Synthesis and Applications of 1,1-Diborylated Cyclopropanes: Facile Route to 1,2-Diboryl-3-methylenecyclopentenes

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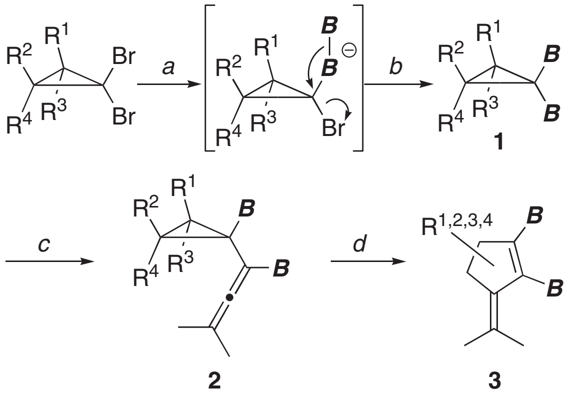
Cyclopropylidene lithium carbenoids reacted with bis(pinacolato)diboron in THF/Et_2O at −110 °C to give various 1,1-diborylated cyclopropanes in good yields. Treatment of the diborylated cyclopropanes with 3-chloro-1-lithio-3-methyl-1-butyne produced the corresponding diborylated allenylcyclopropanes, which underwent ring-expansion in the presence of a Rh catalyst to give 1,2-diborylated methylenecyclopentenes conveniently.

Multiborylated compounds have recently received much attention as polyfunctional organometallic reagents in organic synthesis.[1] Since boryl groups can be readily transformed into several other functionalities,[2] multiborylated carbon frameworks act as valuable building blocks for both biologically active substances and functional organic materials. We have recently developed a convenient synthesis of 1,1-diborylated alkenes from alkylidene-type lithium carbenoids with diboron and furthermore demonstrated their synthetic utility as reagents for stereoselective synthesis of tetrasubstituted alkenes including 1,1,2-triaryl-1-alkenes.[3] To extend the scope of 1,1-diborylation methodology, we turned our attention to 1,1-diborylated cyclopropanes,[4] because polysubstituted cyclopropanes are attractive not only as target framework but also as reactive substrates in transition-metal catalyzed reactions.[5] Thus, 1,1-diborylcyclopropanes are expected to serve as versatile precursors of polyfunctional diborylated reagents. We report herein facile synthesis of 1,1-diborylated cyclopropanes based on 1,1-diborylation of cyclopropylidene carbenoids (Scheme 1).[6] In addition, synthetic transformation of the diborylated cyclopropanes into 1,2-diboryl-3-methylenecyclopentenes is demonstrated.

Treatment of 1,1-dibromocyclopropanes, which are easily accessible by dibromocarbene addition to alkenes, with bis(pinacolato)diboron at −110 °C gave the desired 1,1-diborylcyclopropanes **1** in good to high yields as summarized in Table 1. All **1** were colorless solid and stable toward silica gel and oxygen. Not only tri- and tetrasubstituted cyclopropanes **1a**–**1d** but also fused and hexasubstituted ones **1e**–**1g** were obtained.



Scheme 1. a) BuLi, bis(pinacolato)diboron (***B*** = pinacolatoboryl), b) warming to rt, c) LiC≡CCMe$_2$Cl, d) Rh catalyst.

Table 1. Synthesis of 1,1-diborylcyclopropanes **1**

Entry	R^1	R^2	R^3	R^4	**1**	Yield/%
1	Vinyl	H	H	H	**1a**	86
2	Ph	H	H	H	**1b**	81
3	Ph	H	Ph	H	**1c**	74
4	Ph	H	H	Ph	**1d**	75
5	$-(CH_2)_4-$		H	H	**1e**	84
6	$-CH_2O(CH_2)_2-$		H	H	**1f**	90
7	Me	Me	Me	Me	**1g**	91

[a] Conditions: dibromocyclopropane (1.00 mmol), bis(pinacolato)diboron (1.00 mmol), THF(2 mL)/Et_2O(1 mL), BuLi (1.05 mmol), −110 °C, 15 min, then warming to rt.

To demonstrate the synthetic utility of **1**, we planned two-step approach to vic-diborylated *cyclopentenes* being difficult to prepare via Pt-catalyzed vic-diborylation of alkynes,[7] which was applicable only to prepare *acyclic* 1,2-diborylalkenes. Thus, we envisioned that allenylidene insertion into a carbon–boron bond of **1** followed by ring-enlargement of the resulting allenylcyclopropanes **2** would produce 1,2-diboryl-3-methylenecyclopentenes **3**. Treatment of 3-chloro-3-methyl-1-butyne with butyllithium in THF/Et_2O at −90 °C followed by addition of **1** at −110 °C produced the corresponding allenylcyclopropanes **2** as summarized in Table 2. The reaction is considered to involve a borate formation of **1** with the lithium acetylide, in which the cyclopropyl moiety undergoes 1,2-migration with release of the chloride ion in a S_N2' fashion.[8]

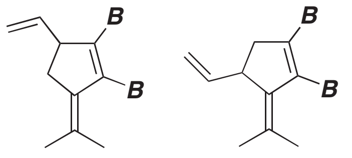
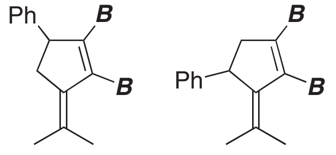
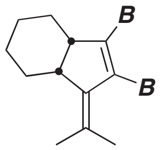
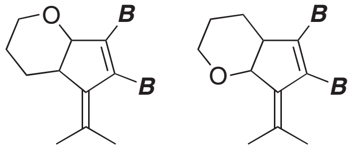
Table 2. Synthesis of allenylcyclopropanes **2**

Entry	R^1	R^2	R^3	R^4	**2**	Yield/%
1	vinyl	H	H	H	**2a**	32
2	Ph	H	H	H	**2b**	60
3	Ph	H	Ph	H	**2c**	61
4	$-(CH_2)_4-$		H	H	**2e**	48
5	$-[CH_2O(CH_2)_2]-$		H	H	**2f**	52

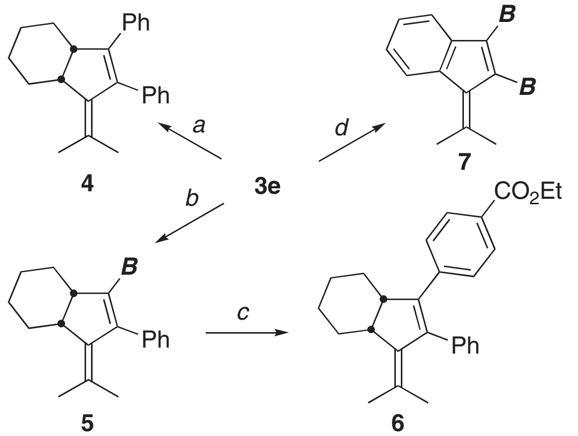
[a] Conditions: 3-chloro-3-methyl-1-butyne (1.05 mmol), BuLi (1.05 mmol), THF(2 mL)/Et_2O(2 mL), −90 °C, then **1** (1.00 mmol) in THF (1 mL), −110 °C.

With **2** in hand, we carried out Rh-catalyzed rearrangement of **2** under the conditions reported by Saigo and co-workers.[9] Thus, heating a benzene solution of **2** in the presence of 10 mol % of such a Rh catalyst as [Rh(COD)$_2$]BF$_4$, RhCl(COD)$_2$,

Table 3. Synthesis of 1,2-diborylcyclopentenes **3**[a]

Entry	Catalyst	**3**: Yield/%
1	A	 **3a**: 49% (80:20)[b]
2	B	 **3b**: 79% (55:45)[b]
3	B	 **3e**: 58%
4	C	 **3f**: 46% (57:43)[b]

[a]Conditions: **2** (0.25 mmol), 10 mol % of a catalyst (A: [Rh(MeCN)$_2$(cod)]BF$_4$, B: [Rh(cod)$_2$]BF$_4$, C: [RhCl(cod)]$_2$), benzene (0.75 mL), 80 °C. [b]The values in parentheses are isomer ratios and regiochemistry is not determined.



Scheme 2. Conditions: a) iodobenzene (3 equiv.), PdCl$_2$(dppf) (10 mol %), 3 M KOH aq. (6 equiv.), DME, 60 °C, 89% yield. b) iodobenzene (1.5 equiv.), PdCl$_2$(dppf) (5 mol %), 3 M KOH aq. (3 equiv.), THF, 60 °C, 86% yield. c) *p*-EtO$_2$CC$_6$H$_4$I (1.7 equiv.), PdCl$_2$(dppf) (5 mol %), 3 M KOH aq. (3 equiv.), THF, 60 °C, 55% yield. d) DDQ, benzene, rt, 54%.

or [Rh(MeCN)$_2$(COD)]BF$_4$ at reflux for 24 h gave **3** as a mixture of regioisomers (Table 3). Although further study on regiocontrol of the rearrangement is necessary, the two-step protocol is found effective for the construction of vic-diborylated cyclopentene frameworks that are difficult to prepare alternatively.

Finally, some synthetic transformations of **3e** are demonstrated in Scheme 2. Pd-catalyzed cross-coupling reaction of **3e** with iodobenzene produced diphenylated product **4** or mono-phenylated product **5** as a single stereoisomer in good yield, respectively, simply by tuning the solvent and the amount of the iodide. Hence, two different aryl groups can be introduced stepwise into **3e** at will as demonstrated in the preparation of **6**. Oxidation of **3e** with DDQ gave diborylated benzofulvene **7** which can be derivatized to polyfunctional fulvenes.

In conclusion, we have demonstrated a convenient access to 1,1-diborylated cyclopropanes and their synthetic utility as precursors of vic-diborylated methylenecyclopentenes. Further studies on preparation and reactions of diborylated reagents are in progress in our laboratory.

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