A Convenient One-Pot Procedure to Arylcyclobutenes from Arylacetylenes

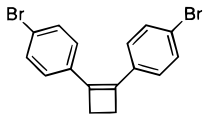
Tamotsu Takahashi,*[,†,‡] Baojian Shen,[‡] Kiyohiko Nakajima,[†,§] and Zhenfeng Xi[†,||]

Catalysis Research Center and Graduate School of Pharmaceutical Sciences, Hokkaido University, and CREST, Science and Technology Corporation (JST), Sapporo 060-0811, Japan, Department of Chemistry, Aichi University of Education, Kariya, Aichi 448-8542, Japan, and Department of Chemistry, Peking University, Beijing 100871, China

Received April 6, 1999

Introduction

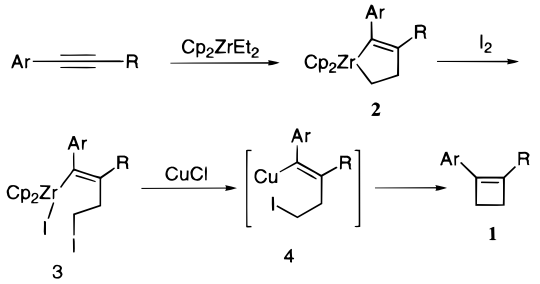
The design and synthesis of conjugated polymers or oligomers with various repeat units are of great current interest.[1−3] Small rings such as cyclobutenes with a well-defined skeleton have not been used as units or monomers in conjugated polymers, to our knowledge. One major reason is the limited number of convenient preparative methods of conjugated cyclobutene derivatives such as 1,2-diaryl cyclobutenes.[4] Negishi et al.[4d] have recently reported that 1,2-disubstituted cyclobutene derivatives can be prepared from the reaction of ^{t}BuLi and 1,4-diiodo-1-alkenes which are isolated from treatment of zirconacyclopentenes[5] with I_2. However, the use of ^{t}BuLi does not tolerate other functional groups in the starting diiodides. In fact, preparation of **1a** by this



1a

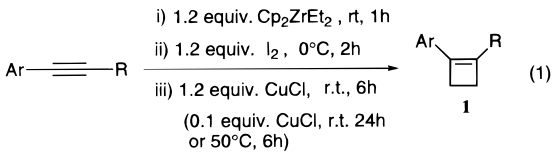
method did not give a satisfactory result. On the other hand, we have already reported selective halogenation reactions[6] and CuCl-assisted new carbon−carbon bond formation reactions[7] of zirconacyclopentenes. In the course of our further investigations, we found that an intramolecular coupling between alkyl iodide and the alkenylcopper moiety in **4** led to the formation of cyclobutene derivatives as shown in Scheme 1. And this combination can provide a convenient one-pot procedure from readily available arylacetylene and Cp_2ZrEt_2 to arylcyclobutenes. Furthermore, the use of CuCl could tolerate a wide variety of functional groups, and thus, preparation of **1a** would become easily available. Herein we would like to report a convenient one-pot procedure which affords **1a** and various other 1,2-diarylcyclobutene derivatives.

Scheme 1



Results and Discussion

We have reported that, when the substituent in the a position of a zirconacyclopentene is an aryl group, monoiodinolysis of the zirconacyclopentene gives only monoalkyl iodide in high yield.[6] As we expected, addition of 1.2 equiv of I_2 to the zirconacyclopentene of bis(4-bromophenyl)acetylene, followed by addition of 1.2 equiv of CuCl in a one-pot reaction, afforded a clean formation of 1,2-bis(4-bromophenyl)cyclobutene (**1a**) in 64% isolated yield (eq 1, Table 1). The aryl bromides remained intact



(1)

during this reaction. Also, aryl chloride in **1b**, aryl bromide in **1c**, and aryl iodide in **1d** were all tolerated. Symmetrically substituted cyclobutene and unsymmetrically substituted cyclobutenes with aryl groups could be readily prepared by this one-pot operation. In addition, we found that the CuCl-mediated cyclization for cyclobutene formation could be a catalytic reaction. Addi-

† CREST.
‡ Hokkaido University.
§ Aichi University.
|| Peking University.

(1) *Organic Materials for Non-Linear Optics II*; Hann, R. A., Bloor, D., Eds.; Redwood Press: Melksham, England, 1991.

(2) (a) *Introduction to Molecular Electronics*; Petty, M. C., Bryce, M. R., Bloor, D., Eds.; Oxford University Press: New York, 1995. (b) Tour, J. M. *Chem. Rev.* **1996**, *96*, 537.

(3) (a) Pearson, D. L.; Tour, J. M. *J. Org. Chem.* **1997**, *62*, 1376. (b) Jones, L., II; Schumm, J. S.; Tour, J. M. *J. Org. Chem.* **1997**, *62*, 1388.

(4) (a) *Houben-Weyl's Methods of Organic Chemistry, Additional and Supplementary Volumes to the 4th Edition*; de Meijere, A., Ed; Georg Thieme Verlag: Stuttgart, Germany, 1997; Col. E 17f, pp 615−826. (b) Durst, T.; Breau, L. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon: Tokyo, 1991; Vol. 5, p 675. (c) Negishi, E.; Liu, F.; Choueiry, D.; Mohamud, M. M.; Silveira, A., Jr.; Reeves, M. *J. Org. Chem.* **1996**, *61*, 8325. (d) Newman, M. S.; Kaugars, G. *J. Org. Chem.* **1965**, *30*, 3295. (e) Fry, A. J.; Moore, R. H. *J. Org. Chem.* **1968**, *33*, 425. (f) Hill, E. A.; Engel, M. R. *J. Org. Chem.* **1971**, *36*, 1356. (g) Photis, J. M.; Paquette, L. A. *J. Am. Chem. Soc.* **1974**, *96*, 4715. (h) Hill, E. A. *J. Am. Chem. Soc.* **1972**, *94*, 7462. (i) Snider, B. B.; Rodini, D. J.; Conn, R. S. E.; Sealfon, S. *J. Am. Chem. Soc.* **1979**, *101*, 5283. (j) Reed, M. W.; Pollart, D. J.; Perri, S. T.; Foland, L. D.; Moore, H. W. *J. Org. Chem.* **1988**, *53*, 2477. (k) Kasai, K.; Liu, Y.; Hara, R.; Takahashi, T. *Chem. Commun.* **1998**, 1989. (l) Liu, Y.; Sun, W.-H.; Nakajima, K.; Takahashi, T. *Chem. Commun.* **1998**, 1133. (m) Takahashi, T.; Xi, Z.; Rischer, R.; Huo, S.; Xi, C.; Nakajima, K. *J. Am. Chem. Soc.* **1997**, *119*, 4561.

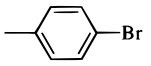
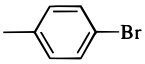
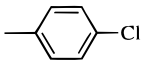
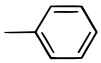
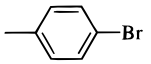
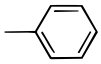
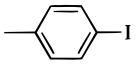
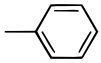
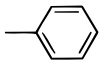
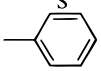
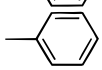
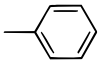
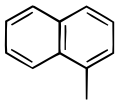
(5) Takahashi, T.; Kageyama, M.; Denisov, V.; Hara, R.; Negishi, E. *Tetrahedron Lett.* **1993**, *34*, 687.

(6) (a) Takahashi, T.; Aoyagi, K.; Hara, R.; Suzuki, N. *J. Chem. Soc., Chem. Commun.* **1993**, 1042. (b) Takahashi, T.; Aoyagi, K.; Kondakov, D. Y. *J. Chem. Soc., Chem. Commun.* **1994**, 747. (c) Aoyagi, K.; Kasai, K.; Kondakov, D. Y.; Hara, R.; Suzuki, N.; Takahashi, T. *Inorg. Chim. Acta* **1994**, *220*, 319.

(7) (a) Takahashi, T.; Xi, Z.; Kotora, M.; Xi, C.; Nakajima, K. *Tetrahedron Lett.* **1996**, *37*, 7521. (b) Kasai, K.; Kotora, M.; Suzuki, N.; Takahashi, T. *J. Chem. Soc., Chem. Commun.* **1995**, 109. (c) Takahashi, T.; Kotora, M.; Kasai, K.; Suzuki, N. *Tetrahedron Lett.* **1994**, *35*, 5685. See also: (d) Takahashi, T.; Kotora, M.; Kasai, K.; Suzuki, N.; Nakajima, K. *Organometallics* **1994**, *13*, 3, 4183. (e) Takahashi, T.; Kotora, M.; Xi, Z. *J. Chem. Soc., Chem. Commun.* **1995**, 361. (f) Takahashi, T.; Hara, R.; Nishihara, Y.; Kotora, M. *J. Am. Chem. Soc.* **1996**, *118*, 5154.

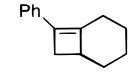
10.1021/jo990596c CCC: $18.00
Published on Web 10/21/1999

Table 1. One-Pot Preparation of Arylcyclobutene Derivatives via Zirconacyclopentenes

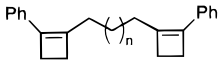
Ar	R	Product	Isolated yield (%)
		**1a**	64
		**1b**	65
		**1c**	63
		**1d**	61
		**1e**	51
		**1f**	86
	-$C_{10}H_{21}{}^n$	**1g**	59
	-$C_4H_9{}^n$	**1h**	76

tion of 0.1 equiv of CuCl instead of 1.2 equiv of CuCl afforded similar results. However, it required a longer reaction time (24 h) or higher reaction temperature (50 °C, 6 h).

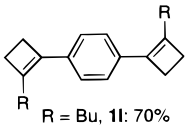
Bicyclic compound **1i** was obtained in 62% isolated yield from its corresponding bicyclic zirconacyclopentene.[8] Bridged 1,2-disubstituted cyclobutenes **1j**−**m** were also



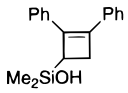
1i: 62%



1j: n = 2, 65%.
1k: n = 3, 81%.



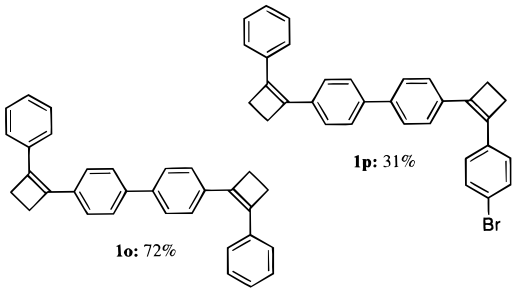
R = Bu, **1l**: 70%
R = Ph, **1m**: 36%



1n: 62%

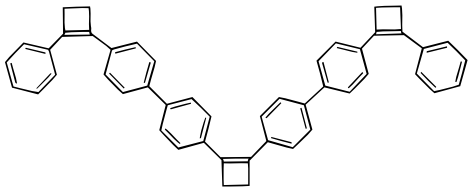
easily prepared in good isolated yields (**1j**, 65%; **1k**, 81%; **1l**, 70%; **1m**, 36%) starting from their corresponding bridged zirconacyclopentenes.[9] Trisubstituted cyclobutene derivative **1n** was obtained in 62% yield. Formation of the bridged 1,2-disubstituted cyclobutene **1m** has been further verified by X-ray crystallography (see the Supporting Information).[10]

As demonstrations using the halide-substituted cyclobutene derivatives as monomers, a variety of bridged 1,2-disubstituted cyclobutene derivatives containing two cyclobutene units (**1o**, 72%; **1p**, 31%) and three cyclobutene units (**1q**, 55%) could be readily obtained by applying the known methods.[11]



1o: 72%

1p: 31%



1q: 55%

Experimental Section[12]

Representative Procedure for the Preparation of 1,2-Disubstituted Cyclobutenes: Synthesis of 1,2-Bis(4-bromophenyl)cyclobutene (1a). To a solution of Cp_2ZrCl_2 (2.4 mmol, 700 mg) in THF (15 mL) was added ethylmagnesium bromide (4.8 mmol, 5.05 mL, 0.95 mol/L THF solution) at −78 °C. After the solution was stirred for 1 h at −78 °C, 1,2-bis(4-bromophenyl)acetylene (672 mg, 2.0 mmol) was added and the reaction mixture was allowed to be warmed to 0 °C for 3 h. Iodine (2.4 mmol, 609 mg) was then added at 0 °C, and the mixture was stirred for an additional 3 h. Copper(I) chloride (2.4 mmol, 238 mg) was added, and the mixture was stirred at room temperature for 6 h. The reaction mixture was then quenched with 3 N HCl and extracted with hexane. The extract was washed with water, $NaHCO_3$ (20% aqueous solution), water, NaS_2O_3, water, and brine and dried over $MgSO_4$. Filtration and evaporation provided a solid substance. Column chromatography on silica gel with hexane as the eluent afforded 466 mg (64%, purity > 98%) of the desired compound: mp 118.0−119.0 °C; ^{1}H NMR ($CDCl_3$, Me_4Si) δ 7.44 (d, J = 8.5 Hz, 4H), 7.34 (d, J = 8.5 Hz, 4H), 2.74 (s, 4H); ^{13}C NMR ($CDCl_3$, Me_4Si) δ 138.20, 134.62, 131.51, 127.52, 121.40, 26.80. Anal. Calcd for $C_{16}H_{12}Br_2$: C, 52.78; H, 3.32; Br, 43.89. Found: C, 52.44; H, 3.43; Br, 43.23. HRMS: calcd for $C_{16}H_{12}Br_2$, 361.9305; found, 361.9311.

When a catalytic amount of CuCl (0.1 equiv) was used, the reaction mixture was stirred for 24 h at room temperature or for 6 h at 50 °C.

For preparation of bridged cyclobutenes **1j**−**m**, the procedure was essentially the same as the above. The ratio of the reagents was as follows: 1.2 mmol of Cp_2ZrCl_2; 2.4 mmol of EtMgBr; 0.5 mmol of diyne; 1.2 mmol of I_2; 1.2 mmol of CuCl.

1-Phenyl-2-(2-thienyl)cyclobutene (1e): ^{1}H NMR ($CDCl_3$, Me_4Si) δ 7.64−7.62 (m, 2H), 7.37−7.17 (m, 5H), 7.01−6.97 (m, 1H), 2.81−2.77 (m, 4H); ^{13}C NMR ($CDCl_3$, Me_4Si) δ 136.54, 131.60, 131.40, 128.34, 128.31, 127.49, 127.08, 126.04, 125.13, 124.46, 27.53, 26.69. HRMS: calcd for $C_{14}H_{12}S$, 212.0659; found, 212.0656.

1,2-Diphenylcyclobutene (1f):[13] mp 134.8−135.2 °C; ^{1}H NMR ($CDCl_3$, Me_4Si) δ 7.52 (d, J = 7.2 Hz, 4H), 7.31 (t, J = 7.2 Hz, 4H), 7.23 (t, J = 7.2 Hz, 2H), 2.77 (s, 4H); ^{13}C NMR ($CDCl_3$,

(8) Negishi, E.; Cederbaum, F. E.; Takahashi, T. *Tetrahedron Lett.* **1986**, *27*, 2829.

(9) (a) Takahashi, T.; Xi, Z.; Nishihara, Y.; Huo, S.; Kasai, K.; Aoyagi, K.; Denisov, V.; Negishi, E. *Tetrahedron* **1997**, *53*, 9123. (b) Takahashi, T.; Kasai, K.; Xi, Z.; Denisov, V. *Chem. Lett.* **1995**, 347.

(10) The X-ray data for **1m** have been deposited in the Cambridge Crystallographic Data Center: $C_{26}H_{22}$; fw = 334.46; monoclinic space group $P2_1$ (No. 4); a = 10.0508(6), b = 7.6936(5), c = 11.861(1) Å; b = 92.197(6)°; V = 916.5(1) Å^3; R = 0.047, R_w = 0.055 based on 1860 observed reflections.

(11) King, A. O.; Negishi, E.; Villani, F. J.; Silveira, A. *J. Org. Chem.* **1978**, *43*, 358.

(12) For a general Experimental Section, see our recent paper: Takahashi, T.; Xi, Z.; Yamazaki, A.; Liu, Y.; Nakajima, K.; Kotora, M. *J. Am. Chem. Soc.* **1998**, *120*, 1672−1680.

(13) (a) Newman, M. S.; Kaugars, G. *J. Org. Chem.* **1965**, *30*, 3295. (b) Dodson, R. M.; Zielske, A. G. *J. Org. Chem.* **1967**, *32*, 28. (c) McMurry, J. E.; Kees, K. L. *J. Org. Chem.* **1977**, *42*, 2655.

Me_4Si) δ 138.74, 136.20, 128.29, 127.45, 126.06, 26.79. HRMS: calcd for $C_{16}H_{14}$, 206.1095; found, 206.1096.

1-Octyl-2-phenylcyclobutene (1g): ^{1}H NMR ($CDCl_3$, Me_4Si) δ 7.38−7.19 (m, 5H), 2.67−2.65 (m, 2H), 2.49−2.42 (m, 4H), 1.59−1.53 (m, 2H), 1.42−1.32 (m, 14H), 0.96−0.93 (t, J = 7 Hz, 3H); ^{13}C NMR ($CDCl_3$, Me_4Si) δ 143.58, 137.04, 136.34, 128.22, 126.28, 125.54, 31.96, 30.13, 29.79, 29.67, 29.60, 29.38, 27.60, 27.30, 25.75, 22.72, 14.09. HRMS: calcd for $C_{20}H_{30}$, 270.2346; found, 270.2345.

1-Butyl-2-(1-naphthyl)cyclobutene (1h): ^{1}H NMR ($CDCl_3$, Me_4Si) δ 8.35−8.33 (d, J = 8 Hz, 1H) 7.95−7.83 (m, 2H), 7.59−7.52 (m, 4H), 3.07−3.06 (m, 2H), 2.73−2.71 (m, 2H), 2.37 (m, 2H), 1.62−1.45 (m, 4H), 1.03−0.99 (t, J = 7.5 Hz, 3H); ^{13}C NMR ($CDCl_3$, Me_4Si) δ 145.65, 137.54, 134.56, 133.85, 131.23, 128.27, 126.99, 125.98, 125.54, 125.47, 125.32, 125.23, 30.18, 29.74, 29.46, 28.18, 22.74, 13.91. HRMS: calcd for $C_{18}H_{20}$, 236.1564; found, 236.1569.

7-Phenylbicyclo[4.2.0]oct-6(7)-ene (1i): ^{1}H NMR ($CDCl_3$, Me_4Si) δ 7.34−7.15 (m, 5H), 2.83−2.76 (m, 2H), 2.45−2.31 (m, 2H), 2.19−2.07 (m, 2H), 1.91−1.75 (m, 2H), 1.41−1.27 (m, 2H), 1.18−1.12 (m, 1H); ^{13}C NMR ($CDCl_3$, Me_4Si) δ 146.65, 136.58, 131.83, 128.22, 126.20, 125.41, 37.66, 34.41, 33.20, 27.22, 26.78, 25.03. HRMS: calcd for $C_{14}H_{16}$, 184.1251; found, 184.1269.

1,3-Bis(2-phenylcyclobutenyl)butane (1j): ^{1}H NMR ($CDCl_3$, Me_4Si) δ 7.32−7.14 (m, 10H), 2.61−2.59 (m, 4H), 2.43−2.42 (m, 8H), 1.61−1.58 (m, 4H); ^{13}C NMR ($CDCl_3$, Me_4Si) δ 143.21, 137.28, 136.23, 128.27, 126.36, 125.54, 29.92, 27.60, 27.28, 25.78. HRMS: calcd for $C_{24}H_{26}$, 314.2033; found, 314.2031.

1,4-Bis(2-phenylcyclobutenyl)pentane (1k): ^{1}H NMR ($CDCl_3$, Me_4Si) δ 7.45−7.11 (m, 10H), 2.57−2.13 (m, 10H), 1.69−1.29 (m, 8H); ^{13}C NMR ($CDCl_3$, Me_4Si) δ 143.44, 137.13, 136.27, 128.27, 126.34, 125.54, 30.02, 29.77, 27.60, 27.15, 25.77. HRMS: calcd for $C_{25}H_{28}$, 328.2190; found, 328.2181.

1,4-Bis(2-butylcyclobutenyl)benzene (1l): ^{1}H NMR ($CDCl_3$, Me_4Si) δ 7.26 (m, 4H), 2.59−2.36 (m, 12H), 1.52−1.35 (m, 8H), 0.94−0.90 (t, J = 7.5 Hz, 6H); ^{13}C NMR ($CDCl_3$, Me_4Si) δ 143.35, 136.96, 134.40, 125.47, 29.92, 29.49, 27.68, 25.73, 22.83, 13.99. HRMS: calcd for $C_{22}H_{30}$, 294.2346; found, 294.2355.

1,4-Bis(2-phenylcyclobutenyl)benzene (1m): mp 158.4−159.0 °C; ^{1}H NMR ($CDCl_3$, Me_4Si) δ 7.53−7.48 (m, 8H), 7.33−7.21 (m, 6H), 2.76 (s, 8H); ^{13}C NMR ($CDCl_3$, Me_4Si) δ 138.98, 138.46, 136.27, 135.22, 128.30, 127.46, 126.13, 125.93, 26.89, 26.65. Anal. Calcd for $C_{26}H_{22}$: C, 93.37; H, 6.63. Found: C, 93.44; H, 6.64. HRMS: calcd for $C_{26}H_{22}$, 334.1720; found, 334.1717.

Synthesis of 1,2-Diphenyl-3-(hydroxydimethylsilyl)cyclobutene (1n). To a solution of Cp_2ZrCl_2 (701 mg, 2.4 mmol) in THF (10 mL) was added ethylmagnesium bromide (4.8 mmol, 4.706 mL, 1.02 mol/L THF solution) at −78 °C. After the solution was stirred for 1 h at −78 °C, diphenylacetylene (356 mg, 2.0 mmol) was added. And then the reaction mixture was warmed to 0 °C and stirred for 3 h. Then ethoxydimethylvinylsilane (4.0 mmol, 521 mg) was added and the mixture was stirred for 3 h at 50 °C. After this, iodine (2.4 mmol, 609 mg) was added at −78 °C and the mixture was warmed to room temperature and stirred for 1 h. Finally copper(I) chloride (2.4 mmol, 238 mg) was added and the mixture was stirred at 50 °C for 1 h. The reaction mixture was quenched with water and extracted with ether. The organic phase was washed with water, $NaHCO_3$ (20% aqueous solution), water, NaS_2O_3 (saturated aqueous solution), water, and brine, and dried over $MgSO_4$. Filtration, evaporation, and column chromatography on silica gel (1:1 hexane/Et_2O, v/v) afforded 349 mg (62%) of the desired compound (pale yellow oily substance): ^{1}H NMR ($CDCl_3$, Me_4Si) δ 7.58−7.49 (m, 4H), 7.37−7.21 (m, 6H), 2.92−2.87 (m, 1H), 2.81−2.79 (m, 1H), 2.71−2.67 (m, 1H); ^{13}C NMR ($CDCl_3$, Me_4Si) δ 141.19, 136.88, 136.53, 135.90, 128.32 (2C), 128.26 (2C), 127.51, 127.14, 126.58 (2C), 125.54 (2C), 31.55, 27.59, −1.54, −1.85. HRMS: calcd for $C_{18}H_{20}OSi$, 280.1282; found, 280.1286.

Representative Procedure for the Preparation of 1o−p: Synthesis of 1,1′-Bis(2-phenylcyclobutenyl)-4,4′-biphenyl (1o). To a THF solution of 1-(4-bromophenyl)-2-phenylcyclobutene (**1c**) (2.0 mmol), prepared and isolated as described above, was added *n*-BuLi (2 mmol), and the mixture was stirred at 0 °C for 1 h. After addition of flame-dried zinc chloride (3.0 mmol), to the reaction mixture was added 1-(4-bromophenyl)-2-phenylcyclobutene (**1c**) (2.0 mmol) and a catalytic amount of $Pd(PPh_3)_4$ (0.1 mmol) at room temperature.[11] After being heated to 50 °C and stirred for 6 h, the reaction mixture was quenched with 3 N HCl and extracted with Et_2O. The extract was washed with water, $NaHCO_3$ (20% aqueous solution), water, NaS_2O_3, water, and brine, and dried over $MgSO_4$. Filtration and evaporation provided a solid substance. Column chromatography on silica gel with hexane as the eluent afforded 592 mg (72% isolated yield, purity > 98%) of the desired compound: mp 180.5−182.5 °C (decomp); ^{1}H NMR ($CDCl_3$, Me_4Si) δ 7.61−7.23 (m, 18H), 2.81 (s, 8H); ^{13}C NMR ($CDCl_3$, Me_4Si) δ 139.66, 139.12, 138.34, 136.27, 135.21, 128.35, 127.52, 126.72, 126.52, 126.14, 26.94, 26.78. HRMS: calcd for $C_{32}H_{26}$, 410.2033; found, 410.2044.

Acknowledgment. We thank the Ministry of Education, Science, Sports, and Culture of Japan for the support of this study.

Supporting Information Available: Text providing characterization data for **1b**−**d**,**p**,**q** and experimental details for the X-ray analysis of **1m**, an X-ray structure of **1m**, tables of crystallographic data, positional and thermal parameters, and bond lengths and angles for **1m**, and ^{1}H and ^{13}C NMR spectra of **1a**−**q** (26 pages). This material is available free of charge via the Internet at http://pubs.acs.org.

JO990596C