Organometallics **2001,** *20,* 2487−2491

Cycloaddition Reactions of Nitrile Oxides to 2,4-Silyl- and Germyl-Substituted Thiophene-1,1-dioxides

Edmunds Lukevics,* Pavel Arsenyan, Sergey Belyakov, Juris Popelis, and Olga Pudova

Latvian Institute of Organic Synthesis, Aizkraukles 21, Riga, LV-1006, Latvia

Received February 5, 2001

2,4-Silyl- and germyl-substituted thiophene-1,1-dioxides as well as 5,5′- and 4,4′-bis(trimethylsilyl)-2,2′-bithiophene-1,1-dioxides were prepared from the corresponding thiophenes and bithiophenes by oxidation with *m*-CPBA in CH_2Cl_2 at room temperature. The [2+3] dipolar cycloaddition of nitrile oxides to the double C═C bonds of thiophene-1,1-dioxides has been investigated. It was shown that in the series of 2,4-disubstituted thiophene-1,1-dioxides only the $C_{(4)}{=}C_{(5)}$ double bond interacts with acetonitrile oxide to give fused thienoisoxazolines. Addition of acetonitrile oxide to 5,5′-bis(trimethylsilyl)-2,2′-bithiophene-1,1-dioxide was accompanied by desilylation. Isomeric 4,4′-bis(trimethylsilyl)-2,2′-bithiophene-1,1-dioxide was inactive in the reaction with acetonitrile oxide. Cycloaddition of benzonitrile oxide with all mentioned sulfones did not occur. The molecular structures of 2,4-bis(trimethylsilyl)thiophene-1,1-dioxide, 2-trimethylgermyl-4-trimethylsilylthiophene-1,1-dioxide, 2-trimethylsilyl-4-trimethylgermyl-1,1-dioxide, 2,4-bis(trimethylgermyl)thiophene-dioxide, 5,5′-bis(trimethylsilyl)-2,2′-bithiophene-1,1-dioxide, and 4,4-dioxo-3-methyl-5,6a-bis(trimethylgermyl)-3a,6a-dihydrothieno[2,3-d]isoxazoline-2 were studied by X-ray diffraction.

Introduction

Thiophene-1,1-dioxides undergo a wide variety of reactions as heterocyclic sulfones containing unsaturated butadiene fragment. Due to their structure thiophene-1,1-dioxides act as dienophiles or dienes in reactions of [2+2], [2+3], [2+4], [4+2], and [4+6] cycloaddition.[1]

It has been shown that *tert*-butyl, trimethylsilyl, and trimethylgermyl 2,5-disubstituted thiophene-1,1-dioxides[2] are very convenient models for comparison of the influence of different substituents on the reactivity of vinyl groups in various reactions, such as [2+3] dipolar cycloaddition of nitrile oxides[2a] and nucleophilic addition of secondary amines.[2b] Cytotoxic activity of *tert*-butyl-, silyl-, and germyl-substituted 4,4-dioxo-4a,6a-dihydrothieno[2,3-*d*]isoxazolines prepared by the [2+3] dipolar cycloaddition was tested in vitro on four tumor cell lines. The experimental evaluation of cytotoxic properties also clearly indicates the strong influence of the Me_3M (M = C, Si, Ge) group in position 5 of fused isoxazolines on tumor growth inhibition, increasing from slightly active 5-*tert*-butyl derivatives to considerable more active silyl- and germyl-containing analogues.[3]

Recently the efficient incorporation of thiophene-1-oxide and thiophene-1,1-dioxide units into the backbone of a π-conjugated oligomers by Stille coupling of bromothiophene-1,1-dioxides with thienylstannanes in the presence of $Pd(AsPh_3)_4$[4] or by the conversion of intermediate polymers containing zirconacyclopentadiene fragments into new thiophene-based materials was proposed by Tilley.[5]

Results and Discussion

Synthesis of Thiophene-1,1-dioxides. 2,4-Disubstituted thiophenes **1a**−**d** were prepared from 3-trimethylsilyl- and 3-trimethylgermylthiophenes by lithiation with *n*-BuLi in dry ether and subsequent silylation or germylation of intermediate lithium derivatives by trimethylsilyl or trimethylgermyl chlorides (Scheme 1). Yields of 2,4-disubstituted thiophenes were 55−58%. The synthesis of bithiophenes **1e**,**f** was realized through oxidative coupling of 2-lithio-5-trimethylsilyl- and 2-lithio-4-trimethylsilylthiophenes with $CuCl_2$ (Scheme 2).

Analogous to 2,5-disubstituted thiophenes, 2,4-silyl- and germyl-disubstituted thiophenes **1a**−**d** are readily oxidized to corresponding thiophene-1,1-dioxides **2a**−**d** by *m*-chloroperbenzoic acid (*m*-CPBA) in methylene chloride at room temperature. Sulfones **2a**−**d** prepared in good yields (55−60%) are colorless crystalline solids

---

[1] (a) Nakayama, J.; Sugihara, Y. *Top. Curr. Chem.* **1999**, *205*, 131. (b) Nakayama, J.; Nagasawa, H.; Sugihara, Y.; Ishii, A. *Heterocycles* **2000**, *52*, 365. (c) Nakayama, J.; Nagasawa, H.; Sugihara, Y.; Ishii, A. *J. Am. Chem. Soc.* **1997**, *119*, 9077. (d) Nagasawa, H.; Sugihara, Y.; Ishii, A.; Nakayama, J. *Bull. Chem. Soc. Jpn.* **1999**, *72*, 1919.

[2] (a) Lukevics, E.; Arsenyan, P.; Belyakov, S.; Popelis, J.; Pudova, O. *Organometallics* **1999**, *18*, 3187. (b) Lukevics, E.; Arsenyan, P.; Belyakov, S.; Popelis, J.; Pudova, O. *Eur. J. Org. Chem.* **2000**, 3139.

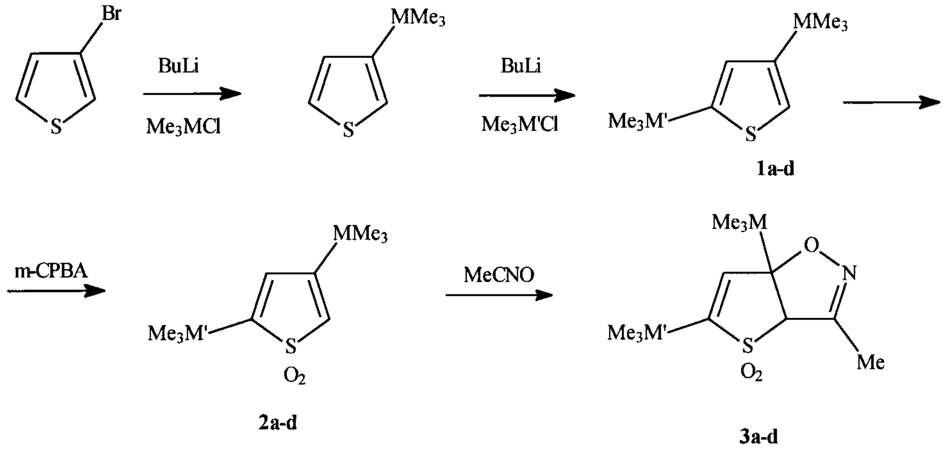
[3] Lukevics, E.; Arsenyan, P.; Shestakova, I.; Zharkova, O.; Kanepe, I.; Mezapuke, R.; Pudova, O. *Metal-Based Drugs* **2000**, *7*, 63.

[4] (a) Barbarella, G.; Favaretto, L.; Sotgiu, G.; Zambianchi, M.; Antolini, L.; Pudova, O.; Bongini, A. *J. Org. Chem.* **1998**, *63*, 5497. (b) Barbarella, G.; Favaretto, L.; Sotgiu, G.; Zambianchi, M.; Fattory, V.; Cocchi, M.; Cacialli, F.; Gigli, G.; Cingolani, R. *Adv. Mater.* **1999**, *11*, 1375. (c) Antolini, L.; Tedesco, E.; Barbarella, G.; Favaretto, L.; Sotgiu, G.; Zambianchi, M.; Casarivi, D.; Gigli, G.; Cingolani, R. *J. Am. Chem. Soc.* **2000**, *122*, 9006. (d) Gigli, G.; Barbarella, G.; Favaretto, L.; Cacialli, F.; Cingolani, R. *Appl. Phys. Lett.* **1999**, *75*, 439.

[5] (a) Jiang, B.; Tilley, T. D. *J. Am. Chem. Soc.* **1999**, *121*, 9744. (b) Suh, M. C.; Jiang, B.; Tilley, T. D. *Angew. Chem., Int. Ed.* **2000**, *39*, 2870.

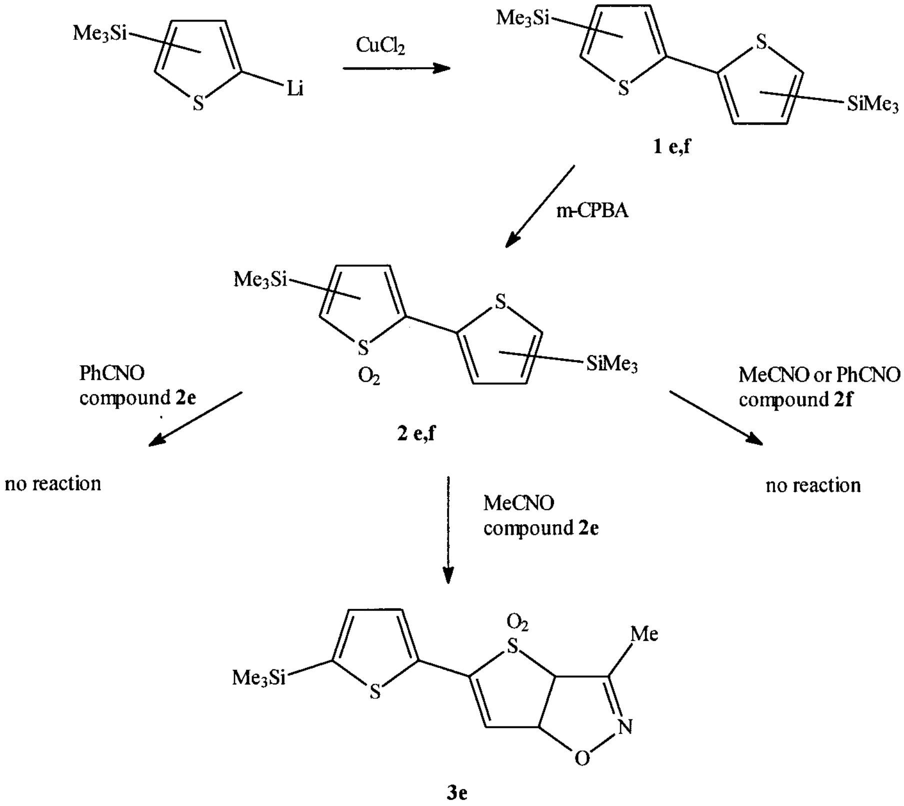
10.1021/om0100885 CCC: $20.00
Publication on Web 05/15/2001

Scheme 1



a, M=M'=Si; **b**, M=Si, M'=Ge; **c**, M=Ge, M'=Si; **d**, M=M'=Ge

Scheme 2



e, 5,5'-bis(trimethylsilyl); **f**, 4,4'-bis(trimethylsilyl)

that are thermally and moisture stable compounds. Sulfur atoms of bithiophenes **1e**,**f** are less active to oxidation as compared with 2,5- and 2,4-disubstituted thiophenes due to conjugation of aromatic rings. As a result, the yield of bithiophene-1,1-dioxides **2e**,**f** did not exceed 36%.

X-ray Diffraction of Thiophene-1,1-dioxides 2a–e. The molecular structures of 2,4-disubstituted thiophene-1,1-dioxides **2a**–**d** (Figure 1) and 5,5′-bis(trimethylsilyl)-2,2′-bithiophene-1,1-dioxide **2e** (Figure 2) were studied by X-ray diffraction. The main geometric parameters of 2,4-disubstituted sulfones **2a**–**d** and bithiophene-1,1-dioxide **2e** are presented in Table 1. The five-membered thiophene-1,1-dioxide heterocycle of all compounds as well as in previously reported 2,5-disubstituted thiophene-1,1-dioxides[2a] is planar. The crystals of sulfones **2a**–**d** are isomorphous. The molecular packing of 2,4-**2a**–**d** and 2,5-silyl(germyl)-disubstituted thiophene-1,1-dioxides is completely different. In the case of compounds **2a**–**d** the molecules are in general positions, while the molecules of 2,5-silyl(germyl)thiophene-1,1-dioxides lie in special positions.

The particularity of the crystal structure of the bithienyl derivative is the presence of two independent molecules. One of the molecules lies in general position, while the other molecule is in special position approximately perpendicular to molecules in general position. The molecule of bithiophene-1,1-dioxide **2e** is not

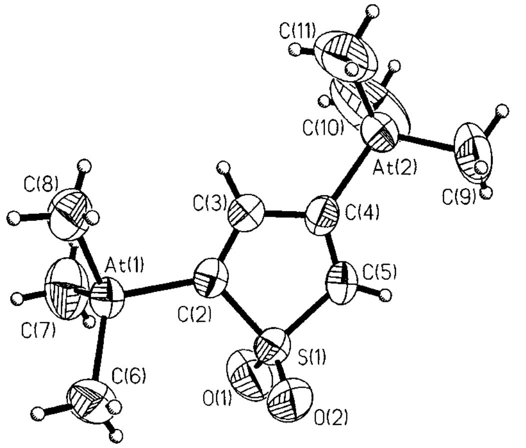


Figure 1. Molecular structure of 2,4-disubstituted thiophene-1,1-dioxides **2a**−**d** (thermal elipsoids are given for compound **2d**).

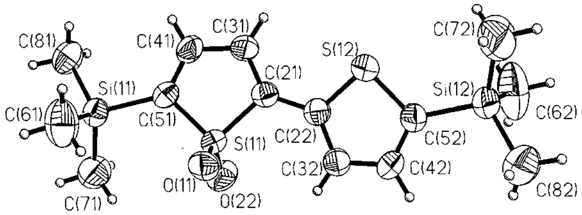


Figure 2. Molecular structure of sulfone **2e**.

symmetrical; therefore the disorder of oxygen atoms occurs for molecules in special positions (Figure 3). In contrast with 5,5′-bis(trimethylsilyl)-2,2′-bithiophene and other 5,5′-disubstituted thiophenes[6] having two trans-orientated coplanar thienyl groups, heterocycles of molecules **2e** in general positions are twisted with respect to each other, forming a dihedral angle of 19.4(1)°. For molecules **2e** in special positions these heterocycles are coplanar. The bithienyl-1,1-dioxide fragment in both independent molecules of sulfone **2e** also has a transoid arrangement of sulfur atoms.

Synthesis of Fused Isoxazolines. Previously it has been shown that the regioselectivity of nitrile oxide cycloaddition to 2,5-disubstituted thiophene-1,1-dioxides strongly depends on the group Me_3M (M = C, Si, Ge) nature and the method of nitrile oxide generation.[2a] To study the influence of the substituent position in the sulfone ring on the reaction pathway, the [2+3] dipolar cycloaddition of aceto- and benzonitrile oxides to the double C=C bonds of 2,4-disubstituted thiophene-1,1-dioxides **2a**−**f** has been investigated. Acetonitrile oxide prepared in situ by the Mukaiyama−Hoshito method[7] reacts with thiophene-1,1-dioxides **2a**−**f** regioselectively to give only one isomer from four possible regioisomeric products. The NMR spectroscopic data obtained for reaction products correspond to the formation of fused isoxazolines **3a**−**d** (Scheme 1). The structure of compound **3d** was studied by X-ray diffraction.

These experimental results confirm the increased reactivity of the $C_{(4)}{=}C_{(5)}$ double bond in sulfones **2a**−**d** as compared with the $C_{(2)}{=}C_{(3)}$ bond. The demetalation of silyl and germyl groups does not occur. As in the case of 2,5-disubstituted thiophene-1,1-dioxides,[2a] only one $C_{(4)}{=}C_{(5)}$ double bond of 2,4-disubstituted derivatives is involved in the interaction, the second $C_{(2)}{=}C_{(3)}$ bond being inactive despite a 4-fold excess of acetonitrile oxide. Yields of the fused isoxazolines **3a**−**d** are 72−86%. In contrast with 2,5-disubstituted thiophene-1,1-dioxides, sulfones **2a**−**d** did not react with benzonitrile oxide generated in situ by dehydrohalogenation of the benzhydroxamic acid chloride with triethylamine.[8]

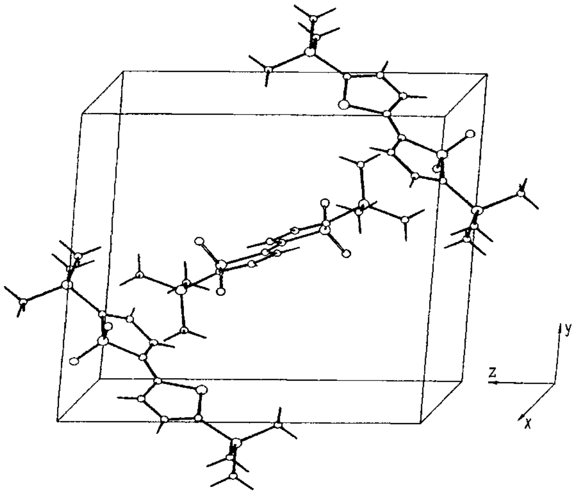


Figure 3. Molecular packing of sulfone **2e**.

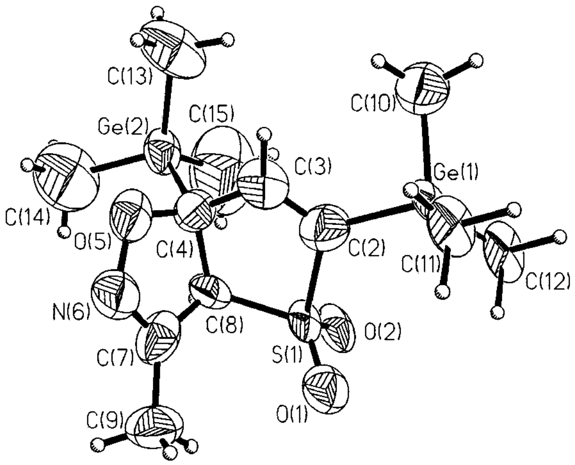


Figure 4. Molecular structure of fused isoxazoline **3d**.

The reaction pathway of acetonitrile oxide with 5,5′-bis(trimethylsilyl)-2,2′-bithiophene-1,1-dioxide **2e** is analogous to reaction with 2,5-bis(trimethylsilyl)thiophene-1,1-dioxide.[2a] The cycloaddition is also accompanied by desilylation to form isoxazoline **3e** in 49% yield. Our attempts to add benzonitrile oxide to the compound **2e** were unsuccessful. Taking into account these results, it may be concluded that the introduction of a thiophene ring between the trimethysilyl group and the thiophene-1,1-dioxide fragment decreases the reactivity of the double C=C bond due to π-conjugation of aromatic and butadiene systems. In the case of isomeric 4,4′-bis-

---

[6] (a)Alemán, C.; Brillas, E.; Davies, A. G.; Fajarí, L.; Giró, D.; Juliá, L.; Péres, J. J.; Rius, J. *J. Org. Chem.* **1993**, *58*, 3091. (b) Lukevics, E.; Barbarella, G.; Arsenyan, P.; Belyakov, S.; Pudova, O. *Chem. Heterocycl. Compd.* **2000**, *36*, 630.

[7] Mukaiyama, T.; Hoshito, T. *J. Am. Chem. Soc.* **1960**, *82*, 5339.

[8] (a) Weidner-Wells, M. A.; Fraga-Spano, S. A.; Turchi, I. J. *J. Org. Chem.* **1998**, *63*, 6319. (b) Lukevics, E.; Arsenyan, P.; Belyakov, S.; Popelis, J.; *J. Organomet. Chem.* **1998**, *558*, 155. (c) Lukevics, E.; Arsenyan, P.; Belyakov, S.; Popelis, J. *Main Group Met. Chem.* **1998**, *21*, 557. (d) Lukevics, E.; Arsenyan, P. *Chem. Heterocycl. Compd.* **1998**, *34*, 989.

Table 1. Geometric Parameters of 2,4-Disubstituted Thiophene-1,1-dioxides

compound	$r(C_{(2)}{=}C_{(3)})$, Å	$r(C_{(3)}-C_{(4)})$, Å	$r(C_{(4)}{=}C_{(5)})$, Å	$r(C_{(2)}-S)$, Å	$r(C_{(5)}-S)$, Å	$r(M-C_{(4)})$, Å	$r(M'-C_{(2)})$, Å	$\angle C_{(2)}SC_{(5)}$, deg
2a	1.331(5)	1.488(5)	1.301(6)	1.7658(4)	1.772(4)	1.891(4)	1.873(4)	93.87(2)
2b	1.340(7)	1.486(7)	1.320(7)	1.762(5)	1.767(5)	1.823(9)	1.934(6)	93.7(3)
2c	1.314(8)	1.486(7)	1.294(9)	1.757(6)	1.773(7)	1.963(7)	1.888(6)	93.6(3)
2d	1.325(7)	1.489(7)	1.320(7)	1.754(4)	1.761(6)	1.949(5)	1.947(5)	94.0(3)

(trimethylsilyl)-2,2′-bithiophene-1,1-dioxide **2f** cycloaddition with acetonitrile oxide as well as with benzonitrile oxide failed to occur (Scheme 2).

X-ray Diffraction of 4,4-Dioxo-3-methyl-5,6a-bis(trimethylgermyl)-3a,6a-dihydrothieno[2,3-*d*]isoxazoline-2 (3d). To confirm the regioselectivity of [2+3] dipolar cycloaddition to 2,4-disubstituted thiophene-1,1-dioxides, the molecular structure of 4,4-dioxo-3-methyl-5,6a-bis(trimethylgermyl)-3a,6a-dihydrothieno[2,3-*d*]-isoxazoline-2 was studied by X-ray diffraction (Figure 4). Single crystals were obtained by crystallization from a hexane−CH_2Cl_2 (1:1) mixture. Two five-membered rings of the fused isoxazoline system in compound **3d** are almost planar and form a dihedral angle of 114.7(12)°.

Experimental Section

General Experimental Procedures. ^{1}H, ^{13}C, and ^{29}Si NMR spectra were recorded on a Varian Mercury 200 spectrometer at 200.06, 50.31, and 39.74 MHz correspondingly at 303 K. The chemical shifts are given relative to TMS from solvent ($CDCl_3$) signal ($\delta_H = 7.25$ ppm). Mass spectra were recorded on a Hewlett-Packard apparatus (70 eV). GC analysis was performed on a Varian 3700 instrument equipped with a flame-ionizing detector using a capillary column (5 m × 0.53 mm, df = 2.65 μ, HP-1, carrier gas nitrogen). The melting points were determined on a digital melting point analyzer (Fisher); the results are given without correction.

2-Trimethylsilyl-, 2-trimethylgermyl-,[9] and 2,4-bis(trimethylsilyl)thiophenes[10] and 5,5′-bis(trimethylsilyl)-2,2′-bithiophene[6a] were obtained according to known procedures. 2,4-Bis(trimethylsilyl)thiophene-1,1-dioxide[10] was prepared by oxidation of 2,4-bis(trimethylsilyl)thiophene by *m*-CPBA.

2-Trimethylgermyl-4-trimethylsilylthiophene (1b). To a solution of 3-trimethylsilylthiophene (3.86 g, 0.025 mol) in 60 mL of ethyl ether was added 10 mL of 2.5 N *n*-BuLi in hexanes (0.025 mol) at room temperature. After 1 h, 3.8 g (0.025 mol) of trimethylchlorogermane was added dropwise. The reaction mixture was refluxed for 2 h, hydrolyzed with a saturated solution of ammonium chloride, extracted with ether, dried over Na_2SO_4, and evaporated. The residue was distilled (122−125 °C, 15 mmHg), and 3.8 g (56% yield) of pure **1b** as a colorless liquid was obtained. MS: *m/e* 274 ($M^{•+}$). ^{1}H NMR: δ 0.26 (s, 9H), 0.45 (s, 9H), 7.20 (d, 1H, $J = 1.0$ Hz), 7.65 (d, 1H, $J = 1.0$ Hz). ^{13}C NMR: δ −0.40, −0.25, 136.0, 137.1, 141.4, 142.2. ^{29}Si NMR: δ −8.32. Anal. Calcd for $C_{10}H_{20}GeSSi$: C, 43.99; H, 7.38; S, 11.74. Found: C, 44.06; H, 7.39; S, 11.61.

2-Trimethylsilyl-4-trimethylgermylthiophene (1c). Yield: 58%. Bp: 129−131 °C, 15 mmHg. MS: *m/e* 274 ($M^{•+}$). ^{1}H NMR: δ 0.32 (s, 9H), 0.39 (s, 9H), 7.25 (d, 1H, $J = 0.8$ Hz), 7.58 (d, 1H, $J = 0.8$ Hz). ^{13}C NMR: δ −0.94, 0.1, 134.9, 138.0, 140.5, 142.6. ^{29}Si NMR: δ −6.70. Anal. Calcd for $C_{10}H_{20}GeSSi$: C, 43.99; H, 7.38; S, 11.74. Found: C, 43.95; H, 7.43; S, 11.74.

2,4-Bis(trimethylgermyl)thiophene (1d). Yield: 55%. Bp: 144−145 °C, 15 mmHg. MS: *m/e* 318 ($M^{•+}$). ^{1}H NMR: δ 0.38 (s, 9H), 0.45 (s, 9H), 7.17 (d, 1H, $J = 0.9$ Hz), 7.56 (d, 1H, $J = 0.9$ Hz). ^{13}C NMR: δ −0.9, −0.2, 135.0, 137.6, 142.3, 143.4. Anal. Calcd for $C_{10}H_{20}Ge_2S$: C, 37.83; H, 6.35; S, 10.10. Found: C, 37.66; H, 6.38; S, 10.46.

4,4′-Bis(trimethylsilyl)-2,2′-bithiophene (1f). To a solution of 0.02 mol of 3-trimethylsilylthiophene (3.12 g) in 30 mL of dry ether was added dropwise 0.02 mol of 2.5 M BuLi in hexane (8 mL). After 1 h, the reaction mixture was cooled to −30 °C and dry $CuCl_2$ (0.02 mol, 2.7 g) was added by portions. Then the solution was allowed to warm to room temperature and treated with 40 mL of 3 M HCl. The mixture was extracted with CH_2Cl_2, and the organic layer was washed with brine, dried over $MgSO_4$, and evaporated. After evaporation the residue was chromatographed on silica gel with petroleum ether as eluent to give **1f** (3.0 g) as a crystalline solid. Yield: 98%. Mp: 70−72 °C. MS: *m/e* 310 ($M^{•+}$). ^{1}H NMR: δ 0.264 (s, Me_3Si); 7.17 (d, 1H, $J = 1.4$ Hz); 7.26 (d, 1H, $J = 1.4$ Hz). ^{13}C NMR: δ −0.7, 128.4, 130.5, 138.0, 142.9. ^{29}Si NMR: δ −7.91. Anal. Calcd for $C_{14}H_{22}S_2Si_2$: C, 54.14; H, 7.14; S, 20.65. Found: C, 54.05; H, 7.17; S, 20.41.

Oxidation of Thiophenes and Bithiophenes. A solution of 2,4-disubstituted thiophenes **1b**−**d** or disubstituted 2,2′-bithiophenes **1e**,**f** (5 mmol) in 10 mL of CH_2Cl_2 was added dropwise to a solution of 70% *m*-CPBA (2.47 g, 10 mmol) in CH_2Cl_2. After being stirred for 4 h at room temperature, the reaction mixture was cooled to −50 °C, and the precipitate of *m*-chlorobenzoic acid was filtered off. After evaporation of the solvent, the residue was recrystallized from a hexanes−ether (2:1) mixture to yield 2,4-disubstituted thiophene-1,1 dioxides **2b**−**d** as white crystalline solids. Bis(trimethylsilyl)-2,2′-bithiophene-1,1-dioxides **2e**,**f** were purified by chromatography on silica gel with petroleum ether−CH_2Cl_2 (2:1) as eluent.

2-Trimethylgermyl-4-trimethylsilylthiophene-1,1-dioxide (2b). Yield: 60%. Mp: 134−135 °C. MS: *m/e* 291 ($M^{•+}$ − Me). ^{1}H NMR: δ 0.35 (s, 9H), 0.37 (s, 9H), 6.62 (d, 1H, $J = 0.8$ Hz), 6.71 (d, 1H, $J = 0.8$ Hz). ^{13}C NMR: δ −2.47, −1.69, 136.0, 138.5, 143.4, 147.0. ^{29}Si NMR: δ −4.13. Anal. Calcd for $C_{10}H_{20}GeO_2SSi$: C, 39.38; H, 6.61; S, 10.51. Found: C, 39.32; H, 6.68; S, 10.46.

2-Trimethylsilyl-4-trimethylgermylthiophene-1,1-dioxide (2c). Yield: 60%. Mp: 103−104 °C. MS: *m/e* 291 ($M^{•+}$ − Me). ^{1}H NMR: δ 0.12 (s, 9H), 0.50 (s, 9H), 6.62 (d, 1H, $J = 0.8$ Hz), 6.66 (d, 1H, $J = 0.8$ Hz). ^{13}C NMR: δ −2.48, −1.67, 137.4, 138.2, 145.2, 146.0. ^{29}Si NMR: δ −6.06. Anal. Calcd for $C_{10}H_{20}GeO_2SSi$: C, 39.38; H, 6.61; S, 10.51. Found: C, 39.14; H, 6.64; S, 10.50.

2,4-Bis(trimethylgermyl)thiophene-1,1-dioxide (2d). Yield: 55%. Mp: 105 °C. MS: *m/e* 337 ($M^{•+}$ − Me). ^{1}H NMR: δ 0.37 (s, 9H), 0.51 (s, 9H), 6.62 (s), 6.64 (s). ^{13}C NMR: δ −1.57, −0.62, 137.3, 138.0, 146.5, 148.1. Anal. Calcd for $C_{10}H_{20}Ge_2O_2S$: C, 34.36; H, 5.77; S, 9.18. Found: C, 34.42; H, 5.74; S, 9.23.

5,5′-Bis(trimethylsilyl)-2,2′-bithiophene-1,1-dioxide (2e). Yield: 36%. Mp: 142 °C. MS: *m/e* 342 ($M^{•+}$). ^{1}H NMR: δ 0.32 (s), 0.37 (s), 6.60 (d, 1H, $J = 4.45$ Hz), 6.91 (d, 1H, $J = 4.45$ Hz), 7.23 (d, 1H, $J = 3.60$ Hz), 7.66 (d, 1H, $J = 3.60$ Hz). ^{13}C NMR: δ −1.6, −0.3, 117.5, 129.8, 134.2, 135.3, 137.3, 140.8, 143.9, 145.3. ^{29}Si NMR: δ −5.8, −5.5. Anal. Calcd for $C_{14}H_{22}O_2S_2Si_2$: C, 49.09; H, 6.47; S, 18.72. Found: C, 49.12; H, 6.49; S, 18.68.

4,4′-Bis(trimethylsilyl)-2,2′-bithiophene-1,1-dioxide (2f). Yield: 30%. Mp: 120 °C. MS: *m/e* 342 ($M^{•+}$). ^{1}H NMR: δ 0.25

---

[9] (a) Lukevics, E.; Pudova, O. A.; Popelis, Yu.; Erchak, N. P. *Zh. Obshch. Chem.* **1981**, *51*, 115. (b) Thames, S. F.; Edwards, L. H.; Jacobs, T. N.; Grube, P. L.; Pinkerton F. H. *J. Heterocycl. Chem.* **1972**, *9*, 1259. (c) Benkeser, R. A.; Currie, R. B. *J. Am. Chem. Soc.* **1948**, *70*, 1780.

[10] Donovan, A. R. M.; Shepherd, M. K. *Tetrahedron Lett.* **1994**, *35*, 4425.

Table 2. Crystal Data and Measurement Conditions for Compounds 2a−e and 3d

	2a	**2b**	**2c**	**2d**	**2e**	**3d**
molecular weight	260.5	305.0	305.0	349.5	513.9	406.6
cryst syst	monoclinic	monoclinic	monoclinic	monoclinic	triclinic	triclinic
space group	$P2_1/c$	$P2_1/c$	$P2_1/c$	$P2_1/c$	$P\bar{1}$	$P\bar{1}$
unit cell dimens						
a (Å)	11.510(2)	11.592(1)	11.575(2)	11.631(2)	6.728(2)	9.865(3)
b (Å)	10.371(2)	10.463(1)	10.345(2)	10.367(2)	14.538(3)	9.887(5)
c (Å)	12.985(1)	13.012(1)	13.027(2)	13.006(2)	14.822(3)	11.535(4)
α (deg)	90	90	90	90	99.06(2)	89.05(3)
β (deg)	97.620(11)	98.460(9)	97.178(14)	98.005(13)	96.50(2)	67.25(2)
γ (deg)	90	90	90	90	90.61(2)	61.60(3)
cell volume V (Å^3)	1536.3(4)	1561.0(2)	1547.7(5)	1553.0(4)	1421.9(6)	893.0(6)
molecular multiplicity, Z	4	4	4	4	3	2
D_x (g cm^{-3})	1.126	1.298	1.309	1.495	1.200	1.512
abs coeff μ (mm^{-1})	0.350	2.156	2.175	3.988	0.406	3.485
F(000)	560	632	632	704	546	412
radiation	Mo Kα graphite-monochromated					
wavelength λ (Å)	0.71069					
cryst size (mm)	0.50 × 0.40 × 0.15	0.50 × 0.50 × 0.25	0.60 × 0.40 × 0.10	0.75 × 0.60 × 0.60	0.60 × 0.40 × 0.20	0.60 × 0.50 × 0.50
$2\theta_{max}$ (deg)	50	50	50	50	45	45
no. of ind reflns collected	2733	2751	2725	2762	3747	2127
no. of obsd ($I > 2\sigma(I)$) reflns collected	1752	1765	1486	2080	2823	1039
goodness-of-fit	1.040	0.998	0.981	1.090	1.134	0.941
R-factor	0.0646	0.0476	0.0621	0.0473	0.0629	0.0937[a]
structure solution and refinement methods	refs 11a,c	refs 11a,c	refs 11a,c	refs 11a,c	refs 11b,c	refs 11b,c

[a] The value of the R-factor is connected with insufficient quality of crystals.

(s, 9H), 0.27 (s, 9H), 6.57 (d, 1H, $J = 1.1$ Hz), 6.63 (d, 1H, $J = 1.1$ Hz), 7.45 (d, 1H, $J = 1.0$ Hz), 7.62 (d, 1H, $J = 1.0$ Hz). ^{13}C NMR: δ −2.6, −0.76, 119.6, 130.3, 132.8, 133.0, 134.3, 137.0, 144.0, 145.2. ^{29}Si NMR: δ −7.2. Anal. Calcd for $C_{14}H_{22}O_2S_2Si_2$: C, 49.09; H, 6.47; S, 18.72. Found: C, 49.07; H, 6.51; S, 18.65.

Synthesis of Isoxazolines. Interaction of Acetonitrile Oxide with Thiophen-1,1-dioxides 2a−f. Nitroethane (0.02 mol) and triethylamine (2 drops) in dry benzene (40 mL) were added dropwise during 4 h to a mixture of thiophene-1,1-dioxide (0.02 mol) and phenylisocyanate (0.04 mol) in dry benzene at room temperature. After some minutes CO_2 began to release and diphenylurea precipitated. The mixture was heated for 4 h at 70−80 °C. After cooling to room temperature diphenylurea was filtered and the solvent was evaporated. The residue was chromatographed on neutral Al_2O_3 using CH_2Cl_2 as eluent. All fused isoxazolines **3**−**6** were separated as colorless oils. Some of them crystallized after 3−10 days.

4,4-Dioxo-3-methyl-5,6a-bis(trimethylsilyl)-3a,6a-dihydrothieno[2,3-*d*]isoxazoline-2 (3a). Yield: 80%. Mp: 82−84 °C. MS: *m*/*e* 302 ($M^{\bullet+} - 15$). ^{1}H NMR: δ 0.18 (s, 9H) 0.32 (s, 9H) 2.27 (d, 3H, 1.0 Hz) 4.20 (d, 1H, 1.0 Hz) 6.55 (s, 1H). ^{13}C NMR: δ −3.43, −0.35, 13.3, 75.9, 89.2, 128.9, 147.0, 150.6. ^{29}Si NMR: δ −4.52, 5.31. Anal. Calcd for $C_{12}H_{23}NO_3SSi_2$: C, 45.39; H, 7.30; N, 4.41; S, 10.1. Found: C, 45.45; H, 7.38; N, 4.48; S, 10.42.

4,4-Dioxo-3-methyl-5-trimethylsilyl-6a-trimethylgermyl-3a,6a-dihydrothieno[2,3-*d*]isoxazoline-2 (3b). Yield: 76%. Mp: 88−89 °C. MS: *m*/*e* 348 ($M^{\bullet+} - 15$). ^{1}H NMR: δ 0.21 (s, 9H) 0.47 (s, 9H) 2.25 (d, 3H, $J = 1.0$ Hz) 4.19 (d, 1H, $J = 1.0$ Hz) 6.51 (s, 1H). ^{13}C NMR: δ −3.44, −0.23, 13.4, 75.7, 89.6, 129.8, 150.7. ^{29}Si NMR: δ 5.36. Anal. Calcd for $C_{12}H_{23}GeNO_3SSi$: C, 39.81; H, 6.40; N, 3.87; S, 8.86. Found: C, 39.69; H, 6.48; N, 3.59; S, 8.65.

4,4-Dioxo-3-methyl-5-trimethylgermyl-6a-trimethylsilyl-3a,6a-dihydrothieno[2,3-*d*]isoxazoline-2 (3c). Yield: 86%. Mp: 77−78 °C. MS: *m*/*e* 348 ($M^{\bullet+} - 15$). ^{1}H NMR: δ 0.32 (s, 9H) 0.33 (s, 9H) 2.23 (d, 3H, $J = 1.0$ Hz) 4.21 (d, 1H, $J = 1.0$ Hz) 6.56 (s, 1H). ^{13}C NMR: δ −3.22, −0.33, 13.3, 76.2, 89.7, 128.8, 147.8, 151.0. ^{29}Si NMR: δ −4.50. Anal. Calcd for $C_{12}H_{23}GeNO_3SSi$: C, 39.81; H, 6.40; N, 3.87; S, 8.86. Found: C, 39.87; H, 6.43; N, 3.79; S, 8.95.

4,4-Dioxo-3-methyl-5,6a-bis(trimethylgermyl)-3a,6a-dihydrothieno[2,3-*d*]isoxazoline-2 (3d). Yield: 72%. Mp: 106 °C. MS: *m*/*e* 392 ($M^{\bullet+} - 15$). ^{1}H NMR: δ 0.33 (s, 9H) 0.49 (s, 9H) 2.23 (d, 3H, $J = 1.0$ Hz) 4.18 (d, 1H, $J = 1.0$ Hz) 6.47 (s, 1H). ^{13}C NMR: δ −3.27, −0.24, 13.3, 76.0, 90.0, 133.5, 145.7, 150.9. Anal. Calcd for $C_{12}H_{23}Ge_2NO_3S$: C, 35.45; H, 5.70; N, 3.45; S, 7.89. Found: C, 35.59; H, 5.62; N, 3.52; S, 7.97.

4,4-Dioxo-3-methyl-5-(5-trimethylsilyl-2-thienyl)-3a,6a-dihydrothieno[2,3-*d*]isoxazoline-2 (3e). Yield: 49%. MS: *m*/*e* 327 ($M^{\bullet+}$). ^{1}H NMR: δ 0.32 (s, 9H), 2.32 (d, 3H, $J = 1.2$ Hz) 4.70 (dd, 1H, $J = 1.2$ Hz, $J = 9.4$ Hz), 5.90 (dd, 1H, $J = 3.2$ Hz, $J = 9.4$ Hz), 6.57 (d, 1H, $J = 3.2$ Hz), 6.65−6.74 (m, 2H). ^{13}C NMR: δ −0.5; 10.7; 71.5; 79.9; 124.7; 129.0; 129.5; 134.8; 139.2; 149.5; 154.5. ^{29}Si NMR: δ −5.4. Anal. Calcd for $C_{12}H_{23}NO_3S_2Si$: C, 47.68; H, 5.23; N, 4.28; S, 19.58. Found: C, 47.73; H, 5.11; N, 4.32; S, 19.82.

Crystal Structure Determination. The crystals were measured on a Syntex $P2_1$, four-circle computer-controlled single-crystal diffractometer. Crystal data and details of structure determination and refinement are collected in Table 2.

Acknowledgment. We are grateful to the Latvian Taiho Foundation for financial support.

Supporting Information Available: X-ray crystallography files, in CIF format, for the structure determination of **2a**−**e** and **3d**. This material is available free of charge via the Internet at http://pubs.acs.org.

OM0100885

---

(11) (a) Scheldrick, G. M. *Acta Crystallogr.* **1990**, *A46*, 467. (b) Andrianov, V. I. *Kristallografiya* **1987**, *32*, 228. (c) Mishnev, A. F.; Belyakov, S. V. *Kristallografiya* **1988**, *33*, 835.