Nickel-Catalyzed Cross Coupling of Cyclopropyl Grignard Reagents with Benzylic Dithioacetals. Regioselective Ring Opening of Cyclopropylcarbinyl Organometallic Intermediates. Novel Synthesis of Substituted Dienes†,[1a,b]

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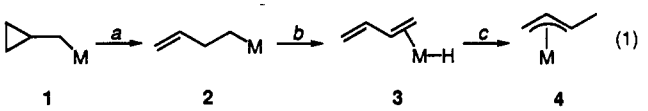
The reactions of various cyclopropylmagnesium bromides with benzylic dithioacetals afforded the corresponding substituted conjugate dienes in good yields. These reactions can be considered as using cyclopropyl anion as an allyl anion synthon. The reaction shows high regio- and stereoselectivity to give *E* isomers predominantly, if not exclusively. The nature of the substituent(s) in the ring-opening process in the (cyclopropylcarbinyl)nickel intermediate has been investigated in detail. An aryl or vinyl substituent gives regioselective ring opening at the more substituted carbon–carbon bond, an alkyl substituent being unselective. β-Heteroatom elimination in these nickel-catalyzed cross-coupling reactions has been used for regioselective synthesis of 1,4-dienes.

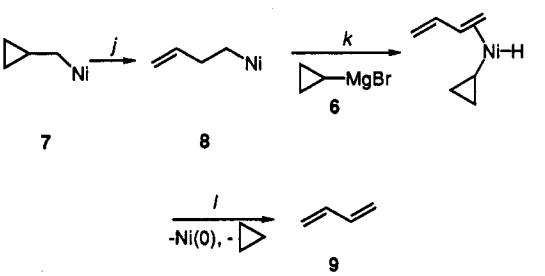
Whereas the ring-opening processes of cyclopropylcarbinyl radicals and cations are highly versatile in organic synthesis,[2] the synthetic applications of the rearrangement of the cyclopropylcarbinyl organometallic compounds **1** are limited.[3] In most cases, the homoallylic organometallic species **2** thus generated may rearrange to yield the thermodynamically more stable π-allyl complexes **4** (eq 1).[3] Diene is rarely liberated[3i,n] from complex **3** because



(1)

1 **2** **3** **4**

the addition of the hydridic species to the diene ligand in **3** (step c) may be highly facile to give **4**. When such a kind of insertion step (step c) can be blocked, the overall transformation would serve as a useful synthesis of conjugated dienes. We recently reported a series of nickel-catalyzed cross-coupling reactions of dithioacetals **5** with Grignard reagents.[4] The reaction in general involves a formal displacement of one of the carbon–sulfur bonds followed by a β-hydride elimination process (Scheme 1). We have previously shown that the elimination step *h* would require the association of the Grignard reagent to the metal center (step *g*);[5] the nickel hydridic species thus generated may undergo a rapid reductive elimination (step *i*), and the active catalyst is regenerated by liberating the alkene moiety. Accordingly, when the cyclopropyl Grignard reagent **6** is employed, the (cyclopropylcarbinyl)nickel intermediate **7** is expected. Rearrangement of **7** to the homoallylic moiety **8** followed by β-hydride elimination would afford the corresponding diene **9** (eq 2). The rapid



7 **8** **6** (2) **9**

reductive-elimination step *l* would be extremely important for the isolation of diene because the insertion step *c* (eq 1) will be blocked. In this paper, we report a full account on the use of such a rearrangement in the synthesis of butadienes **9**.[6]

Results and Discussion

Prototype. The coupling reactions of dithioacetals **5** with the cyclopropylmagnesium bromide **6** in the presence of a catalytic amount of $NiCl_2(PPh_3)_2$ in refluxing benzene gave the corresponding dienes **9** in satisfactory yields. The results are summarized in Table 1. Dithioacetals derived from aromatic aldehydes or ketones reacted smoothly to give the corresponding substituted 1,3-butadienes.

The reactions shown in Table 1 are highly stereoselective; the stereochemistries of the C_1–C_2 double bond in dienes, whenever applicable, are predominantly, if not exclusively, in the *E* configuration, when five-membered dithiolanes

† Dedicated to Professor Fa-Ching Chen on the occasion of his 80th birthday.

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(1) (a) This work was initiated while D.K.P.N. and T.-Y.L. were at the Chinese University of Hong Kong. (b) Taken in part from the Ph.D. thesis of C.C.Y., National Taiwan University, 1993. (c) Recipient of the Croucher Foundation Studentship, 1988–1990.

(2) For a recent review, see: Wong, H. N. C.; Hon, M.-Y.; Tse, C.-W.; Yip, Y.-C.; Tanko, J.; Hudlicky, T. *Chem. Rev.* **1989,** *89,* 165.

(3) (a) Hill, E. A.; Park, Y. W. *J. Organomet. Chem.* **1988,** *356,* 1. (b) Lehmkuhl, H.; Fustero, S. *Liebigs Ann. Chem.* **1980,** 1361. (c) Lehmkuhl, H.; Rufinska, A.; Benn, R.; Schroth, G.; Mynott, R. *Liebigs Ann. Chem.* **1981,** 317. (d) Lehmkuhl, H.; Naydowski, C.; Danowski, F.; Bellenbaum, M.; Benn, R.; Rufinska, A.; Schroth, G.; Mynott, R. *Chem. Ber.* **1984,** *117,* 3231. (e) Green, M.; Hughes, R. P. *J. Chem. Soc., Dalton Trans.* **1976,** 1880. (f) Larock, R.C.; Varaprath, S. *J. Org. Chem.* **1984,** *49,* 3432 and references therein. (g) Larock, R. C.; Yum, E. K. *Synlett* **1990,** 529. (h) Morizawa, Y.; Oshima, K.; Nozaki, H. *Tetrahedron Lett.* **1982,** *23,* 2871. (i) Chiusoli, G. P.; Losta, M.; Pallini, L.; Terenghi, G. *Transition Met. Chem.* **1982,** *7,* 304. (j) Ketley, A. D.; Braatz, J. A. *J. Organomet. Chem.* **1967,** *9,* 5. (k) Fournet, G.; Balme, G.; Gore, J. *Tetrahedron Lett.* **1987,** *28,* 4533. (l) Fournet, G.; Balme, G.; Barieux, J. J.; Gore, J. *Tetrahedron* **1988,** *44,* 5821. (m) Donaldson, W. A.; Brodt, C. A. *J. Organomet Chem.* **1987,** *330,* C33. (n) Parkin, G.; Bunel, E.; Burger, B. J.; Trimmer, M. S.; van Asselt, A.; Bercaw, J. E. *J. Mol. Cat.* **1987,** *41,* 21. (o) Shono, T.; Yoshimura, T.; Matsumura, Y.; Oda, R. *J. Org. Chem.* **1968,** *33,* 876.

(4) For a review, see: Luh, T.-Y. *Acc. Chem. Res.* **1991,** *24,* 257.

(5) (a) Ni, Z.-J.; Mei, N.-W.; Shi, X.; Tzeng, Y.-L.; Wang, M. C.; Luh, T.-Y. *J. Org. Chem.* **1991,** *56,* 4035. (b) Mei, N.-W.; Luh, T.-Y. Unpublished results.

(6) Preliminary communication: Ng, D. K. P.; Luh, T.-Y. *J. Am. Chem. Soc.* **1989,** *111,* 9119.

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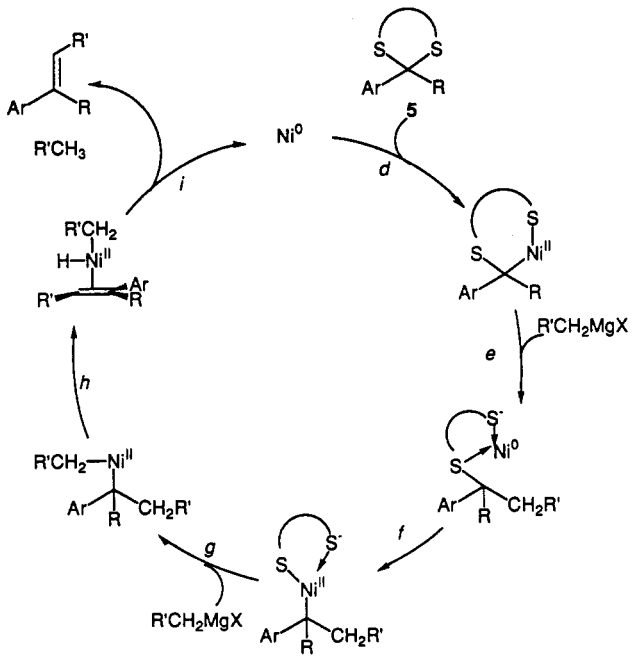
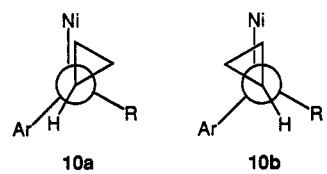
Scheme 1

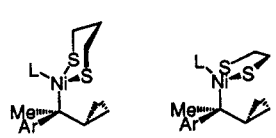


were employed. This observed selectivity can best be rationalized by considering the ring-opening process of intermediate **10**; the cis coplanarity of the C–Ni bond and the β,γ-bond in the cyclopropyl moiety may be requisite.[3e] Since the conformer **10a** would be more stable than the conformer **10b** from the steric point of view (R = H or Me), *E* isomers were formed selectively.



10a **10b**

Although the yields of the reactions depend slightly on the ring size of the dithioacetals, five-membered dithiolanes giving 5–10% higher yields than the corresponding dithianes (Table 1, entries 1–4), the stereoselectivity (entries 6–9) of this rearrangement was affected significantly by the ring size of the sulfur heterocycles. We have previously shown that both sulfur moieties of the leaving group ($-S(CH_2)_nS-$, where n = 2, 3) may remain coordinated to the metal center during the course of the catalytic process.[7] Consequently, the steric environment around the nickel will be different (**11a** vs **11b**) when different



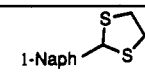
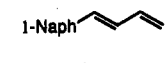
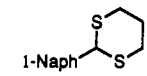
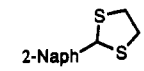
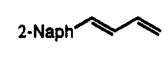
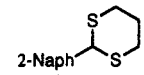
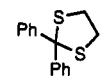
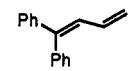
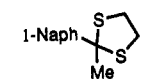
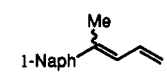
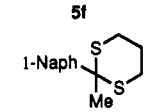
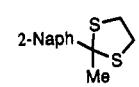
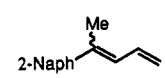
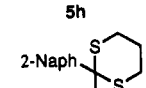
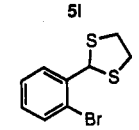
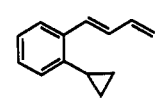
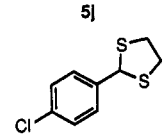
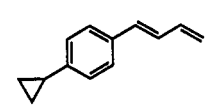
11a **11b**

ring sizes of dithioacetals are employed. Since the six-membered metallocycle **11a** would be more sterically hindered than its five-membered analogue **11b**, the ring-opening process in the former (entries 7 and 9) would be less selective than that in the latter (entries 6 and 8).

It is well documented that aryl halides can couple with Grignard reagents under similar reaction conditions.[8]

(7) Wong, K.-T.; Ni, Z.-J.; Luh, T.-Y. *J. Chem. Soc., Perkin Trans. 1* **1991**, 3113.
(8) Kumada, M. *Pure Appl. Chem.* **1980**, *52*, 669.

Table 1. $NiCl_2(PPh_3)_2$-Catalyzed Coupling Reactions of Cyclopropylmagnesium Bromide (6) with Benzylic Dithioacetals (5)

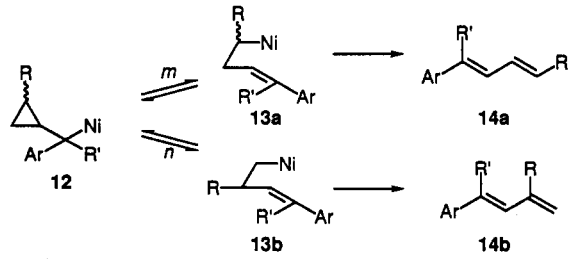
entry no.	substrate	product	% yield
1	 **5a**	 **9a**	66
2	 **5b**	**9a**	60
3	 **5c**	 **9b**	72
4	 **5d**	**9b**	65
5	 **5e**	 **9c**	88
6	 **5f**	 **9d**	77 (*E*/*Z* = 83/17)
7	 **5g**	**9d**	65 (*E*/*Z* = 60/40)
8	 **5h**	 **9e**	75 (*E*/*Z* = 93/7)
9	 **5i**	**9e**	65 (*E*/*Z* = 67/33)
10[a]	 **5j**	 **9f**	70
11[a]	 **5k**	 **9g**	63

[a] 5 equiv of cyclopropylmagnesium bromide was employed.

Consequently, substrates containing such a functionality would also react; hence, both cyclopropyl and butadienyl moieties would be introduced in one step (entries 10 and 11).

2-Substituted Cyclopropyl Grignard Reagents. When 2-substituted cyclopropyl Grignard reagents are used, the intermediate **12** would be expected to reversibly undergo a ring-opening process in two different ways (Scheme 2). Path *m* would lead to **13a**, and the resulting diene **14a** would have the substituent R at the terminal carbon atom. On the other hand, path *n* would give **13b**, which results in the formation of internally substituted butadiene **14b**. The selectivity of these two pathways apparently depends on the relative stability of the organonickel species **13a** versus **13b** thus generated and also on the relative rate of β-hydride elimination from the respective **13**. Accordingly, several substituted cyclopro-

Scheme 2

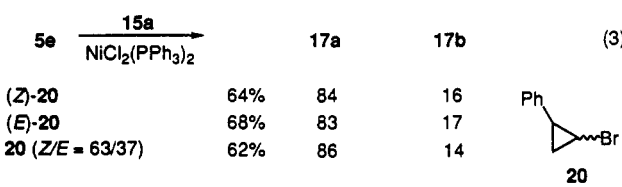


pylmagnesium bromides were employed for this purpose. In general, these Grignard reagents were less reactive, and therefore the reactions were carried out at elevated temperature in refluxing toluene. The results are summarized in Table 2.

When the substituent was an aryl group, rearrangement proceeded preferentially via path *m* to give the terminally substituted dienes in good yield (Table 2, entries 12–16). The ring-opening process with cyclopropyl Grignard reagents having an aliphatic substituent at the C-2 position is nonselective, and a mixture of internally and terminally substituted butadienes was obtained (entry 19). The extension of this coupling reaction to allylic substrates, leading to the formation of hexatrienes, has been executed (entries 20–23).

The regioselective migration of the carbon–carbon bond of the corresponding aryl-substituted (cyclopropylcarbinyl)nickel intermediate **12** is essentially electronic in nature. The benzylic nickel intermediate (**13a**, R = Ar) is apparently more stable than the homobenzylic counterpart (**13b**, R = Ar). The selective formation of the terminally substituted dienes can thus be rationalized. Since no such enhancement in the stability of the transition-metal alkyl complexes (**13a** vs **13b**, R = alkyl) would occur, the ring-opening process becomes less selective.

The stereochemistry of the substituent on the cyclopropyl bromides, from which the Grignard reagents were prepared, has no effect on the selectivity of the ring-opening process. To illustrate this, the reactions of **5e** with **15a** prepared from *cis*- or *trans*- or a 63/37 mixture of *cis*- and *trans*-2-phenyl-1-bromocyclopropanes (**20**) afforded similar product distribution (eq 3). It is well

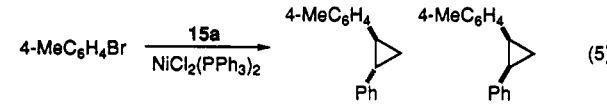


5e	**15a** / $NiCl_2(PPh_3)_2$	**17a**	**17b**	(3)
(*Z*)-**20**	64%	84	16	
(*E*)-**20**	68%	83	17	
20 (*Z*/*E* = 63/37)	62%	86	14	

20

documented that a fast equilibrium occurs between a cyclopropylcarbinyl organometallic species and a homoallylic intermediate (eq 4).[3] As such, the product distribution

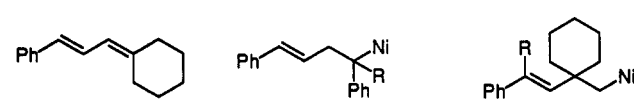
would be independent of the stereochemistry of the starting bromocyclopropanes. Alternatively, rapid inversion of the cyclopropyl Grignard reagents or cyclopropylnickel intermediate may also occur, leading to an equilibrium mixture of products. Indeed, cis–trans isomerization of the substituted cyclopropyl moiety has been observed under these conditions. Thus, the cross coupling of aryl bromide **21** with the Grignard reagent **15a** prepared from *cis*- or *trans*- or a 50/50 mixture of *cis*- and *trans*-**20** gave 70/30, 83/17, or 76/24 mixture of the (*E*)- and (*Z*)-diarylcyclopropanes **22** (eq 5).



		22a	**22b**	(5)
(*Z*)-**20**	88%	70	30	
(*E*)-**20**	92%	83	17	
20 (*Z*/*E* = 50/50)	92%	76	24	

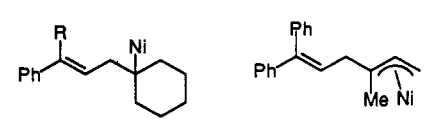
The regioselectivity of the ring-opening process was also affected by the ring size of the dithioacetals employed (cf. entries 17 and 18, Table 2), when substituted cyclopropyl Grignard reagents were employed. As mentioned previously, both sulfur moieties of the leaving group ($-S(CH_2)_nS-$, where n = 2, 3) may remain coordinated to the metal center during the course of the catalytic process.[7] Again, the steric environment around the nickel will be different when different ring sizes of dithioacetals were employed, a six-membered substrate being less selective.

2,2-Disubstituted Cyclopropyl Grignard Reagents. When both hydrogens at the C_2 position were replaced by substituents, the ring-opening process appeared to be dependent on the nature of the substrates and the substituents. Representative results are summarized in Table 3. When one of the substituents or both were aryl groups, rearrangement proceeded via path *m* (Scheme 2) and dienes having substituents at both terminal carbons were obtained (Table 3, entries 24–27). The selectivity is understandable because the more stable benzylic nickel intermediate **29** will be formed. In the coupling reactions with **23b**, intermediate **29**, where R is a methyl group, will undergo β-hydride elimination in two different directions, leading to the formation of a mixture of isomeric olefins **24** and **25** (entries 25 and 27).



26c **29** **30 a** R = Ph
b R = H

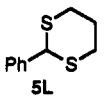
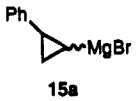
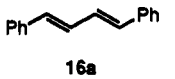
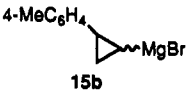
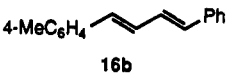
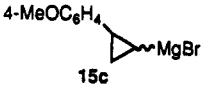
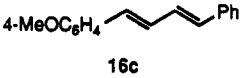
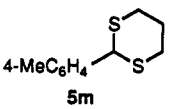
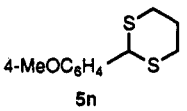
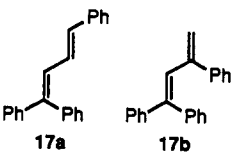
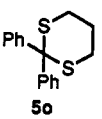
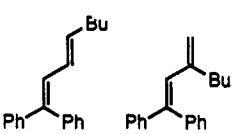
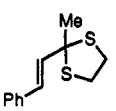
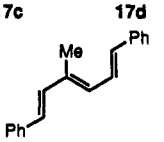
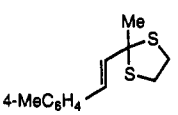
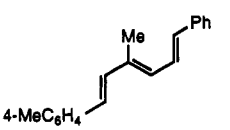
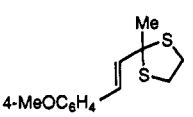
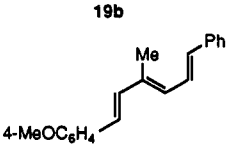
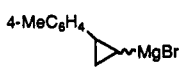
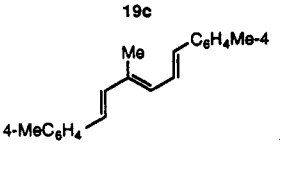
The couplings reactions with **23c** are worthy of comment. When **5e** was employed, the reaction gave **26b** exclusively (entry 28). Because of the severe steric repulsion between the phenyl group and the cyclohexane moiety in intermediate **30a**, the ring-opening process would preferentially proceed via path *m* (Scheme 2), even though the tertiary organonickel intermediate **31a** is formed. On the other hand, when benzaldehyde derivative **5L** was used, the coupling product **27** was isolated in addition to small amount of **26c** (entry 29). The neopentyl intermediate **30b** can not undergo β-hydride elimination. Consequently, **30b** will first associate with the Grignard reagent **23c** followed by reductive elimination to yield **27**.



31 a R = Ph
b R = H

32

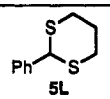
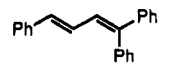
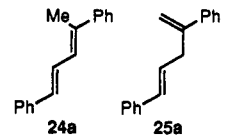
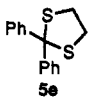
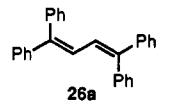
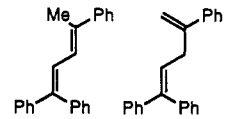
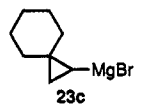
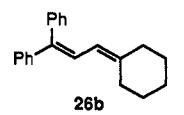
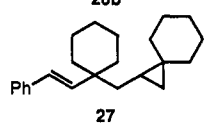
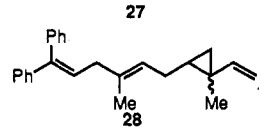
Table 2. $NiCl_2(PPh_3)_2$-Catalyzed Coupling Reactions of 2-Substituted Cyclopropylmagnesium Bromide (15) with Benzylic and Allylic Dithioacetals

entry no.	substrate	RMgBr	product	% yield
12	 **5L**	 **15a**	 **16a**	78
13	**5L**	 **15b**	 **16b**	66
14	**5L**	 **15c**	 **16c**	70
15	 **5m**	**15a**	**16b**	62
16	 **5n**	**15a**	**16c**	68
17	 **5e**	**15a**	 **17a** **17b**	62 (**17a**/**17b** = 86/14)
18	 **5o**	**15a**	**17a** **17b**	60 (**17a**/**17b** = 67/33)
19	**5e**	 **15d**	 **17c** **17d**	62 (**17c**/**17d** = 50/50)
20	 **18a**	 **15a**	 **19a**	40
21	 **18b**	**15a**	 **19b**	41
22	 **18c**	**15a**	 **19c**	41
23	**18b**	 **15b**	 **19d**	40

As for an aryl substituent, when the Grignard reagent contained a vinyl substituent, the rearrangement occurred via path *m* (Scheme 2) to generate the π-allyl intermediate **32**, which undergoes a similar carbon–carbon bond-forming process via reductive elimination leading to **28** (entry 30).

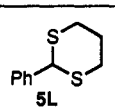
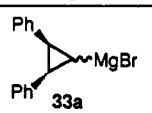
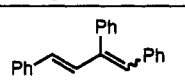
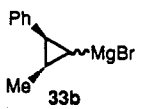
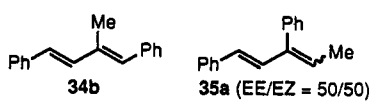
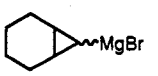
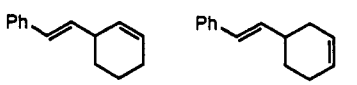
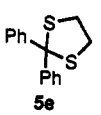
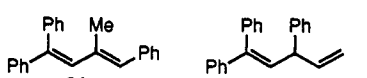
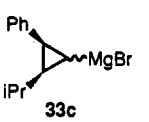
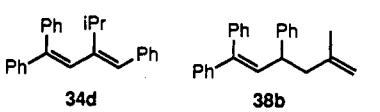
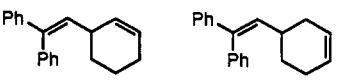
2,3-Disubstituted Cyclopropyl Grignard Reagents. The coupling reactions with 2,3-disubstituted cyclopropyl Grignard reagents appeared to be more complicated than expected. Typical examples are outlined in Table 4. The reaction of **5L** with **33a** gave a mixture of (*EE*)- and (*EZ*)-**34a** (entry 31). Whereas the formation of (*EZ*)-**34a** may be expected from the mechanistic point of view, the *EE*

Table 3. $NiCl_2(PPh_3)_2$-Catalyzed Coupling Reactions of 2,2-Disubstituted Cyclopropylmagnesium Bromides (23) with Benzylic Dithioacetals

entry no.	substrate	RMgBr	product	% yield
24	 **5L**	 **23a**	 **17a**	69
25	**5L**	 **23b**	 **24a** **25a**	72 (**24a**/**25a** = 75/25)
26	 **5e**	**23a**	 **26a**	87
27	**5e**	**23b**	 **24b** **25b**	78 (**24b**/**25b** = 67/33)
28	**5e**	 **23c**	 **26b**	72
29	**5L**	**23c**	 **27**	62[a]
30	**5e**	 **23d**	 **28**	58 (E/Z = 50/50)

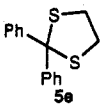
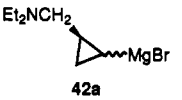
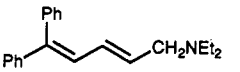
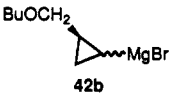
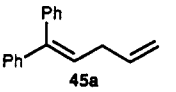
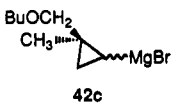
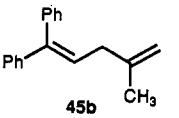
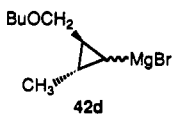
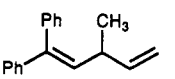
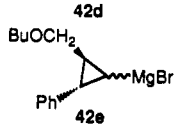
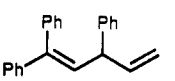
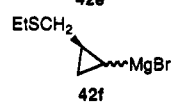
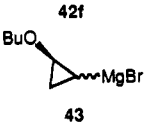
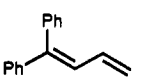
[a] **26c** was also isolated in 5% yield.

Table 4. $NiCl_2(PPh_3)_2$-Catalyzed Coupling Reactions of 2,3-Disubstituted Cyclopropylmagnesium Bromide (33) with Benzylic Dithioacetals

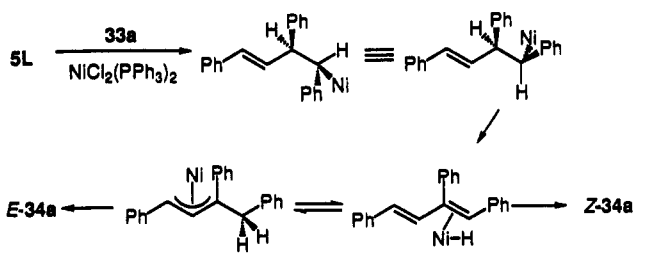
entry no.	substrate	RMgBr	product	% yield
31	 **5L**	 **33a**	 **34a** (EE/EZ = 57/43)	68
32	**5L**	 **33b**	 **34b** **35a** (EE/EZ = 50/50)	77 (**34b**/**35a** = 60/40)
33	**5L**	 **33d**	 **36a** **37a**	67 (**36a**/**37a** = 60/40)
34	 **5e**	**33b**	 **34c** **38a**	72 (**34c**/**38a** = 33/67)
35	**5e**	 **33c**	 **34d** **38b**	64 (**34d**/**38b** = 37/63)
36	**5e**	**33d**	 **36b** **37b**	67 (**36b**/**37b** = 40/60)

isomer may arise from the isomerization of (*EZ*)-**34a** by the in situ generated nickel hydride species (Scheme 3). Similarly, the reactions with 7-norcarylmagnesium bromide (**33d**) gave a mixture of isomeric nonconjugated dienes **36** and **37** (entries 33 and 36). Since there is a requirement of cis coplanarity between the C–Ni bond and the migrating C–C bond in the ring-opening process leading to **39**,[3e] β-hydride elimination of the homoallylnickel intermediate **39** can only afford **36** because the stereochemical requirement prohibits the generation of

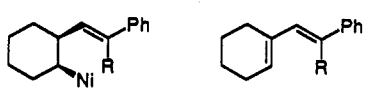
Table 5. $NiCl_2(PPh_3)_2$-Catalyzed Coupling Reactions of 2-Substituted Cyclopropylmagnesium Bromides Containing Heteroatom Substituents with 5e

entry no.	substrate	RMgBr	product	% yield
37	 5e	 42a	 44	41
38	5e	 42b	 45a	70
39	5e	 42c	 45b	52
40	5e	 42d	 45c	60
41	5e	 42e	 38a	48
42	5e	 42f	45a	62
43	5e	 43	 9c	68

Scheme 3

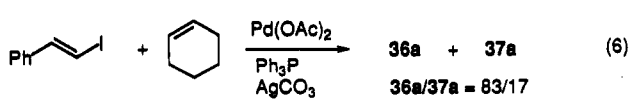


the corresponding conjugate diene **40**. Dienes **37** were obtained via a similar mechanism proposed in Scheme 3.



39 R = H or Ph **40**

The structures of dienes **36a** and **37a** were proved by independent synthesis (eq 6).[9] Interestingly, the Heck



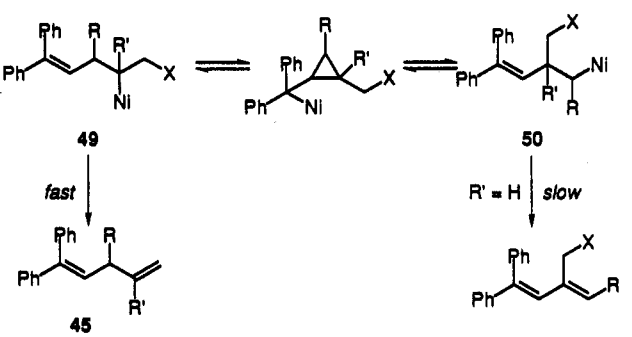
(6)

reaction of (*E*)-2-iodostyrene with cyclohexene also afforded a mixture of **36a** and **37a**. The palladium analog of **39** also underwent a process similar to that exhibited in the nickel-catalyzed reaction to proceed the double-bond migration leading to the formation of **36a** and **37a**.

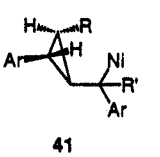
When Grignard reagents **33b,c** were employed, the reaction were nonselective, a mixture of isomers being obtained (entries 32, 34, and 35). Because of severe steric interactions would be expected in the reaction intermediates **41**, the ring-opening process proceeded competitively

(9) Larock, R. C.; Gong, W. H. *J. Org. Chem.* **1989**, *54*, 2047. Abelman, M. M.; Oh, T.; Overman, L. E. *J. Org. Chem.* **1989**, *54*, 179.

Scheme 4



via either path *m* or *n*. Isomerization of the double bond also occurred to release the steric strain.

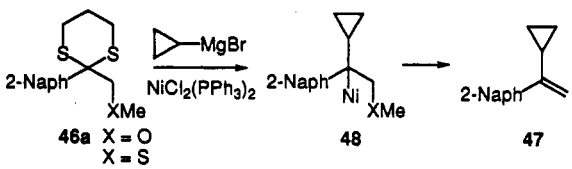


41

2-Substituted Cyclopropyl Grignard Reagents Containing a Heteroatom in the Substituent. In contrast to the simple aliphatic substituents as depicted earlier, the presence of a heteroatom substituent on the aliphatic substituent gave interesting selectivity. Thus, the reaction of **42a** with **5e** afforded aminopentadiene **45** selectively; we speculate that rearrangement occurs via path *m* (Scheme 2) (entry 37, Table 5).

The Grignard reagents having oxygen substituents behaved interestingly. Treatment of 2-(butoxymethyl)-cyclopropyl Grignard reagents with **5e** yielded strikingly the corresponding 1,4-dienes **45** exclusively (entries 38–41, Table 5), the butoxy group being eliminated. The sulfur analog behaved similarly (entry 42). The selectivity of the reactions of heteroatom-containing substituted cy-

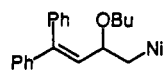
clopropyl Grignard reagents is striking. Among these reactions, the migration of the carbon–carbon bond in the cyclopropyl ring resulted in the formation of the heteroatom β to the nickel-substituted carbon. We have previously shown that β-R_3Sn, -OR, and -SR groups are facilely eliminated under the nickel-catalyzed cross-coupling conditions.[10] To illustrate, the reaction of cyclopropylmagnesium bromide (**6**) with **46** gave vinylcyclopropane derivatives **47** in moderate yields. These results indicated



46a X = O, X = S **48** **47** (7)

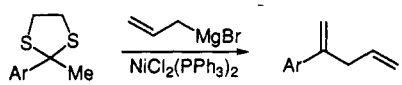
that the rate of elimination of these heteroatom moieties in intermediate **48** would be much faster than that of the ring-opening process and that of β-hydride elimination. As described earlier, there exists a rapid equilibrium between cyclopropylcarbinyl and homoallylic organometallic species (eq 4); hence, the two homoallylic species **49** and **50** will also undergo a rapid equilibrium.[3] Consequently, the exclusive formation of **45** can be rationalized within the framework of the Curtin–Hammett principle[11] (Scheme 4).

Strikingly, a similar reaction with 2-butyoxycyclopropylmagnesium bromide **43** gave **9c** (entry 43). Presumably, the ring-opening process proceeded via path *n* (Scheme 2), leading to the formation of intermediate **A**, from which a butoxy group is eliminated. A mechanism similar to that described in Scheme 4 would also operate here.



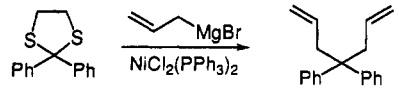
A

Comparison with the Reactions with Allyl Grignard Reagents.[5] We have previously shown that allylmagnesium halides also couple with dithioketals under the nickel-catalyzed conditions to give, instead of conjugated dienes, 1,4-dienes **51** (eq 8).[5] When the dithioketals



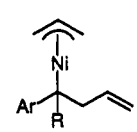
51 (8)

were derived from diaryl ketones, geminal diallylation products **52** were obtained (eq 9).[5b] On the other hand,

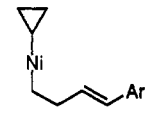


5e **52** (9)

dithioacetals of aromatic aldehydes afforded a mixture of geminal diallylation and diene products.[5b] Although the reaction with the allyl Grignard reagent, like that with the cyclopropyl Grignard reagent, may involve a homoallylic nickel intermediate, the natures of the reactive intermediates may not be identical. We have previously shown that the association of the Grignard reagent is the prerequisite for the β-hydride elimination under these nickel-catalyzed cross-coupling conditions.[4,5] Accordingly, when allyl Grignard reagent was employed, the benzylic–homoallylic π-allyl intermediate **53** was generated. On the other hand, the simple homoallylic organonickel species **54** would be expected, when the cyclopropyl Grignard reagent was used. The difference in intermediates of these reactions (**53** vs **54**) may account for the difference in the products.



53



54

Conclusion

In summary, we have demonstrated a novel methodology for the synthesis of substituted butadienes from dithioacetals and cyclopropyl Grignard reagents. These reactions involve an unprecedented procedure using cyclopropyl anion as an allyl anion synthon. The reaction shows high regio- and stereoselectivity to give *E* isomers predominantly, if not exclusively. We have also accomplished the first systematic investigation on the nature of the substituent(s) in the ring-opening process in the (cyclopropylcarbinyl)nickel intermediate. These results may imply that other metal-catalyzed rearrangements of the cyclopropylcarbinyl systems may also behave similarly. In addition, the extention of β-heteroatom elimination in these nickel-catalyzed cross-coupling reactions leads to regioselective formation of 1,4-dienes.

Experimental Section

General Procedure for the Reaction of Dithioacetals with Cyclopropylmagnesium Bromide (6). Magnesium turnings (97 mg, 4.0 mg-atom) were placed in a 25-mL flask equipped with a stirrer, a condenser, and a nitrogen inlet. The apparatus was flame-dried and flushed with nitrogen. Cyclopropyl bromide (0.32 mL, 4.0 mmol) in THF (6 mL) was added under nitrogen, and the reaction mixture was stirred for 30 min until all the Mg turnings were dissolved. THF was then removed in vacuo; dithioacetal **5** (1.0 mmol), $NiCl_2(PPh_3)_2$ (33 mg, 0.05 mmol), and benzene (10 mL) were added under nitrogen. The mixture was then heated under reflux for 18–24 h. The resulting solution was quenched with saturated NH_4Cl (10 mL), and then diluted with ether (60 mL). The organic portion was washed with aqueous NaOH (10%, 3 × 30 mL) and water (2 × 30 mL). After drying over $MgSO_4$ and filtering, the filtrate was evaporated in vacuo to give the residue, which was chromatographed on silica gel using hexane as eluent. The isomeric mixture was separated by preparative HPLC.

Reaction of 5a with 6. According to the general procedure, **5a** (232 mg, 1.0 mmol), upon treatment with **6** (4.0 mmol), was converted to diene **9a** (119 mg, 66%): bp 125–128 °C (0.2 mm, Kugelrohr) (lit.[12] bp 134–136 °C (0.2 mm)); IR (neat) ν 3058, 2964, 1633, 1593, 1509, 1393, 1261, 1002, 795, 774 cm^{-1}; ^1H NMR ($CDCl_3$, 200 MHz) δ 5.23 (partially resolved dd, J = 10.5 Hz, 1 H), 5.39 (partially resolved dd, J = 16.6 Hz, 1 H), 6.66 (dt, J = 16.6, 10.5 Hz, 1 H), 6.85 (dd, J = 10.5, 15.3 Hz, 1 H), 7.31–8.16 (m, 8 H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 117.9, 123.5, 123.7, 124.0, 125.6, 125.8, 126.1, 128.0, 128.6, 129.7, 132.5, 133.9, 134.7, 137.5; MS *m/z* 180 (M^+, base peak), 179, 165; HRMS calcd for $C_{14}H_{12}$ 180.0939, found 180.0938.

Reaction of 5b with 6. According to the general procedure, **5b** (246 mg, 1.0 mmol) was treated with **6** (4.0 mmol), converting it to diene **9a** (108 mg, 60%).

(10) Shiu, L.-L.; Yu, C. C.; Wong, K.-T.; Chen, B.-L.; Cheng, W.-L.; Yuan, T.-M.; Luh, T.-Y. *Organometallics* **1993**, *12*, 1018.

(11) Carey, F. A.; Sundberg, R. J. *Advanced Organic Chemistry*, 3rd ed.; Plenum: New York, 1990; Part A, p 215.

(12) Bailey, A. S.; Shuttleworth, A. J. *J. Chem. Soc. C* **1968**, *9*, 1115.

Reaction of 5c with 6. By employment of the general procedure, **5c** (232 mg, 1.0 mmol) was allowed to react with **6** (4.0 mmol) to afford **9b** (130 mg, 72%): mp 79–81 °C; IR (KBr) ν 3082, 3053, 3008, 1614, 1586, 1572, 1003, 817, 742 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 5.21 (partially resolved dd, J = 10.5 Hz, 1 H), 5.38 (partially resolved dd, J = 17.0 Hz, 1 H), 6.57 (dt, J = 17.0, 10.5 Hz, 1 H), 6.72 (d, J = 15.6 Hz, 1 H), 6.92 (dd, J = 10.5, 15.6 Hz, 1 H), 7.40–7.81 (m, 7 H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 117.7, 123.5, 125.9, 126.3, 126.5, 127.7, 128.0, 128.2, 130.0, 133.0 (two overlapping signals), 133.7, 134.7, 137.3; MS m/z 180 (M^+), 179 (100), 178, 165; HRMS calcd for $C_{14}H_{12}$ 180.0939, found 180.0932.

Reaction of 5d with 6. According to the general procedure, **5d** (246 mg, 1.0 mmol), upon treatment with **6** (4.0 mmol), was converted to diene **9b** (117 mg, 65%).

Reaction of 5e with 6. According to the general procedure, **5e** (258 mg, 1.0 mmol) was allowed to react with **6** (4.0 mmol) to give **9c** (182 mg, 88%): bp 117–120 °C (0.2 mm, Kugelrohr) (lit.[13] bp 130 °C (0.2 mm)); IR (neat) ν 3080, 3055, 3025, 1494, 1444, 905, 765, 699 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 5.12 (partially resolved dd, J = 10.1 Hz, 1 H), 5.38 (partially resolved dd, J = 16.8 Hz, 1 H), 6.44 (ddd, J = 10.1, 11.0, 16.8 Hz, 1 H), 6.71 (d, J = 11.0 Hz, 1 H), 7.18–7.41 (m, 10 H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 118.4, 127.4, 127.5, 127.6, 128.2, 128.6, 130.5, 135.1, 139.8, 142.2, 143.3; MS m/z 206 (M^+, base peak), 205, 191, 165, 128, 115, 91; HRMS calcd for $C_{16}H_{14}$ 206.1096, found 206.1089.

Reaction of 5f with 6. By employment of the general procedure, **5f** (246 mg, 1.0 mmol) was treated with **6** (4.0 mmol) to afford **9d** (149 mg, 77%; E/Z = 83/17). The two isomers were separated by preparative GC. (*E*)-**9d**: IR (neat) ν 3057, 3005, 2967, 1639, 1595, 1022, 801, 777 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 2.27 (s, 3 H), 5.20–5.29 (m, 2 H), 6.17 (d, J = 10.9 Hz, 1 H), 6.84 (dt, J = 16,8, 10.9 Hz, 1 H), 7.28–7.97 (m, 7 H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 19.4, 117.2, 124.8, 125.4, 125.6, 125.8, 125.9, 127.2, 128.4, 130.9, 131.3, 133.2, 137.6, 143.5; HRMS calcd for $C_{15}H_{14}$ 194.1096, found 194.1076. (Z)-**9d**: ^{1}H NMR ($CDCl_3$, 200 MHz) δ 2.18 (s, 3 H), 4.81 (partially resolved dd, J = 10.3 Hz, 1 H), 5.14 (partially resolved dd, J = 16.9 Hz, 1 H), 5.88 (quasi dt, J = 16.9, 10.5 Hz, 1 H), 6.38 (d, J = 10.7 Hz, 1 H), 7.21–7.24 (m, 1 H), 7.39–7.49 (m, 3 H), 7.74–7.88 (m, 3 H); MS m/z (relative intensity) 194 (M^+, 30), 179 (100), 165 (22); HRMS calcd for $C_{15}H_{14}$ 194.1096, found 194.1110.

A similar reaction with **5g** afforded **9d** in 65% yield (E/Z = 60/40).

Reaction of 5h with 6. According to the general procedure, **5h** (246 mg, 1.0 mmol) was treated with **6** (4.0 mmol) to yield **9e** (146 mg, 75%; E/Z = 93/7). The two isomers were separated by preparative GC. (*E*)-**9e**: mp 45–48 °C; IR (KBr) ν 3056, 2964, 1631, 1598, 1503, 1435, 1412, 1382, 1019, 989, 897, 854, 816, 747 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 2.27 (s, 3 H), 5.23 (partially resolved dd, J = 10.0 Hz, 1 H), 5.37 (partially resolved dd, J = 16.5 Hz, 1 H), 6.62 (d, J = 11.0 Hz, 1 H), 6.82 (ddd, J = 10.0, 11.0, 16.5 Hz, 1 H), 7.35–7.50 (m, 2 H), 7.61 (partially resolved dd, J = 8.0 Hz, 1 H), 7.71–7.90 (m, 4 H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 16.0, 117.7, 124.2, 124.6, 125.8, 126.2, 127.6, 127.8, 128.2, 128.4, 132.9, 133.7, 136.6, 140.4; MS m/z 194 (M^+), 179 (base peak), 178, 165, 152; HRMS calcd for $C_{15}H_{14}$ 194.1096, found 194.1091. (*Z*)-**9e**: ^{1}H NMR ($CDCl_3$, 200 MHz) δ 2.18 (s, 3 H), 4.96 (partially resolved dd, J = 10.0 Hz, 1 H), 5.21 (partially resolved dd, J = 16.8 Hz, 1 H), 6.22 (d, J = 11.0 Hz, 1 H), 6.45 (quasi dt, J = 16.8, 10.6 Hz, 1 H), 7.33–7.47 (m, 2 H), 7.66 (br s, 1 H), 7.70–7.83 (m, 4 H); MS m/z (relative intensity) 194 (M^+, 30), 179 (100), 165 (22); HRMS calcd for $C_{15}H_{14}$ 194.1096, found 194.1109.

A similar reaction with **5i** afforded **9e** in 65% yield (E/Z = 67/33).

Reaction of 5j with 6. By using the general procedure, **5j** (261 mg, 1.0 mmol) was treated with **6** (5.0 mmol) to give **9f** (119 mg, 70%): bp 95–100 °C (0.2 mm); IR (neat) ν 3082, 3003, 1598, 1482, 1453, 1002, 919, 899, 753 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 0.65–0.76 (m, 2 H), 0.85–0.99 (m, 2 H), 1.87–2.02 (m, 1 H), 5.17 (partially resolved dd, J = 10.0 Hz, 1 H), 5.33 (partially resolved dd, J = 16.3 Hz, 1 H), 6.58 (dt, J = 16.3, 10.0 Hz, 1 H), 6.73 (dd, J = 10.0, 15.2 Hz, 1 H), 7.02–7.09 (m, 1 H), 7.12–7.22 (m, 3 H), 7.48–7.50 (m, 1 H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 7.1, 13.5, 117.2, 125.3, 126.1, 126.7, 127.6, 130.8, 130.9, 137.5, 137.8, 140.5; MS m/z 170 (M^+), 155, 141, 129 (base peak), 128, 115, 91; HRMS calcd for $C_{13}H_{14}$ 170.1096, found 170.1081.

Reaction of 5k with 6. By using the general procedure, the reaction of **5k** (217 mg, 1.0 mmol) and **6** (5.0 mmol) afforded diene **9g** (107 mg, 63%): IR (neat) ν 3082, 3006, 2963, 1610, 1513, 1459, 1436, 1046, 1018, 965, 902 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 0.66–0.72 (m, 2 H), 0.92–1.00 (m, 2 H), 1.82–1.92 (m, 1 H), 5.13 (partially resolved dd, J = 10.2 Hz, 1 H), 5.30 (partially resolved dd, J = 16.8 Hz, 1 H), 6.49 (dt, J = 16.8, 10.2 Hz, 1 H), 6.52 (d, J = 15.3 Hz, 1 H), 6.74 (dd, J = 10.2, 15.3 Hz, 1 H), 7.01 (d, J = 8.3 Hz, 2 H), 7.29 (d, J = 8.3 Hz, 2 H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 9.1, 15.3, 116.8, 126.0, 126.5, 128.8, 132.8, 137.4, 143.7; MS m/z 170 (M^+), 155, 141, 129 (base peak), 128, 115, 91; HRMS calcd for $C_{13}H_{14}$ 170.1096, found 170.1093.

General Procedure for the Reaction of Dithioacetals with Substituted Cyclopropylmagnesium Bromide. Magnesium powder (240 mg, 10.0 mmol) was placed in a 50-mL flask fitted with a stirrer, a condenser, and a nitrogen inlet. The setup was flame-dried and flushed with nitrogen. Substituted cyclopropyl bromide (4.0 mmol) in THF (6 mL) and a catalytic amount of ethylene dibromide (0.1 mL) were then added under nitrogen. The exothermic reaction brought the solution to reflux, and the mixture was stirred at room temperature for 30 min to 4 h. The solvent was removed in vacuo; then dithioacetal (1.0 mmol), $NiCl_2(PPh_3)_2$ (33 mg, 0.050 mmol), and toluene (10 mL) were added under nitrogen. The mixture was refluxed for 24–60 h. The resulting solution was quenched with saturated NH_4Cl (10 mL) and then diluted with ether (60 mL). The organic portion was washed with aqueous NaOH (10%, 3 × 30 mL) and water (2 × 30 mL). After drying over $MgSO_4$ and filtering, the filtrate was evaporated in vacuo to give the residue, which was chromatographed on silica gel using hexane as eluent.

Reaction of 5L with 15a. By using the general procedure, **5L** (200 mg, 1.0 mmol) was allowed to react with the Grignard reagent **15a** prepared from 1-bromo-2-phenylcyclopropane (1.20 g, 6.0 mmol) and Mg powder (300 mg, 12.0 mmol) to give **16a** (165 mg, 78%): mp 149–152 °C (hexane) (lit.[14] mp 152.5–153.5 °C); IR (KRr) ν 3023, 1490, 1445, 1073, 992, 912, 830, 738, 687 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 6.67 (dd, J = 2.9, 12.0 Hz, 2 H), 6.96 (dd, J = 2.9, 12.0 Hz, 2 H), 7.20–7.46 (m, 10 H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 126.5, 127.6, 128.7, 129.4, 132.9, 137.6; MS m/z 206 (M^+), 205, 129, 128, 115, 91 (base peak); HRMS calcd for $C_{16}H_{14}$ 206.1096, found 206.1094. Anal. Calcd: C, 93.15; H, 6.85. Found: C, 92.97; H, 6.59.

Reaction of 5L with 15b. According to the general procedure, **5L** (196 mg, 1.0 mmol) was allowed to react with the Grignard reagent **15b** prepared from 1-bromo-2-(4-methylphenyl)cyclopropane (800 mg, 4.0 mmol) and Mg powder (240 mg, 10 mmol) to give **16b** (145 mg, 66%); mp 158–160 °C (lit.[15] mp 160–162 °C); ^{1}H NMR ($CDCl_3$, 200 MHz) δ 2.32 (s, 3 H), 6.57–6.71 (m, 2 H), 6.81–7.02 (m, 2 H), 7.09–7.45 (m, 9 H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 21.2, 125.3, 126.3, 126.8, 127.4, 128.3, 128.6, 129.4, 132.2, 132.8, 134.6, 137.5; MS m/z (relative intensity) 220 (M^+, 100), 205 (15), 105 (2); HRMS calcd for $C_{17}H_{20}$ 220.1252, found 220.1243.

Reaction of 5L with 15c. According to the general procedure, **5L** (196 mg, 1.0 mmol) was allowed to react with the Grignard reagent **15c** prepared from 1-bromo-2-(*p*-methoxyphenyl)cyclopropane (840 mg, 4.0 mmol) and Mg powder (240 mg, 10 mmol) to give **16c** (170 mg, 70%); mp 160–162 °C (lit.[15] mp 161–162.5 °C); ^{1}H NMR ($CDCl_3$, 200 MHz) δ 3.81 (s, 3 H), 6.61 (d, J = 14.8 Hz, 2 H), 6.76–7.00 (m, 4 H), 7.18–7.45 (m, 7 H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 55.3, 114.1, 126.2, 127.3, 127.6, 128.6, 129.5, 130.2, 131.6, 132.4, 137.5, 159.2; MS m/z (relative intensity) 236 (M^+, 100) 220 (15), 205 (34), 178 (10), 159 (14), 91 (4); HRMS calcd for $C_{17}H_{16}O$ 236.1195, found 236.1201.

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Reaction of 5m with 15a. According to the general procedure, the reaction of **5m** (210 mg, 1.0 mmol) with **15a** (4.0 mmol) afforded **16b** (136 mg, 62%).

Reaction of 5n with 15a. According to the general procedure, the reaction of **5n** (226 mg, 1.0 mmol) with **15a** (4.0 mmol) afforded **16c** (160 mg, 68%).

Reaction of 5e with 15a. By employment of the general procedure, **5e** (258 mg, 1.0 mmol) was allowed to react with **15a** (6.0 mmol) to yield a mixture of **17a** and **17b** (175 mg, 62%, **17a/17b** = 86/14). **17a**: mp 94–95 °C (lit.[13] mp 96.5–97.5 °C); IR (KBr) ν 3064, 3036, 1599, 1497, 1490, 1446, 972, 966, 774, 767, 753, 701, 695, 689 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 6.69–6.78 (m, 1 H), 6.84–6.96 (m, 2 H), 7.13–7.44 (m, 15 H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 126.5, 127.2, 127.5, 127.6, 128.2, 128.6, 130.6, 133.9, 137.7, 139.9, 142.4, 143.3; MS *m/z* 282 (M^+, base peak), 191, 165; HRMS calcd for $C_{22}H_{18}$ 282.1409, found 282.1404. **17b**: [16] ^{1}H NMR ($CDCl_3$, 200 MHz) δ 5.03 (d, J = 1.3 Hz, 1 H), 5.38 (d, J = 1.3 Hz, 1 H), 6.74 (s, 1 H), 7.06–7.40 (m, 15 H).

A similar reaction of **5o** with **15a** afforded a mixture of **17a** and **17b** in 6% yield (E/Z = 67/33).

Reaction of 5e with 15d. According to the general procedure, treatment of **5e** (258 mg, 1.0 mmol) with **15d** prepared from 1-bromo-2-*n*-butylcyclopropane (700 mg, 4.0 mmol) and Mg powder (240 mg, 10 mmol) afforded a mixture of **17c** and **17d** (160 mg, 62%, **17c/17d** = 50/50). The two isomers were separated by preparative HPLC. **17c**: ^{1}H NMR ($CDCl_3$, 300 MHz) δ 0.79 (t, J = 7.2 Hz, 3 H), 1.08–1.19 (m, 2 H), 1.23–1.36 (m, 2 H), 1.89 (t, J = 7.8 Hz), 4.77 (br s, 1 H), 4.88 (br s, 1 H), 6.49 (s, 1 H), 7.10–7.35 (m, 10 H); MS *m/z* (relative intensity) 262 (M^+, 3), 207 (28), 183 (56), 167 (37), 105 (100), 91 (15), 77 (11); HRMS calcd for $C_{20}H_{22}$ 262.1722, found 262.1713. **17d**: ^{1}H NMR ($CDCl_3$, 300 MHz) δ 0.85 (t, J = 7 Hz, 3 H), 1.24–1.35 (m, 4 H), 2.01–2.14 (m, 2 H), 5.88 (dt, J = 15.1, 7.0 Hz, 1 H), 6.15 (dd, J = 10.8, 15.1 Hz, 1 H), 6.65 (d, J = 10.8 Hz, 1 H), 7.10–7.40 (m, 10 H); MS *m/z* (relative intensity) 262 (M^+, 7), 207 (100), 178 (34), 105 (58), 91 (11), 77 (13); HRMS calcd for $C_{20}H_{22}$ 262.1722, found 262.1714.

Reaction of 18a with 15a. According to the general procedure, **18a** (222 mg, 1.0 mmol) was allowed to react with **15a** (4.0 mmol) to give **19a** (98 mg, 40%); ^{1}H NMR ($CDCl_3$, 300 MHz) δ 2.09 (s, 3 H), 6.39 (d, J = 11.3, 1 H), 6.61 (d, J = 16.1 Hz, 1 H), 6.62 (d, J = 15.2 Hz, 1 H), 6.91 (d, J = 16.1 Hz, 1 H), 7.19–7.24 (m, 3 H), 7.32 (t, J = 7.5 Hz, 4 H), 7.44 (d, J = 8.0 Hz, 4 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 12.9, 125.4, 126.3, 126.4, 127.3, 127.5, 127.9, 128.6, 132.4, 133.0, 133.5, 136.0, 137.7; MS *m/z* (relative intensity) 246 (M^+, 100), 231 (14), 155 (36), 91 (11); HRMS calcd for $C_{19}H_{18}$ 246.1409, found 246.1409.

Reaction of 18b with 15a. According to the general procedure, **18b** (236 mg, 1.0 mmol) was allowed to react with **15a** (4.0 mmol) to give **19b** (106 mg, 41%); ^{1}H NMR ($CDCl_3$, 300 MHz) δ 2.09 (s, 3 H), 2.35 (s, 3 H), 6.38 (d, J = 11.4 Hz, 1 H), 6.60 (d, J = 16.0 Hz, 1 H), 6.62 (d, J = 15.4 Hz, 1 H), 6.88 (d, J = 16.0 Hz, 1 H), 7.14 (d, J = 7.9 Hz, 2 H), 7.19–7.24 (m, 2 H), 7.30–7.36 (m, 3 H), 7.45 (d, J = 7.9 Hz, 2H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 12.9, 21.2, 125.5, 126.3, 126.4, 127.4, 127.8, 128.6, 129.4, 131.9, 132.5, 132.6, 134.9, 136.2, 137.1, 137.8; MS *m/z* (relative intensity) 260 (M^+, 100), 245 (13), 169 (20), 105 (37); HRMS calcd for $C_{20}H_{20}$ 260.1565, found 260.1555.

Reaction of 18c with 15a. According to the general procedure, **18c** (252 mg, 1.0 mmol) was allowed to react with **15a** (4.0 mmol) to yield **19c** (110 mg, 41%); ^{1}H NMR ($CDCl_3$, 300 MHz) δ 2.07 (s, 3 H), 3.80 (s, 3 H), 6.34 (d, J = 11.3 Hz, 1 H), 6.56 (d, J = 15.9 Hz, 1 H), 6.59 (d, J = 15.3 Hz, 1 H), 6.78 (d, J = 15.9 Hz, 1 H), 6.85 (d, J = 6.6 Hz, 2 H), 7.12–7.44 (m, 9 H); MS *m/z* (relative intensity) 276 (M^+, 100), 261 (18), 185 (38), 121 (95), 91 (12); HRMS calcd for $C_{20}H_{20}O$ 276.1514, found 276.1511.

Reaction of 18b with 15b. According to the general procedure, **18b** (236 mg, 1.0 mmol) was treated with **15b** (4.0 mmol) to afford **19d** (109 mg, 40%); ^{1}H NMR ($CDCl_3$, 300 MHz) δ 2.06 (s, 3 H), 2.33 (s, 6 H), 6.35 (d, J = 11.2 Hz, 1 H), 6.56 (d, J = 16.0 Hz, 1 H), 6.57 (d, J = 15.1 Hz, 1 H), 6.85 (d, J = 16.0 Hz, 1 H), 7.08–7.16 (m, embodied a doublet J = 8.0 Hz, 5 H), 7.32 (d, J = 8.0 Hz, 4 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 12.8, 21.2, 124.5, 126.2, 127.5, 129.3, 132.0, 132.6, 134.9, 135.5, 137.0, 137.3; MS *m/z* (relative intensity) 274 (M^+, 100), 259 (30), 169 (73), 105 (100), 91 (24), 77 (12); HRMS calcd for $C_{21}H_{22}$ 274.1722, found 274.1724.

Reaction of 5L with 23a. According to the general procedure, treatment of **5L** (196 mg, 1.0 mmol) with **23a** prepared from 2,2-diphenylcyclopropyl bromide (1.09 g, 4.0 mmol) and Mg powder (240 mg, 10 mmol) afforded **17a** (195 mg, 69%).

Reaction of 5L with 23b. According to the general procedure, treatment of **5L** (196 mg, 1.0 mmol) with **23b** prepared from 1-bromo-1-methyl-2-phenylcyclopropane (840 mg, 4.0 mmol) and Mg powder (240 mg, 10 mmol) afforded a mixture of **24a** and **25a** (158 mg, 72%, **24a/25a** = 75/25). Attempts to separate these isomers by preparative HPLC or GC were unsuccessful. **24a**:[17] ^{1}H NMR ($CDCl_3$, 200 MHz) δ 2.28 (s, 3 H), 6.65 (d, J = 10 Hz, 1 H), 6.67 (d, J = 15.4 Hz, 1 H), 7.14–7.51 (m, 11 H). **25a**: ^{1}H NMR ($CDCl_3$, 200 MHz) δ 3.39 (d, J = 6.4 Hz, 2 H), 5.14 (d, J = 1.4 Hz, 1 H), 5.42 (d, J = 1.4 Hz, 1 H), 6.34 (dt, J = 6.2, 15.8 Hz, 1 H), 6.48 (d, J = 15.8 Hz, 1 H), 7.14–7.51 (m, 10 H).

Reaction of 5e with 23a. According to the general procedure, treatment of **5e** (260 mg, 1.0 mmol) with **23a** prepared from 2,2-diphenylcyclopropyl bromide (1.09 g, 4.0 mmol) and Mg powder (240 mg, 10 mmol) afforded **26a** (310 mg, 87%): mp 198–199 °C (hexane) (lit.[18] mp 202 °C); IR (KBr) ν 3057, 1599, 1497, 1444, 1351, 1076, 1029, 764, 704, 691 cm^{-1}; ^{1}H NMR δ 6.78 (s, 2 H), 7.14–7.46 (m, 20 H); ^{13}C NMR δ 126.0, 127.3, 127.5, 127.7, 128.2, 128.3, 130.7, 140.1, 142.6, 144.1; HRMS calcd for $C_{28}H_{22}$ 358.1722, found 358.1722.

Reaction of 5e with 23b. According to the general procedure, the reaction of **5e** (258 mg, 1.0 mmol) with **23b** prepared from 1-bromo-2-methyl-2-phenylcyclopropane (840 mg, 4.0 mmol) and Mg powder (240 mg, 10.0 mmol) yielded a mixture of **24b** and **25b** (231 mg, 78%, **24b/25b** = 67/33). The two isomers were separated by preparative HPLC. **24b**: mp 116–118 °C; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 2.29 (s, 3 H), 6.57 (d, J = 11.5 Hz, 1 H), 7.05 (d, J = 11.5 Hz, 1 H), 7.18–7.38 (m, 15 H); ^{13}C NMR ($CDCl_3$, 50 MHz) 16.2, 124.7, 125.1, 125.6, 126.0, 127.0, 127.3, 127.7, 128.1, 128.2, 129.7, 130.7, 137.5, 140.0, 142.9, 143.0, 143.1; MS *m/z* (relative intensity) 296 (M^+, 100), 281 (42), 269 (53), 167 (31), 105 (25); HMRS calcd for $C_{23}H_{20}$ 296.1565, found 296.1555. **25b** (contaminated with a trace amount of **24b**): ^{H} NMR ($CDCl_3$, 200 MHz) δ 3.29 (d, J = 7.4 Hz, 2 H), 5.15 (d, J = 1.2 Hz, 1 H), 5.37 (d, J = 1.2 Hz, 1 H), 6.14 (t, J = 7.4 Hz, 1 H), 7.16–7.45 (m, 15 H); MS *m/z* (relative intensity) 296 (M^+, 100), 281 (48), 205 (50), 167 (28), 105 (22); HMRS calcd for $C_{23}H_{20}$ 296.1565, found 296.1579.

Reaction of 5e with 23c. According to the general procedure, **5e** (258 mg, 1.0 mmol) was allowed to react with **23c** prepared from 1-bromospiro[2.5]octane (760 mg, 4.0 mmol) and Mg powder (240 mg, 10 mmol) to yield **26b** (197 mg, 72%): IR (neat) 3051, 1661, 1594, 1490, 1443, 1260, 1030, 801, 765 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 1.58–1.79 (m, 6 H), 2.05–2.21 (m, 2 H), 2.38–2.52 (m, 2 H), 5.88 (d, J = 11.5 Hz, 1 H), 6.94 (d, J = 11.5 Hz, 1 H), 7.21–7.41 (m, 10 H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 26.8, 27.8, 28.6, 29.5, 37.7, 120.0, 123.7, 126.8, 127.0, 127.4, 128.1, 130.6, 140.2, 145.9; MS *m/z* (relative intensity) 274 (100), 231 (6), 217 (12); HRMS calcd for $C_{21}H_{22}$ 274.1721, found 274.1718.

Reaction of 5L with 23c. According to the general procedure, the reaction of **5L** (196 mg, 1.0 mmol) with **23c** (4.0 mmol) afforded **27** (168 mg, 62%) and **26c** (13 mg, 5%). **27**: ^{1}H NMR ($CDCl_3$, 300 MHz) δ −0.15 (apparent t, J = 4.5 Hz, 1 H), 0.32 (dd, J = 4.0, 8.3 Hz, 1 H), 0.43 (m, 1 H), 1.15–1.73 (m, 22 H), 6.10 (d, J = 16.5 Hz, 1 H), 6.28 (d, J = 16.5 Hz, 1 H), 7.17 (t, J = 7.2 Hz, 1 H), 7.28 (t, J = 8.1 Hz, 2 H), 7.37 (d, J = 8.5 Hz, 2 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 19.4, 19.5, 22.3, 22.5, 22.6, 25.7, 26.0, 26.8, 31.3, 35.8, 36.9, 38.1, 40.4, 41.2, 126.0, 126.7, 127.7, 128.5, 138.5, 139.7; MS *m/z* (relative intensity) 308 (M^+, 17), 225 (21), 185 (100), 129 (31), 117 (34), 91 (20); HRMS calcd for $C_{21}H_{22}$ 308.2504, found 308.2501. **26c**: ^{1}H NMR ($CDCl_3$, 200 MHz) δ 1.53–1.70 (m, 4 H), 2.14–2.32 (m, 2 H), 2.34–2.50 (m, 2H), 5.92 (d, J = 11.4

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Hz, 1 H), 6.45 (d, J = 15.5 Hz, 1 H), 7.05 (dd, J = 11.0, 15.5 Hz, 1 H), 7.17–7.41 (m, 5 H); MS m/z (relative intensity) 198 (M^+, 4), 162 (100), 133 (47), 99 (44); HRMS calcd for $C_{15}H_{28}$ 198.1408, found 198.1402.

Reaction of 5e with 23d. According to the general procedure, treatment of **5e** (258 mg, 1.0 mmol) with **23d** prepared from 1-bromo-2-methyl-2-vinylcyclopropane (650 mg, 4.0 mmol) and Mg powder (240 mg, 4.0 mmol) gave **28** (176 mg, 58%, E/Z = 1:1). Attempts to separate these two isomers were unsuccessful. In the ^{1}H NMR spectrum, there exhibited four sets of methyl singlets at δ 1.09, 1.15, 1.60, and 1.70, two sets of doublets (J = 7.6 Hz) at δ 2.75 and 2.83, and two sets of triplets (J = 7.6 Hz) at δ 6.00 and 6.10.

Reaction of 5L with 33a. According to the general procedure, the reaction of **5L** (200 mg, 1.0 mmol) with **33a** prepared from 1-bromo-2,3-*cis,trans*-diphenylcyclopropane (1.09 g, 4.0 mmol) and Mg powder (240 mg, 10.0 mmol) afforded **34a** (190 mg, 68%, E/Z = 57/43). The two isomers were separated by preparative HPLC. (*Z*)-**34a**: mp 105–108 °C (lit.[19] mp 110 °C (2-propanol)); IR (KBr) ν 3056, 3022, 1597, 1494, 1443, 753, 698 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 6.56 (d, J = 16.2 Hz, 1 H), 6.64 (s, 1 H), 7.21–7.49 (m, 16 H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 126.7, 127.1, 127.2, 127.5, 127.6, 128.2, 128.3, 128.6, 129.3, 129.7, 131.3, 134.2, 137.6, 137.7, 141.3, 142.3; MS m/z 282 (M^+), 191, 162 (base peak), 113; HRMS calcd for $C_{22}H_{18}$ 282.1409, found 282.1408. (*E*)-**34a**: mp 70–73 °C; IR (KBr) ν 3025, 1595, 1570, 1489, 1444, 750, 704, 691 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 6.15 (d, J = 15.9 Hz, 1 H), 6.72 (s, 1 H), 6.88–6.91 (m, 2 H), 7.07–7.43 (m, 14 H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 126.5, 126.9, 127.4, 128.0, 128.6, 128.9, 129.4, 129.6, 131.3, 131.9, 134.4, 136.8, 137.4, 138.3, 141.7; MS m/z 282 (M^+, base peak), 205, 191, 162, 113; HRMS calcd for $C_{22}H_{18}$ 282.1409, found 282.1422.

Reaction of 5L with 33b. According to the general procedure, (*E*)-2-phenyl-3-(methylphenyl)-1-bromocyclopropane (840 mg, 4.0 mmol) was converted to the corresponding Grignard reagent **33b** by stirring with Mg powder (240 mg, 10 mmol) in THF (6 mL) for 1 h. Upon treatment with this Grignard reagent, **5L** (196 mg, 1.0 mmol) was transformed into **34b** and (*E*)- and (*Z*)-**35a** (170 mg, 77%; **34b**/(*E*)-**35a**/(*Z*)-**35a** = 3/1/1). The isomers were separated by preparative HPLC. **34b**:[17] ^{1}H NMR ($CDCl_3$, 200 MHz) δ 2.16 (s, 3 H), 6.68 (d, J = 16 Hz, 1 H), 6.69 (s, 1 H), 7.02 (d, J = 16 Hz, 1 H), 7.20–7.52 (m, 10 H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 13.9, 126.4, 126.6, 127.3, 127.9, 128.1, 128.6, 129.2, 132.2, 134.1, 135.8, 137.6, 137.8; MS m/z (relative intensity) 220 (M^+, 100), 205 (74), 193 (25), 129 (55), 105 (38); HRMS calcd for $C_{17}H_{16}$ 220.1252, found 220.1250. (*E*)-**35a**: ^{1}H NMR ($CDCl_3$, 200 MHz) δ 1.97 (d, J = 7.4 Hz, 3 H), 5.64 (q, J = 7.4 Hz, 1 H), 6.36 (d, J = 16 Hz, 1 H), 7.15–7.76 (m, 11 H); HRMS calcd for $C_{17}H_{16}$ 220.1252, found 220.1260. (*Z*)-**35a**: ^{1}H NMR ($CDCl_3$, 200 MHz) δ 1.61 (d, J = 7.2 Hz, 3 H), 5.93 (q, J = 7.2 Hz, 1 H), 5.98 (d, J = 17.6 Hz, 1 H), 6.97 (d, J = 17.6 Hz, 1 H), 7.14–7.40 (m, 10 H); HRMS calcd for $C_{17}H_{16}$ 220.1252, found 220.1246.

Reaction of 5L with 33d. According to the general procedure, **5L** (200 mg, 1.0 mmol) was allowed to react with **33d** prepared from 7-bromobicyclo[4.1.0]heptane (700 mg, 4.0 mmol) and Mg powder (240 mg, 10.0 mmol) to give a mixture of **36a** and **37a** (120 mg, 67%; **36a**/**37a** = 60/40). Attempts to separate these two isomers were not successful. **36a**:[9] ^{1}H NMR ($CDCl_3$, 200 MHz) δ 1.44–1.92 (m, 4 H), 1.98–2.16 (m, 2 H), 2.86–3.00 (m, 1 H), 5.60–5.84 (m, 2 H), 6.18 (dd, J = 7.3, 15.9 Hz, 1 H), 6.40 (d, J = 15.9 Hz, 1 H), 7.16–7.41 (m, 5 H). **37a**[20] ^{1}H NMR ($CDCl_3$, 200 MHz) δ 1.44–1.92 (m, 2 H), 1.98–2.16 (m, 4 H), 2.36–2.50 (m, 1 H), 5.60–5.84 (m, 2 H), 6.23 (dd, J = 7.0, 16.0 Hz, 1 H), 6.38 (d, J = 16.0 Hz, 1 H), 7.16–7.41 (m, 5 H).

Reaction of 5e with 33b. According to the general procedure, **5e** (258 mg, 1.0 mmol) was treated with **33b** (4.0 mmol) to give a mixture of **34c** and **38a** (213 mg, 72%, **34c**/**38a** = 33/67). These isomers were not separated. **34c**: ^{1}H NMR ($CDCl_3$, 200 MHz) δ 1.63 (s, 3 H), 6.59 (s, 1 H), 6.76 (s, 1 H), 7.11–7.46 (m, 10 H). **38a** exhibited the same properties as those of the authentic sample prepared from **5e** (entry 41, Table 5).

Reaction of 5e with 33c. According to the general procedure, (*E*)-2-phenyl-3-(ethylphenyl)-1-bromocyclopropane (840 mg, 4.0 mmol) was converted to the corresponding Grignard reagent **33c** by stirring with Mg powder (240 mg, 10 mmol) in THF (6 mL). Upon treatment with this Grignard reagent, **5e** (258 mg, 1.0 mmol) was transformed into **34d** (78 mg, 24%) and **38b** (130 mg, 40%). **38b**: ^{1}H NMR ($CDCl_3$, 200 MHz) δ 1.52 (s, 3 H), 2.44 (d, J = 7.8 Hz, 1 H), 3.60 (td, J = 7.8, 10.4 Hz, 1 H), 4.68 (br s, 1 H), 4.73 (br s, 1 H), 6.23 (d, J = 10.4 Hz, 1 H), 7.11–7.37 (m, 15 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 22.2, 43.6, 46.4, 112.4, 126.1, 127.0, 127.3, 128.1, 128.5, 129.9, 132.6, 140.0, 141.3, 142.6, 143.4, 145.3; MS m/z (relative intensity) 324 (M^+, 15), 269 (100), 191 (70), 91 (14); HRMS calcd for $C_{25}H_{24}$ 324.1878, found 324.1880. **34d**: ^{1}H NMR ($CDCl_3$, 200 MHz) δ 1.16 (d, J = 6.8 Hz, 6 H), 3.05 (hept, J = 6.8 Hz, 1 H), 6.01 (s, 1 H), 6.60 (s, 1 H), 6.85 (br d, J = 8.0 Hz, 2 H), 7.07–7.35 (m, 13 H); HRMS calcd for $C_{25}H_{24}$ 324.1878, found 324.1882.

Reaction of 5e with 33d. According to the general procedure, dithioacetal **5e** (260 mg, 1.0 mmol), upon treatment with **33d** (4.0 mmol), was transformed into a mixture of **36b** and **37b** (170 mg, 67%; **36b**/**37b** = 40/60). Attempts to separate these two isomers were unsuccessful. **36b**: ^{1}H NMR ($CDCl_3$, 200 MHz) δ 1.40–1.60 (m, 4 H), 1.92–2.14 (m, 2 H), 2.86–2.98 (m, 1 H), 5.49–5.75 (m, 2 H), 5.93 (d, J = 10.4 Hz, 1 H), 7.16–7.39 (m, 10 H). **37b**: ^{1}H NMR ($CDCl_3$, 200 MHz) δ 1.68–1.80 (m, 2 H), 1.92–2.14 (m, 4 H), 2.36–2.48 (m, 1 H), 5.49–5.75 (m, 2 H), 5.99 (d, J = 10.0 Hz, 1 H), 7.16–7.39 (m, 10 H).

Coupling Reaction of (*E*)-1-Iodo-2-phenylethene with Cyclohexene. Into a 25-mL flask equipped with a stirrer, a condenser, and a nitrogen inlet were placed (*E*)-1-iodo-2-phenylethene (0.23 g, 1.0 mmol), cyclohexene (0.41 g, 5.0 mmol), $Pd(OAc)_2$ (7.0 mg, 3 mol %), Ph_3P (24 mg, 9 mol %), Ag_2CO_3 (0.55 g, 2.0 mmol), and MeCN (12 mL). The mixture was stirred at 80 °C under nitrogen for 48 h. After the solvent was evaporated, the residue was subjected to chromatography (*n*-hexane) to give **36a** and **37a** as an inseparable mixture (0.083 g, 45%; **36a**/**37a** = 5/1). The ^{1}H NMR data of these compounds were identical with those of the compounds reported above.

Reaction of 5e with 42a. According to the general procedure, treatment of **5e** (129 mg, 0.5 mmol) with $NiCl_2(PPh_3)_2$ and **42a**, prepared from 2-((diethylamino)methyl)-1-bromocyclopropane (820 mg, 4.0 mmol) and Mg powder (240 mg, 10 mmol), afforded **44** (119 mg, 41%): ^{1}H NMR ($CDCl_3$, 300 MHz) δ 0.99 (t, J = 7.1 Hz, 6 H), 2.49 (q, J = 7.1 Hz, 4 H), 3.08 (d, J = 6.3 Hz, 2 H), 5.92 (dt, J = 6.3 Hz, 15.3 Hz, 1 H), 6.68 (d, J = 10.8 Hz, 1 H), 7.18–7.37 (m, 10 H); MS m/z (relative intensity) 291 (M^+, 100), 262 (15), 219 (45), 124 (35), 98 (42), 91 (35), 86 (58); HRMS calcd for $C_{21}H_{25}N$ 291.1987, found 291.1982.

Reaction of 5e with 42b. According to the general procedure, treatment of **5e** (129 mg, 0.5 mmol) with $NiCl_2(PPh_3)_2$ (66 mg, 0.10 mmol) and **42b** prepared from 2-(butoxymethyl)-1-bromocyclopropane (1.04 g, 5.0 mmol) and Mg powder (240 mg, 10 mmol) afforded **45a**[21] (77 mg, 70%): ^{1}H NMR ($CDCl_3$, 200 MHz) δ 2.85 (br t, J = 7.4 Hz, 2 H), 5.01 (br d, J = 10 Hz, 1 H), 5.07 (br d, J = 17.2 Hz, 1 H), 5.87 (ddt, J = 7.4, 10, 17.2 Hz, 1 H), 6.09 (t, J = 7.4 Hz, 1 H), 7.15–7.40 (m, 10 H); ^{13}C NMR (50 MHz) δ 34.0, 115.1, 126.6, 126.9, 127.0, 127.3, 128.0, 128.1, 128.4, 129.8, 136.9; MS m/z (relative intensity) 220 (M^+, 100), 205 (60), 142 (42), 129 (88), 91 (20); HRMS calcd for $C_{17}H_{16}$ 220.1252, found 220.1249.

Relative of 5e with 42c. According to the general procedure, treatment of **5e** (129 mg, 0.5 mmol) with $NiCl_2(PPh_3)_2$ (66 mg, 0.10 mmol) and **42c** prepared from 2-(butoxymethyl)-2-methyl-1-bromocyclopropane (1.11 g, 5.0 mmol) and Mg powder (240 mg, 10 mmol) afforded **45b** (60 mg, 52%): ^{1}H NMR ($CDCl_3$, 200 MHz) δ 1.71 (s, 3 H), 2.77 (d, J = 7.8 Hz, 2 H), 4.75 (br s, 2 H), 6.13 (t, J = 7.8 Hz, 1 H), 7.15–7.38 (m, 10 H); MS m/z (relative intensity) 234 (M^+, 60), 219 (34), 194 (100), 166 (34), 105 (12); HRMS calcd for $C_{18}H_{18}$ 234.1209, found 234.1421.

Reaction of 5e with 42d. According to the general procedure, treatment of **5e** (129 mg, 0.5 mmol) with $NiCl_2(PPh_3)_2$ (66 mg,

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(20) Rodriguez, J.; Waegell, P. B. *J. Organomet. Chem.* **1987**, *333*, C25.
(21) Eisch, J. J.; Merkley, J. H. *J. Am. Chem. Soc.* **1979**, *101*, 1148.

0.10 mmol) and **42d** prepared from 2-(butoxymethyl)-3-methyl-1-bromocyclopropane (1.11 g, 5.0 mmol) and Mg powder (240 mg, 10 mmol) yielded **45c** (70 mg, 60%): ^{1}H NMR ($CDCl_3$, 300 MHz) δ 1.10 (d, J = 6.8 Hz, 3 H), 2.96–3.04 (m, 1 H), 4.93–5.00 (m, 2 H), 5.83 (ddd, J = 5.8, 10.3, 17.2 Hz, 1 H), 5.88 (d, J = 10.1 Hz, 1 H), 7.17–7.37 (m, 10 H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 20.7, 37.6, 112.8, 126.8, 126.9, 127.2, 128.0, 128.1, 129.7, 132.9, 140.1, 140.7, 142.8; MS m/z (relative intensity) 234 (M^+, 100), 219 (57), 205 (30), 143 (63), 91 (23); HRMS calcd for $C_{18}H_{18}$ 234.1409, found 234.193.

Reaction of 5e with 42e. According to the general procedure, treatment of **5e** (129 mg, 0.5 mmol) with $NiCl_2(PPh_3)_2$ (66 mg, 0.10 mmol) and **42e** prepared from 2-phenyl-3-(butoxymethyl)-1-bromocyclopropane (1.42 g, 5.0 mmol) and Mg powder (240 mg, 10 mmol) gave **38a** (142 mg, 48%); IR ν 3025, 1634, 1597, 1493, 1446, 919, 873, 764 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 4.17 (dd, J = 6.1, 10.3 Hz, 1 H), 5.06–5.17 (m, 2 H), 6.03 (ddd, J = 6.1, 10.3, 16.7 Hz, 1 H), 6.20 (d, J = 10.3 Hz, 1 H), 7.16–7.41 (m, 15H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 48.9, 115.2, 126.3, 127.1, 127.2, 127.4, 127.7, 128.1, 128.2, 128.5, 129.7, 129.9, 139.8, 140.5, 141.7, 142.3, 143.3; MS m/z (relative intensity) 296 (M^+, 40), 205 (100), 191 (32), 165 (40), 91 (42); HRMS calcd for $C_{23}H_{20}$ 296.1565, found 296.1569.

Reaction of 5e with 43. According to the general procedure, treatment of **5e** (129 mg, 0.5 mmol) with $NiCl_2(PPh_3)_2$ (66 mg, 0.10 mmol) and **43** prepared from 2-butoxy-1-bromocyclopropane (960 mg, 5.0 mmol) and Mg powder (240 mg, 10.0 mmol) afforded **9c** (70 mg, 68%).

Reaction of 5e with 42f. According to the general procedure, treatment of **5e** (129 mg, 0.5 mmol) with $NiCl_2(PPh_3)_2$ (66 mg, 0.10 mmol) and **42f** prepared from 2-((ethylthio)methyl)-1-bromocyclopropane (970 mg, 5.0 mmol) and Mg powder (240 mg, 10.0 mmol) afforded **45a** (68 mg, 62%).

Reaction of 21 with 15a Prepared from (*E*)- and (*Z*)-20.[22] 2-Phenyl-1-bromocyclopropane (**20**; 784 mg, 4.0 mmol; Z/E = 50/50) was converted to the corresponding Grignard reagent **15a** by stirring with Mg powder (240 mg, 10.0 mmol) in THF (6 mL) for 1 h. THF then was removed in vacuo, and toluene (10 mL) was added. To this Grignard reagent were added $NiCl_2(PPh_3)_2$ (33 mg, 0.05 mmol) and *p*-methylbromobenzene (0.12 mL, 1.0 mmol), and the mixture was refluxed for 16 h to afford, after the usual workup, (*E*)-**22** and (*Z*)-**22** (191 mg, 92%; E/Z = 76/24). (*E*)-**22**: ^{1}H NMR ($CDCl_3$, 200 MHz) δ 1.36–1.43 (m, 2 H), 2.07–2.14 (m, 2 H), 2.30 (s, 3 H), 6.99–7.30 (m, 9 H); MS m/z (relative intensity) 208 (M^+, 86), 193 (100), 178 (36), 115 (78), 91 (14); HRMS calcd for $C_{16}H_{16}$ 208.1252, found 208.1255. (*Z*)-**22**: ^{1}H NMR ($CDCl_3$, 200 MHz) δ 1.23–1.35 (m, 1 H), 1.39–1.48 (m, 1 H), 2.19 (s, 3 H), 2.42 (dd, J = 6.4, 8.6 Hz, 2 H, 12% NOE enhancement upon irradiation at δ 1.42 and no NOE enhancement upon irradiation at δ 1.30), 6.71–7.14 (m, 9 H); MS m/z (relative intensity) 208 (M^+, 86), 193 (100), 178 (36), 115 (68), 91 (20); HRMS calcd for $C_{16}H_{16}$ 208.1252, found 208.1246.

(22) Bromides **20** were prepared according to the literature procedure (cf.: Hausser, J. W.; Grubber, M. J. *J. Org. Chem.* **1972**, *37*, 2648). The isomers were separated by preparative GC. Spectroscopic data for (*E*)-**20**: ^{1}H NMR ($CDCl_3$, 300 MHz) δ 1.42–1.53 (m, 2 H), 2.40 (ddd, J = 3.5, 6.7, 10.0 Hz, 1 H), 3.02 (ddd, J = 3.5, 4.5, 8.0 Hz, 1 H), 7.05–7.08 (m, 2 H), 7.21–7.32 (m, 3 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 18.9, 21.6, 26.8, 125.9, 126.5, 128.5, 139.8. Spectroscopic data for (*Z*)-**20**: ^{1}H NMR ($CDCl_3$, 300 MHz) δ 1.32 (ddd, J = 4.6, 6.9, 7.5 Hz, 1 H), 1.57 (ddd, J = 6.9, 7.5, 9.5 Hz, 1 H), 2.31 (dt, J = 7.5, 9.5 Hz, 1 H), 3.31 (dt, J = 4.6, 7.5 Hz, 1 H), 7.23–7.36 (m, 5 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 14.2, 22.1, 24.0, 126.8, 127.9, 129.2, 137.1.

Reaction of 21 with 15a Prepared from (*Z*)-20. According to the above procedure, treatment of **21** (0.12 mL, 1.0 mmol) with **15a** prepared from (*Z*)-**20** (784 mg, 4.0 mmol) and Mg powder (240 mg, 10.0 mmol) afforded (*E*)-**22** and (*Z*)-**22** (183 mg, 88%; E/Z = 70/30).

Reaction of 21 with 15a Prepared from (*E*)-20. According to the above procedure, treatment of **21** (0.12 mL, 1.0 mmol) with **15a** prepared from (*E*)-**20** (784 mg, 4.0 mmol) and Mg powder (240 mg, 10.0 mmol) afforded (*E*)-**22** and (Z)-**22** (191 mg, 92%; E/Z = 83/17).

Reaction of 5e with 15a Prepared from (*E*)- and (*Z*)-20. According to the general procedure, treatment of **5e** (258 mg, 1.0 mmol) with **15a** prepared from (*E*)- and (*Z*)-**20** (784 mg, 4.0 mmol; E/Z = 37/63) and Mg powder (240 mg, 10.0 mmol) afforded **17a** and **17b** (175 mg, 62%; **17a**/**17b** = 86/14).

Reaction of 5e with 15a Prepared from (*Z*)-20. According to the general procedure, treatment of **5e** (258 mg, 1.0 mmol) with (*Z*)-**15a** prepared from (*Z*)-**20** (784 mg, 4.0 mmol) and Mg powder (240 mg, 10.0 mmol) afforded **17a** and **17b** (180 mg, 64%; **17a**/**17b** = 84/16).

Reaction of 5e with 15a Prepared from (*E*)-20. According to the general procedure, treatment of **5e** (258 mg, 1.0 mmol) with (*E*)-**15a** prepared from (*E*)-**20** (784 mg, 4.0 mmol) and Mg powder (240 mg, 10.0 mmol) afforded **17a** and **17b** (192 mg, 68%; **17a**/**17b** = 83/17).

Reaction of 46a with 6. According to the general procedure, a mixture of **46a** (290 mg, 1.0 mmol) and $NiCl_2(PPh_3)_2$ (33 mg, 0.05 mmol) in benzene (10 mL) with **6** (5 mL, 1.2 M in benzene, 6.0 mmol) was heated under reflux for 33 h. After workup and chromatographic separation, **47** was obtained as a colorless liquid (120 mg, 62%). An analytical sample was obtained by preparative GC: IR (neat) 3082, 3056, 3005, 1621, 1596, 1504, 1278, 1132, 1019, 937, 891, 858, 819, 749 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 0.60–0.67 (m, 2 H), 0.84–0.94 (m, 2 H), 1.69–1.83 (m, 1 H), 5.03 (br s, 1 H), 5.41 (br s, 1 H), 7.39–7.49 (m, 2 H), 7.67–7.86 (m, 4 H), 8.05 (s, 1 H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 6.7, 15.7, 109.7, 124.6, 124.8, 125.7, 126.0, 127.5, 127.6, 128.2, 132.9, 133.4, 138.9, 149.2; MS m/z (relative intensity) 194 (M+, 99), 179 (100), 165 (28), 153 (27), 141 (15), 128 (9), 115 (2); HRMS calcd for $C_{15}H_{14}$ 194.1096, found 194.1084.

Reaction of 46b with 6. According to the procedure described above, a benzene solution (10 mL) of **46b** (306 mg, 1.0 mmol) and $NiCl_2(PPh_3)_2$ (33 mg, 0.05 mmol) was treated with **6** (5 mL, 1.2 M in benzene, 6.0 mmol) under reflux for 33 h to give **47** (108 mg, 56%) after the usual workup.

4,4-Diphenyl-1,6-heptadiene (52). According to the general procedure described above, a benzene solution (8 mL) of **5e** (272 mg, 1.0 mmol) and $NiCl_2(PPh_3)_2$ (33 mg, 0.05 mmol) was treated with allylmagnesium bromide (8.0 mL, 1.0 M in benzene, 8.0 mmol) under reflux for 18 h to give **52** (136 mg, 55%) after the usual workup: mp 54–56 °C; ^{1}H NMR ($CDCl_3$, 200 MHz) δ 2.86 (d, J = 6.9 Hz, 4 H), 4.92–5.03 (m, 4 H), 5.23–5.44 (m, 2 H), 7.12–7.33 (m, 10 H); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 42.1, 107.6, 117.7, 125.7, 127.8, 127.9, 128.4, 134.6; HRMS calcd for $C_{19}H_{20}$ 248.1565, found 248.1554.

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