

Effect of Water Molecules on the Cycloaromatization of Non-Conjugated Aromatic Tetraynes

Tomikazu Kawano,* Hiroki Inai, Kazuhiro Miyawaki, and Ikuo Ueda

The Institute of Scientific and Industrial Research, Osaka University, 8-1 Mihogaoka, Ibaraki, Osaka 567-0047

Received January 5, 2006; E-mail: kawano@sanken.osaka-u.ac.jp

Cycloaromatization of the thienyl tetrayne **1**, which was prepared in several steps from bis(trimethylsilyl)butadiyne and 3-bromothiophene-2-carbaldehyde, in benzene (0.33 mM) in the presence of molecular sieves 3A at room temperature gave the indeno[2,1-*b*]thiophene ring-fused 1*H*-2-benzopyran derivative **10** and indeno[2,1-*b*]thiophene derivative **11** in 11 and 40% yields, respectively. In contrast, cycloaromatization of **1** in the presence of water molecules at room temperature gave the indeno[2,1-*b*]thiophene ring-fused 1*H*-2-benzopyran derivative **10** and the indene ring-fused indeno[2,1-*b*]thiophene derivative **12** in 82 and 14% yields, respectively. Cycloaromatization of the phenyl tetrayne **9** in the presence of water molecules at room temperature also resulted in a dramatic change in product yields.

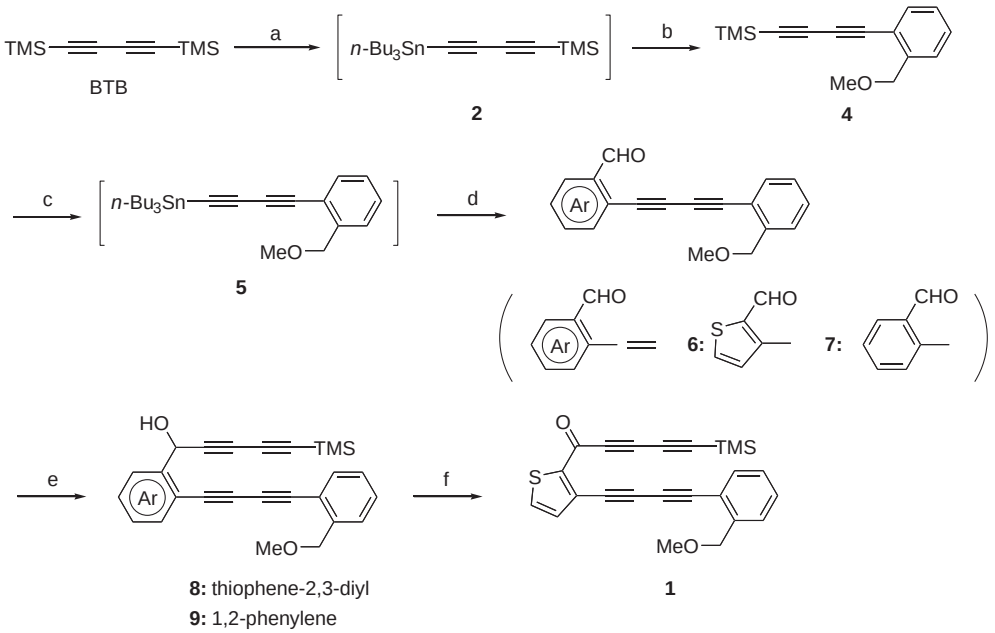
The cyclization of conjugated polyyne systems such as enediyne (the Bergman cyclization), enyne–allene (the Saito–Myers cyclization), and enyne–ketene (the Moore cyclization) forms arene radicals with DNA-cleaving activity.[1] While much effort and most recent investigations have focused on using these diradical-forming methods for DNA cleavage,[2] Grissom and Calkins first utilized the Bergman cycloaromatization of 1,2-diethynylbenzene derivatives as a means of generating a radical for carrying out a subsequent radical ring annulation reaction to give 3,4-dihydrobenz[*e*]indenes.[3–5] Since then, many examples have been reported using the resulting carbon diradicals for the construction of multicyclic systems.[1] We have recently reported that aromatic acyclic polyyne derivatives undergo cycloaromatization under mild conditions to afford polycyclic aromatic compounds such as fluorenol and semibullvalene skeletons.[6–11] In the course of elucidating the reaction mechanism into the cycloaromatization of non-conjugated aromatic polyyne derivatives, we examined the effects of a variety of factors, including solvent, temperature, and concentration, on the cycloaromatization. We describe herein the effects of water molecules on the cycloaromatization of the thienyl tetrayne **1** and phenyl tetrayne **9**, which are among the non-conjugated aromatic tetraynes.[12]

Results and Discussion

Preparation of Non-Conjugated Thienyl Tetraynes and Phenyl Tetraynes. Scheme 1 provides an outline for the preparation of the non-conjugated thienyl tetrayne and phenyl tetrayne derivatives **1** and **9**. Trimethylsilyl-monoprotected butadiynylstannane **2** was prepared in situ by lithiation of bis(trimethylsilyl)butadiyne (BTB),[13] followed by stannylation of the resulting monolithio derivative. The Stille coupling reaction of the stannane **2** with iodide **3**, which was prepared in 96% yield by *O*-methylation of commercially available 2-iodobenzyl alcohol in tetrahydrofuran (THF) at 0 °C,[7] in the presence of dichlorobis(triphenylphosphine)palladium(II) [$PdCl_2(PPh_3)_2$] in toluene at 110 °C, afforded the coupling product **4** in 99% yield. Cleavage of the silyl group of **4** with potassium carbonate in methanol at 0 °C, followed by stannylation by tributyltin chloride in diisopropylamine at room temperature, gave the stannane **5**, which was used for the next step without purification because of its instability. The Stille coupling reaction of **5** with commercially available 3-bromothiophene-2-carbaldehyde in the presence of [$PdCl_2(PPh_3)_2$] in toluene at 80 °C gave the coupling product **6** in 77% yield. Similarly, the reaction of **5** with commercially available 2-bromobenzaldehyde under similar conditions gave the coupling product **7** in 90% yield. The resulting coupling products **6** and **7** were allowed to react with a monolithio derivative of BTB in ether at −78 °C to afford alcohol derivatives **8** and **9** in 91 and 83% yields, respectively. Dess–Martin oxidation of **8** in dichloromethane (CH_2Cl_2) at 0 °C gave the desired product **1** in almost quantitative yield. This compound was also used for the next step without further purification due to its instability.

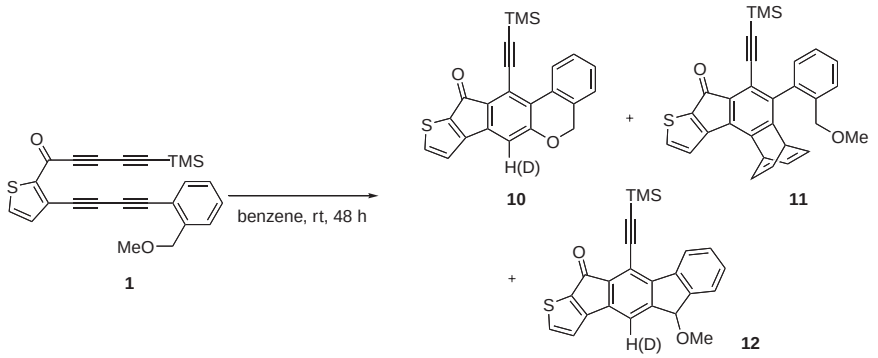
Cycloaromatization of Thienyl Tetraynes. In the first place, we examined the cycloaromatization of the thienyl tetrayne **1**. The results are summarized in Table 1. Cycloaromatization of **1** in benzene (0.33 mM) in the presence of molecular sieves 3A at room temperature gave the indeno[2,1-*b*]thiophene ring-fused 1*H*-2-benzopyran derivative **10** and indeno[2,1-*b*]thiophene derivative **11** in 11 and 40% yields, respectively (Entry 1). The production of **11** suggests that a radical intermediate is involved in the cycloaromatization of **1** under anhydrous conditions. In contrast, cycloaromatization of **1** in benzene in the presence of excess H_2O (100 equivalents) at room temperature proceeded smoothly to give the indeno[2,1-*b*]thiophene ring-fused 1*H*-2-benzopyran derivative **10** and indene ring-fused indeno[2,1-*b*]thiophene derivative **12** in 82 and 14% yields, respectively (Entry 2). When deuterium oxide (D_2O) was used instead of H_2O, compounds **10** and **12**, both of which were deuterated at the 7- and 6-positions of each molecular framework, were obtained in 78 and 21% yields, respectively (Entry 3). No production of **11** under hydrous conditions suggests that an ionic intermediate is involved in the cycloaromatization of **1** in the presence of H_2O. Similarly, we also examined the cycloaromatization of **1** under higher concentra-

Published on the web June 6, 2006; doi:10.1246/bcsj.79.944



Scheme 1. Preparation of non-conjugated aromatic tetrayne derivatives. *Reagents and Conditions*: (a) (1) MeLi–LiBr, Et_2O, rt; (2) *n*-Bu_3SnCl, rt; (b) 1-iodo-(2-methoxymethyl)benzene (**3**), [$PdCl_2(PPh_3)_2$], toluene, 110 °C (99%); (c) (1) K_2CO_3, MeOH, 0 °C, (2) *n*-Bu_3SnCl, diisopropylamine, rt; (d) 3-bromothiophene-2-carbaldehyde (for **6**), 2-bromobenzaldehyde (for **7**), [$PdCl_2(PPh_3)_2$], toluene, 80 °C (77% for **6**, 90% for **7**); (e) MeLi–LiBr, BTB, Et_2O, −78 °C (91% for **8**, 83% for **9**); (f) (for **8**) Dess–Martin periodinane, CH_2Cl_2, 0 °C (99%).

Table 1. Cycloaromatization of Thienyl Tetraynes



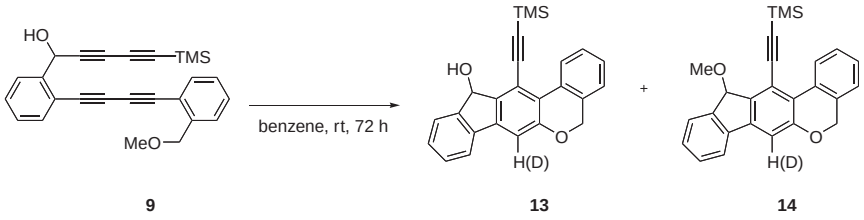
			Yield/%[a]		
Entry	Concentration/mM	Conditions	**10**	**11**	**12**
1	0.33	MS 3A	11	40	—[b]
2	0.33	H_2O (100 equiv)	82	—	14
3	0.33	D_2O (100 equiv)	78 (90)[c]	—	21 (78)
4	50	MS 3A	24	17	—
5	50	H_2O (100 equiv)	84	—	12
6	50	D_2O (100 equiv)	83 (96)	—	15 (77)

a) Isolated yield. b) Not detected. c) Deuteration degree determined by ^1H NMR integration in parenthesis.

tion (50 mM). However, no concentration-dependence for cycloaromatization of **1** under similar conditions was observed (Entries 4–6).

Cycloaromatization of Phenyl Tetraynes. We next examined the cycloaromatization of the phenyl tetrayne **9**. The results are summarized in Table 2. Cycloaromatization of **9** in benzene (0.33 mM) in the presence of molecular sieves 3A at room temperature gave the fluorene ring-fused 1*H*-2-benzopyran derivatives **13** and **14** in lower yields of 23 and 11%, respectively (Entry 1). In contrast, cycloaromatization of **9** in benzene in the presence of excess H_2O (100 equivalents) at room temperature proceeded smoothly to give **13** and **14** in 73 and 5% yields, respectively (Entry 2). When D_2O was used instead of H_2O, compounds **13** and **14**, both of which were deuterated at the 7-position of each molecular framework, were obtained in 71 and 4% yields, respectively (Entry 3).

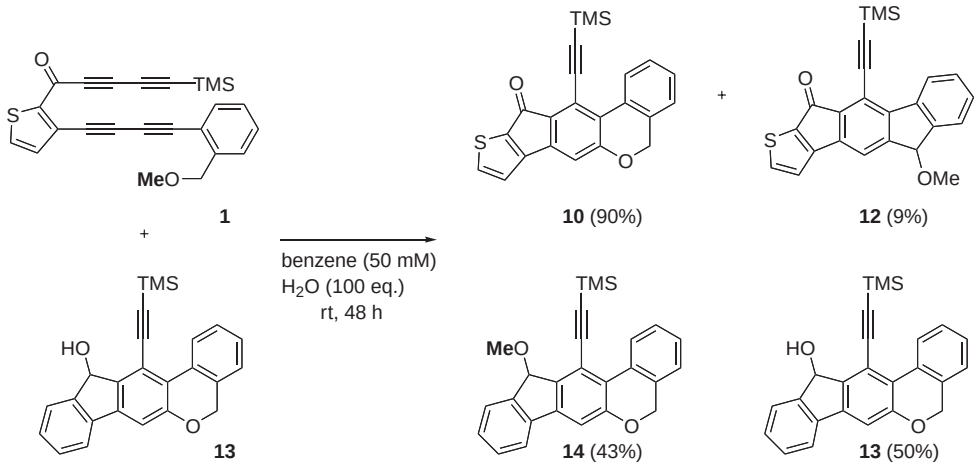
Table 2. Cycloaromatization of Phenyl Tetraynes



9 **13** **14**

Entry	Concentration/mM	Conditions	Yield/%[a] **13**	Yield/%[a] **14**
1	0.33	MS 3A	23	11
2	0.33	H_2O (100 equiv)	73	5
3	0.33	D_2O (100 equiv)	71 (90)[b]	4 (92)
4	50	MS 3A	20	24
5	50	H_2O (100 equiv)	40	54
6	50	D_2O (100 equiv)	35 (94)	45 (95)

a) Isolated yield. b) Deuteration degree determined by ^{1}H NMR integration in parenthesis.

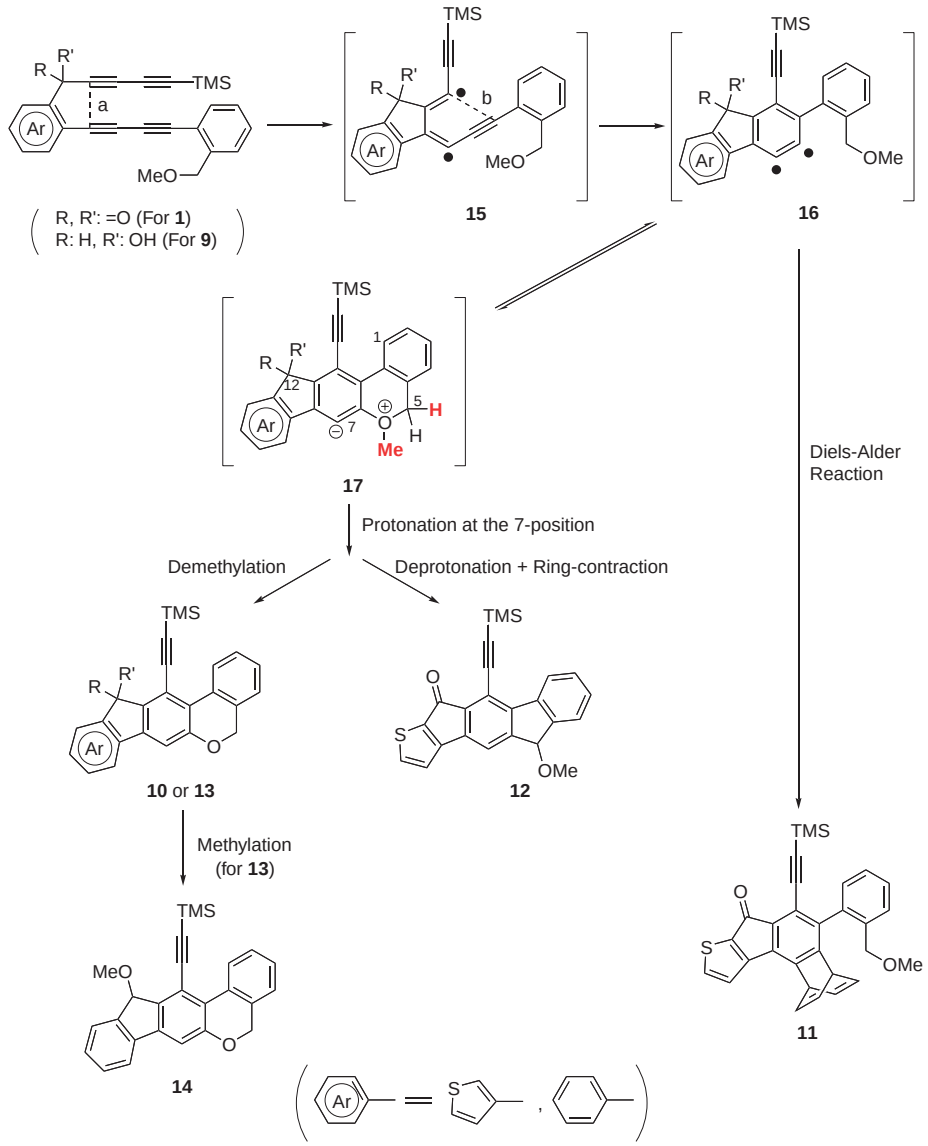


Scheme 2. Cycloaromatization of the thienyl tetrayne **1** in the presence of the fluorene ring-fused 1*H*-2-benzopyran derivative **13**.

In this reaction, no production of a Diels–Alder adduct such as **11** in the cycloaromatization of **1** under hydrous conditions suggests that ionic species are a key intermediate in the cycloaromatization of **9**. Similarly, we also examined the cycloaromatization of **9** under higher concentration (50 mM). Increasing the concentrations of the cyclization dramatically changed the yield of compound **14** up to ca. 50% yield, though no dependence on concentration for cycloaromatization of **9** under anhydrous conditions was observed (Entries 4–6).

Cycloaromatization of the Thienyl Tetrayne 1 in the Presence of the Fluorene Ring-Fused 1*H*-2-Benzopyran 13. To examine the mechanism for the formation of **14** in detail, we investigated the cycloaromatization of the thienyl tetrayne **1** in the presence of the fluorene ring-fused 1*H*-2-benzopyran derivative **13**, as shown in Scheme 2. Cycloaromatization of **1** in benzene (50 mM) in the presence of an equimolar amount of **13** and excess H_2O (100 equivalent) gave the methylated fluorene ring-fused 1*H*-2-benzopyran derivative **14** in 43% yield, as well as 90% yield of the indeno[2,1-*b*]thiophene ring-fused 1*H*-2-benzopyran derivative **10**, and 9% yield of the indene ring-fused indeno[2,1-*b*]thiophene derivative **12**, along with recovery (50%) of **13**. These results indicate that cycloaromatization of **9** under higher concentration (50 mM) in the presence of H_2O consequently takes place in a mode of intermolecular reaction, and that compound **14** is obtained by methylation of the hydroxy functional group of **13**.

Plausible Reaction Mechanism for the Cycloaromatization. A plausible mechanism for the cycloaromatization of non-conjugated aromatic tetraynes is illustrated in Scheme 3. Activation of the non-conjugated tetrayne system is triggered by cyclization of the position "a" in the initial step, followed by cyclization of the position "b" to the (σ,σ)-1,2-didehydrobenzene diradical **16** via the diradical **15**. Diels–Alder reaction of **16** with benzene as a solvent yields the indenothiophene derivative **11**. Cyclization of compound **16** can affords the intermediate **17**, which is made up of five rings. The intermediate **17** is rapidly protonated at the 7-position by a proton source such as water molecules. Then, the following demethylation gives indenothiophene **10** or fluorene ring-fused 1*H*-2-benzopyran derivative **13**. Methylation of **13** yields the methylated fluorene ring-fused 1*H*-2-benzopyran derivative **14**. Abstraction of a proton in the pyran ring of **17** after protonation, followed by ring-contraction to a five-membered ring from a six-membered ring produces the fluorene ring-fused indenothio-



Scheme 3. A plausible mechanism for the construction of the polycyclic aromatic compounds **10**–**14**.

phene **12**. In view of considering the plausible reaction mechanism we suggested, no production of Diels–Alder product on cycloaromatization of the phenyl tetrayne **9** may be because the intermediate **16** is unstable and chemical equilibrium shifts to **17** to a great extent. Lower yields of products for cycloaromatization of **9** under anhydrous conditions may be also caused by the instability of **16**. No ring-contraction product like compound **12** in the cycloaromatization of **9** was obtained because a benzylic hydroxy proton that is located at the 12-position of **17** is more acidic than the proton, which is located at the 5-position of **17**. Demethylation would be caused by the hydroxy functional group of **17**. It can be concluded that water molecules act as an important factor for the displacement of the equilibrium to **17** and for the stabilization of the intermediate **17**.

Conclusion

In conclusion, we have demonstrated that cycloaromatization of non-conjugated aromatic tetraynes proceeds smoothly to give a series of new polycyclic aromatic compounds, and that water molecules play an important role in the cycloaromatization of non-conjugated aromatic tetraynes. Furthermore, we have found that cycloaromatization of non-conjugated tetraynes in this study takes place in a radical or ionic reaction mode according to the reaction conditions.

Experimental

General. All reactions were carried out under an argon atmosphere with dry solvents under anhydrous conditions unless otherwise noted. Solvents and reagents were purified by literature methods where necessary.[14] All melting points were determined on a Yanagimoto micro melting point apparatus (Yanaco MP-500D) and are uncorrected. Infrared (IR) spectra were recorded on a Perkin-Elmer system 2000 FT-IR spectrometer. UV absorption spectra were obtained using a Hitachi 260-30 spectrophotometer. ^{1}H NMR spectra were recorded on a JEOL JNM-LA400 (400 MHz) spectrometer; chemical shifts (δ) are reported in parts per million relative to tetramethylsilane (TMS). Splitting patterns are designated as s, singlet; d, doublet; t, triplet; q, quartet; m,

multiplet; br, broad; dsp, double of septets. Mass spectra (MS) were recorded on a JEOL JMS-600 mass spectrometer. Elemental analyses were performed by the Materials Analysis Center of the Institute of Scientific and Industrial Research, Osaka University. Column chromatography was performed on Merck silica gel 60. Compound **3** was prepared from commercially available 2-iodobenzyl alcohol according to the literature procedure.[8]

1-Methoxymethyl-2-[4-(trimethylsilyl)buta-1,3-diynyl]benzene (4). To a solution of bis(trimethylsilyl)butadiyne (2.64 g, 13.6 mmol) in ether (15 mL) was added dropwise a solution of methyllithium–lithium bromide complex (1.5 M, 6.05 mL, 9.08 mmol) in ether at room temperature. After being stirred at the same temperature for 5 h, tributyltin chloride (2.46 mL, 9.08 mmol) was added to the resulting reaction mixture at room temperature, and the reaction mixture was stirred at the same temperature for 2 h. After being concentrated in vacuo, the resulting residue was diluted with benzene, and then filtered through a pad of Celite. The filtrate was evaporated to dryness under reduced pressure to give the trimethylsilyl-monoprotected butadiynylstannane **2**. To a solution of **2** in toluene (40 mL) were added iodide **3** (150 mg, 6.05 mmol), and dichlorobis(triphenylphosphine)palladium(II) [$PdCl_2(PPh_3)_2$] (211 mg, 0.303 mmol) at 0 °C. After being stirred at 110 °C for 2 h, the resulting reaction mixture was cooled to room temperature, and treated with 10% aqueous potassium fluoride. After being stirred for 0.5 h and filtrated through a pad of Celite, the resulting mixture was extracted with benzene. The organic layer was washed with H_2O and brine, and then dried over anhydrous $MgSO_4$. After removal of the solvent, the residue was purified by column chromatography (silica gel, hexane–AcOEt) to give **4** (1.47 g, 99%) as a brown oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.48–7.43 (m, 2H), 7.36–7.32 (m, 1H), 7.22 (m, 1H), 4.60 (s, 2H), 3.24 (s, 3H), 0.23 (s, 9H); IR (neat): 2350 cm^{-1}; FABMS (NBA) m/z 243 $[(M+H)]^+$; Found: C, 74.22; H, 7.53%. Calcd for $C_{15}H_{18}OSi$: C, 74.33; H, 7.49%.

3-{4-[2-(Methoxymethyl)phenyl]buta-1,3-diynyl}thiophene-2-carbaldehyde (6). To a solution of **4** (1.00 g, 4.06 mmol) in methanol (15 mL) was slowly added potassium carbonate (57.0 mg, 0.41 mmol) at 0 °C, and then the resulting reaction mixture was stirred at the same temperature for 1 h. After being neutralized by 1 M hydrochloric acid, the mixture was extracted with ether. The oraganic layer was washed with H_2O and brine, and then dried over anhydrous $MgSO_4$. After removal of the solvent, the residue was purified by column chromatography (benzene) to give the de-protected compound. The resulting compound was added to a mixture of *N*,*N*-diisopropylethylamine (8 mL) and tributyltin chloride (2.20 mL, 8.12 mmol) at 0 °C. After being stirred at the same temperature for 2 h, the reaction mixture was evaporated in vacuo. The residue was diluted with benzene, filtrated through a pad of Celite, and then evaporated to dryness under reduced pressure to afford the stannane **5**. To a solution of **5** and commercially available 3-bromothiophene-2-carbaldehyde in toluene (30 mL) was added [$PdCl_2(PPh_3)_2$] (119 mg, 0.169 mmol). After being heated under reflux for 2 h, the reaction mixture was cooled to room temperature, and treated with 10% aqueous potassium fluoride. After being stirred for 0.5 h and filtrated through a pad of Celite, the resulting mixture was extracted with benzene. The organic layer was washed with H_2O and brine, and then dried over anhydrous $MgSO_4$. After removal of the solvent, the residue was purified by column chromatography (silica gel, hexane–AcOEt) to give **6** (698 mg, 77%) as pale yellow needles; mp 64.5–65.5 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.17 (s, 1H), 7.70 (d, $J = 4.9$ Hz, 1H), 7.56 (d, $J = 7.8$ Hz, 1H), 7.50 (d, $J = 7.8$ Hz, 1H), 7.42 (t, $J = 7.8$ Hz, 1H), 7.29 (t, $J = 7.8$ Hz, 1H), 7.26 (d, $J = 4.9$ Hz, 1H), 4.66 (s, 2H), 3.48 (s, 3H); IR (KBr): 2350, 2200, 1655 cm^{-1}; FABMS (NBA) m/z 281 $[(M+H)]^+$; Found: C, 72.61; H, 4.11; S, 11.45%. Calcd for $C_{17}H_{12}O_2S$: C, 72.83; H, 4.31; S, 11.44%.

2-{4-[2-(Methoxymethyl)phenyl]buta-1,3-diynyl}benzaldehyde (7). This compound was prepared from the stannane **5** and 2-bromobenzaldehyde according to the method used for the preparation of **6**. Colorless needles; yield 90%; mp 53.5–54.0 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.52 (s, 1H), 7.94–7.92 (m, 1H), 7.66–7.25 (m, 7H), 4.66 (s, 2H), 3.48 (s, 3H); IR (KBr): 2210, 1700 cm^{-1}; FABMS (NBA) m/z 298 $[(M+H)]^+$; Found: C, 83.33; H, 5.04%. Calcd for $C_{19}H_{14}O_2$: C, 83.19; H, 5.14%.

1-(3-{4-[2-(Methoxymethyl)phenyl]buta-1,3-diynyl}thiophen-2-yl)-5-(trimethylsilyl)penta-2,4-diyn-1-ol (8). To a solution of bis(trimethylsilyl)butadiyne (1.36 g, 7.00 mmol) in ether (15 mL) was added dropwise a solution of methyllithium–lithium bromide complex (1.5 M, 2.33 mL, 3.50 mmol) in ether at room temperature. After being stirred at the same temperature for 5 h, the resulting lithium acetylide was cooled to −78 °C. The lithium acetylide was added dropwise to a solution of **6** (470 mg, 1.75 mmol) in dry ether (15 mL)–THF (5.0 mL), and then the reaction mixture was stirred at room temperature for 3 h. After treatment with saturated aqueous ammonium chloride, the reaction mixture was extracted with ether. The organic layer was washed with H_2O and brine, and then dried over anhydrous $MgSO_4$. After removal of the solvent, the residue was purified by column chromatography (silica gel, hexane–AcOEt) to give **8** (642 mg, 91%) as a pale yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.54 (d, $J = 7.6$ Hz, 1H), 7.49 (d, $J = 7.6$ Hz, 1H), 7.40 (t, $J = 7.6$ Hz, 1H), 7.27 (t, $J = 7.6$ Hz, 1H), 7.26 (d, $J = 5.1$ Hz, 1H), 7.08 (d, $J = 5.1$ Hz, 1H), 6.00 (d, $J = 5.4$ Hz, 1H), 4.66 (s, 2H), 3.49 (s, 3H), 2.53 (d, $J = 5.4$ Hz, 1H), 0.20 (s, 9H); IR (neat): 3340, 2350, 2100 cm^{-1}; FABMS (NBA) m/z 403 $[(M+H)]^+$; Found: C, 71.40; H, 5.39; S, 7.78%. Calcd for $C_{24}H_{22}O_2SSi$: C, 71.60; H, 5.51; S, 7.96%.

1-(2-{4-[2-(Methoxymethyl)phenyl]buta-1,3-diynyl}phenyl)-5-(trimethylsilyl)penta-2,4-diyn-1-ol (9). This compound was prepared from the aldehyde **7** according to the method used for the preparation of **8**. Pale yellow oil; yield 83%; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.69 (d, $J = 7.8$ Hz, 1H), 7.55 (d, $J = 7.8$ Hz, 2H), 7.48 (d, $J = 7.3$ Hz, 1H), 7.44–7.36 (m, 2H), 7.34–7.25 (m, 2H), 5.94 (s, 1H), 4.67 (s, 2H), 3.52 (s, 3H), 2.81 (s, 1H), 0.19 (s, 9H); IR (KBr): 3350, 2220, 2100 cm^{-1}; FABMS (NBA) m/z 397 $[(M+H)]^+$; Found: C, 78.52; H, 5.89%. Calcd for $C_{26}H_{24}O_2Si$: C, 78.75; H, 6.10%.

1-(3-{4-[2-(Methoxymethyl)phenyl]buta-1,3-diynyl}thiophen-2-yl)-5-(trimethylsilyl)penta-2,4-diyn-1-one (1). To a solution of **8** (200 mg, 0.497 mmol) in dry CH_2Cl_2 (80 mL) was added the Dess–Martin reagent (1.05 g, 2.49 mmol) at 0 °C. After being stirred at the same temperature for 0.5 h, the reaction mixture was poured into saturated aqueous sodium hydrogencarbonate, and then extracted with CH_2Cl_2. The organic layer was washed with H_2O and brine, and then dried over anhydrous $MgSO_4$. After removal of the solvent, the residue was purified by column chromatography (silica gel, hexane–AcOEt) to give **1** (198 mg, 99%) as a yellow powder; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62 (d, $J = 5.1$ Hz, 1H), 7.54 (d, $J = 7.8$ Hz, 1H), 7.49 (d, $J = 7.8$ Hz, 1H), 7.40 (t, $J = 7.8$ Hz, 1H), 7.26 (d, $J = 5.1$ Hz, 1H), 7.24 (t, $J = 7.8$ Hz, 1H), 4.67 (s, 2H), 3.49 (s, 3H), 0.14 (s, 9H); FABMS (NBA) m/z 401 $[(M+H)]^+$. This compound was used for the next step without further purification due to its instability.

Cycloaromatization of 1 under Anhydrous Conditions. To

a solution of **1** (100 mg, 0.248 mmol) in dry benzene (750 mL or 5.0 mL) was added molecular sieves 3A at room temperature. After being stirred at room temperature for 48 h, the resulting reaction mixture was filtrated, and then the filtrate was evaporated in vacuo to give an oily residue. The residue was purified by column chromatography (silica gel, hexane–AcOEt) to give **10** and **11**.

Indeno[2,1-*b*]thiophene Ring-Fused 1*H*-2-Benzopyran 10: Yellow plates; mp 129.4–129.8 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.79 (d, $J = 7.6$ Hz, 1H), 7.71 (d, $J = 4.6$ Hz, 1H), 7.40–7.30 (m, 2H), 7.20 (d, $J = 7.6$ Hz, 1H), 7.10 (d, $J = 4.6$ Hz, 1H), 6.86 (s, 1H), 5.05 (s, 2H), 0.34 (s, 9H); IR (KBr): 2150, 1700 cm^{-1}; FABMS (NBA) m/z 387 $[(M + H)]^+$; Found: C, 71.20; H, 4.65; S, 8.47%. Calcd for $C_{23}H_{18}O_2SSi$: C, 71.47; H, 4.69; S, 8.30%.

Indeno[2,1-*b*]thiophene 11: Yellow powder; mp 74.3–75.3 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78 (d, $J = 4.9$ Hz, 1H), 7.55 (d, $J = 7.3$ Hz, 1H), 7.44 (t, $J = 7.3$ Hz, 1H), 7.42 (d, $J = 4.9$ Hz, 1H), 7.36 (t, $J = 7.3$ Hz, 1H), 7.07 (d, $J = 7.3$ Hz, 1H), 6.88–6.85 (m, 2H), 6.72–6.67 (m, 2H), 5.28 (t, $J = 5.9$ Hz, 1H), 4.54 (t, $J = 5.9$ Hz, 1H), 4.22 (d, $J = 12.2$ Hz, 1H), 4.13 (d, $J = 12.2$ Hz, 1H), 3.20 (s, 3H), −0.04 (s, 9H); IR (KBr): 2140, 1700 cm^{-1}; FABMS (NBA) m/z 479 $[(M + H)]^+$; Found: C, 75.04; H, 5.23; S, 6.77%. Calcd for $C_{30}H_{26}O_2SSi$: C, 75.27; H, 5.47; S, 6.70%.

Cycloaromatization of 1 in the Presence of Water. To a solution of **1** (100 mg, 0.248 mmol) in dry benzene (750 mL or 5.0 mL) was added H_2O (0.45 mL, 100 equivalents) at room temperature. After being stirred at room temperature for 48 h, the resulting solution was evaporated in vacuo to give an oily residue. The residue was purified by column chromatography (silica gel, hexane–AcOEt) to give **10** and **12**.

Indene Ring-Fused Indeno[2,1-*b*]thiophene 12: Yellow plates; mp 202.5–203.0 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.60 (d, $J = 7.1$ Hz, 1H), 7.74 (d, $J = 4.6$ Hz, 1H), 7.60 (d, $J = 7.1$ Hz, 1H), 7.43 (t, $J = 7.1$ Hz, 1H), 7.40 (s, 1H), 7.37 (t, $J = 7.1$ Hz, 1H), 7.13 (d, $J = 4.6$ Hz, 1H), 5.53 (s, 1H), 3.03 (s, 3H), 0.41 (s, 9H); IR (KBr): 2150, 1700 cm^{-1}; FABMS (NBA) m/z 401 $[(M + H)]^+$; Found: C, 71.69; H, 4.88; S, 7.88%. Calcd for $C_{24}H_{20}O_2SSi$: C, 71.96; H, 5.03; S, 8.01%.

Cycloaromatization of Non-Conjugated Phenyl Tetrayne 9. Compounds **13** and **14** were obtained according to the methods for the cycloaromatization of **1**.

Fluorene Ring-Fused 1*H*-2-Benzopyran 13: Yellow plates; mp 63.5–64.0 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.78–8.76 (m, 1H), 7.70–7.68 (m, 2H), 7.63–7.61 (m, 1H), 7.43–7.41 (m, 2H), 7.30 (s, 1H), 7.23–7.21 (m, 2H), 5.84 (d, $J = 3.3$ Hz, 1H), 5.05 (d, $J = 12.9$ Hz, 1H), 5.04 (d, $J = 12.9$ Hz, 1H), 3.38 (d, $J = 3.4$ Hz, 1H), 0.36 (s, 9H); IR (KBr): 3565, 2140 cm^{-1}; FABMS (NBA) m/z 383 $[(M + H)]^+$; Found: C, 78.47; H, 5.52%. Calcd for $C_{25}H_{22}O_2Si$: C, 78.50; H, 5.80%.

Methylated Fluorene Ring-Fused 1*H*-2-Benzopyran 14: Brown oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.91–8.89 (m, 1H), 7.41–7.19 (m, 8H), 5.63 (s, 1H), 5.06 (d, $J = 12.7$ Hz, 1H), 4.99 (d, $J = 12.7$ Hz, 1H), 3.27 (s, 3H), 0.33 (s, 9H); IR (KBr): 2210, 1700 cm^{-1}; FABMS (NBA) m/z 397 $[(M + H)]^+$; Found: C, 78.70; H, 6.35%. Calcd for $C_{26}H_{24}O_2Si$: C, 78.75; H, 6.10%.

Cycloaromatization of 1 in the Presence of 13. To a solution of **1** (100 mg, 0.248 mmol) in dry benzene (50 mL) were added H_2O (0.45 mL, 100 equivalent) and **13** (95 mg, 0.248 mmol) at room temperature. After being stirred at the same temperature for 48 h, the resulting solution was evaporated in vacuo to give an oily residue. The residue was purified by column chromatography (silica gel, hexane–AcOEt) to give **10** (90%), **12** (9%), and **14** (43%), along with the recovery of **13** (50%).

We thank the Materials Analysis Center of ISIR-Sanken, Osaka University for assisting us with elemental analysis.

References

1 K. K. Wang, *Chem. Rev.* **1996**, *96*, 207.

2 For examples, see: a) A. L. Smith, K. C. Nicolaou, *J. Med. Chem.* **1996**, *39*, 2103. b) K. C. Nicolaou, W.-M. Dai, *Angew. Chem., Int. Ed. Engl.* **1991**, *30*, 1387. c) K. C. Nicolaou, P. Maligres, J. Shin, E. de Leon, D. Rideout, *J. Am. Chem. Soc.* **1990**, *112*, 7825. d) R. Nagata, H. Yamanaka, E. Murahashi, I. Saito, *Tetrahedron Lett.* **1990**, *31*, 2907. e) A. G. Myers, E. Y. Kuo, N. S. Finney, *J. Am. Chem. Soc.* **1989**, *111*, 8057. f) T. P. Lackhart, P. B. Comita, R. G. Bergman, *J. Am. Chem. Soc.* **1981**, *103*, 4082. g) R. G. Bergman, *Acc. Chem. Res.* **1973**, *6*, 25. h) G. C. Johnson, J. J. Stofko, Jr., T. P. Lockhart, D. W. Brown, R. G. Bergman, *J. Org. Chem.* **1979**, *44*, 4215.

3 J. W. Grissom, D. Klingberg, D. Huang, B. J. Slattery, *J. Org. Chem.* **1997**, *62*, 603.

4 J. W. Grissom, T. L. Calkins, *J. Org. Chem.* **1993**, *58*, 5422.

5 J. W. Grissom, T. L. Calkins, *Tetrahedron Lett.* **1992**, *33*, 2315.

6 T. Kawano, H. Inai, K. Miyawaki, I. Ueda, *Tetrahedron Lett.* **2005**, *46*, 1233.

7 K. Miyawaki, T. Kawano, I. Ueda, *Tetrahedron Lett.* **2000**, *41*, 1447.

8 K. Miyawaki, T. Kawano, I. Ueda, *Tetrahedron Lett.* **1998**, *39*, 6923.

9 T. Kawano, C. Ikemoto, I. Ueda, *Tetrahedron Lett.* **1998**, *39*, 6491.

10 K. Miyawaki, R. Suzuki, T. Kawano, I. Ueda, *Tetrahedron Lett.* **1997**, *38*, 3943.

11 The thienyl tetrayne **1**, which has a carbonyl functional group, was selected because **1** can cycloaromatize at room temperature, whereas no cycloaromatization of thienyl tetrayne possessing a hydroxy group takes place at room temperature. The phenyl tetrayne **9**, which has a hydroxy functional group, was selected because **9** can cycloaromatize at room temperature, whereas cycloaromatization of phenyl tetrayne possessing a carbonyl group rapidly decomposes at room temperature.

12 A. B. Holmes, C. L. D. Jenning-White, A. H. Schulthess, B. Akinde, D. R. M. Walton, *J. Chem. Soc., Chem. Commun.* **1979**, 840.

13 R. C. Larock, L. W. Harrison, *J. Am. Chem. Soc.* **1984**, *106*, 4218.

14 *Purification of Laboratory Chemicals*, ed. by D. D. Perrin, W. L. Armarego, Pergamon, New York, **1988**.