Organic LETTERS

Letter

pubs.acs.org/OrgLett

Rhodium(III)-Catalyzed Oxidative Alkenylation of 1,3-Dithiane-Protected Arenecarbaldehydes via Regioselective C−H Bond Cleavage

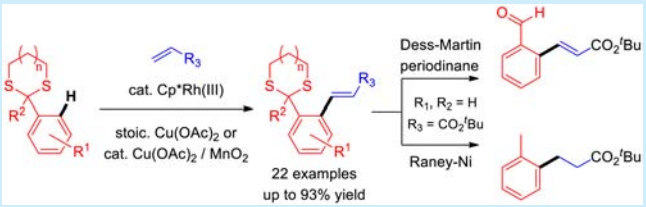
Yuto Unoh,[†] Koji Hirano,[†] Tetsuya Satoh,*[,†,‡] and Masahiro Miura*[,†]

[†]Department of Applied Chemistry, Faculty of Engineering, Osaka University, Suita, Osaka 565-0871, Japan

[‡]JST, ACT-C, 4-1-8 Honcho, Kawaguchi, Saitama 332-0012, Japan

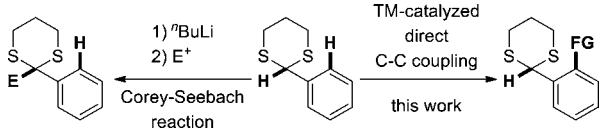
Supporting Information

ABSTRACT: A Rh(III)-catalyzed direct alkenylation of 2-aryl-1,3-dithiane derivatives with alkenes has been developed. The 1,3-dithiane group can serve as an effective directing group for the exclusively monoselective alkenylation under mild oxidative conditions. The directing group is readily removable after the coupling event.



1,3-Dithianes are attractive building blocks in organic synthesis because of their utility as unique umpolung acyl anionic synthons.[1] Since the Corey and Seebach groups reported their elegant work on dithiane carboanion chemistry (Scheme 1, left),[1]

Scheme 1. 1,3-Dithiane-Based C−C Bond-Forming Reaction



these umpolung synthons have been applied in various synthetic sequences, especially in natural product synthesis.[2] After nearly a half century since the first disclosure, 1,3-dithiane chemistry still plays a significant role in C−C bond-forming reactions, and considerable efforts have continuously been made to uncover the new application of 1,3-dithianes.[3] For example, Smith and co-workers developed anion-relay chemistry using 2-silyl-1,3-dithiane derivatives.[2b,3a−d] More recently, Schmink[3e] and Walsh[3f] independently reported the palladium-catalyzed arylation of the relatively acidic 2-position of 2-aryl-1,3-dithianes.

Meanwhile, the transition-metal-catalyzed direct functionalization reactions of non- or less acidic C−H bonds have recently been regarded as powerful synthetic tools from atom- and step-economical points of view and extensively studied, especially for the last two decades.[4] Among them, the chelation-assisted regioselective version with the aid of a directing group to enable regioselective functionalization is highly useful in precise synthesis.[4,5] So far, a variety of functional groups containing oxygen and nitrogen atoms have been utilized as effective directing groups in a wide range of reactions. However, the use of sulfur-containing directing groups has been less explored[6,7] because it is generally believed that they coordinate metal centers too strongly to suppress the catalytic activity. In particular, the coordination of a sulfide sulfur is known to be tight. Recently, Sheppard and co-workers have reported that a 1,3-dithiane moiety can act as a directing group to allow the regioselective acetoxylation of 2-homoallyl-1,3-dithianes by using a stoichiometric amount of $Pd(OAc)_2$.[8] In the context of our continuous studies on rhodium-catalyzed C−H bond functionalization,[4m,n,ac,9] we have succeeded in utilizing this directing group to a catalytic transformation. Thus, the direct alkenylation of 2-aryl-1,3-dithianes and their analogues is achievable at their ortho-position selectively (Scheme 1, right). In addition, the 1,3-dithiane group has been found to be readily removable after the directed alkenylation. These new findings are described herein.

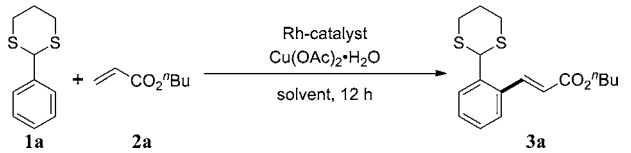
First, we carried out optimization studies using 2-phenyl-1,3-dithiane (**1a**) and *n*-butyl acrylate (**2a**) as model substrates (Table 1). In an initial attempt, **1a** (0.25 mmol) was treated with **2a** (0.5 mmol) in the presence of $[Cp^*Rh(MeCN)_3(SbF_6)_2]$ (0.005 mmol, 2 mol %) and $Cu(OAc)_2{\cdot}H_2O$ (0.5 mmol) in diglyme at 100 °C under N_2 for 12 h. As a result, the desired dehydrogenative coupling product **3a** was formed in 22% GC yield (entry 1). $[Cp^*RhCl_2]_2$ was inactive in this reaction (entry 2). The yield of **3a** was somewhat improved at a lower temperature of 60 °C (entry 3). However, a further decrease of temperature to 40 °C reduced the yield (entry 4). Next, various solvents were screened (entries 5−10). Among them, THF gave the best result to afford **3a** in 45% yield. AgOAc was totally ineffective as oxidant (entry 11). Eventually, the desired coupling product **3a** was obtained in 92% yield (87% isolated yield) by a higher loading of $[Cp^*Rh(MeCN)_3(SbF_6)_2]$ (8 mol %) and the elongation of reaction time (entry 13).

With the effective conditions in hands (entry 13 in Table 1), we next examined the substrate scope of this reaction (Scheme 2). A number of (4-substituted phenyl)dithianes **1b−f** underwent coupling with alkene **2a** smoothly to afford the

Received: December 26, 2014
Published: January 16, 2015

DOI: 10.1021/ol503722r
Org. Lett. 2015, 17, 704−707

Table 1. Optimization Studies for Rh-Catalyzed Direct Alkenylation of 2-Phenyl-1,3-dithiane 1a[a]



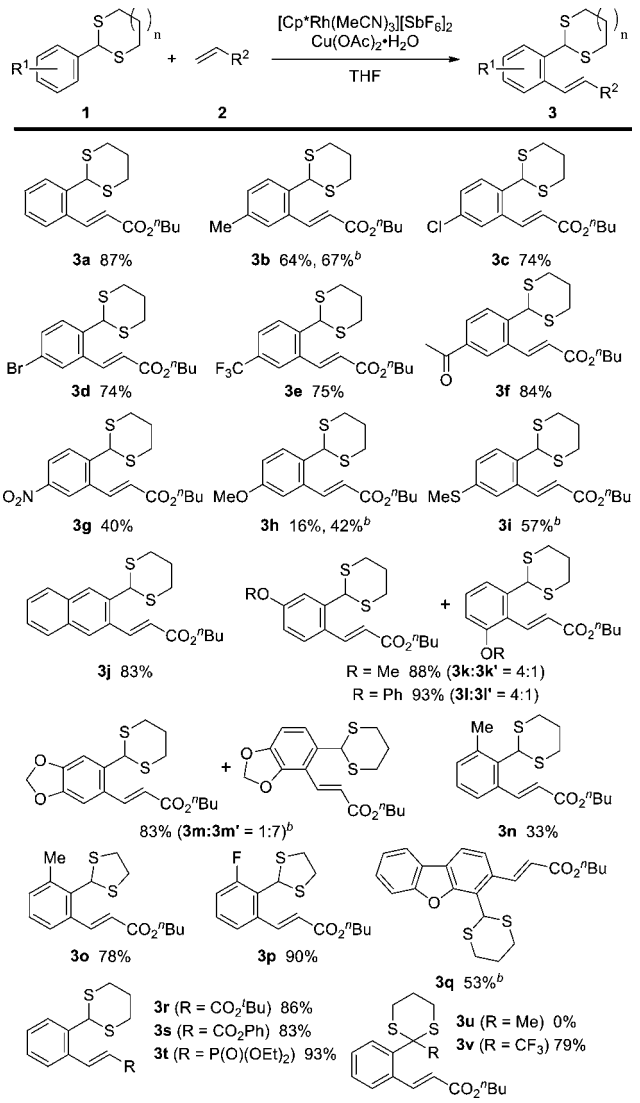
entry	Rh catalyst (mol %)	solvent	temp (°C)	yield[b] (%)
1	$[Cp^*Rh(MeCN)_3][SbF_6]_2$ (2)	diglyme	100	22
2	$[Cp^*RhCl_2]_2$(1)	diglyme	100	trace
3	$[Cp^*Rh(MeCN)_3][SbF_6]_2$ (2)	diglyme	60	31
4	$[Cp^*Rh(MeCN)_3][SbF_6]_2$ (2)	diglyme	40	16
5	$[Cp^*Rh(MeCN)_3][SbF_6]_2$ (2)	DCE	60	8
6	$[Cp^*Rh(MeCN)_3][SbF_6]_2$ (2)	$PhCF_3$	60	12
7	$[Cp^*Rh(MeCN)_3][SbF_6]_2$ (2)	MeOH	60	6
8	$[Cp^*Rh(MeCN)_3][SbF_6]_2$ (2)	acetone	60	37
9	$[Cp^*Rh(MeCN)_3][SbF_6]_2$ (2)	MeCN	60	2
10	$[Cp^*Rh(MeCN)_3][SbF_6]_2$ (2)	THF	60	45
11[c]	$[Cp^*Rh(MeCN)_3][SbF_6]_2$ (2)	THF	60	trace
12	$[Cp^*Rh(MeCN)_3][SbF_6]_2$ (4)	THF	60	51
13[d]	$[Cp^*Rh(MeCN)_3][SbF_6]_2$ (8)	THF	60	92 (87)

[a]Reaction conditions: **1a** (0.25 mmol), **2a** (0.5 mmol), Rh catalyst, $Cu(OAc)_2·H_2O$ (0.5 mmol), solvent (2 mL) under N_2 for 12 h. [b]GC yield. Yield after purification is given in parentheses. [c]AgOAc (0.5 mmol) was used as oxidant instead of $Cu(OAc)_2·H_2O$. [d]For 24 h.

corresponding alkenylated products **3b**–**f** in fair to good yields.[10] Notably, Cl and Br groups were intact under the reaction conditions to enable the further functionalization of products **3c** and **3d**. It is known that an acetyl function also acts as directing group that leads to ortho-alkenylation under rhodium catalysis.[11] However, the observed selective formation of **3f** from **1f** indicates that 1,3-dithiane is a more effective directing group than acetyl under the present catalytic system. The reactions of 4-nitro **1g** and 4-methoxy **1h** substrates were sluggish to give compounds **3g** and **3h** in 40% and 16% yield, respectively, under standard conditions. In the latter case, a significant amount of deprotected anisaldehyde was formed due to the instability of **1h**. Therefore, the reaction conditions for this substrate were reexamined briefly (see the Supporting Information for details). As a result, the use of the $[Cp^*Rh(MeCN)_3(SbF_6)_2]$ (8 mol %)/$Cu(OAc)_2·H_2O$ (20 mol %)/activated MnO_2 (2 equiv) system improved the yield up to 42%. Under similar conditions, 4-methylthio-substituted substrate **1i** was also converted to **3i** with reasonable efficiency.

Naphthyl-containing substrate **1j** reacted with **2a** at the less hindered position to produce **3j** exclusively. Treatment of 3-methoxy- (**1k**) and 3-phenoxy- substituted (**1l**) substrates predominantly gave **3k** and **3l**, in which the alkenylation took place at sterically less hindered positions, along with minor amounts of **3k**′ and **3l**′. In contrast, the reaction of piperonal-derived **1m** gave more congested **3m**′ preferentially, probably due to an additional directing effect by the tethered oxygen atom.[12] 2-Methyl-substituted substrate **1n** showed low reactivity probably because of steric repulsion between the methyl group and the bulky dithiane moiety. Interestingly, the use of a less hindered five-membered 1,3-dithiolane as the directing group made the reaction efficient even with 2-substituted substrates. Thus, 2-(2-methylphenyl)-1,3-dithiolane (**1o**) and 2-(2-fluorophenyl)-1,3-dithiolane (**1p**) coupled with **2a** to give **3o** and **3p** in 78 and 90% yields, respectively. The present procedure was also

Scheme 2. Reaction of 2-Aryl-1,3-dithianes and Dithiolanes 1 with Alkenes 2a[a]



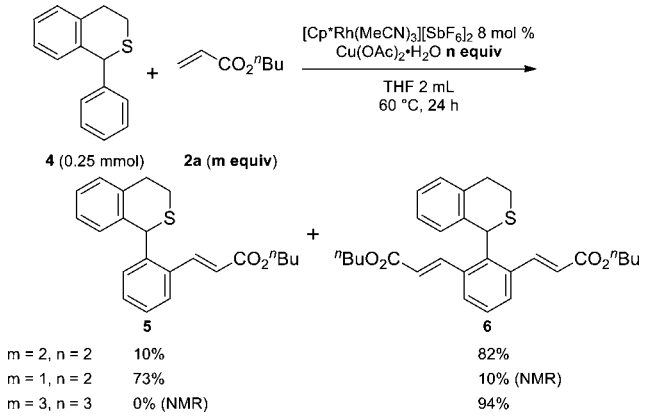
[a]Reaction conditions: **1** (0.25 mmol), **2** (0.5 mmol), $[Cp^*Rh(MeCN)_3][SbF_6]_2$ (0.02 mmol), $Cu(OAc)_2·H_2O$ (0.5 mmol), in THF (2 mL) at 60 °C under N_2 for 24 h. Isolated yields are shown. [b]With $Cu(OAc)_2·H_2O$ (0.05 mmol) and activated MnO_2 (0.5 mmol) instead of $Cu(OAc)_2·H_2O$ (0.5 mmol).

effective for the C3 selective alkenylation of a dibenzofuran framework to produce **3q** selectively. Other alkenes such as *tert*-butyl acrylate (**2b**), phenyl acrylate (**2c**), and diethyl vinylphosphonate (**2d**) could be employed in place of **2a** in the reaction of **1a** to give **3r**–**t** in 83–93% yields. In addition, the reactions of ketone-derived substrates were examined. Acetophenone-derived **1u** was completely decomposed under the reaction conditions to form a significant amount of acetophenone. On the other hand, trifluoroacetophenone-derived **1v** smoothly reacted with **2a** to afford **3v** in 79% yield. This suggests that the CF_3 group stabilizes the starting material to suppress a cationic decomposition pathway.[13]

This Rh catalysis was also applicable to a substrate bearing a cyclic monosulfide (Scheme 3).[6d] Treatment of cyclic sulfide **4** with **2a** under standard conditions resulted in the formation of monoalkenylated product **5** and dialkenylated product **6** in 10% and 82% yield, respectively. In this reaction, both **5** and **6** could

DOI: 10.1021/ol503722r
Org. Lett. 2015, 17, 704–707

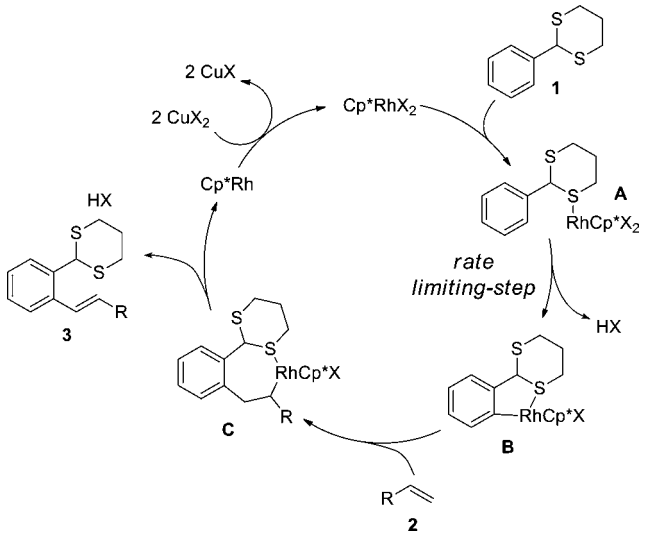
Scheme 3. Reaction of Cyclic Sulfide 4 with Alkene 2a



be selectively prepared by using the appropriate amounts of alkene **2a** and oxidant $Cu(OAc)_2 \cdot H_2O$. Thus, reducing the amount of **2a** gave monoalkenylated product **5** predominantly and increasing the amounts of **2a** and the Cu salt gave **6** exclusively.

A plausible mechanism for the reaction of 2-phenyl-1,3-dithiane (**1a**) with alkene **2** is illustrated in Scheme 4.

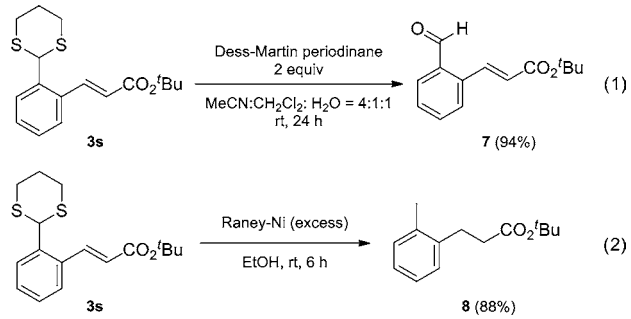
Scheme 4. Plausible Reaction Mechanism



Coordination of the dithiane moiety of **1a** to a Rh(III) center and subsequent C−H bond cleavage at the ortho position of a resulting intermediate **A** take place to form a five-membered rhodacycle intermediate **B**.[6d,7a] Then, alkene insertion and subsequent β-hydrogen elimination via an intermediate **C** may occur to produce alkenylated product **3**. The resulting Rh(I) species seems to be oxidized by a Cu(II) oxidant to regenerate a Rh(III) active species.

To provide further mechanistic insight, we carried out some deuterium-labeling experiments (see the Supporting Information for details).[14] The kinetic isotope effects were examined through the reactions of **1a**-d_0 and **1a**-d_5 with alkene **2a**. The k_H/k_D values were found to be 4.1 (two parallel reactions: Figure S1, Supporting Information) and 4.0 (intermolecular competition: eq S3, Supporting Information). Moreover, when **1a**-d_5 was treated with or without alkene **2a** under standard conditions for 100 min, no D/H exchange at the ortho positions of **1a**-d_5 and product **3a**-d_4 was observed (eqs S4 and S5, Supporting Information). These results suggest that the cyclometalation step of **A** to **B** is irreversible and is the rate-limiting step of this coupling.

Finally, the further reactions of an alkenylated product were carried out. Treatment of **3s** with 2 equiv of the Dess−Martin periodinane reagent in a $MeCN/CH_2Cl_2/H_2O$ cosolvent system at room temperature[15] resulted in deprotection to furnish aldehyde **7** in an excellent yield (eq 1). It should be noted that the



direct ortho-alkenylation of aromatic aldehydes is still challenging.[16] Jeganmohan[16a] and Prabhu[16b] independently reported Ru(II)-catalyzed versions though the scope is limited to electron-rich aromatic aldehydes. Therefore, the present procedure appears to be a useful alternative for synthesizing a wide range of ortho-alkenylated aromatic aldehydes. Moreover, the reductive desulfurization/alkene reduction of **3s** was also achieved by a simple treatment with Raney-Ni to afford **8** in 88% yield (eq 2).

In summary, we have demonstrated that the rhodium-catalyzed direct ortho-alkenylation of 2-phenyl-1,3-dithiane and its analogues can be conducted efficiently. This provides a new strategy for dithiane-based C−C bond-forming chemistry. Further development of sulfur-assisted catalytic transformation reactions is now in progress in our laboratory.

■ ASSOCIATED CONTENT

Supporting Information

Experimental procedures, additional results, and characterization data of products. This material is available free of charge via the Internet at http://pubs.acs.org.

■ AUTHOR INFORMATION

Corresponding Authors

*E-mail: satoh@chem.eng.osaka-u.ac.jp.
*E-mail: miura@chem.eng.osaka-u.ac.jp.

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

This work was partly supported by Grants-in-Aid from MEXT, JSPS, and JST, Japan.

■ REFERENCES

(1) (a) Corey, E. J.; Seebach, D. *Angew. Chem., Int. Ed.* **1965**, *4*, 1075. (b) Seebach, D.; Corey, E. J. *J. Org. Chem.* **1975**, *40*, 231. (c) Seebach, D. *Angew. Chem., Int. Ed.* **1979**, *18*, 239.

(2) For reviews, see: (a) Yus, M.; Nájera, C.; Foubelo, F. *Tetrahedron* **2003**, *59*, 6147. (b) Smith, A. B., III; Adams, C. M. *Acc. Chem. Res.* **2004**, *37*, 365. For recent examples of natural product synthesis with dithiane-based C−C-forming strategies, see: (c) Geum, S.; Lee, H.-Y. *Org. Lett.*

DOI: 10.1021/ol503722r
Org. Lett. 2015, 17, 704−707

2014, *16*, 2466. (d) Xu, S.; Gu, J.; Li, H.; Ma, D.; Xie, X.; She, X. *Org. Lett.* **2014**, *16*, 1996. (e) Paterson, I.; Haslett, G. W. *Org. Lett.* **2013**, *15*, 1338. (f) Henrot, M.; Richter, M. E. A.; Maddaluno, J.; Hertweck, C.; De Paolis, M. *Angew. Chem., Int. Ed.* **2012**, *51*, 9587. (g) Lee, K.; Kim, H.; Hong, J. *Angew. Chem., Int. Ed.* **2012**, *51*, 5735.

(3) (a) Smith, A. B., III; Pitram, S. M.; Boldi, A. M.; Gaunt, M. J.; Sfouggatakis, C.; Moser, W. H. *J. Am. Chem. Soc.* **2003**, *125*, 14435. (b) Smith, A. B., III; Xiang, M. *J. Am. Chem. Soc.* **2006**, *128*, 66. (c) Melillo, B.; Smith, A. B., III. *Org. Lett.* **2013**, *15*, 2282. (d) Chen, M. Z.; Gutierrez, O.; Smith, A. B., III. *Angew. Chem., Int. Ed.* **2014**, *53*, 1279. (e) Baker Dockrey, S. A.; Makepeace, A. K.; Schmink, J. R. *Org. Lett.* **2014**, *16*, 4730. (f) Yucel, B.; Walsh, P. J. *Adv. Synth. Catal.* **2014**, *356*, 3659. (g) Denmark, S. E.; Cullen, L. R. *Org. Lett.* **2014**, *16*, 70. (h) Kyasa, S. K.; Dussault, P. H. *Org. Lett.* **2014**, *16*, 5235. (i) Du, W.; Tian, L.; Lai, J.; Huo, X.; Xie, X.; She, X.; Tang, S. *Org. Lett.* **2014**, *16*, 2470. (j) Wang, Y.; Zheng, Z.; Zhang, L. *Angew. Chem., Int. Ed.* **2014**, *53*, 9572. (k) Chen, M. Z.; Micalizio, G. C. *J. Am. Chem. Soc.* **2012**, *134*, 1352.

(4) Selected recent reviews for C−H functionalization: (a) Dyker, G. *Angew. Chem., Int. Ed.* **1999**, *38*, 1698. (b) Kakiuchi, F.; Chatani, N. *Adv. Synth. Catal.* **2003**, *345*, 1077. (c) Godula, K.; Sames, D. *Science* **2006**, *312*, 67. (d) Alberico, D.; Scott, M. E.; Lautens, M. *Chem. Rev.* **2007**, *107*, 174. (e) Beccalli, E. M.; Broggini, G.; Martinelli, M.; Sottocornola, S. *Chem. Rev.* **2007**, *107*, 5318. (f) Park, Y. J.; Park, J.-W.; Jun, C.-H. *Acc. Chem. Res.* **2008**, *41*, 222. (g) Ferreira, E. M.; Zhang, H.; Stoltz, B. M. *Tetrahedron* **2008**, *64*, 5987. (h) Kakiuchi, F.; Kochi, T. *Synthesis* **2008**, 3013. (i) Li, C.-J. *Acc. Chem. Res.* **2009**, *42*, 335. (j) McGlacken, G. P.; Bateman, L. M. *Chem. Soc. Rev.* **2009**, *38*, 2447. (k) Daugulis, O.; Do, H.-Q.; Shabashov, D. *Acc. Chem. Res.* **2009**, *42*, 1074. (l) Chen, X.; Engle, K. M.; Wang, D.-H.; Yu, J.-Q. *Angew. Chem., Int. Ed.* **2009**, *48*, 5094. (m) Satoh, T.; Miura, M. *Synthesis* **2010**, 3395. (n) Satoh, T.; Miura, M. *Chem.—Eur. J.* **2010**, *16*, 11212. (o) Sun, C.-L.; Li, B.-J.; Shi, Z.- J. *Chem. Commun.* **2010**, *46*, 677. (p) Colby, D. A.; Bergman, R. G.; Ellman, J. A. *Chem. Rev.* **2010**, *110*, 624. (q) Lyons, T. W.; Sanford, M. S. *Chem. Rev.* **2010**, *110*, 1147. (r) Lapointe, D.; Fagnou, K. *Chem. Lett.* **2010**, *39*, 1118. (s) Ackermann, L. *Chem. Rev.* **2011**, *111*, 1315. (t) Liu, C.; Zhang, H.; Shi, W.; Lei, A. *Chem. Rev.* **2011**, *111*, 1780. (u) Kuninobu, Y.; Takai, K. *Chem. Rev.* **2011**, *111*, 1938. (v) Wencel-Delord, J.; Droge, T.; Liu, F.; Glorius, F. *Chem. Soc. Rev.* **2011**, *40*, 4740. (w) Cho, S. H.; Kim, J. Y.; Kwak, J.; Chang, S. *Chem. Soc. Rev.* **2011**, *40*, 5068. (x) Mitchell, E. A.; Peschiulli, A.; Lefevre, N.; Meerpoel, L.; Maes, B. U. W. *Chem.—Eur. J.* **2012**, *18*, 10092. (y) Engle, K. M.; Mei, T.-S.; Wasa, M.; Yu, J.-Q. *Acc. Chem. Res.* **2012**, *45*, 788. (z) Colby, D. A.; Tsai, A. S.; Bergman, R. G.; Ellman, J. A. *Acc. Chem. Res.* **2012**, *45*, 814. (aa) Patureau, F. W.; Wencel-Delord, J.; Glorius, F. *Aldrichimica Acta* **2012**, *45*, 31. (ab) Chiba, S. *Chem. Lett.* **2013**, *41*, 1554. (ac) Miura, M.; Satoh, T.; Hirano, K. *Bull. Chem. Soc. Jpn.* **2014**, *87*, 751.

(5) For pioneering work, see: Murai, S.; Kakiuchi, F.; Sekine, S.; Tanaka, Y.; Kamatani, A.; Sonoda, M.; Chatani, N. *Nature* **1993**, *366*, 529.

(6) Limited examples of sulfur-containing group directed aromatic C−H bond functionalization have been reported: (a) Samanta, R.; Antonchick, A. P. *Angew. Chem., Int. Ed.* **2011**, *50*, 5217. (b) Yu, M.; Xie, Y.; Xie, C.; Zhang, Y. *Org. Lett.* **2012**, *14*, 2164. (c) Wesch, T.; Leroux, F. R.; Colobert, F. *Adv. Synth. Catal.* **2013**, *355*, 2139. (d) Zhang, X.-S.; Zhu, Q.-L.; Zhang, Y.-F.; Li, Y.-B.; Shi, Z.-J. *Chem.—Eur. J.* **2013**, *19*, 11898. (e) Yokoyama, Y.; Unoh, Y.; Hirano, K.; Satoh, T.; Miura, M. *J. Org. Chem.* **2014**, *79*, 7649. (f) Nobushige, K.; Hirano, K.; Satoh, T.; Miura, M. *Org. Lett.* **2014**, *16*, 1188. (g) Wang, B.; Shen, C.; Yao, J.; Yin, H.; Zhang, Y. *Org. Lett.* **2014**, *16*, 46.

(7) For examples of sulfur-containing group directed acyl C−H bond functionalization, see: (a) Willis, M. C.; Randell-Sly, H. E.; Woodward, R. L.; Currie, G. S. *Org. Lett.* **2005**, *7*, 2249. (b) Willis, M. C. *Chem. Rev.* **2010**, *110*, 725. (c) Zhou, B.; Yang, Y.; Shi, J.; Feng, H.; Li, Y. *Chem.—Eur. J.* **2013**, *19*, 10511.

(8) Mann, S. E.; Aliev, A. E.; Tizzard, G. J.; Sheppard, T. D. *Organometallics* **2011**, *30*, 1772.

(9) For early work, see: (a) Ueura, T.; Satoh, T.; Miura, M. *Org. Lett.* **2007**, *9*, 1407. (b) Ueura, K.; Satoh, T.; Miura, M. *J. Org. Chem.* **2007**, *72*, 5362.

(10) In contrast to aryldithianes, 2-(cyclohex-1-en-1-yl)-1,3-dithiane did not undergo the alkenylation under similar conditions.

(11) Patureau, F. W.; Besset, T.; Glorius, F. *Angew. Chem., Int. Ed.* **2011**, *50*, 1064.

(12) (a) Sonoda, M.; Kakiuchi, F.; Chatani, N.; Murai, S. *Bull. Chem. Soc. Jpn.* **1997**, *70*, 3117. (b) Kalyani, D.; Sanford, M. S. *Org. Lett.* **2005**, *7*, 4149. (c) Chen, J.; Song, G.; Pan, C.-L.; Li, X. *Org. Lett.* **2010**, *12*, 5426. (d) Webb, N. J.; Marsden, S. P.; Raw, S. A. *Org. Lett.* **2014**, *16*, 4718.

(13) Kuroboshi, M.; Hiyama, T. *J. Fluorine Chem.* **1994**, *69*, 127.

(14) For an essay on the deuterium kinetic isotope effects in C−H bond functionalization, see: Simmons, E. M.; Hartwig, J. F. *Angew. Chem., Int. Ed.* **2012**, *51*, 3066.

(15) Langille, N. F.; Dakin, L. A.; Panek, J. S. *Org. Lett.* **2003**, *5*, 575.

(16) (a) Padala, K.; Jeganmohan, M. *Org. Lett.* **2012**, *14*, 1134. (b) Lanke, V.; Prabhu, K. R. *Org. Lett.* **2013**, *15*, 6262. (c) Park, S. H.; Kim, J. Y.; Chang, S. *Org. Lett.* **2011**, *13*, 2372. (d) Shi, Z.; Schröder, N.; Glorius, F. *Angew. Chem., Int. Ed.* **2012**, *51*, 8092. (e) Zhang, T.; Wu, L.; Li, X. *Org. Lett.* **2013**, *15*, 6294. (f) Zhang, T.; Qi, Z.; Zhang, X.; Wu, L.; Li, X. *Chem.—Eur. J.* **2014**, *20*, 3283.

DOI: 10.1021/ol503722r
Org. Lett. 2015, 17, 704−707