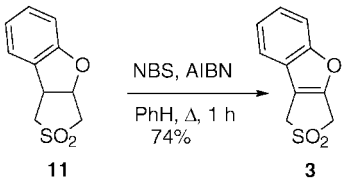
Aromatization of Compounds 11−13. Oxidative aromatization of heterocycles can be achieved by a number of methods. However, care should be taken in systems containing a 3-sulfolene moiety to avoid thermal SO_2 extrusion.[2] Hence, the reaction temperatures for the aromatization of **11**−**13** were carefully chosen. Since quinoxaline-fused 3-sulfolene has been prepared from the

Scheme 6



corresponding dihydro- and tetrahydroquinoxaline systems[11] by DDQ or MnO_2 oxidation, these oxidants were tested at first. Disappointingly, neither of the oxidants was found effective to aromatize **11**−**13** in refluxing benzene. No higher temperatures were examined because *N*-acetylindolo-3-sulfolene[18] is known to decompose at 80−110 °C. An indirect method of aromatization was therefore considered.

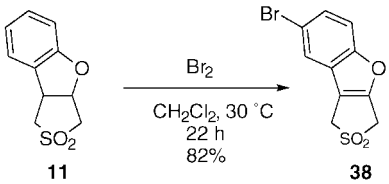
Thus, compound **11** was subject to radical bromination condition (NBS, AIBN in refluxing benzene for 1 h) and the desired benzofurano-3-sulfolene **3** was obtained in 74% yield, presumably via a sequence of radical bromination and dehydrobromination. The reaction time should be kept short because prolonged heating resulted in the formation of unseparable multibrominated products and poorer yield of **3** (eq 1).



(eq 1)

When compound **3** was treated with excess of Br_2 (3 equiv) in refluxing CH_2Cl_2 for 48 h, the starting material was completely consumed, and a complex mixture was obtained. Although the reaction was too complex to analyze, the product mixture contains no SO_2 functionality. In the absence of Br_2, compound **3** also gradually lost SO_2 and produced a complex mixture in refluxing CH_2Cl_2. This is why the reaction time should not exceed 1 h during the conversion of **11** to **3**. The ease of SO_2 extrusion from **3** appeared to us somewhat unusual since the SO_2 extrusion requires temperatures higher than 140 °C for most heteroaromatic-fused 3-sulfolenes.[1]

Aromatization of **11** could also be achieved by treatment with Br_2 at 30 °C for 22 h (eq 2). In addition to aromatizaion, one bromine atom was introduced onto the benzene ring, and **38** was obtained in 82% yield. Apparently, both radical bromination for aromatization of the dihydrofuran moiety and ionic bromination of the benzene ring occurred. When this reaction was carried out at higher temperatures, a complex mixture of multibrominated products was formed and no trace of compound **3** was detected.



(eq 2)

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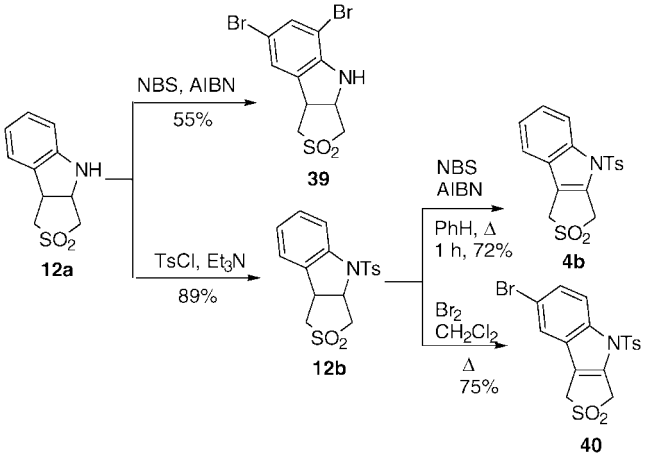
(29) (a) Proteau, P. J.; Hopkins, P. B. *J. Org. Chem.* **1985**, *50*, 141. (b) Hopkins, P. B.; Fuchs, P. L. *J. Org. Chem.* **1978**, *43*, 1208. (c) Gundermann, K. D.; Holtman, P. *Angew. Chem., Int. Ed. Engl.* **1986**, *5*, 678.

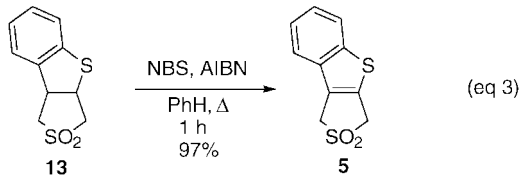
Scheme 7



Compound **3** could not have been the intermediate in the reaction shown in eq 2. Otherwise at least some of **38** should have been produced when **3** was treated with Br_2 in refluxing CH_2Cl_2. Therefore, aromatic bromine substitution of **11** must be faster than that of **3** upon treatment with Br_2. In other words, benzofuran is less reactive than dihydrobenzofuran toward electrophilic bromine substitution on the benzene ring. This may be due to the weaker electron-donating ability of the furan oxygen whose lone pair of electrons are more delocalized than the dihydrofuran oxygen.

Initial attempts to aromatize compound **12a** (R = H) to the corresponding indole **4a** (R = H) by NBS-induced bromination failed (Scheme 7). When compound **12a** (R = H) was treated with NBS (1.3 equiv) and AIBN in refluxing benzene, compound **39** was formed in 55% yield along with 44% of recovered starting material. The ease of aromatic bromination of compound **12a** must be due to the activating effect of the nitrogen atom. To avoid aromatic bromination, compound **12a** was partially deactivated by conversion to sulfonamide **12b** (R = Ts). As expected, the reaction of **12b** with NBS/AIBN in refluxing benzene for 2 h gave the indole **4b** (R = Ts) in 72% yield (Scheme 7). Similar to the case of benzofurano-3-sulfolene system, both aromatization and benzene ring bromination occurred when compound **12b** was treated with excess of Br_2 in CH_2Cl_2 under reflux where compound **40** was produced in 75% yield.

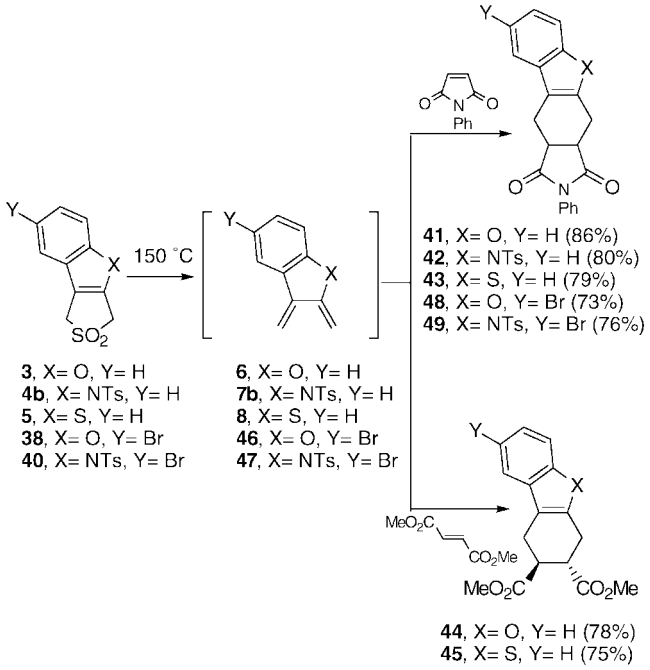
Aromatization of the benzothiophene system is the easiest among the three systems. When compound **13** was treated with NBS and AIBN in benzene under reflux for 1 h, the desired aromatic compound **5** was formed in 97% yield (eq 3).



(eq 3)

Reactions of Compounds 3−5. Compounds **3**, **4b**, and **5** were treated with *N*-phenylmaleimide or dimethyl fumarate, under thermal conditions (150 °C). In all cases, SO_2 was extruded, and the cycloadducts **41**, **42**, **43**, **44**, and **45** were obtained in 86%, 80%, 79%, 78%, and 75% yield, respectively (Scheme 8). The transient

Scheme 8



intermediacy of the corresponding *o*-quinodimethanes **6**, **7b** (R = Ts), and **8** was thus evidenced.

The ring-brominated benzofurano-3-sulfolene **38** and indolo-3-sulfolene **40** were also demonstrated to be precursors for the corresponding *o*-quinodimethanes **46** and **47**, respectively, by thermolysis and trapping reactions with *N*-phenylmaleimide at 150 °C. The Diels−Alder cycloadducts **48** (73%) and **49** (76%) were produced accordingly.

N-Acetylindolo-3-sulfolene is known to lose SO_2 at 80−110 °C.[18] In our study, the SO_2 extrusion reaction of benzofurano-3-sulfolene **3** takes place in refluxing CH_2Cl_2. These thermolysis temperatures are substantially lower than those required for furano-[5] and pyrrolo-3-sulfolenes[3] (about 160−180 °C), which in turn are lower than that required for benzo-3-sulfolenes[30] (210−230 °C). It is also known that the thermolysis of pyrazino-[12] and quinoxalino-3-sulfolenes[11] occurs only above 290 °C. It appears that the aromaticity of the heterocycle fused to 3-sulfolene has significant influence on the temperature required for the extrusion of SO_2. Since the conversion of a fused-3-sulfolene to the corresponding *o*-quinodimethane involves the breakdown of the aromaticity of the heterocycle, the energy barrier required for its SO_2 extrusion reaction should be dependent on the loss of stabilization during the process. Indeed, the order of the temperatures required for SO_2 extrusion from the above-mentioned heteroaromatic-fused 3-sulfolenes is parallel to the order of their aromatic stabilizing energies.[31]

A large number of derivatives of 3-sulfolenes have been prepared by deprotonation−alkylation process. Thus, compounds **3**−**5** were subject to this reaction sequence.

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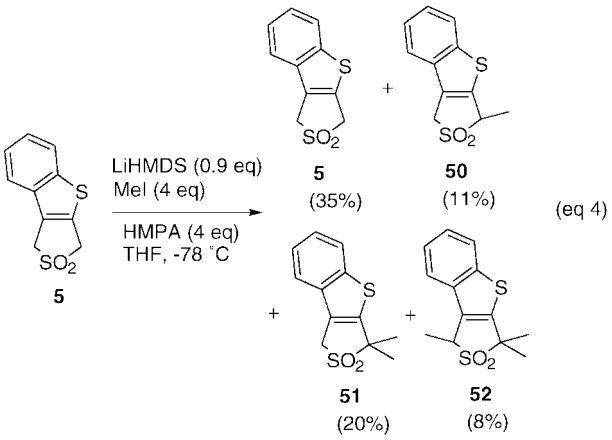
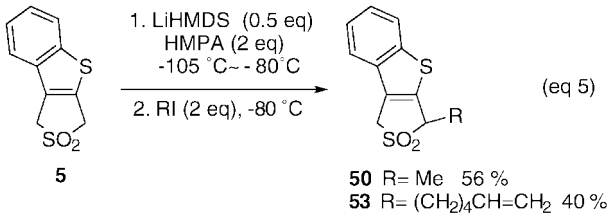
(31) (a) Chesnut, D. B. *J. Comput. Chem.* **1995**, *16*, 1227. (b) Vészpremi, T.; Nyulászi, L.; Várnai, P. *J. Mol. Struct. (THEOCHEM)* **1995**, *358*, 55. (c) Schleyer, P. von R.; Freeman, P. K.; Jiao, H.; Goldfuss, B. *Angew. Chem., Int. Ed. Engl.* **1995**, *34*, 337. (d) Schleyer, P. von R.; Maerker, C.; Dransfeld, A.; Jiao, H.; van Eikema Hommes, J. R. *J. Am. Chem. Soc.* ***1996***, *118*, 6317. (e) Chao, I.; Lu, H. F.; Chou, T. S. *J. Org. Chem.* **1997**, *62*, 7882.

When compound **5** was stirred with LiHMDS (0.9 equiv), MeI (4 equiv), and HMPA (4 equiv) at −78 °C for 1 h, the methylated product **50** was produced in 11% yield along with recovered starting material **5** (35%), the dimethylated product **51** (20%), and the trimethylated product **52** (8%) (eq 4). Although deprotonation and methylation reactions proceeded, rapid anion exchange provides this complex product mixture.



(eq 4)

To avoid multialkylation, we modified the experimental procedure slightly by varying the reaction temperature and the order of the addition of the reagents. Thus, 3-sulfolene **5** was first mixed with HMPA (2 equiv) in THF at −105 °C, and then LiHMDS (0.5 equiv) was added dropwise to generate the green-colored anion. After the solution was warmed to −80 °C, MeI (2 equiv) was added all at once. In this way, the monomethylated product **50** was produced in 56% yield without multimethylation. Under the same condition, hexenylated benzofurano-3-sulfolene **53** could also be prepared in 40% yield (eq 5).



(eq 5)

The regiochemistry of these methylation reactions involving **5** to **50** and **51** was determined by a 2D NMR NOESY experiment of compound **51**. This analysis revealed an NOE correlation between the two protons on the unsubstituted α-carbon (C-1) of the sulfone functionality and one of the aromatic protons, indicating they are in close proximity (Figure 1). Since monomethylated compound **50** must be the intermediate for the formation of the dimethylated product **51**, the regiochemistry of methylation of **50** can therefore be deduced unambiguously to be that shown in eq 5.

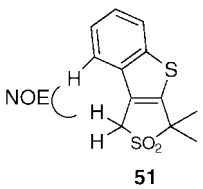
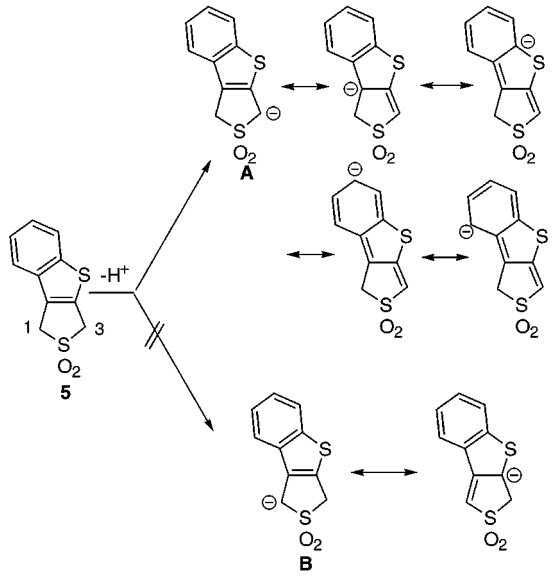
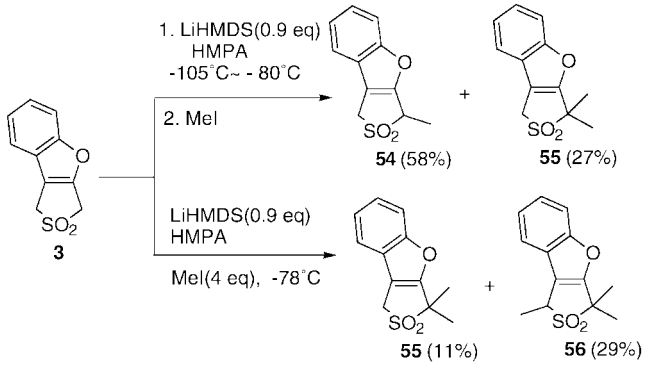


Figure 1. NOE correlation in compound **51**.

Scheme 9



Scheme 10

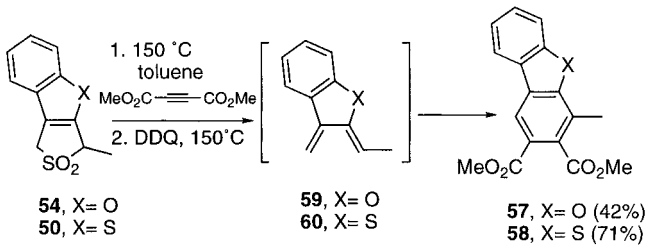


Deprotonation of **5** may lead to carbanion **A** or **B**. Thermodynamically carbanion **A** is more stable than **B** due to abundance of resonance structures (Scheme 9). Kinetically, deprotonation at the 3-position leading to **A** is also favored for steric reasons. Therefore, the first deprotonation/methylation of **5** takes place selectively at the 3-position to form product **50**.

Benzofurano-3-sulfolene **3** behaved similarly in deprotonation/alkylation reactions. When **3** was stirred with LiHMDS (0.9 equiv), MeI (4 equiv), and HMPA (4 equiv) at −78 °C for 1 h, the dimethylated product **55** and trimethylated product **56** were obtained in 11% and 29% yield, respectively. Surprisingly, no monomethylated product was detected under this reaction condition. On the other hand, if MeI (4 equiv) was added all at once to the preformed sulfolenyl carbanion (generated by deprotonation of **3** with LiHMDS in the presence of HMPA at −105 °C and warmed to −80 °C), the monomethylated product **54** was formed in 58% yield, along with 27% of **55** (Scheme 10). Apparently, anion exchange of the sulfolenyl anions proceeded almost as fast as methylation reactions.

The α-methylated sulfolenes also lose SO_2 readily upon thermolysis. When compounds **54** and **50** were heated at 150 °C in the presence of dimethyl acetylenedicarboxylate followed by oxidation with DDQ, the dibenzofuran **57** and dibenzothiophene **58** were produced in 42%

Scheme 11



54, X= O
50, X= S

59, X= O
60, X= S

57, X= O (42%)
58, X= S (71%)

and 71%, respectively (Scheme 11), indicating the presence of the corresponding substituted *o*-quinodimethanes **59** and **60** as the intermediates.

In summary, we have demonstrated the success of thermal generation and trapping of benzo-fused heteroaromatic *o*-quinodimethanes **6**, **7**, **8**, **46**, **47**, **59**, and **60** from the corresponding 3-sulfolenes. The efficient preparation of 3-sulfolenes **3**−**5** and the ease of derivatization make this approach useful for the construction of multicyclic heteroaromatics.

Experimental Section

General Procedure. ^{1}H NMR spectra were determined on a Bruker AC-300 NMR spectrometer as solutions in $CDCl_3$. IR spectra were determined on a Perkin-Elmer Paragon 1000 IR spectrophotometer. Mass spectra and high-resolution mass spectra were determined on a VG 70-250S mass spectrometer. Elemental analysis were performed on a Perkin-Elmer 240C analyzer. Dichloromethane, THF, and toluene were freshly distilled from CaH_2, K, and Na, respectively, before use.

4-(2-Methoxyphenyl)-2-sulfolene (21). Method I: A solution of 3-sulfolene **19** (271 mg, 2.29 mmol), 2-iodoanisole **20** (0.30 mL, 2.31 mmol), triethylamine (0.32 mL, 2.30 mmol), tetrabutylammonium bromide (774 mg, 2.40 mmol), and $Pd(OAc)_2$ (52 mg, 0.23 mmol) in dried benzene (15 mL) was stirred in a foil-covered, stoppered flask at room temperature for 20 h. The solvent was removed under reduced pressure, and the crude product was purified by column chromatography (silica gel, hexane/EtOAc, 2:1) to give 246 mg of **21** (48%) as a white solid. **Method II**: A solution of $NaNO_2$ (0.48 g, 6.96 mmol) in water (3 mL) was added dropwise to an ice-cold mixture of *o*-anisidine **22** (0.70 mL, 6.21 mmol) in 47% HBF_4 (3.50 mL, 15.56 mmol). Stirring was continued for 1 h at 0 °C, after which time the methanol (3 mL) solution of 3-sulfolene **19** (1.03 g, 8.73 mmol) and $Pd(OAc)_2$ (0.08 g, 0.36 mmol) were added to the mixture. The resulting mixture was then heated at reflux for 1 h. Water (5 mL) was added, and the aqueous solution was extracted with CH_2Cl_2 (20 mL × 3). The combined organic layers were dried with $MgSO_4$ and concentrated under reduced pressure. The residue was purified by column chromatography (silica gel, hexane/EtOAc, 2:1) to give 246 mg of **21** (80%): mp 79−81 °C; IR (KBr) 3085, 1585, 1454, 1434, 1241, 1111, 1016, 880, 753 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 3.14 (dd, J = 13.5, 5.2 Hz, 1 H), 3.68 (dd, J = 13.5, 8.5 Hz, 1 H), 3.85 (s, 3 H), 4.68−4.74 (m, 1 H), 6.71−6.78 (m, 2 H), 6.91 (d, J = 8.5 Hz, 1 H), 6.95 (t, J = 7.7 Hz, 1 H), 7.11 (d, J = 7.7 Hz, 1 H), 7.30 (t, J = 8.5 Hz, 1 H); MS (*m*/*z*) 224 (M^+) (100%), 193, 159, 145, 129, 115, 91, 77, 62. Anal. Calcd for $C_{11}H_{12}O_3S$: C, 58.91; H, 5.40. Found: C, 58.55; H, 5.63.

4-(2-Hydroxyphenyl)-2-sulfolene (24). A solution of compound **21** (937 mg, 4.20 mmol) in 47% HBr (20 mL) was heated reflux for 3 h. The excess HBr was removed in vacuo, and the residue was neutralized with saturated aqueous $NaHCO_3$. The aqueous layer was extracted with CH_2Cl_2 (20 mL × 3). The combined organic layers were dried with $MgSO_4$ and concentrated in vacuo. The residue was purified by column chromatography (silica gel, hexane/EtOAc, 2:1) to give 688 mg of **24** (78%) as a white solid: mp 142−144 °C; IR (KBr) 3410, 3105, 1596, 1451, 1267, 1101, 887, 750 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 3.23 (dd, J = 13.4, 5.2 Hz, 1 H), 3.73 (dd, J = 13.3, 8.3 Hz, 1 H), 4.67−4.74 (m, 1 H), 5.34 (bs, 1 H), 6.74−6.81 (m, 3 H), 6.94 (t, J = 7.8 Hz, 1 H), 7.11 (d, J = 7.5 Hz, 1 H), 7.19 (t, J = 7.7 Hz, 1 H); MS (*m*/*z*) 210 (M^+), 193, 145, 131 (100%), 118, 103, 91, 77, 69. Anal. Calcd for $C_{10}H_{10}O_3S$: C, 57.13; H, 4.79. Found: C, 57.06; H, 5.00.

1,3,3a,8b-Tetrahydrothieno[3,4-*b*]benzofuran 2,2-Dioxide (11). To a solution of compound **24** (608 mg, 2.90 mmol) in THF−H_2O (1:1, 40 mL) was added solid $NaHCO_3$ until saturation, and the resulting mixture was stirred for 20 h. THF was removed under reduced pressure, and the aqueous layer extracted with CH_2Cl_2 (50 mL × 3). The combined organic layers were dried with $MgSO_4$ and concentrated in vacuo. The residue was purified by column chromatography (silica gel, hexane/EtOAc, 2:1) to give 589 mg of **11** (97%) as a white solid: mp 174−175 °C; IR (KBr) 3023, 2963, 1597, 1480, 1332, 1242, 1125, 1108, 970, 897, 749 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 3.17 (dd, J = 13.4, 7.7 Hz, 1 H), 3.43 (dd, J = 14.2, 4.7 Hz, 1 H), 3.52−3.63 (m, 2 H), 4.30 (dd, J = 16.9, 8.4 Hz, 1 H), 5.47 (ddd, J = 12.3, 7.4, 4.7 Hz, 1 H), 6.84 (d, J = 8.0 Hz, 1 H), 6.95 (t, J = 7.4 Hz, 1 H), 7.18−7.27 (m, 2 H); MS (*m*/*z*) 210 (M^+), 145, 131 (100%), 110, 103, 91, 77, 62. Anal. Calcd for $C_{10}H_{10}O_3S$: C, 57.13; H, 4.79. Found: C, 57.02; H, 4.83.

4-(2-Iodoanilino)-2-sulfolene (31). A solution of 3,4-dibromosulfolane (0.91 g, 3.28 mmol) and 2-iodoaniline (5.75 g, 26.26 mmol) in dried MeOH (40 mL) was heated at reflux in a dark-brown flask for 84 h. The solvent was removed under reduced pressure, and the crude product was purified by column chromatography (silica gel, hexane/EtOAc, 2:1) to give 0.67 g of **31** in 61% yield as a light-yellow solid: mp 92−93 °C; IR (KBr) 3387, 3070, 1578, 1489, 1301, 1133, 738 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 3.15 (dd, J = 13.5, 4.2 Hz, 1 H), 3.82 (dd, J = 13.5, 7.4 Hz, 1 H), 4.91−4.94 (m, 1 H), 5.15−5.23 (m, 1 H), 6.56 (t, J = 7.5 Hz, 1 H), 6.90 (d, J = 8.1 Hz, 1 H), 7.00 (s, 2 H), 7.28 (t, 7.6 Hz, 1 H), 7.72 (d, J = 8.1 Hz, 1 H); ^{13}C NMR (acetone-d_6) δ 53.4, 55.4, 86.1, 112.9, 121.0, 130.5, 134.7, 140.4, 140.6, 146.6; MS (*m*/*z*) 335 (M^+) (100%), 271, 245, 207, 167, 144, 117, 91, 71; HRMS calcd for $C_{10}H_{10}INO_2S$ 334.9477, found 334.9478.

1,3,3a,8b-Tetrahydrothieno[3,4-*b*]indole 2,2-Dioxide (12a). To a solution of compound **31** (128 mg, 0.38 mmol) in dried benzene (20 mL) heated under reflux was added slowly a solution of Bu_3SnH (0.15 mL, 0.56 mmol) and AIBN (30 mg, 0.18 mmol) in MeOH (5 mL). The reaction mixture was refluxed for 2 h after which time the solution was removed under reduced pressure, the crude product was purified by column chromatography (silica gel, hexane/EtOAc, 2:1) to give 64 mg of **12a** (80%) as a white solid: mp 122−123 °C; IR (KBr) 3363, 3004, 2935, 1606, 1485, 1291, 1138, 754 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 3.14 (dd, J = 13.4, 8.9 Hz, 1 H), 3.25 (dd, J = 13.4, 5.2 Hz, 1 H), 3.38−3.50 (m, 2 H), 4.14 (dd, J = 17.5, 8.8 Hz, 1 H), 4.68 (ddd, J = 13.0, 7.6, 5.3 Hz, 1 H), 6.65 (d, J = 7.7 Hz, 1 H), 6.78 (t, J = 7.7 Hz, 1 H), 7.10 (t, J = 7.4 Hz, 1 H), 7.10 (d, J = 7.4 Hz, 1 H); ^{13}C NMR (acetone-d_6) δ 42.9, 55.0, 56.9, 59.2, 110.1, 119.3, 125.4, 129.2, 129.8, 151.5; MS (*m*/*z*) 209 (M^+), 144, 130 (100%), 117, 103, 91, 77, 65; HRMS calcd for $C_{10}H_{11}NO_2S$ 209.0511, found 209.0504.

3-Bromo-4-(2-bromophenylthio)sulfolane (34). To a solution of NBS (6.1 g, 34.3 mmol) in CH_2Cl_2 (60 mL) was added dropwise 2-bromothiophenol (4.0 mL, 33.3 mmol), and the reaction mixture was stirred for 30 min. To this solution was then added dropwise a solution of 3-sulfolene (4.0 g, 34.1 mmol) in CH_2Cl_2 (15 mL), and the resulting mixture was stirred at room temperature for 30 h. After the solvent was removed under reduced pressure, the crude product was purified by column chromatography (silica gel, hexane/EtOAc, 2:1) to give 5.9 g of **34** (44%) as a white solid: mp 91−92 °C; IR (KBr) 3009, 2950, 1444, 1402, 1311, 1182, 1121, 1019, 930, 842, 748 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 3.22 (dd, J = 13.9, 6.0 Hz, 1H), 3.52 (dd, J = 14.2, 5.7 Hz, 1H), 3.80 (dd, J = 13.9, 7.4 Hz, 1H), 4.03 (dd, J = 14.2, 6.8 Hz, 1H), 4.24 (dd, J = 13.3, 6.1 Hz, 1H), 4.48 (dd, J = 12.3, 6.0 Hz, 1H), 7.26 (td, J = 8.0, 1.4 Hz, 1H), 7.36 (td, J = 7.4, 1.4 Hz, 1H), 7.59 (dd, J = 7.4, 1.5 Hz, 1H), 7.69 (dd, J = 8.0, 1.4 Hz, 1H); MS (*m*/*z*) 388 (M^+ + 4), 386 (M^+ + 2), 384 (M^+), 307, 305, 243, 241, 216, 214,

189, 187, 162, 135, 108 (100%), 69. Anal. Calcd for $C_{10}H_{10}Br_2O_2S_2$: C, 31.11; H, 2.61. Found: C, 31.31; H, 2.63.

4-(2-Bromophenylthio)-2-sulfolene (35). Method I: To a solution of NaOMe [prepared from Na metal (40 mg, 1.74 mmol)] in dried MeOH (10 mL) at 0 °C was added dropwise 2-bromothiophene (0.28 mL, 2.33 mmol), and the reaction mixture was stirred at 0 °C for 10 min. To this thiophenoxide solution was then added dropwise a solution of 4-bromo-2-sulfolene **37** (381 mg, 1.93 mmol) in dried MeOH (8 mL), and the resulting mixture was stirred at room temperature for 24 h. After the solvent was removed under reduced pressure, the crude product was purified by column chromatography (silica gel, hexane/EtOAc, 2:1) to give 437 mg of **35** (91%) as a white solid. **Method II**: To a solution of compound **34** (0.63 g, 1.63 mmol) in dried CH_2Cl_2 was added pyridine (0.33 mL, 4.08 mmol), and the resulting mixture was refluxed for 3 days. After the solvent was removed under reduced pressure, the crude product was purified by column chromatography (silica gel, hexane/EtOAc, 2:1) to give 0.45 g of **35** (91%) as a white solid: mp 65−66 °C; IR (KBr) 3093, 2949, 1443, 1292, 1149, 1014, 881 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.28 (dd, J = 14.2, 3.5 Hz, 1 H), 3.87 (dd, J = 14.2, 8.1 Hz, 1 H), 4.92−4.96 (m, 1 H), 6.94−7.03 (m, 2 H), 7.26 (td, J = 7.6, 1.5 Hz, 1 H), 7.43 (td, J = 7.6, 1.2 Hz, 1 H), 7.63 (dd, J = 7.9, 1.5 Hz, 1 H), 7.69 (dd, J = 7.9, 1.2 Hz, 1 H); MS (m/z) 306 ($M^+ + 2$), 304 (M^+), 242, 240, 188, 161, 128, 108 (100%), 85, 69. Anal. Calcd for $C_{10}H_9BrO_2S_2$: C, 39.35; H, 2.97. Found: C, 39.35; H, 2.88.

1,3,3a,8b-Tetrahydrothieno[3,4-*b*]benzothiophene 2,2-Dioxide (13). To a solution of compound **35** (450 mg, 1.48 mmol) in dried benzene (40 mL) heated under reflux was added slowly a solution of Bu_3SnH (0.6 mL, 2.23 mmol) and AIBN (117 mg, 0.71 mmol) in anhydrous benzene (10 mL). The reaction mixture was heated at reflux for 2 h after which time the solution was removed under reduced pressure. The crude product was purified by column chromatography (silica gel, hexane/EtOAc, 2:1) to give 202 mg of **13** (61%) as a white solid: 121−122 °C; IR (KBr) 2999, 2942, 1440, 1394, 1275, 1092, 905, 734 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.28 (dd, J = 9.1, 5.4 Hz, 1 H), 3.43 (dd, J = 8.9, 5.4 Hz, 1 H), 3.46−3.60 (m, 2 H), 4.34 (dd, J = 16.1, 8.2 Hz, 1 H), 4.54 (dd, J = 16.1, 8.2 Hz, 1 H), 7.14 (s, 1 H), 7.15 (s, 1 H), 7.19−7.24 (m, 2 H); MS (m/z) 226 (M^+), 162, 147 (100%), 134, 129, 91, 71. Anal. Calcd for $C_{10}H_{10}O_2S_2$: C, 53.07; H, 4.45. Found: C, 53.14; H, 4.35.

1,3-Dihydrothieno[3,4-*b*]benzofuran 2,2-Dioxide (3). A solution of compound **11** (208 mg, 0.99 mmol), NBS (230 mg, 1.29 mmol), and AIBN (83 mg, 0.51 mmol) in dried benzene (30 mL) was heated at reflux for 1.5 h after which the solvent was removed under reduced pressure. The crude product was purified by column chromatography (silica gel, hexane/EtOAc, 4:1) to give 152 mg of **3** (74%) as a white solid: 137−138 °C; IR (KBr) 2974, 1445, 1292, 1225, 1112, 749 cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.43 (s, 4 H), 7.32 (t, J = 7.3 Hz, 1 H), 7.39 (t, J = 7.3 Hz, 1 H), 7.47 (d, J = 7.3 Hz, 1 H), 7.55 (d, J = 7.3 Hz, 1 H); ^{13}C NMR ($CDCl_3$) δ 53.9, 55.5, 110.7, 112.1, 119.7, 124.0, 124.3, 125.5, 145.8, 156.8; MS (m/z) 208 (M^+), 144 (100%), 115, 89, 63, 51; HRMS calcd for $C_{10}H_8O_3S$ 208.0194, found 208.0202.

7-Bromo-1,3-dihydrothieno[3,4-*b*]benzofuran 2,2-Dioxide (38). A solution of compound **11** (133 mg, 0.63 mmol) and bromine (0.07 mL, 1.37 mmol) in CH_2Cl_2 (15 mL) was stirred at 30−35 °C for 22 h. To the reaction mixture was added saturated aqueous $Na_2S_2O_3$ (5 mL). The layers were separated, and the aqueous layers were extracted with CH_2Cl_2 (20 mL × 3). The combined organic phase was dried with $MgSO_4$ and concentrated under reduced pressure. The crude product was purified by column chromatography (silica gel, hexane/EtOAc, 4:1) to give 148 mg of **38** (82%) as a white solid: mp 139−140 °C; IR (KBr) 2977, 1432, 1303, 1225, 1117, 974, 802, 759 cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.40 (s, 2 H), 4.44 (s, 2 H), 7.43 (d, J = 8.8 Hz, 1 H), 7.49 (dd, J = 8.8, 1.9 Hz, 1 H), 7.62 (d, J = 1.9 Hz, 1 H); MS (m/z) 288 ($M^+ + 2$), 286 (M^+), 224 (100%), 222, 198, 177, 149, 115, 62. Anal. Calcd for $C_{10}H_7BrO_3S$: C, 41.83; H, 2.46. Found: C, 41.45; H, 2.40.

5,7-Dibromo-1,3,3a,8b-tetrahydrothieno[3,4-*b*]indole 2,2-Dioxide (39). A solution of compound **12a** (18.3 mg, 0.09 mmol), NBS (21.6 mg, 0.12 mmol), and AIBN (5.0 mg, 0.03 mmol) in dried benzene (6 mL) was heated at reflux for 1.5 h. The solvent was removed under reduced pressure. The crude product was purified by column chromatography (silica gel, hexane/EtOAc, 4:1) to give 17.7 mg of **39** (55%) as a white solid: mp 184−186 °C; IR (KBr) 3382, 3064, 3005, 2950, 2907, 1604, 1570, 1472, 1295, 1246, 1156, 1125, 864, 682 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.15 (dd, J = 14.1, 9.7 Hz, 1H), 3.31 (dd, J = 13.7, 5.4 Hz, 1H), 3.41−3.53 (m, 2H), 4.26 (dd, J = 17.8, 8.9 Hz, 1H), 4.43 (bs, 1H), 4.70−4.85 (m, 1H), 7.15 (s, 1H), 7.40 (d, J = 1.7 Hz, 1H); ^{13}C NMR (acetone-d_6) δ 43.6, 54.6, 56.3, 58.6, 102.6, 109.5, 127.8, 133.5, 133.6, 140.4; MS (m/z) 369 ($M^+ + 4$), 367 ($M^+ + 2$), 365 (M^+), 288 (100%), 286, 221, 195, 149, 115, 89; HRMS calcd for $C_{10}H_9Br_2NO_2S$ 364.8721, found 364.8716.

4-Toluenesulfonyl-1,3,3a,8b-tetrahydrothieno[3,4-*b*]indole 2,2-Dioxide (12b). A solution of compound **12a** (468 mg, 2.24 mmol), Et_3N (0.78 mL, 5.60 mmol), and TsCl (676 mg, 3.55 mmol) in dried CH_2Cl_2 (30 mL) was heated at reflux for 45 h. After the solvent was removed under reduced pressure, the crude product was purified by column chromatography (silica gel, hexane/EtOAc, 2:1) to give 725 mg of **12b** (89%) as a white solid: mp 178−180 °C; IR (KBr) 3020, 2951, 1593, 1456, 1345, 1299, 1155, 749 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.38 (s, 3 H), 3.07 (dd, J = 13.3, 8.6 Hz, 1 H), 3.42−3.52 (m, 2 H), 3.72 (ddd, J = 14.2, 8.0, 2.3 Hz, 1 H), 4.04 (dd, J = 18.2, 8.8 Hz, 1 H), 4.83 (dd, J = 17.6, 7.8 Hz, 1 H), 7.04−7.11 (m, 2 H), 7.25 (d, J = 8.3 Hz, 2 H), 7.26−7.33 (m, 1 H), 7.63−7.70 (m, 1 H), 7.65 (d, J = 8.2 Hz, 2 H); MS (m/z) 363 (M^+), 299, 208, 155, 144 (100%), 130, 117, 91, 77, 65. Anal. Calcd for $C_{17}H_{17}NO_4S_2$: C, 56.18; H, 4.71; N, 3.85. Found: C, 55.90; H, 4.68; N, 3.72.

4-Toluenesulfonyl-1,3-dihydrothieno[3,4-*b*]indole 2,2-Dioxide (4b). A solution of compound **12b** (102 mg, 0.28 mmol), NBS (75 mg, 0.42 mmol), and AIBN (46 mg, 0.28 mmol) in dried benzene (20 mL) was heated at reflux for 1 h. The solvent was removed under reduced pressure. The crude product was purified by column chromatography (silica gel, hexane/EtOAc, 4:1) to give 81 mg of **4b** (80%) as a white solid: mp 143−145 °C; IR (KBr) 2980, 1371, 1314, 1174, 1114, 753 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.37 (s, 3 H), 4.34 (s, 2 H), 4.68 (s, 2 H), 7.25−7.44 (m, 5 H), 7.71 (d, J = 8.5 Hz, 2 H), 8.10 (d, J = 8.3 Hz, 1 H); ^{13}C NMR ($CDCl_3$) δ 29.7, 54.1, 56.0, 113.7, 114.4, 119.6, 124.4, 125.9, 126.1, 126.1, 128.0, 130.3, 134.7, 137.0, 145.9; MS (m/z) 361 (M^+), 297, 232, 142 (100%); HRMS calcd for $C_{17}H_{15}NO_4S_2$ 361.0444, found 361.0446.

7-Bromo-4-toluenesulfonyl-1,3-dihydrothieno[3,4-*b*]indole 2,2-Dioxide (40). A solution of compound **12b** (53 mg, 0.15 mmol) and bromine (0.02 mL, 0.39 mmol) in CH_2Cl_2 (10 mL) was heated at reflux for 24 h. To the reaction mixture was added saturated aqueous $Na_2S_2O_3$ (5 mL) and extracted with CH_2Cl_2 (20 mL × 3). The combined organic layers were dried with $MgSO_4$ and concentrated under reduced pressure. The crude product was purified by column chromatography (silica gel, hexane/EtOAc, 4:1) to give 48 mg of **40** (75%) as a white solid: 38−39 °C; IR (KBr) 3104, 3069, 2975, 2925, 1589, 1367, 1298, 1167, 1114, 988, 927, 809, 771 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.38 (s, 3 H), 4.30 (s, 2 H), 4.66 (s, 2 H), 7.28 (d, J = 8.3 Hz, 2 H), 7.51 (d, J = 8.8 Hz, 1 H), 7.53 (s, 1 H), 7.69 (d, J = 8.4 Hz, 2 H), 7.97 (d, J = 8.7 Hz, 1 H); MS (m/z) 377 ($M^+ + 2 - SO_2$), 375($M^+ - SO_2$), 222, 220, 141, 91, 64 (100%). Anal. Calcd for $C_{17}H_{14}BrNO_4S_2$: C, 46.37; H, 3.20; N, 3.18. Found: C, 46.33; H, 3.09; N, 2.78.

1,3-Dihydrothieno[3,4-*b*]benzothiophene 2,2-Dioxide (5). A solution of compound **13** (27 mg, 0.12 mmol), NBS (30 mg, 0.17 mmol), and AIBN (5 mg, 0.03 mmol) in dried benzene (10 mL) was refluxed for 1.5 h. The solvent was removed under reduced pressure. The crude product was purified by column chromatography (silica gel, hexane/EtOAc, 4:1) to give 26 mg of **5** (97%) as a white solid: mp 164 °C (dec); IR (KBr) 2975, 2927, 1431, 1315, 1255, 1133, 1116, 763 cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.45 (s, 2 H), 4.52 (s, 2 H), 7.40−7.48 (m, 2 H), 7.57−7.61 (m, 1 H), 7.86−7.89 (m, 1 H); MS (m/z) 224 (M^+), 160, 137 (100%), 120 107. Anal. Calcd for $C_{10}H_8O_2S_2$: C, 53.55; H, 3.60. Found: C, 53.31; H, 3.47.

General Procedure for the Diels−Alder Reaction of Heteroaromatic-Fused 3-Sulfolenes 3, 4b, 5, 38, and 40. A solution of a heteroaromatic-fused 3-sulfolene (0.1 mmol) and dienophile (0.8 mmol) in toluene (4 mL) was heated in a sealed tube at 150 °C for 2 h after which time the solvent was removed under reduced pressure. The crude product was purified by column chromatography (silica gel, hexane/EtOAc, 4:1) to give the cycloadduct.

2-Phenyl-3a*β*,4,10,10a*β*-tetrahydro-2*H*,5*H*-pyrrolo[3,4-*b*]dibenzofuran-1,3-dione (41): obtained from the reaction of compound **3** and *N*-phenylmaleimide in 86% yield as a white solid: mp 170−172 °C; IR (KBr) 2928, 1700, 1445, 1387, 1191, 1155, 742, 690 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 3.15 (dd, J = 16.1, 7.9 Hz, 1 H), 3.23 (dd, J = 17.9, 9.1 Hz, 1 H), 3.35 (dd, J = 16.2, 3.5 Hz, 1 H), 3.45 (dd, J = 17.9, 2.8 Hz, 1 H), 3.55 (td, J = 8.9, 3.7 Hz, 1 H), 3.65 (td, J = 8.9, 3.1 Hz, 1 H), 7.20−7.29 (m, 4 H), 7.35−7.48 (m, 5 H); ^{13}C NMR ($CDCl_3$) δ 20.3, 21.8, 38.6, 39.5, 110.6, 111.2, 118.6, 122.7, 124.0, 126.2, 127.3, 128.6, 129.1, 131.7, 150.5, 154.6, 177.9, 178.1; MS (*m*/*z*) 317 (M$^+$), 186, 171, 149, 128, 115, 84, 49 (100%); HRMS calcd for $C_{20}H_{15}NO_3$ 317.1052, found 317.1049.

5-Toluenesulfonyl-2-phenyl-3a*β*,4,10,10a*β*-tetrahydro-2*H*,5*H*-pyrrolo[3,4-*b*]carbazole-1,3-dione (42): obtained from the reaction of compound **4b** and *N*-phenylmaleimide in 80% yield as a white solid: mp 199−201 °C; IR (KBr) 2928, 1708, 1451, 1371, 1174, 1089, 963, 757 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.26 (s, 3 H) 2.92−3.01 (m, 1 H), 3.30−3.41 (m, 2 H), 3.46−3.62 (m, 2 H), 4.11 (dd, J = 17.5, 2.0 Hz, 1 H), 6.94−6.98 (m, 2 H), 7.08 (d, J = 8.3 Hz, 2 H), 7.22−7.44 (m, 6 H), 7.70 (d, J = 10.2 Hz, 2 H), 8.19 (d, J = 8.1 Hz, 1 H); MS (*m*/*z*) 470 (M$^+$), 315, 168 (100%), 143, 91, 65. Anal. Calcd for $C_{27}H_{22}N_2O_4S$: C, 68.92; H, 4.71; N, 5.95. Found: C, 68.53; H, 4.84; N, 5.68.

2-Phenyl-3a*β*,4,10,10a*β*-tetrahydro-2*H*,5*H*-pyrrolo[3,4-*b*]dibenzothiophene-1,3-dione (43): obtained from the reaction of compound **5** and *N*-phenylmaleimide in 79% yield as a white solid: mp 142−143 °C; IR (KBr) 2926, 1704, 1494, 1383, 1182, 754 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.98 (dd, J = 16.0, 5.7 Hz, 1 H), 3.18 (dd, J = 15.4, 5.2 Hz, 1 H), 3.52 (d, J = 16.9 Hz, 1 H), 3.58−3.64 (m, 3 H), 7.01 (d, J = 7.9 Hz, 2 H), 7.27−7.39 (m, 5 H), 7.68 (d, J = 7.8 Hz, 1 H), 7.79 (d, J = 7.8 Hz, 1 H); MS (*m*/*z*) 333 (M$^+$), 185, 136, 120, 107. Anal. Calcd for $C_{20}H_{15}NO_2S$: C, 72.05; H, 4.53; N, 4.20. Found: C, 71.80; H, 4.51; N, 4.05.

2,3-Bis(methoxycarbonyl)-1,2,3,4-tetrahydrodibenzofuran (44): obtained from the reaction of compound **3** and dimethyl fumarate in 78% yield as a white solid: mp 95−97 °C; IR (KBr) 2964, 2850, 1734, 1437, 1350, 1297, 1221, 1170, 1104, 1001, 908, 747 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.78−3.38 (m, 6H), 3.75 (s, 6H), 7.16−7.28 (m, 2H), 7.37−7.43 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 22.9, 25.4, 41.5, 41.7, 52.1, 52.2, 110.9, 118.4, 122.5, 123.6, 127.6, 150.6, 154.7, 173.9, 174.3; MS (*m*/*z*) 288 (M$^+$), 257, 228, 196, 169 (100%), 144, 115; HRMS calcd for $C_{16}H_{16}O_5$ 288.0998, found 288.0999.

2,3-Bis(methoxycarbonyl)-1,2,3,4-tetrahydrodibenzothiophene (45): obtained from the reaction of compound **5** and dimethyl fumarate in 75% yield as a white solid: mp 99−100 °C; IR (KBr) 2954, 1731, 1439, 1174, 753 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.85−2.95 (m, 1H), 3.04−3.11 (m, 1H), 3.17−3.31 (m, 2H), 3.75 (s, 3H), 3.77 (s, 3H), 7.26−7.38 (m, 2H), 7.56 (d, J = 7.8 Hz, 1H), 7.76 (dd, J = 7.59, 1.3 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 26.2, 27.9, 41.4, 42.4, 52.2, 104.4, 120.6, 122.4, 124.2, 127.2, 134.0, 138.6, 138.8, 174.2, 174.6; MS (*m*/*z*) 304 (M$^+$), 273, 244, 185 (100%), 160, 139, 115, 92; HRMS calcd for $C_{16}H_{16}O_4S$ 304.0770, found 304.0777.

8-Bromo-2-phenyl-3a*β*,4,10,10a*β*-tetrahydro-2*H*,5*H*-pyrrolo[3,4-*b*]dibenzofuran-1,3-dione (48): obtained from the reaction of compound **38** and *N*-phenylmaleimide in 73% yield as a white solid: mp 175−177 °C; IR (KBr) 1704, 1447, 1386, 1200, 1178, 798, 746, 693 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 3.10 (dd, J = 16.3, 8.3 Hz, 1 H), 3.22 (dd, J = 17.5, 8.9 Hz, 1 H), 3.28 (dd, J = 16.1, 4.0 Hz, 1 H), 3.41 (dd, J = 20.4, 3.4 Hz, 1 H), 3.54 (td, J = 8.2, 3.3 Hz, 1 H), 3.65 (td, J = 8.9, 3.2 Hz, 1 H), 7.19−7.46 (m, 7 H), 7.58 (d, J = 1.9 Hz, 1 H); ^{13}C NMR ($CDCl_3$) δ 20.1, 21.9, 38.5, 39.4, 110.3, 112.7, 115.9, 121.5, 126.2, 126.8, 128.7, 129.1, 129.3, 131.7, 152.1, 153.4, 177.7, 177.8; MS (*m*/*z*) 397 (M$^+$ + 2), 395 (M$^+$), 186 (100%), 171, 149, 115, 91, 77; HRMS calcd for $C_{20}H_{14}BrNO_3$ 395.0157, found 395.0151.

6-Bromo-5-toluenesulfonyl-2-phenyl-3a*β*,4,10,10a*β*-tetrahydro-2*H*,5*H*-pyrrolo[3,4-*b*]carbazole-1,3-dione (49): obtained from the reaction of compound **40** and *N*-phenylmaleimide in 76% yield as a white solid: 203−205 °C; IR (KBr) 2920, 1690, 1362, 1164, 900, 750, 685, 660 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.26 (s, 3 H), 2.90 (ddd, J = 16.2, 8.1, 1.8 Hz, 1 H), 3.26−3.33 (m, 1 H), 3.35 (d, J = 16.1 Hz, 1 H), 3.54 (td, J = 17.0, 9.3 Hz, 1 H), 3.55 (td, J = 16.9, 8.9 Hz, 1 H), 4.1 (dd, J = 17.6, 2.1 Hz, 1 H), 6.91−6.94 (m, 2 H), 7.1 (d, J = 8.2 Hz, 2 H), 7.32−7.43 (m, 4 H), 7.55 (d, J =2.0 Hz, 1 H), 7.7 (d, J = 9.2 Hz, 2 H), 8.0 (d, J = 8.9 Hz, 1 H); MS (*m*/*z*) 550 (M$^+$), 548, 391, 363, 307, 261, 167, 149 (100%), 136, 107. Anal. Calcd for $C_{27}H_{21}BrN_2O_4S$: C, 59.02; H, 3.85; N, 5.10. Found: C, 58.99; H, 3.77; N, 4.95.

3-Methyl-1,3-dihydrothieno[3,4-*b*]benzothiophene 2,2-Dioxide (50). Method I: To a solution of compound **5** (108 mg, 0.49 mmol) and hexamethyl phosphoramide (0.17 mL, 0.98 mmol) in THF (10 mL) cooled at −105 °C was slowly added a solution of lithium hexamethyldisilazide (LiHMDS,0.2 M, 0.23 mmol). After the solution was warmed to −80 °C, methyl iodide (0.06 mL, 0.96 mmol) was added at once. The stirring was continued for 2 h after which time the reaction was quenched by EtOAc. The solvent was removed under reduced pressure and the crude product was purified by HPLC (hexane/EtOAc, 4:1) to give 31 mg of **50** (56%) as a white solid: mp 154−155 °C; IR (KBr) 2960, 2911, 2352, 1303, 1131, 758 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.72 (d, J = 7.0 Hz, 3 H), 4.43 (s, 2H), 4.54 (q, J = 7.0 Hz, 1 H), 7.39−7.48 (m, 2 H), 7.59 (dd, J = 6.0, 2.3 Hz, 1 H), 7.88 (dd, J = 6.8, 3.1 Hz, 1 H); MS (*m*/*z*) 238 (M$^+$), 174 (100%), 147, 129, 115. Anal. Calcd for $C_{11}H_{10}O_2S_2$: C, 55.44; H, 4.23. Found: C, 55.46; H, 4.28. **Method II**: To a solution of compound **5** (60 mg, 0.27 mmol), methyl iodide (0.07 mL, 1.12 mmol), and hexamethyl phosphoramide (0.20 mL, 1.15 mmol) in THF (10 mL) cooled at −78 °C was slowly added a solution of lithium hexamethyldisilazide (LiHMDS, 0.26 mmol) in THF (2 mL). The stirring was continued for 2 h after which time the reaction was quenched by EtOAc. The solvent was removed under reduced pressure, and the crude product was purified by HPLC (hexane/EtOAc, 4:1). Under this condition, compounds **50** (11%), **51** (20%), and **52** (8%) were obtained.

3,3-Dimethyl-1,3-dihydrothieno[3,4-*b*]benzothiophene 2,2-Dioxide (51): mp 164−166 °C; IR (KBr) 2926, 2362, 1298, 1121, 753 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.75 (s, 6H), 4.41 (s, 2H), 7.37−7.47 (m, 2H), 7.59 (dd, J = 6.5, 2.0 Hz, 1H), 7.87 (dd, J = 6.9, 2.3 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 23.9, 53.0, 65.0, 122.0, 123.0, 123.3, 125.3, 125.4, 135.2, 139.7, 143.8; MS (*m*/*z*) 252 (M$^+$), 188 (100%), 173, 147, 129; HRMS calcd for $C_{12}H_{12}O_2S_2$ 252.0280, found 252.0278.

1,3,3-Trimethyl-1,3-dihydrothieno[3,4-*b*]benzothiophene 2,2-Dioxide (52): mp 168−169 °C; IR (KBr) 2981, 2933, 1446, 1297, 1120, 767 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.59 (s, 6H), 1.78 (d, J = 7.1 Hz, 3H), 4.51 (q, J = 7.2 Hz, 1H), 7.39 (td, J = 7.3, 1.9 Hz, 1H), 7.44 (td, J = 7.3, 1.5 Hz, 1H), 7.68 (d, J = 7.7 Hz, 1H), 7.88 (d, J = 7.8 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 15.1, 23.6, 25.9, 59.6, 63.9, 121.8, 123.3, 125.0, 125.1, 128.5, 134.8, 139.9, 142.7; MS (*m*/*z*) 266 (M$^+$), 202, 187 (100%), 172, 147, 128, 115; HRMS calcd for $C_{13}H_{14}O_2S_2$ 266.0436, found 266.0428.

3-(5-Hexenyl)-1,3-dihydrothieno[3,4-*b*]benzothiophene 2,2-Dioxide (53). To a solution of compound **5** (60 mg, 0.27 mmol) and hexamethyl phosphoramide (0.2 mL, 1.15 mmol) in THF (10 mL) cooled at −105 °C was slowly added a solution of lithium hexamethyldisilazide (LiHMDS, 0.2 M, 0.23 mmol). After the solution was warmed to −80 °C, 6-iodo-1-hexene (240 mg, 1.14 mmol) was added at once. The stirring was continued for 2 h after which time the reaction was quenched by EtOAc. The solvent was removed under reduced pressure, and the crude product was purified by HPLC (hexane/EtOAc, 4:1) to give 28 mg of **53** (40%) as a white solid: mp 83−85 °C; IR (KBr) 2925, 2361, 1306, 1134 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.40−1.51 (m, 2 H), 1.59−1.65 (m, 2 H), 1.70−1.94 (m, 1 H), 2.01−2.18 (m, 3 H), 4.27−4.38 (m, 1 H),

4.33 (s, 2 H), 4.88−5.00 (m, 2 H), 5.68−5.82 (m, 1 H), 7.30−7.40 (m, 2 H), 7.48−7.53 (m, 1 H), 7.76−7.83 (m, 1 H); ^{13}C NMR ($CDCl_3$) δ 26.2, 28.5, 30.2, 33.2, 54.8, 66.1, 114.8, 122.0, 123.0, 125.2, 125.4, 125.5, 134.8, 136.0, 138.2, 140.3; MS (*m*/*z*) 306 (M^+), 242 (100%), 185, 173, 160, 147, 129, 115, 64; HRMS calcd for $C_{16}H_{18}O_2S_2$ 306.0749, found 306.0754.

3-Methyl-1,3-dihydrothieno[3,4-*b*]benzofuran 2,2-Dioxide (54) and 3,3-Dimethyl-1,3-dihydrothieno[3,4-*b*]-benzofuran 2,2-Dioxide (55). To a solution of compound **3** (80 mg, 0.38 mmol) and hexamethyl phosphoramide (0.20 mL, 1.15 mmol) in THF (10 mL) cooled at −105 °C was slowly added a solution of lithium hexamethyldisilazide (LiHMDS, 0.09 M, 0.19 mmol). After the solution was warmed to −80 °C, methyl iodide (0.10 mL, 1.46 mmol) was added at once. The stirring was continued for 2 h after which time the reaction was quenched by EtOAc. The solvent was removed under reduced pressure and the crude product was purified by HPLC (hexane/EtOAc, 4:1) to give 24 mg of **54** (58%) and 12 mg of **55** (27%). Compound **54**: a white solid, mp 78−80 °C; IR (KBr) 2921, 2361, 1450, 1307, 1116, 748 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.71 (d, J = 6.7 Hz, 3H), 4.31−4.44 (m, 1H), 4.39 (s, 2H), 7.31 (td, J = 7.2, 1.3 Hz, 1H), 7.38 (td, J = 7.5, 1.4 Hz, 1H), 7.46 (d, J = 7.2 Hz, 1H), 7.54 (d, J = 7.5 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 12.8, 54.3, 58.5, 108.7, 112.1, 119.7, 123.9, 124.3, 125.4, 150.9, 156.5; MS (*m*/*z*) 222 (M^+), 158 (100%), 131, 115, 102, 77, 64; HRMS calcd for $C_{11}H_{10}O_3S$ 222.0351, found 222.0348. Compound **55**: a white solid, mp 93−95 °C; IR (KBr) 2970, 2931, 2361, 1298, 1227, 1117, 751 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.73 (s, 6H), 4.36 (s, 2H), 7.31 (t, J = 7.4 Hz, 1H), 7.37 (td, J = 7.3, 1.3 Hz, 1H), 7.47 (d, J = 8.1 Hz, 1H), 7.54 (d, J = 8.0 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 21.4, 52.8, 62.1, 106.4, 112.0, 119.7, 123.7, 124.4, 125.2, 155.4, 156.1; MS (*m*/*z*) 236 (M^+), 172 (100%), 157, 128, 115, 102, 77, 63; HRMS calcd for $C_{12}H_{12}O_3S$ 236.0507, found 236.0509.

1,3,3-Trimethyl-1,3-dihydrothieno[3,4-*b*]benzofuran 2,2-Dioxide (56). To a solution of compound **3** (35 mg, 0.17 mmol), methyl iodide (0.05 mL, 0.80 mmol), and hexamethyl phosphoramide (0.12 mL, 0.69 mmol) in THF (5 mL) cooled at −78 °C was slowly added a solution of lithium hexamethyldisilazide (LiHMDS, 0.07 M, 0.15 mmol). The stirring was continued for 2 h after which time the reaction was quenched by EtOAc. The solvent was removed under reduced pressure, and the crude product was purified by HPLC (hexane/EtOAc, 4:1) to give compounds **55** (11%) and **56** (29%). Compound **56**: white solid, mp 91−93 °C; IR (KBr) 2923, 1448, 1311, 1102, 748 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.71−1.76 (m, 9H), 4.48 (q, J = 7.0 Hz, 1H), 7.30 (td, J = 7.3, 1.2 Hz, 1H), 7.37 (td, J = 7.4, 1.4 Hz, 1H), 7.53 (t, J = 7.8 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ 14.4, 22.0, 22.2, 59.4, 61.8, 112.2, 119.4, 123.7, 124.3, 125.2, 137.4, 154.7, 156.3; MS (*m*/*z*) 250 (M^+), 218, 203, 186, 171, 84, 49 (100%); HRMS calcd for $C_{13}H_{14}O_3S$ 250.0664, found 250.0661.

2,3-Bis(methoxycarbonyl)-4-methyldibenzofuran (57). A solution of compound **54** (17 mg, 0.08 mmol) and dimethyl acetylenedicarboxylate (0.07 mL, 0.57 mmol) in benzene (5 mL) was heated at 150 °C for 2 h. Then DDQ (140 mg, 0.62 mmol) was added and heated at 150 °C for 3 h. After the solvent was removed under reduced pressure, the crude product was purified by column chromatography (silica gel, hexane/EtOAc, 4:1) to give 10 mg of **57** (42%) as a white solid: mp 98−100 °C; IR (KBr) 2955, 1731, 1439, 1358, 1276, 1237, 1204, 1146, 1050, 758; ^{1}H NMR ($CDCl_3$) δ 2.57 (s, 3H), 3.95 (s, 3H), 4.00 (s, 3H), 7.40 (t, J = 7.5 Hz, 1H), 7.52 (t, J = 7.7 Hz, 1H), 7.62 (d, J = 8.5 Hz, 1H), 7.98 (d, J = 7.5 Hz, 1H), 8.48 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 29.7, 52.5, 52.7, 112.0, 120.3, 120.9, 121.2, 122.8, 123.5, 123.6, 124.0, 128.2, 134.4, 157.1, 166.3, 169.4; MS (*m*/*z*) 298 (M^+), 267 (100%), 251, 224, 208, 180, 152; HRMS calcd for $C_{17}H_{14}O_5$ 298.0841, found 298.0829.

2,3-Bis(methoxycarbonyl)-4-methyldibenzothiophene (58). A solution of compound **50** (34 mg, 0.14 mmol) and dimethyl acetylenedicarboxylate (0.14 mL, 1.14 mmol) in benzene (5 mL) was heated at 150 °C for 2 h. Then DDQ (260 mg, 1.14 mmol) was added and heated at 150 °C for 3 h. After the solvent was removed under reduced pressure, the crude product was purified by column chromatography (silica gel, hexane/EtOAc, 4:1) to give 32 mg of **58** (71%) as a white solid: mp 128−130 °C; IR (KBr) 2957, 1723, 1589, 1548, 1400, 1340, 1272, 1235, 1193, 1160, 1115, 1021, 765, 739; ^{1}H NMR ($CDCl_3$) δ 2.57 (s, 3H), 3.97 (s, 3H), 4.01 (s, 3H), 7.50−7.53 (m, 2H), 7.87−7.90 (m, 1H), 8.19−8.23 (m, 1H), 8.65 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 18.0, 52.6, 52.7, 121.2, 122.3, 122.9, 124.6, 125.1, 127.7, 129.8, 132.4, 135.3, 139.8, 145.0, 166.4, 169.7, 185.8; MS (*m*/*z*) 314 (M^+), 300, 282, 269, 224 (100%), 196, 139; HRMS calcd for $C_{17}H_{14}O_4S$ 314.0613, found 314.0618.

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Supporting Information Available: ^{1}H NMR spectra for all compounds and ^{13}C NMR for compounds **3**, **4b**, **12a**, **31**, **42**, **44**, **47**, **48**, **51**, **54**−**61** (51 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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