Convenient and General Synthesis of 1-Monoorganyl- and 1,2-Diorganylcyclobutenes via Cyclialkylation

Ei-ichi Negishi,* Fang Liu, Danièle Choueiry, and Mohamud M. Mohamud†

Department of Chemistry, Purdue University, West Lafayette, Indiana 47907

Augustine Silveira, Jr., and Mark Reeves

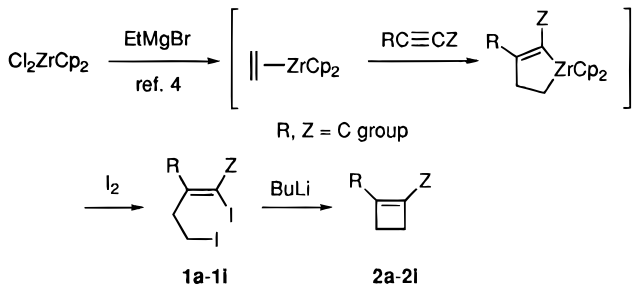
Department of Chemistry, State University of New York at Oswego, Oswego, New York 13126

Received July 8, 1996

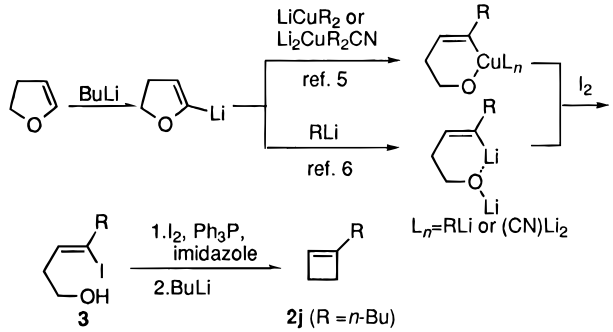
We report herein that the cyclialkylation reactions involving (4-halo-1-alkenyl)metals[1] are widely applicable to the synthesis of 1-monoorganyl-, and 1,2-diorganylcyclobutenes and related heterofunctional cyclobutenes containing a metal group or iodine at an alkenyl carbon center. These latter compounds can be readily converted to 1,2-diorganylcyclobutenes via cross-coupling involving organometals, such as those containing Li[2] and Zn(Pd)[3] (Schemes 1−3). Recent developments of novel procedures for the preparation of stereo- and regiodefined (4-halo-1-alkenyl)metals and the corresponding iodides (**1**) via Zr-promoted alkene−alkyne coupling[4] and those of 4-iodo-3-buten-1-ols (**3**),[5,6] readily convertible to **1**, via treatment of 5-lithio-2,3-dihydrofuran with organocoppers or organolithiums have made it possible to achieve the reported general synthesis of cyclobutenes via cyclialkylation.

Synthetic methods permitting direct synthesis of cyclobutenes[7] that are not substituted with alkylidene, benzo, or heteroatom groups, such as oxo, from acyclic precursors are relatively rare.[8−13] Representative earlier methods include (i) photocyclization of 1,3-butadienes,[8] (ii) photocycloaddition of alkynes with enones,[9] (iii) treatment of 1,4-dichloro-1-butenes with Mg,[10] (iv) base-induced extrusion of SO_2 from sulfones,[11] (v) Lewis acid-catalyzed cycloaddition of alkynes with alkenes,[12] and (vi) condensation of propiolic esters with olefins catalyzed by $CpFe(CO)_2BF_4$.[13] Unfortunately, these reactions either give relatively low yields of cyclobutenes often produced along with other significant byproducts or appear to be of limited scope. Although the McMurry olefination[14a] is promising, 1,2-diphenylcyclobutene appears to be the only reported example.[14] In short, none has been demonstrated to be general, high-yielding, and selective. We previously reported two related but discrete cyclialkylation routes to cyclobutenes.[1] One involves a σ-type cyclialkylation of (4-halo-1-alkenyl)lithiums related to the Parham synthesis of benzocyclobutenes.[15] The other proceeds via a novel π-type cyclization of (4-halo-1-(trimethylsilyl)-1-alkenyl)metals. Although the potential synthetic utility of these reactions has already been indicated by their application to the synthesis of grandisol[1a] and sterpurene,[16] the scopes of these reactions as reported in our previous papers[1] were rather limited.

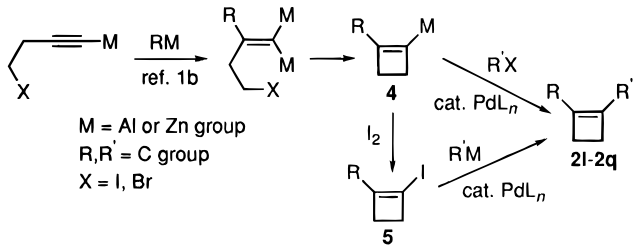
Scheme 1



Scheme 2



Scheme 3



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S0022-3263(96)01277-7 CCC: $12.00

Table 1. Preparation of Cyclobutenes via Reaction of Alkynes with Et_2ZrCp_2 Followed by Iodinolysis and Cyclialkylation Induced by BuLi[a]

substituents			cyclobutenes	yield of **2** (%)
Z	R	**1**[b]	(**2**)	isolated (by NMR)
n-Pr	*n*-Pr	**1a**	**2a**	87 (86)
n-Bu	*n*-Bu	**1b**	**2b**	83
Ph	Ph	**1c**	**2c**	73 (81)
Ph	*p*-ClC_6H_4	**1d**[c]	**2d**	90 (95)
Ph	Me	**1e**	**2e**	(75)
CH_2=C(Me)	Ph	**1f**[d]	**2f**	82 (88)
n-BuC≡C	*n*-Bu	**1g**	**2g**	80 (90)
Ph	*n*-BuC≡C	**1h**[e]	**2h**	86 (95)
PhC≡C	*n*-Bu	**1i**	**2i**	87 (90)
n-Bu	H	**1j**	**2j**	45
Me	H	**1k**	**2k**	75

[a] The cyclization reaction was carried out in Et_2O using 1.1 equiv of *n*-BuLi at −78 to 23 °C unless otherwise stated. [b] Prepared by the reaction of the corresponding alkynes with Et_2ZrCp_2 followed by iodinolysis at −78 °C in THF, unless otherwise stated. [c] A 1:1 regioisomeric mixture. [d] A 5:1 mixture of two regioisomers in which **1f** is the major isomer. [e] A roughly 1:1 mixture of two regioisomers.

All of these reactions require as intermediates tri- and tetrasubstituted alkenes represented by **1**. Although the π-cyclialkylation reaction does not require stereodefined **1**, the σ-cyclialkylation reaction would in most cases. Thus, the scope of this methodology critically hinges on the ready accessibility of **1**. Very few synthetically attractive routes to **1** were known[17] at the time of our previous publications.[1]

Recent development of the Zr-promoted alkene−alkyne coupling reactions[4] (Scheme 1) and some alkylative reactions of 2-lithio-1-oxa-2-cyclopentene[5,6] (Scheme 2) prompted us to examine their applicability to the synthesis of cyclobutenes. Diiodides **1a**−**i** were prepared in one pot by the reaction of the corresponding alkynes with Et_2ZrCp_2 generated *in situ* by treatment of Cl_2ZrCp_2 with 2 equiv of EtMgBr,[4] and (*Z*)-4-iodo-3-octen-1-ol (**3**) was prepared by treatment of dihydrofuran with *n*-BuLi[6] followed by iodinolysis. Conversion of **3** to the corresponding diiodide (**1j**) was achieved with 1.3 equiv each of I_2, PPh_3, and imidazole.[18] (*Z*)-1,4-Diiodo-2-methyl-1-butene (**1k**) was prepared via iodination of (*Z*)-4-iodo-3-methyl-3-buten-1-ol, which, in turn, was obtained by the reaction of 3-butyn-1-ol with Me_3Al and Cp_2ZrCl_2[19] followed by heating and iodinolysis.[20] Treatment of **1a**−**k** with 1.1 equiv of *n*-BuLi in ether initially at −78 °C followed by gradual warming to 23 °C cleanly produced **2a**−**k** in the yields shown in Table 1.

In most cases the reaction was clean and high-yielding. In view of the fact that primary alkyl iodides react with alkyllithiums to undergo a rapid Li−I exchange,[21] the observed clean formation of cyclobutenes in high yields indicates either that alkenyl iodides are considerably more reactive than alkyl halides or that rapidly equilibrating reversible Li−I exchange leads to conversion of all intermediates to cyclobutenes. It is also striking that potentially dangerous β-dehydroiodination of homoallyl iodides with organolithiums has not been observed to any detectable extent. On the other hand, the intermolecular reaction of (*E*)-1-octenyllithium with 4-iodo-2-methyl-1-butene under comparable conditions proceeded mostly via β-elimination, producing the cross-coupling product in only 8% yield.

Since the formation of 1-mono- and 1,2-disubstituted cyclobutenes via 4-halo-1-iodo-1-alkenes (**1**) is a regioconvergent transformation, the regiochemistry of the Zr-promoted alkene−alkyne coupling is inconsequential. As a result, the Zr-promoted alkene−alkyne coupling−alkenyllithium cyclialkylation protocol provides a highly general route to 1,2-diorganylcyclobutenes, as attested by the results summarized in Table 1. On the other hand, the *cis* relationship between the iodoethyl group and the C_{sp}2-bound iodine atom is required, unless alkenyllithium intermediates are configurationally flexible, in accord with the notion that the cyclialkylation of alkenyllithiums is a σ-type cyclization process.[1] Thus, the *E* isomer of **1k** gave mainly the anticipated β-elimination product, *i.e.*, 2-methyl-1,3-butadiene. The reaction, however, did produce a minor amount (5−10%) of **2k**. Although small, the formation of **2k** to the extent indicated above is unexpected in view of our previous observation that the corresponding reactions of (*E*)-1,5-diiodo-1-pentene and (*E*)-1,6−diiodo-1-hexene did not give the desired cycloalkenes to any detectable extents.[1b] At present, the precise course of the formation of **2k** is unclear.

As previously reported by us,[1b] cyclialkylation of 4-halo-1-metallo-1-alkynes containing Al and Zn provides an efficient route to cyclobutenylmetals (**4**) readily convertible to the corresponding iodides **5** (Scheme 3). Since either **4** or **5** are, in principle, convertible to 1,2-diorganylcyclobutenes via cross-coupling, their Pd-catalyzed cross-coupling reactions using Zn as the metal countercation[3] as well as the reaction of **5** with alkyllithiums were examined. As the results summarized in Table 2 indicate, this 4-halo-1-metallo-1-butyne cyclization−cross-coupling protocol also provides a general route to 1,2-diorganylcyclobutenes.[22] Specifically, primary alkyl, alkenyl, aryl, and alkynyl groups can be readily introduced to substitute the metal group of **4** or the iodine atom of **5**. In summary, the two protocols reported herein collectively provide, perhaps for the first time, a general route to 1-monoorganyl- and 1,2-diorganylcyclobutenes.

Experimental Section

General Procedures. Manipulations involving organometallics were carried out under a dry Ar atmosphere. Flash chromatographic separations were carried out on 230−400 mesh silica gel 60. ^1H and ^{13}C NMR spectra were recorded in $CDCl_3$, unless otherwise indicated, on 200 and 300 MHz spectrometers. NMR yields were determined by using dibromomethane or mesitylene as an internal reference. GLC analysis was performed with a column packed with SE-30 Chromosorb W using a TC detector. Melting points were reported uncorrected. All commercially available reagents were used directly without further purification, unless otherwise mentioned. THF was distilled from sodium benzophenone ketyl. Zinc chloride and zinc bromide were dried at 50−100 °C under ≤1 mmHg for several hours.

Preparation of 1,4-Diiodo-1-butenes. (a) (*Z*)-1,4-Diiodo-3-*n*-propyl-3-heptene (1a). Representative Procedure. To a solution of Cp_2ZrCl_2 (2.92 g, 10 mmol) in THF (30 mL) at −78 °C was added dropwise EtMgBr (1.0 M in THF, 20 mL, 20

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Table 2. Preparation of 1,2-Diorganylcyclobutenes via Cross-Coupling Reactions of 1-Iodo- or 1−Metallacyclobutenes

starting cyclobutene	organometal or organic halide	catalyst	1,2-diorganylcyclobutene R	R′	yield[a] (%)
5a	*n*-BuLi	none	Me	*n*-Bu	72
5a	PhZnCl	$Pd(PPh_3)_4$	Me	Ph	75
5a	(*E*)-*n*-BuCH=CHAlBu$_2$	$Pd(PPh_3)_4$	Me	(*E*)-*n*-BuCH=CH	68 (78)
5a	*n*-HexC≡CZnCl	$Pd(PPh_3)_4$	Me	*n*-HexC≡C	78 (81)
4b[b]	(*E*)-*n*-BuCH=CHI	$Pd(PPh_3)_4$	allyl	(*E*)-*n*-BuCH=CH	(95)
4b[c]	(*E*)-*n*-BuCH=CHI	$Pd(PPh_3)_4$	allyl	(*E*)-*n*-BuCH=CH	(62)
5b	PhZnCl	$Pd(PPh_3)_4$	allyl	Ph	(86)
4b[c]	PhI	$Pd(PPh_3)_4$	allyl	Ph	(75)
4b[c]	*n*-BuC≡CZnCl	$Pd(PPh_3)_4$	allyl	*n*-BuC≡C	(68)

[a] Isolated yield. The numbers in parentheses are NMR yields. [b] Generated by treatment of **5b** with *t*-BuLi (2 equiv) followed by addition of $ZnBr_2$. [c] Generated *in situ* via cyclialkylation.

mmol). After 1 h, a solution of 4-octyne (1.45 mL, 10 mmol) in THF (1 mL) was added, and the mixture was stirred at 0 °C for 2 h.[4] The reaction mixture was then cooled to −78 °C, treated with a solution of I_2 (7.62 g, 30 mmol) in THF (20 mL), gradually warmed to 23 °C and stirred overnight, quenched with 3 N HCl, extracted with Et_2O (2×), washed with aqueous $NaHCO_3$, $Na_2S_2O_3$, and NaCl, dried over $MgSO_4$, filtered, and concentrated *in vacuo*. Flash chromatography (hexanes) afforded 2.96 g (76%) of the title compound (>97% *Z*) as a pale yellow oil: ^{1}H NMR δ 0.90 (t, J = 7 Hz, 6 H), 1.3−1.65 (m, 4 H), 2.18 (t, J = 7 Hz, 2 H), 2.48 (t, J = 7 Hz, 2 H), 2.78 (t, J = 8 Hz, 2 H), 3.16 (t, J = 8 Hz, 2 H) ppm; ^{13}C NMR δ 1.42, 12.86, 13.95, 21.94, 22.84, 33.80, 42.90, 46.81, 107.84, 143.11 ppm; IR (neat) 2956, 1460 cm^{-1}.

(b) (*Z*)-1,4-Diiodo-3-octene (1j). To a mixture of (*Z*)-4-iodo-3-octen-1-ol (*vide infra*) (1.12 g, 4.4 mmol), Ph_3P (1.50 g, 5.7 mmol), and imidazole (389 mg, 5.7 mmol) in CH_2Cl_2 (10 mL) at 23 °C was added a solution of I_2 (1.45 g, 5.7 mmol) in CH_2Cl_2 (20 mL).[18] After 30 min, the mixture was washed with H_2O, aqueous NH_4Cl, and NaCl, dried over $MgSO_4$, filtered, and concentrated *in vacuo*. Flash chromatography (hexanes) afforded 1.28 g (80%) of the title compound as a light pink oil: ^{1}H NMR δ 0.91 (t, J = 7.3 Hz, 3 H), 1.2−1.4 (m, 2 H), 1.4−1.6 (m, 2 H), 2.48 (q, J = 7.1 Hz, 2 H), 2.71 (q, J = 6.9 Hz, 2 H), 3.16 (t, J = 7.1 Hz, 2 H), 5.55 (t, J = 6.5 Hz, 1 H) ppm; ^{13}C NMR δ 3.32, 13.84, 21.27, 31.30, 39.95, 44.90, 112.34, 133.03 ppm; IR (neat) 2956, 1170 cm^{-1}. The required starting material (*Z*)-4-iodo-3-octen-1-ol was prepared in 27% isolated yield (>97% *Z*) as a light brown oil by treatment of 2,3-dihydrofuran (freshly distilled, 2.68 g, 38 mmol) in Et_2O (60 mL) at 0 °C with *n*-BuLi (2.5 M in hexanes, 32 mL, 80 mmol)[6] followed by a solution of I_2 (20.3 g, 80 mmol) in THF (50 mL) in −78 °C: ^{1}H NMR δ 0.90 (t, J = 7.3 Hz, 3 H), 1.2−1.7 (m, 5 H), 2.40 (q, J = 6.6 Hz, 2 H), 2.48 (t, J = 7.3 Hz, 2 H), 3.70 (t, J = 6.5 Hz, 2 H), 5.57 (t, J = 6.7 Hz, 1 H) ppm; ^{13}C NMR δ 13.84, 21.31, 31.46, 39.76, 45.04, 61.38, 112.39, 130.62 ppm; IR (neat) 3334, 2930 cm^{-1}.

(c) (*Z*)-1,4-Diiodo-2-methyl-1-butene (1k) and Its *E* Isomer. The *Z* isomer was prepared from (*Z*)-4-iodo-3-methyl-3-buten-1-ol in the same manner as that of (*Z*)-1,4-diiodo-3-octene in 62% isolated yield as a colorless oil: ^{1}H NMR δ 1.92 (d, J = 1.3 Hz, 3 H), 2.81 (t, J = 7.8 Hz, 2 H), 3.21 (t, J = 7.8 Hz, 2 H), 6.06 (d, J = 1.1 Hz, 1 H); ^{13}C NMR δ 0.40, 23.06, 42.54, 77.14, 145.81 ppm; IR (neat) 3052, 2966, 1434 cm^{-1}. (*Z*)-4-Iodo-3-methyl-3-buten-1-ol was, in turn, obtained in 57% isolated yield (>97% *Z*) as a pale yellow oil from the reaction of 3-butyn-1-ol with Me_3Al (3 equiv) and Cp_2ZrCl_2 (30 mol %) in $(CH_2Cl)_2$[19] followed by refluxing for 5 d and treatment with I_2 (1.5 equiv) in THF:[20] ^{1}H NMR δ 1.54 (br s, 1 H), 1.94 (d, J = 1.4 Hz, 3 H), 2.52 (t, J = 6.8 Hz, 2 H), 3.76 (t, J = 6.8 Hz, 2 H), 5.95−6.05 (m, 1 H) ppm; ^{13}C NMR δ 23.86, 41.64, 60.27, 76.42, 144.38 ppm; IR (neat) 3342, 3052, 1048 cm^{-1}. (*E*)-4-Iodo-3-methyl-3-buten-1-ol was prepared in 65% yield as previously reported.[19] Its conversion to (*E*)-1,4-diiodo-2-methyl-1-butene in 85% yield was performed as described above: ^{1}H NMR δ 1.84 (s, 3 H), 2.76 (t, J = 7.5 Hz, 2 H), 3.22 (t, J = 7.5 Hz, 2 H), 6.06 (d, J = 1.0 Hz, 1 H); ^{13}C NMR δ 2.29, 23.10, 43.22, 77.81, 145.85 ppm; IR (neat) 3050, 1234 cm^{-1}.

Preparation of Cyclobutenes via Cyclialkylation of 1,4-Diiodo-1-butenes. 1,2-Di-*n*-propylcyclobutene (2a). Representative Procedure. To a solution of (*Z*)-1,4-diiodo-3-*n*-propyl-3-heptene (563 mg, 1.44 mmol) in Et_2O (8 mL, or THF) at −78 °C was added *n*-BuLi (2.5 M in hexanes, 0.66 mL, 1.65 mmol) or *t*-BuLi (1.7 M in pentane, 1.73 mL, 2.94 mmol). After 45 min, the mixture was warmed to 23 °C, quenched with H_2O, washed with aqueous NH_4Cl and NaCl, dried over $MgSO_4$, filtered, and concentrated. Flash chromatography (hexanes) afforded 173 mg (87%) of the title compound as a colorless oil: ^{1}H NMR δ 0.89 (t, J = 7.3 Hz, 6 H), 1.3−1.5 (m, 4 H), 1.96 (t, J = 7.4 Hz, 4 H), 2.24 (s, 4 H) ppm; ^{13}C NMR δ 14.14, 20.93, 27.51, 30.59, 140.59 ppm; IR (neat) 2958, 1458 cm^{-1}; MS (EI, 70 eV) *m*/*z* (relative intensity) 138 (M^+, 100), 123 (8), 109 (60), 95 (59), 81 (72), 67 (62); HRMS calcd for $C_{10}H_{18}$ 138.1409, found 138.1404.

(*E*)-2-Methyl-1,5-dodecadiene. To a mixture of 4-iodo-2-methyl-1-butene (231 mg, 1.18 mmol) and (*E*)-1-iodo-1-octene (281 mg, 1.18 mmol) in THF (3 mL) at −78 °C was added *t*-BuLi (1.7 M in pentane, 1.4 mL, 2.38 mmol). After 5 h, the reaction mixture was warmed to 23 °C, stirred for 18 h, quenched with H_2O and 3 N HCl, and dried over Na_2SO_4. NMR analysis of the reaction mixture indicated the formation of 1-octene[23] (74%), 2-methyl-1,3-butadiene[23] (37%), and the title compound (8%), the identity of which was confirmed by coinjection with an authentic sample prepared by the Pd-catalyzed cross-coupling reaction of (*E*)-1-iodo-1-octene with 3-methyl-3-butenylzinc bromide, which, in turn, was prepared by treatment of 3-methyl-3-butenyllithium with dry $ZnBr_2$.[19] The title compound yielded the following spectral data: ^{1}H NMR δ 0.88 (t, J = 7.5 Hz, 3 H), 1.1−1.5 (m, 8 H), 1.71 (s, 3 H), 1.85−2.3 (m, 6 H), 4.65−4.8 (m, 2 H), 5.3−5.5 (m, 2 H) ppm; ^{13}C NMR δ 14.08, 22.46, 22.64, 29.33, 29.56, 30.79, 31.75, 32.57, 37.85, 109.81, 129.57, 130.68, 145.61 ppm; IR (neat) 2958, 1458 cm^{-1}.

1-Iodo-2-methylcyclobutene (4a).[1b] To 4-bromo-1-butyne (1.33 g, 10.0 mmol) in pentane (20 mL) was added successively *n*-BuLi (2.7 M in hexane, 3.7 mL, 10.0 mmol, −78 °C, 30 min), Me_2AlCl (0.96 mL, 10.0 mmol in CH_2Cl_2 (5 mL), −78 °C, 30 min), Cp_2ZrCl_2 (2.92 g, 10.0 mmol), and Me_3Al (1.9 mL, 20 mmol) in CH_2Cl_2 (20 mL) (−78 °C). The reaction mixture was warmed to 23 °C and stirred for 3 h. The reaction mixture was treated at −78 °C with a solution of I_2 (3.81 g, 15.0 mmol) in THF (10 mL), warmed to 0 °C, quenched with a mixture of ice and 3 N HCl, extracted with ether, washed with aqueous $NaHCO_3$, $Na_2S_2O_3$, and NaCl, dried over $MgSO_4$, filtered, and concentrated. Distillation over a pinch of 2,6-di-*tert*-butyl-4-methylphenol afforded 1.1 g (57%) of the title compound as a colorless oil (>97% pure by GLC): bp 78−81 °C (45 mmHg); ^{1}H NMR δ 1.63 (br s, 3 H), 2.72 (br s, 4 H) ppm; ^{13}C NMR δ 16.27, 35.81, 36.25, 82.71, 154.07 ppm; IR (neat) 1640, 1239 cm^{-1}. The required starting compound 4-bromo-1-butyne was prepared by converting 3-butyn-1-ol to its tosylate via lithiation (1.1 equiv of *n*-BuLi) and treatment with *p*-TsCl followed by bromination with LiBr in acetone in 72% yield: bp 47−49 °C (91 mmHg); ^{1}H NMR δ 2.11 (t, J = 3 Hz, 1 H), 2.75 (dt, J = 7, 3 Hz, 2 H), 3.45 (t, J = 7 Hz, 2 H) ppm; IR (neat) 3325, 2950, 1420, 960 cm^{-1}.

2-Allyl-1-cyclobutenylzinc Derivative (4b) and 1-Iodo-2-allylcyclobutene (5b). These compounds were prepared as follows according to the previously reported method.[1b] To a solution of 4-bromo-1-butyne (0.40 g, 3 mmol) in hexane (5 mL) was added at −78 °C *n*-BuLi (2.64 M in heptane, 1.1 mL, 3

(23) Pouchert, C. J.; Behnke, J. *The Aldrich Library of C and H FT NMR Spectra*, 1st ed.; Aldrich Chemical Co., Inc.: Milwaukee, 1993; Vol. 1.

mmol). After 1 h, EtZnCl (1.0 M in CH_2Cl_2, 4 mL, 4 mmol), prepared from 1 equiv each of Et_2Zn and dry $ZnCl_2$ in CH_2Cl_2, was added at −78 °C. The reaction mixture was stirred for 30 min, warmed to 23 °C, and stirred for 3 h. This reaction mixture containing **4b** was used directly in some syntheses of cyclobutenes. For the preparation of **5b**, the solvent were removed and replaced with 10 mL of THF. To this resulting mixture was added a solution of allylzinc bromide prepared from Zn (0.29 g, 4.5 mmol) suspended in 4.5 mL of THF and allyl bromide (0.54 g, 0.39 mL, 4.5 mmol). After being stirred for 12 h at 23 °C, this reaction mixture was quenched with a solution of I_2 (3.04 g, 12 mmol) in 10 mL of THF (−78 to 0 °C), diluted with pentane, treated with aqueous NH_4Cl and $Na_2S_2O_3$, washed with aqueous $NaHCO_3$ and NaCl, dried over $MgSO_4$, and concentrated. Distillation provided 0.45 g (68%) of **5b**:[1b] bp 60−62 °C (5 mmHg); ^{1}H NMR (C_6D_6) δ 2.3−2.4 (m, 2 H), 2.4−2.5 (m, 2 H), 2.54 (d, J = 7 Hz, 2 H), 4.8−5.0 (m, 2 H), 5.65−5.7 (m, 1 H) ppm; ^{13}C NMR δ 34.45, 35.10, 36.35, 83.23, 117.00, 133.13, 155.25 ppm; IR (neat) 3440, 2860, 1630 cm^{-1}.

1-*n*-Butyl-2-methylcyclobutene (2l). To a solution of 1-iodo-2-methylcyclobutene (8.2 g, 42 mmol) in ether (70 mL) was added *n*-BuLi (2.7 M in hexane, 17.4 mL, 47 mmol) at −78 °C. After the solution was stirred for 30 min at 23 °C, THF (20 mL) was added. The reaction mixture was stirred for another 2 h, quenched with water, extracted with ether, washed with aqueous $NaHCO_3$ and NaCl, dried over $MgSO_4$, filtered, and concentrated. The residue was passed through a short column using pentane. Evaporation of pentane and distillation yielded 3.8 g (72%) of the title compound as a colorless oil: bp 78−80 °C (45 mmHg); n^{27}_D 1.4512; IR (neat) 2850, 1425 cm^{-1}. Anal. Calcd for C_9H_{16}: C, 87.12; H, 12.90. Found: C, 86.97; H, 13.05.

Preparation of 1,2-Disubstituted Cyclobutene via Palladium-Catalyzed Cross-Coupling of 1-Iodo-2-alkylcyclobutenes with Organozincs. (a) 1-Phenyl-2-methylcyclobutene (2e). To a solution of freshly dried $ZnCl_2$ (4.90 g, 36 mmol) in THF (20 mL) was added phenyllithium (2.4 M, 15 mL, 36 mmol) dropwise with stirring. After 1 h, this mixture was added to a solution of 1-iodo-2-methylcyclobutene (5.82 g, 30 mmol) and $Pd(PPh_3)_4$ (2.09 g, 1.8 mmol) in THF (40 mL).[3b,c] After 1 h, an aliquot was withdrawn for GLC analysis, which indicated a 79% yield of **2e**. The reaction mixture was quenched with water, extracted with ether, dried over $MgSO_4$, filtered, and concentrated. The residue was passed through a short column using pentane. Evaporation of pentane and distillation yielded 3.24 g (75%) of the title compound as a colorless oil (≥97% pure by GLC): bp 92−95 °C (15 mmHg); n^{27}_D 1.5558. Its NMR and IR spectra were indistinguishable from those of the sample prepared via treatment of (*Z*)-1,4-diiodo-2-methyl-1-phenyl-1-butene with *n*-BuLi.

(b) (*E*)-1-(1-Hexenyl)-2-methylcyclobutene (2m). To a solution of 1-hexyne (4.10 g, 50 mmol) in hexane (32 mL) was added *i*-Bu_2AlH (8.92 mL, 50 mmol) at 23 °C. The reaction mixture was warmed to 50−60 °C and stirred for 6 h. After being cooled to 23 °C, a solution of 1-iodo-2-methylcyclobutene (7.76 g, 40 mmol), dry $ZnCl_2$ (5.40 g, 40 mmol), and $Pd(PPh_3)_4$ (2.30 g, 5 mol %) in THF (40 mL) was added. After 1 h, the reaction mixture was quenched with cold 3 N HCl and worked up as described above. Distillation yielded 4.10 g (68%) of the title compound (≥97% pure by GLC): bp 83−86 °C (5 mmHg); n^{27}_D 1.4881; ^{1}H NMR δ 0.88 (t, J = 6 Hz, 3 H), 1.1−1.6 (m, 6 H), 1.68 (s, 3 H), 1.85−2.8 (m, 4 H), 5.50 (dd, J = 15 and 6 Hz, 1 H), 6.05 (d, J = 15 Hz, 1 H) ppm; ^{13}C NMR δ 13.94 (2 C), 22.34, 25.78, 29.56, 31.80, 32.43, 123.12, 129.81, 137.17, 138.63 ppm; IR (neat) 2900, 1449 cm^{-1}.

(c) 1-Phenyl-2-allylcyclobutene (2o). Representative Procedure for the Use of *in Situ* Generated 4b. To a mixture containing **4b** prepared from 1 mmol of 4-bromo-1-butyne were added at 23 °C a mixture of iodobenzene (0.26 g, 1.3 mmol) and $Pd(PPh_3)_4$ (35 mg, 0.03 mmol) in 5 mL of THF, and the reaction mixture was stirred for 3 h. After the standard workup, examination by NMR spectroscopy of the crude product with an internal standard indicated the formation of the title compound in 75% yield. Chromatographic purification provided its pure sample: ^{1}H NMR δ 2.4−2.5 (m, 2 H), 2.6−2.7 (m, 2H), 3.1−3.2 (m, 2 H), 5.0−5.2 (m, 2H), 5.8−6.0 (m, 1 H), 7.3−7.4 (m, 5 H) ppm; ^{13}C NMR δ 26.08, 27.83, 34.75, 115.97, 125.59, 126.63, 128.31, 134.27, 135.83, 138.28, 139.88 ppm; IR (neat) 3060, 1720, 1680 cm^{-1}; HRMS calcd for $C_{13}H_{14}$ 170.1096, found 170.1093.

The same compound was also prepared in 86% NMR yield by the Pd-catalyzed cross-coupling reaction of **5b** with PhZnCl.

Acknowledgment. We thank the National Science Foundation (CHE-9402288) and the National Institutes of Health (GM 36792) for support of this research. Motohiro Kageyama performed some experiments related to this project.

Supporting Information Available: Characterization data for **1b**−**i**, 4-iodo-2-methyl-1-butene, (*E*)-1-iodo-1-octene, and **2b**−**k**,**n**,**p**,**2q** (7 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.

JO961277D