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Stereoselective Synthesis of (*E*)- and (*Z*)-Fluoroalkenylboronates Using 2-Fluoroalkylideneiodonium Ylides Generated from (2-Fluoro-1-alkenyl)iodonium Salts

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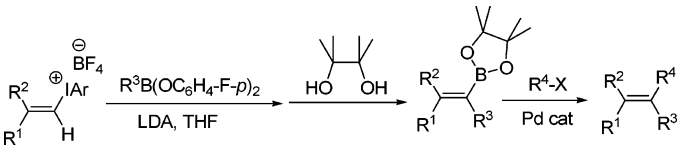

(*E*)- and (*Z*)-(fluoroalkenyl)boronates were prepared stereospecifically by the reaction of 2-fluoroalkylideneiodonium ylide generated from (*E*)- or (*Z*)-(2-fluoroalkenyl)iodonium salts with di(*p*-fluorophenoxy)alkylboranes, followed by transesterification to pinacol esters. The resulting pinacol esters of (fluoroalkenyl)boranes were used for the stereoselective synthesis of trisubstituted fluoroalkenes by cross-coupling reactions.

Introduction

Transition metal-catalyzed cross-coupling reactions of alkenylmetals with aryl or alkenyl halides have been successfully used for the stereoselective synthesis of alkenes with various functional groups.[1] Although (fluoroalkenyl)metals, such as (1-fluoroalkenyl)metals,[2] (1,2-difluoroalkenyl)metals,[3] and (2,2-difluoroalkenyl)metals,[4] have been used as versatile building blocks for fluoroalkene synthesis by cross-coupling reactions,[5] (2-fluoroalkenyl)metals have not been used for the cross-coupling reactions. Recently, we reported the stereoselective synthesis of (*E*)- and (*Z*)-(2-fluoroalkenyl)iodonium salts (**1**)[6] and their use for the synthesis of various fluoroalkenes by cross-coupling reactions.[7] Quite recently, we succeeded in generation of 2-fluoroalkylideneiodonium ylides from **1** and their use for the stereoselective synthesis of (*E*)- and (*Z*)-dialkyl(2-fluoroalkenyl)boranes (**2a**) by the reaction with trialkylboranes (Scheme 1).[8] Though α-hydrogen of alkenyliodonium salts is known to be acidic and is readily abstracted by base, the generated iodonium ylide is unstable and decomposes to a carbene species quickly.[9] By treatment of **1** with LDA in the presence of trialkylborane, the generated iodonium ylide made a borate complex with trialkylborane before decomposition to the carbene. Migration of an alkyl group from the boron to α-carbon with inversion of sp^2 carbon took place as in the

(1) (a) *Metal-catalyzed Cross-coupling Reactions*; Diederich, F., Stang, P. J., Eds.; Wiley-VCH: Weinheim, 1999. (b) *Cross-Coupling Reactions*; Miyaura, N., Ed.; Springer: Berlin, 2002.

(2) Sn: (a) Matthews, D. P.; Waid, P. P.; Sabol, J. S.; McCarthy, J. R. *Tetrahedron Lett.* **1994**, *35*, 5177. (b) Chen, C.; Wilcoxen, K.; Kim, K.; McCarthy, J. R. *Tetrahedron Lett.* **1997**, *38*, 7677. (c) Andrès, D. F.; Laurent, E. G.; Marquet, B. S. *J. Fluorine Chem.* **1998**, *92*, 63. (d) Chen, C.; Wilcoxen, K.; Zhu, Y.-F.; Kim, K.; McCarthy, J. R. *J. Org. Chem.* **1999**, *64*, 3476. (e) Sciotti, R. J.; Pliushchev, M.; Wiedeman, P. E.; Balli, D.; Flamm, R.; Nilius, A. M.; Marsh, K.; Stolarik, D.; Jolly, R.; Ulrich, R.; Djuric, S. W. *Bioorg. Med. Chem. Lett.* **2002**, *12*, 2121. (f) Gernert, D. L.; Ajamie, R.; Ardecky, R. A.; Bell, M. G.; Leibowitz, M. D.; Mais, D. A.; Mapes, C. M.; Michellys, P. Y.; Rungta, D.; Reifel-Miller, A.; Tyhonas, J. S.; Yumibe, N.; Grese, T. A. *Bioorg. Med. Chem. Lett.* **2003**, *13*, 3191. (g) Berkowitz, D. B.; Salud-Bea, R.; Jahng, W.-J. *Org. Lett.* **2004**, *6*, 1821. Si: Hanamoto, T.; Kobayashi, T. *J. Org. Chem.* **2003**, *68*, 6354. Ge: Wang, Z.; Gonzalez, A.; Wnuk, S. F. *Tetrahedron Lett.* **2005**, *46*, 5313.

(3) (a) Lu, L.; Burton, D. J. *Tetrahedron Lett.* **1997**, *38*, 7673. (b) Liu, Q.; Burton, D. J. *Org. Lett.* **2002**, *4*, 1483. (c) Wang, Y.; Burton, D. J. *Org. Lett.* **2006**, *8*, 1109.

(4) Ichikawa, J. *J. Fluorine Chem.* **2000**, *105*, 257 and references cited therein.

(5) (Fluoroalkadienyl)metals were also used for the fluoropolyene synthesis by application to the cross-doupling reactions; see: (a) Shinada, T.; Sekiya, N.; Bojkova, N.; Yoshihara, K. *Synlett* **1995**, 1247. (b) Tsuchikawa, H.; Matsushita, N.; Matsumori, N.; Murata, M.; Oishi, T. *Tetrahedron Lett.* **2006**, *47*, 6187. (c) Sakai, M.; Guan, T; Hara, S. *J. Fluorine Chem.* **2007**, *128*, in press.

(6) (*E*)-isomer: (a) Hara, S.; Yoshida, M.; Fukuhara, T.; Yoneda, N. *Chem. Commun.* **1998**, 965. (b) Yoshida, M.; Kawakami, K.; Hara, S. *Synthesis* **2004**, 2821. (*Z*)-isomer: (c) Yoshida, M.; Hara, S. *Org. Lett.* **2003**, *5*, 573. (d) Yoshida, M.; Osafune, K.; Hara, S. *Synthesis* **2007**, 1542.

(7) (a) Hara, S.; Yamamoto, K.; Yoshida, M.; Fukuhara, T.; Yoneda, N. *Tetrahedron Lett.* **1999**, *40*, 7815. (b) Yoshida, M.; Hara, S.; Fukuhara, T.; Yoneda, N. *Tetrahedron Lett.* **2000**, *41*, 3887. (c) Yoshida, M.; Nagahara, D.; Fukuhara, T.; Yoneda, N.; Hara, S. *J. Chem. Soc., Perkin Trans. 1* **2001**, 2283. (d) Yoshida, M.; Komata, A.; Hara, S. *J. Fluorine Chem.* **2004**, *125*, 527. (e) Yoshida, M.; Komata, A.; Hara, S. *Tetrahedron* **2006**, *62*, 8636.

(8) Hara, S.; Guan, T.; Yoshida, M. *Org. Lett.* **2006**, *8*, 2639.

(9) (a) Kitamura, T.; Stang, P. J. *Tetrahedron Lett.* **1988**, *29*, 1887. (b) Ochiai, M.; Takaoka, Y.; Nagao, Y. *J. Am. Chem. Soc.* **1988**, *110*, 6565.

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SCHEME 1

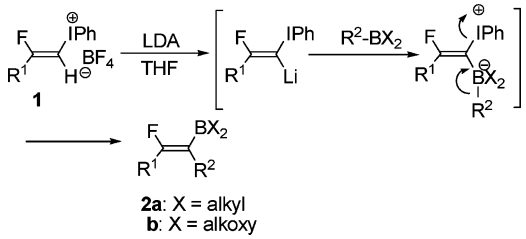
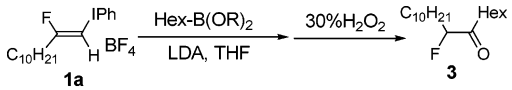
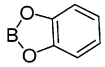


TABLE 1. Reaction of Alkylideneiodonium Ylide with Various Hexylboronates[a]



Entry	-B(OR)$_2$	Yield of **3** (%)[b]
1		0
2		6
3		57
4	$B(OMe)_2$	7
5	$B(OPr^i)_2$	5
6	$B(OPh)_2$	70
7	$B(OC_6H_4\text{-}F\text{-}p)_2$	82

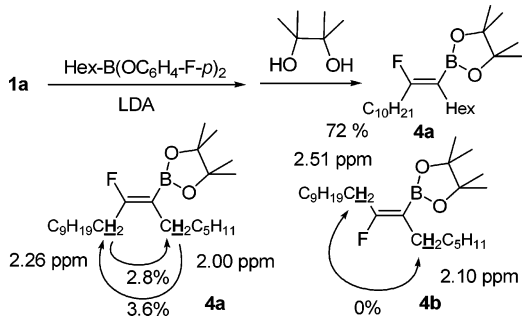
[a] 1.5 equiv of LDA and the boronate to **1a** were used. [b] Isolated yield based on **1a**.

reaction of α-haloalkenylborates to give **2a** stereoselectively.[10] However, the resulting dialkyl(2-fluoroalkenyl)borane **2a** is not stable enough to isolate by column chromatography, and we converted it to 2-fluoroalkene, 1-iodo-2-fluoroalkene, and α-fluoroketone without isolation.[8] (2-Fluoroalkenyl)boronate (**2b**) is more stable than **2a** and suitable for isolation. In particular, a pinacol ester is highly stable and can be purified by silica gel column chromatography.[11] Therefore, we examined the reaction of the iodonium ylide with various alkylboronate derivatives for the preparation of **2b** (Scheme 1).

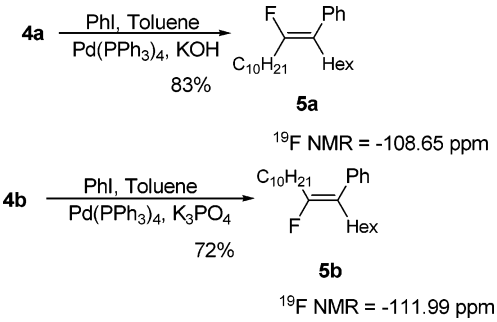
Results and Discussion

Synthesis of (Fluoroalkenyl)boronates. We applied hexylboronate derivatives of various alcohols and phenols to the reaction with the iodonium ylide generated from the (*Z*)-2-fluorododecen-1-yliodonium salt (**1a**),[7] and the yield was obtained after converting the product **2b** to 8-fluorooctadecan-7-one (**3**) by oxidation (Table 1). The boronate derivatives of aliphatic alcohols are less reactive than that of phenols, and **3** was obtained only in poor yield (<10%) (entries 1, 2, 4, and 5). On the other hand, *B*-hexylcatecholborane and hexyldiphenoxyborane gave **3** in 57% and 70% yields, respectively (entries 3 and 6). The best result was obtained using di(*p*-fluorophenoxy)hexylborane, which gave **3** in 82% yield (entry 7).

SCHEME 2



SCHEME 3



Di(*p*-fluorophenoxy)(8-fluoro-7-octadecenyl)borane, prepared by the reaction of **1a** with di(*p*-fluorophenoxy)hexylborane, is moisture sensitive, and its purification by silica gel column chromatography is difficult. Therefore, we converted it to the stable pinacolborane derivative by transesterification[12] and (*E*)-2-(8-fluorooctadec-7-en-7-yl)-4,4,5,5-tetramethyl[1,3,2]-dioxaborolane (**4a**) was obtained in 72% yield after purification by column chromatography. The (*Z*)-isomer (**4b**) was also obtained in 50% yield from the (*E*)-2-fluorododecen-1-yliodonium salt (**1b**)[6] in a similar manner. The yield of **4b** was lower than that of **4a** because of the instability of **4b**.[8] The stereochemistry of **4a** and **4b** was determined by two methods: observation of NOE in their ^{1}H NMR spectra and their conversion to (*Z*)- and (*E*)-trisubstituted fluoroalkenes (**5a** and **5b**). In ^{1}H NMR of (*E*)-isomer **4a**, NOE interaction was observed between the protons attached to the allylic carbons. On the other hand, the NOE interaction of the allylic protons was not observed in (*Z*)-isomer **4b** (Scheme 2).

By the Suzuki−Miyaura coupling reaction with iodobenzene, **4a** and **4b** were converted to (*Z*)- and (*E*)-7-phenyl-8-fluorooctadec-7-ene (**5a**) and (**5b**), respectively,[1b] and their spectra data were in good agreement with the previously reported data (Scheme 3).[8] These results support the (*E*)- and (*Z*)-stereochemistry of **4a** and **4b**.

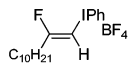
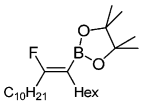
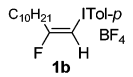
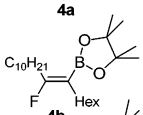
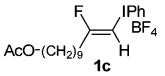
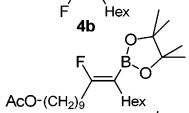
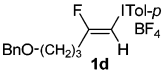
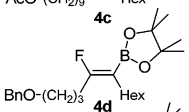
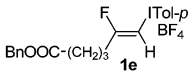
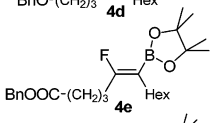
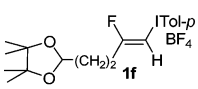
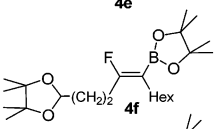
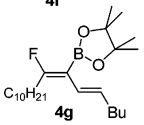
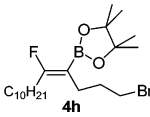
From various (fluoroalkenyl)iodonium salts (**1a**−**f**), corresponding (fluoroalkenyl)boronates (**4a**−**h**) were obtained stereoselectively (Table 2). (Fluoroalkenyl)iodonium salts with functional groups such as acetate (**1c**), benzyl ether (**1d**), ester (**1e**), and acetal (**1f**) can be prepared from corresponding

(10) (a) *Organic Synthesis via Boranes*; Brown, H. C., Ed.; Wiley-Interscience: New York, 1975. (b) Hata, T.; Kitagawa, H.; Masai, H.; Kurahashi, T.; Shimizu, M.; Hiyama, T. *Angew. Chem., Int. Ed.* **2001**, *40*, 790.

(11) Pandya, S. U.; Pinet, S.; Chavant, P. Y.; Vallée, Y. *Eur. J. Org. Chem.* **2003**, 3621.

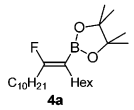
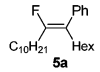
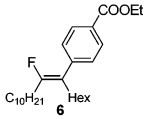
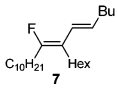
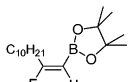
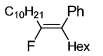
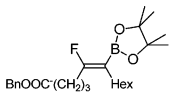
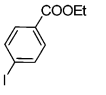
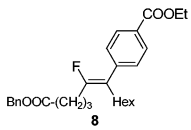
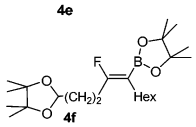
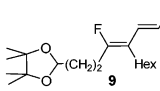
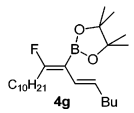
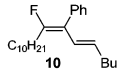
(12) (a) Vaultier, M.; Truchet, F.; Carboni, B.; Hoffmann, R. W.; Denne, I. *Tetrahedron Lett.* **1987**, *28*, 4169. (b) Fresneda, P. M.; Vaultier, M. *Tetrahedron Lett.* **1989**, *30*, 2929. (c) Markó, I. E.; Giard, T.; Sumida, S.; Gies, A.-E. *Tetrahedron Lett.* **2002**, *43*, 2317. (d) Roy, C. D.; Brown, H. C. *J. Organomet. Chem.* **2007**, *692*, 784.

TABLE 2. Stereoselective Synthesis of (2-Fluoroalkenyl)boronates[a]

Iodonium salt	R-B(OPh-F-*p*)$_2$, R	Product	Yield (%)[b]
 **1a**	Hexyl	 **4a**	72
 **1b**	Hexyl	 **4b**	50
 **1c**	Hexyl	 **4c**	63
 **1d**	Hexyl	 **4d**	66
 **1e**	Hexyl	 **4e**	58
 **1f**	Hexyl	 **4f**	64
1a	Hexen-1-yl	 **4g**	60
1a	3-Bromopropyl	 **4h**	50

[a] 1.5 equiv of LDA and R-B(OC6H4-F-*p*)$_2$ to **1** were used. [b] Isolated yield based on **1** used.

TABLE 3. Stereoselective Synthesis of Trisubstituted Fluoroalkenes by the Cross-Coupling Reaction of (Fluoroalkenyl)boronates with Aryl or Alkenyl Halides[a]

Boronate, **4**	Halide	Conditions	Product	Yield (%)[b]
 **4a**	I—Ph	100 °C, 15h	 **5a**	83
4a		80 °C, 2h	 **6**	89
4a		85 °C, 12h	 **7**	77
 **4b**	I—Ph	110 °C, 15h[c]	 **5b**	72
 **4e**		80 °C, 3h	 **8**	80
 **4f**		85 °C, 12h	 **9**	71
 **4g**	I—Ph	95 °C, 12h	 **10**	87

[a] 5 mol % of Pd(PPh$_3$)$_4$, 2 equiv of KOH in EtOH, and 1.2 equiv of halide to **4** were used. [b] Isolated yield based on **4** used. [c] 2 equiv of K_3PO_4 in H_2O was used instead of KOH.

alkynes,[6] and the corresponding functionalized (fluoroalkenyl)-boronates (**4c**−**f**) can be prepared from them. Introduction of the functional groups into **4** using the functionalized alkylboronates is also possible. Using di(*p*-fluorophenoxy)(3-bromopropyl)borane, the (1-bromo-5-fluoropentadecan-4-en-4-yl)boronate (**4h**) was obtained. An alkenylboronate can be also used for the reaction: for example, from di(*p*-fluorophenoxy)hex-1-en-1-ylborane, (8-fluorooctadeca-5,7-dien-7-yl)boronate (**4g**) was obtained stereoselectively.

Application of (Fluoroalkenyl)boronates in the Suzuki−**Miyaura Coupling Reaction.** The resulting (fluoroalkenyl)-boronates were used in the Suzuki−Miyaura coupling reaction for the synthesis of polyfunctionalized trisubstituted fluoroalkenes (Table 3).[1b] The cross-coupling reactions with aryl halides or alkenyl halides proceeded stereospecifically, and from (*E*)-(fluoroalkenyl)boronates (**4a**,**e**−**g**), arylated (*Z*)-fluoroalkenes (**5a**, **6**, **8**) or fluoroalkadienes (**7**, **9**, **10**) were obtained. On the other hand, from (*Z*)-isomer (**4b**), (*E*)-fluoroalkene (**5b**) was selectively formed. The functional groups such as ester, acetal can tolerate the reaction conditions, and corresponding poly-functionalized arylated fluoroalkene (**8**) or fluoroalkadiene (**9**) was obtained stereoselectively. Though we did not optimized the conditions of the cross-coupling well, lower reaction temperature (80−85 °C) is preferable for the functionalized fluoroalkene synthesis.

Summary

We succeeded in the stereoselective synthesis of (fluoroalkenyl)boronates by the reaction of alkylideneiodonium ylide generated from (fluoroalkenyl)iodonium salts with di(*p*-fluorophenoxy)alkylborane. The (fluoroalkenyl)boronates were isolated as stable pinacol esters. Starting from (*E*)- or (*Z*)-fluoroalkenyliodonium salts, (*E*)- or (*Z*)-(fluoroalkenyl)boronates can be prepared stereoselectively. Various functional groups can be introduced into the (fluoroalkenyl)boronates using functionalized (fluoroalkenyl)iodonium salts or functionalized alkylboronates. The resulting (*E*)- and (*Z*)-(fluoroalkenyl)boronates can be used in a cross-coupling reaction with aryl or alkenyl halides for the synthesis of trisubstituted fluoroalkenes.

Experimental Section

1. General Methods. The IR spectra were recorded using an FT/IR-410 spectrophotometer. The ^{1}H NMR (400 MHz) spectra, ^{13}C NMR (100 MHz), ^{19}F NMR (376 MHz), and ^{11}B NMR (128 MHz) spectra were recorded in $CDCl_3$ on an FT NMR spectrometer, and the chemical shifts, δ, are referred to TMS (^{1}H and ^{13}C), $CFCl_3$ (^{19}F), and BF_3 etherate (^{11}B), respectively. The EI-high-resolution mass spectra were measured on a spectrometer. $HBBr_2{-}SMe_2$ and *p*-fluorophenol were purchased from a commercial. (*E*)-(2-Fluorododec-1-enyl)iodonium salt (**1b**) and (*Z*)-2-fluoroalk-1-enyliodonium salts (**1a**,**c**−**f**) were prepared from the corresponding 1-alkynes according to the literatures.[6]

Preparation of Di(*p*-fluorophenoxy)hexylborane. In a 100 mL flask fitted with a reflux condenser were placed 1-hexene (1.68 mg, 20 mmol) and CH_2Cl_2 (15 mL). After the addition of a 1 M CH_2Cl_2 solution of $HBBr_2-SMe_2$ (20 mL, 20 mmol) at room temperature, the mixture was stirred under reflux for 3 h. The reaction mixture was cooled to 0 °C, and *p*-fluorophenol (4.48 g, 40 mmol) in diethyl ether (10 mL) was added. The mixture was stirred at 0 °C for 30 min, and then MeOH (1.28 g, 40 mmol) was added. The mixture was stirred for 10 min and the solvent was removed under reduced pressure. Distillation of the residue under reduced pressure gave di(*p*-fluorophenoxy)hexylborane as a clear liquid (bp 140−145 °C/0.3 mmHg).

Preparation of 8-Fluoro-7-octadecanone (3). General Procedure for the Reaction of 1a with Hexylboronates. To a THF solution (2.5 mL) of **1a** (238 mg, 0.5 mmol) was added at −78 °C a 1 M THF solution (0.75 mL) of hexylboronate (0.75 mmol) and LDA (0.75 mmol), prepared by the addition of a hexane solution of BuLi (0.47 mL of a 1.6 M solution, 0.75 mmol) to diisopropylamine (76 mg, 0.75 mmol) in THF (5 mL). The mixture was stirred at −40 °C for 3 h and at room temperature for 1 h. Then the mixture was cooled to 0 °C, and 30% aq H_2O_2 (10 mL) was added. After being stirred at room temperature for 2 h, the mixture was poured into water and extracted with ether three times. The combined organic layer was dried over $MgSO_4$ and concentrated under reduced pressure. Purification by column chromatography (silica gel/hexane-ether gradient) gave **3**: IR (neat) 2926, 2855, 1725, 1466 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 0.86−0.90 (m, 6H), 1.26−1.60 (m, 24H), 1.69−1.86 (m, 2H), 2.50−2.66 (m, 2H), 4.72 (ddd, J = 50.4, 7.9, 4.2 Hz, 1H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −192.60 to −192.31 (m, 1F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.00, 14.09, 22.47, 22.62, 22.67, 24.52 (d, $^3J_{C-F}$ = 2.9 Hz), 28.82, 29.17, 29.29, 29.33, 29.49, 29.54, 31.55, 31.88, 32.06 (d, $^2J_{C-F}$ = 20.7 Hz), 38.02, 96.07 (d, $^1J_{C-F}$ = 183.6 Hz), 210.49 (d, $^2J_{C-F}$ = 24.6 Hz); HRMS (EI) calcd for $C_{18}H_{35}OF$ 286.2672, found 286.2671.

(*E*)-2-(8-Fluorooctadec-7-en-7-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (4a). General Procedure for (2-Fluoroalkenyl)-boronate. To a THF solution (2.5 mL) of **1a** (238 mg, 0.5 mmol) was added at −78 °C a 1 M THF solution (0.75 mL) of di(*p*-fluorophenoxy)hexylborane (0.75 mmol) and LDA (0.75 mmol) prepared by the addition of a hexane solution of BuLi (0.47 mL of a 1.6 M solution, 0.75 mmol) to diisopropylamine (76 mg, 0.75 mmol) in THF (5 mL). The mixture was stirred at −40 °C for 3 h and at room temperature for 0.5 h. Then the mixture was cooled to 0 °C, and a THF solution (5 mL) of pinacol (591 mg, 5 mmol) was added. After being stirred at 0 °C for 0.5 h and at room temperature for 2 h, the mixture was poured into water and extracted with ether three times. The combined organic layer was dried over $MgSO_4$ and concentrated under reduced pressure. Purification by column chromatography (silica gel/hexane−CH_2Cl_2 gradient) gave **4a** (143 mg) in 72% yield: IR (neat) 2926, 2855, 1662, 1467, 1146 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 0.88 (t, J = 7.1 Hz, 6H), 1.26−1.52 (m, 24 H), 1.28 (s, 12 H), 2.00 (t, J = 7.2 Hz, 2H), 2.26 (dt, J = 23.0, 7.8 Hz, 2H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −85.13 (t, J = 23.2 Hz, 1F); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 14.08 (2C), 22.60, 22.66, 24.71 (4C), 26.42, 28.16 (d, $^2J_{C-F}$ = 10.7 Hz), 29.02, 29.26, 29.31 (2C), 29.37, 29.49, 29.58, 30.60, 31.75, 31.85, 82.94 (2C), 169.12 (d, $^1J_{C-F}$ = 258.0 Hz); ^{11}B NMR (128 MHz, $CDCl_3$) δ 30.6 (s); HRMS (EI) calcd for $C_{24}H_{46}FO_2B$ 396.3575, found 396.3574.

(*Z*)-2-(8-Fluorooctadec-7-en-7-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (4b): IR (neat) 2926, 2856, 1658, 1467, 1147 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 0.86 (t, J = 7.0 Hz, 3H), 0.88 (t, J = 7.1 Hz, 3H), 1.26−1.51 (m, 24H), 1.25 (s, 12H), 2.10 (t, J = 6.9 Hz, 2H), 2.51 (dt, J = 25.2, 7.6 Hz, 2H); ^{19}F NMR ($CDCl_3$, 376 MHz) δ −80.93 (t, J = 24.4 Hz, 1F); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 13.10 (2C), 21.66, 21.68, 23.69 (4C), 24.69 (d, $^3J_{C-F}$ = 10.7 Hz), 26.09, 27.80, 28.02, 28.31, 28.35, 28.57, 28.62, 29.16, 30.20 (d, $^2J_{C-F}$ = 28.6 Hz), 30.78, 30.92, 81.97 (2C), 168.74 (d, $^1J_{C-F}$ = 272.4 Hz); ^{11}B NMR (128 MHz, $CDCl_3$) δ 31.6 (s); HRMS (EI) calcd for $C_{24}H_{46}FO_2B$ 396.3575, found 396.3586

(*E*)-2-(17-Acetoxy-8-fluoroheptadec-7-en-7-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (4c): IR (neat) 2930, 2857, 1741, 1661, 1467, 1146 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 0.88 (t, J = 6.9 Hz, 3H), 1.28−1.65 (m, 22H), 1.28 (s, 12 H), 2.00 (t, J = 7.3 Hz, 2H), 2.05 (s, 3H), 2.26 (dt, J = 23.3, 8.2 Hz, 2H), 4.05 (t, J = 6.8 Hz, 2H); ^{19}F NMR ($CDCl_3$, 376 MHz) δ −85.24 to −85.11 (m, 1F); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 14.07, 21.00, 22.59, 24.70 (4C), 25.86, 26.38, 28.09, 28.19, 28.54, 29.13 (d, $^2J_{C-F}$ = 27.1 Hz), 29.19 (2C), 29.28, 29.32, 30.58 (d, $^3J_{C-F}$ = 2.9 Hz), 31.73, 64.61, 82.95 (2C), 169.01 (d, $^1J_{C-F}$ = 257.1 Hz), 171.22; HRMS (EI) calcd for $C_{25}H_{46}FO_4B$ 440.3473, found 440.3469.

(*E*)-2-(1-Benzyloxy-4-fluoroundec-4-en-5-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (4d): IR (neat) 2929, 2857, 1663, 1145 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 0.87 (t, J = 7.0 Hz, 3H), 1.26−1.28 (m, 8 H), 1.28 (s, 12 H), 1.85 (q, J = 6.8 Hz, 2H), 2.02 (t, J = 7.6 Hz, 2H), 2.41 (dt, J = 23.0, 7.6 Hz, 2H), 3.50 (t, J = 6.2 Hz, 2H), 4.49 (s, 2 H), 7.27−7.34 (m, 5H); ^{19}F NMR ($CDCl_3$, 376 MHz) δ −85.96 to −85.82 (m, 1F); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 14.03, 22.54, 24.66 (4C), 25.79 (d, $^2J_{C-F}$ = 30.4 Hz), 26.36, 28.07 (d, $^3J_{C-F}$ = 9.9 Hz), 28.97, 30.52 (d, $^3J_{C-F}$ = 2.7 Hz), 31.69, 69.18, 72.75, 82.95 (2C), 127.43, 127.51 (2C), 128.26 (2C), 138.40, 168.14 (d, $^1J_{C-F}$ = 256.9 Hz); HRMS (EI) calcd for $C_{24}H_{38}FO_3B$ 404.2898, found 404.2897.

Benzyl (*E*)-5-fluoro-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)dodec-5-enoate (4e): IR (neat) 3034, 2858, 1739, 1661, 1456, 1144 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 0.87 (t, J = 7.0 Hz, 3H), 1.25−1.27 (m, 8 H), 1.27 (s, 12 H), 1.89 (q, J = 7.5 Hz, 2H), 1.97 (t, J = 7.4 Hz, 2H), 2.34 (dt, J = 22.7, 7.5 Hz, 2H), 2.41 (t, J = 7.5 Hz, 2H), 5.11 (s, 2 H), 7.32−7.37 (m, 5 H); ^{19}F NMR ($CDCl_3$, 376 MHz) δ −86.14 to −86.01 (m, 1F); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 14.07, 21.55, 22.58, 24.70 (4C), 28.08, 28.28 (d, $^2J_{C-F}$ = 22.1 Hz), 28.98, 30.48, 30.51, 31.72, 33.34, 66.19, 83.06 (2C), 128.20 (2C), 128.53 (2C), 135.91, 167.35 (d, $^1J_{C-F}$ = 256.9 Hz), 172.92; HRMS (EI) calc. for $C_{25}H_{38}FO_4B$ 432.2847, found 432.2844.

(*E*)-2-[3-Fluoro-1-(4,4,5,5-tetramethyl-1,3-dioxolan-2-yl)dec-3-en-4-yl]-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (4f): IR (neat) 2979, 2931, 2859, 1664, 1146 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 0.88 (t, J = 7.1 Hz, 3H), 1.19−1.27 (m, 8 H), 1.19 (s, 12 H), 1.27 (s, 12 H), 1.79−1.84 (m, 2H), 2.02 (t, J = 7.4 Hz, 2H), 2.39 (dt, J = 22.6, 8.2 Hz, 2H), 5.05 (t, J = 5.1 Hz, 1H); ^{19}F NMR ($CDCl_3$, 376 MHz) δ −85.71 to −85.58 (m, 1F); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 14.09, 22.05 (2C), 22.59, 24.15 (2C), 24.33 (d, $^2J_{C-F}$ = 30.7 Hz), 24.70 (4C), 28.08 (d, $^3J_{C-F}$ = 10.5 Hz), 28.98, 30.50 (d, $^3J_{C-F}$ = 2.9 Hz), 31.76, 32.96, 81.79 (2C), 83.00 (2C), 99.91, 168.07 (d, $^1J_{C-F}$ = 257.5 Hz); HRMS (EI) calcd for $C_{23}H_{42}O_4FB$ 412.3160, found 412.3161.

2-[(5*E*,7*E*)-8-Fluorooctadeca-5,7-dien-7-yl]-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (4g): IR (neat) 2926, 1650, 1376, 1465 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 0.88 (t, J = 7.0 Hz, 3H), 0.89 (t, J = 7.2 Hz, 3H), 1.26−1.53 (m, 20H), 1.32 (s, 12H), 2.08 (dt, J = 6.9, 7.0 Hz, 2H), 2.35 (dt, J = 24.1, 7.7 Hz, 2H), 5.71 (dt, J = 15.9, 7.0 Hz, 1H), 5.98 (d, J = 15.8 Hz, 1H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −88.08 to −87.94 (m, 1F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.89, 14.06, 22.18, 22.64, 24.69 (4C), 26.37, 29.10, 29.11 (d, $^2J_{C-F}$ = 29.8 Hz), 29.28, 29.31, 29.45, 29.56, 31.56, 31.85, 33.17, 83.48 (2C), 125.07 (d, $^3J_{C-F}$ = 12.3 Hz), 133.29 (d, $^3J_{C-F}$ = 9.1 Hz), 167.87 (d, $^1J_{C-F}$ = 255.0 Hz); HRMS (EI) calcd for $C_{24}H_{44}O_2$-FB 394.3418, found 394.3418.

(*E*)-2-(1-Bromo-5-fluoropentadec-4-en-4-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (4h): IR (neat) 2926, 2855, 1662, 1466, 1146 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 0.88 (t, J = 7.1 Hz, 3H), 1.26−1.54 (m, 16H), 1.27 (s, 12H), 1.91 (q, J = 6.9 Hz, 2H), 2.17 (t, J = 7.7 Hz, 2H), 2.31 (dt, J = 23.3, 7.8 Hz, 2H), 3.40 (t, J = 6.5 Hz, 2H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −82.37 to −82.24 (m, 1F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.08, 22.64, 24.71 (4C), 26.40, 26.58 (d, $^3J_{C-F}$ = 10.8 Hz), 29.24, 29.28, 29.31, 29.33 (d, $^2J_{C-F}$ = 30.5 Hz), 29.54, 31.85, 33.42, 33.45, 33.47, 83.10 (2C),

170.52 (d, $^1J_{C-F}$ = 263.3 Hz); HRMS (EI) calcd for $C_{21}H_{39}O_2$FBBr 432.2210, found 432.2210.

Ethyl (*Z*)-4-(8-Fluorooctadec-7-en-7-yl)benzoate (6). General Procedure for the Suzuki−Miyaura Coupling Reaction. To a toluene solution (5 mL) of $Pd(PPh_3)_4$ (29 mg, 0.025 mmol) and **4a** (198 mg, 0.5 mmol) was added a EtOH solution (0.5 mL) of KOH (1 mmol) and ethyl 4-iodobenzoate (166 mg, 0.6 mmol) at room temperature. The mixture was stirred at 80 °C for 2 h, poured into a 3 M aqueous solution of NH_4Cl (40 mL), and extracted with ether three times. The combined organic phase was dried over $MgSO_4$ and concentrated under reduced pressure. Purification by column chromatography (silica gel/hexane−ether gradient) gave **11** (186 mg) in 89% yield: IR (neat) 2926, 2855, 1720, 1465 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.85 (t, J = 7.0 Hz, 3H,), 0.89 (t, J = 7.2 Hz, 3H), 1.24−1.62 (m, 24 H), 1.39 (t, J = 7.3 Hz, 3H), 2.31−2.42 (m, 4 H), 4.37 (q, J = 7.0 Hz, 2H), 7.34 (d, J = 7.8 Hz, 2H), 8.00 (d, J = 8.4 Hz, 2H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −106.48 (t, J = 23.8 Hz, 1F); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.00, 14.10, 14.33, 22.54, 22.67, 26.74, 28.46 (d, $^3J_{C-F}$ = 2.9 Hz), 28.88, 29.04, 29.28 (d, $^2J_{C-F}$ = 25.3 Hz), 29.32, 29.53, 29.58, 30.94, 30.98, 31.55, 31.88, 60.79, 116.87 (d, $^2J_{C-F}$ = 12.5 Hz), 128.51, 128.71 (d, $^4J_{C-F}$ = 3.1 Hz, 2C), 129.23 (2C), 142.51 (d, $^3J_{C-F}$ = 2.2 Hz), 156.64 (d, $^1J_{C-F}$ = 253.9 Hz), 166.56; HRMS (EI) calcd for $C_{27}H_{43}FO_2$ 418.3247, found 418.3251.

(*Z*)-8-Fluoro-7-phenyl-7-octadecene (5a): IR (neat) 2935, 2856, 1685, 1466 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.85 (t, J = 7.1 Hz, 3H), 0.88 (t, J = 6.8 Hz, 3H), 1.22−1.28 (m, 22H), 1.58 (q, J = 7.6 Hz, 2H), 2.28−2.42 (m, 4H), 7.20−7.34 (m, 5H); ^{19}F NMR (376 MHz, $CDCl_3$) δ −108.65 (t, J = 23.7 Hz, 1F). ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.04, 14.12, 22.60, 22.69, 26.84, 28.50 (d, $^3J_{C-F}$ = 2.5 Hz), 28.97, 29.17, 29.26, 29.45, 29.48(d, $^2J_{C-F}$ = 27.5 Hz), 29.58, 31.29, 31.33, 31.62, 31.91, 117.45 (d, $^2J_{C-F}$ = 12.3 Hz), 126.49, 127.93 (2C), 128.72 (d, $^4J_{C-F}$ = 3.3 Hz, 2C), 137.61 (d, $^3J_{C-F}$ = 2.9 Hz), 155.74 (d, $^1J_{C-F}$ = 250.1 Hz); HRMS (EI) calcd for $C_{24}H_{39}F$ 346.3036, found 346.3036.

(*E*)-8-Fluoro-7-phenyl-7-octadecene (5b): IR (neat) 2956, 2925, 2855, 1688, 1466 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.85 (t, J = 7.0 Hz, 3H), 0.88 (t, J = 6.8 Hz, 3H), 1.22−1.49 (m, 24H), 2.10 (dt, J = 23.2, 7.6 Hz, 2H), 2.38−2.39 (m, 2H), 7.13−7.33 (m, 5 H); ^{19}F NMR ($CDCl_3$, 376 MHz) δ −111.99 (t, J = 23.2 Hz, 1F); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 14.07, 14.12, 22.62, 22.68, 27.71 (d, $^3J_{C-F}$ = 1.7 Hz), 28.90, 28.95, 29.26 (d, $^2J_{C-F}$ = 28.3 Hz), 29.29, 29.31, 29.51, 29.57, 29.93, 29.99, 31.63, 31.90, 119.31 (d, $^2J_{C-F}$ = 18.9 Hz), 126.61, 128.11 (2C), 129.04 (d, $^4J_{C-F}$ = 2.9 Hz, 2C), 139.39 (d, $^3J_{C-F}$ = 9.1 Hz), 157.08 (d, $^1J_{C-F}$ = 249.3 Hz); HRMS (EI) calcd for $C_{24}H_{39}F$ 346.3036, found 346.3052.

(5*E*,7*Z*)-8-Fluoro-7-hexyloctadeca-5,7-diene (7): IR (neat) 3040, 2926, 2855, 1665, 1466, 1166 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.84−0.94 (m, 9H), 1.22−1.53 (m, 28 H), 2.06−2.15 (m, 4 H), 2.27 (dt, J = 24.2, 7.7 Hz, 2H), 5.57 (dt, J = 16.2, 7.0 Hz, 1H), 6.41 (dd, J = 16.1, 1.2 Hz, 1H); ^{19}F NMR ($CDCl_3$, 376 MHz) δ −110.56 (t, J = 24.4 Hz, 1F); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 13.96, 14.06, 14.10, 22.29, 22.67, 22.70, 26.61 (d, $^3J_{C-F}$ = 4.8 Hz), 26.82, 29.06 (d, $^2J_{C-F}$ = 28.7 Hz), 29.26, 29.27 (d, $^3J_{C-F}$ = 2.4 Hz), 29.35, 29.45, 29.48, 29.57, 29.62, 31.73, 31.84, 31.92, 32.98, 115.27 (d, $^3J_{C-F}$ = 9.1 Hz), 122.95 (d, $^2J_{C-F}$ = 11.5 Hz), 129.02 (d, $^4J_{C-F}$ = 4.8 Hz), 156.86 (d, $^1J_{C-F}$ = 256.3 Hz); HRMS (EI) calcd for $C_{24}H_{45}F$ 352.3505, found 352.3523.

Ethyl (*Z*)-4-(1-benzyloxy)-4-fluoroundec-4-en-5-yl)benzoate (8): IR (neat) 3032, 2928, 2857, 1718, 1273, 1104 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.83 (t, J = 7.2 Hz, 3H), 1.19−1.23 (m, 8H), 1.39 (t, J = 7.3 Hz, 3H), 1.91 (q, J = 7.1 Hz, 2H), 2.32 (t, J = 7.6 Hz, 2H), 2.53 (dt, J = 23.8, 7.6 Hz, 2H), 3.56 (t, J = 6.1 Hz, 2H), 4.37 (q, 2H), 4.53 (s, 2H), 7.27−7.36 (m, 7H), 8.00 (d, J = 8.6 Hz, 2H); ^{19}F NMR ($CDCl_3$, 376 MHz) δ −107.23 (t, J = 23.7 Hz, 1F); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 13.98, 14.32, 22.52, 25.89 (d, $^2J_{C-F}$ = 29.0 Hz), 26.72, 28.46 (d, $^3J_{C-F}$ = 2.6 Hz), 28.86, 30.91 (d, $^3J_{C-F}$ = 3.8 Hz), 31.52, 60.79, 69.01, 72.93, 117.58 (d, $^2J_{C-F}$ = 11.5 Hz), 127.57, 127.61 (2C), 128.35 (2C), 128.59, 128.67 (d, $^4J_{C-F}$ = 3.6 Hz, 2C), 129.23 (2C), 138.37, 142.34 (d, $^3J_{C-F}$ = 2.6 Hz), 155.81 (d, $^1J_{C-F}$ = 254.9 Hz), 166.50; HRMS (EI) calcd for $C_{27}H_{35}FO_3$ 426.2570, found 426.2571.

(3*Z*,5*E*)-2-(3-Fluoro-4-hexyl-6-phenylhexa-3,5-dienyl)-4,4,5,5-tetramethyl-1,3-dioxolane (9): IR (neat) 29.30, 1654, 1447, 1157 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.90 (t, J = 6.8 Hz, 3H), 1.21 (s, 12H), 1.22−1.49 (m, 8H), 1.82−1.88 (m, 2H), 2.24 (t, J = 7.8 Hz, 2H), 2.49 (dt, J = 23.4, 8.3 Hz, 2H), 5.08 (t, J = 4.9 Hz, 1H), 6.46 (d, J = 16.6 Hz, 1H), 7.20 (d, J = 16.1 Hz, 1H), 7.18−7.45 (m, 5H); ^{19}F NMR ($CDCl_3$, 376 MHz) δ −107.36 (t, J = 23.7 Hz, 1F); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 14.09, 22.05 (2C), 22.64, 24.19 (2C), 24.42 (d, $^2J_{C-F}$ = 28.0 Hz), 26.30 (d, $^3J_{C-F}$ = 3.8 Hz), 29.16 (d, $^3J_{C-F}$ = 2.4 Hz), 29.40, 31.68, 33.19, 81.87 (2C), 99.78, 116.09 (d, $^3J_{C-F}$ = 8.6 Hz), 122.25 (d, $^2J_{C-F}$ = 11.5 Hz), 126.26 (2C), 126.76 (d, $^4J_{C-F}$ = 4.8 Hz), 127.07, 128.53 (2C), 137.91, 158.19 (d, $^1J_{C-F}$ = 260.9 Hz); HRMS (EI) calcd for $C_{25}H_{37}FO_2$ 388.2777, found 388.2778.

(5*E*,7*Z*)-8-Fluoro-7-phenyloctadeca-5,7-diene (10): IR (neat) 3032, 2957, 2926, 2855, 1660, 1465 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.87 (t, J = 7.3 Hz, 3H), 0.88 (t, J = 6.7 Hz, 3H), 1.28−1.43 (m, 18H), 1.61 (q, J = 7.6 Hz, 2H), 2.07 (dt, J = 7.0, 7.2 Hz, 2H), 2.48 (dt, J = 24.2, 7.7 Hz, 2H), 5.24 (dt, J = 15.6, 7.2 Hz, 1H), 6.22 (dd, J = 15.5, 1.6 Hz, 1H), 7.18−7.37 (m, 5H); ^{19}F NMR ($CDCl_3$, 376 MHz) δ −103.75 (t, J = 24.8 Hz, 1F); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 13.91, 14.11, 22.24, 22.69, 26.71, 28.75 (d, $^2J_{C-F}$ = 28.0 Hz), 29.01, 29.34, 29.38, 29.57, 29.60, 31.51, 31.90, 32.92, 119.67 (d, $^2J_{C-F}$ = 18.4 Hz), 125.92 (d, $^3J_{C-F}$ = 5.5 Hz), 126.84, 127.96 (2C), 130.03 (d, $^4J_{C-F}$ = 1.9 Hz, 2C), 133.52 (d, $^3J_{C-F}$ = 10.3 Hz), 135.55 (d, $^3J_{C-F}$ = 3.8 Hz), 157.46 (d, $^1J_{C-F}$ = 255.8 Hz); HRMS (EI) calcd for $C_{24}H_{37}F$ 344.2879, found 344.2878.

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Supporting Information Available: ^{1}H and ^{13}C NMR spectra of all boronate and fluoroalkene products. This material is available free of charge via the Internet at http://pubs.acs.org.

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