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Pd-NHC-catalyzed Alkynylation of General Aryl Sulfides with Alkynyl Grignard Reagents

Alexandre Baralle,[a] Hideki Yorimitsu,*[a] and Atsuhiro Osuka[a]

Abstract: Cross-coupling reactions of unactivated aryl sulfides with alkynylmagnesium chloride have been invented to afford 1-aryl-1-alkynes with the aid of a palladium/*N*-heterocyclic carbene complex. Noteworthy is by far the widest scopes of aryl sulfides and alkynes while known cross-coupling alkynylation of aryl sulfur electrophiles required activated azaaryl sulfides, thiolactams, or arenesulfonyl chlorides. The alkynylation of aryl sulfides is compatible with typical protecting groups and functional groups. The alkynylation is applied to the synthesis of benzofuran-based fluorescent molecules by taking advantage of characteristic organosulfur chemistry.

Alkynylation of aryl halides to synthesize arylacetylenes is absolutely crucial in organic synthesis and has found numerous applications in the synthesis of bioactive molecules as well as π-extended functional materials.[1] While the Sonogashira reaction is a very reliable and useful method,[2] there still remains ample room to develop new methods for alkynylation of more challenging substrates.

Despite their synthetic potential, aryl sulfides represent an underdeveloped class of substrates as surrogates of aryl halides[3] since the substrates often serve as catalyst poisons[4] as well as their C–S bonds are strong to retard oxidative addition.[5] Compared with cross-coupling of aryl sulfides with alkyl- and arylmetal reagents,[6,7] catalytic alkynylation of aryl sulfides has indeed been reported only sporadically. Known cross-coupling alkynylation of aryl sulfur electrophiles always required special substrates such as activated azaaryl sulfides,[8] thiolactams or their equivalents,[9] which require (sub)stoichiometric amounts of copper salts, and arenesulfonyl chlorides containing a hexavalent sulfur.[10] To the best of our knowledge, there are no reports on cross-coupling alkynylation of unactivated aryl sulfides despite its seeming simplicity. Here we report the first example of such alkynylation.

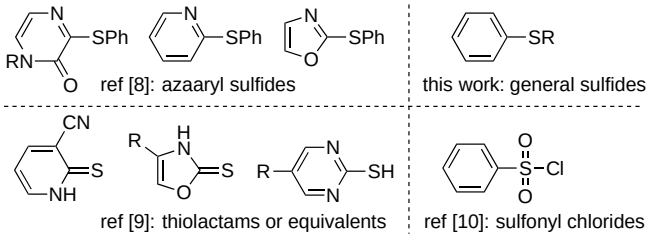
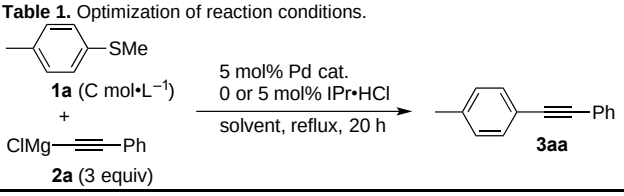


Chart 1. Types of aryl sulfides as substrates for catalytic alkynylation.

Considering strong interactions between a transition metal and a thiolate anion, we assume that arylpalladium thiolates that are formed through oxidative addition are rather reluctant to undergo transmetalation, especially with moderately reactive alkynylmetal species. We hence envisioned using alkynyl Grignard reagents that are readily generated from terminal alkyne and ethylmagnesium chloride, expecting smoother transmetalation compared with alkynylcopper or -zinc species. A palladium-catalyzed reaction of methyl *p*-tolyl sulfide (**1a**) with phenylethynylmagnesium chloride (**2a**) was thus set as a model reaction, and reaction conditions were optimized (Table 1).

Table 1. Optimization of reaction conditions.



entry	Pd cat.	IPr•HCl	solvent	C	yield [%][a]
1	[IPrPdCl(π-allyl)]	–	THF	0.1	8
2	Pd-PEPPSI-IPr	–	THF	0.1	15
3	Pd-PEPPSI-SIPr	–	THF	0.1	0
4	Pd-PEPPSI-IPent	–	THF	0.1	0
5	Pd-PEPPSI-IMes	–	THF	0.1	0
6	Pd-PEPPSI-IPr^{Me}	–	THF	0.1	0
7	Pd-PEPPSI-IPr^{Cl}	–	THF	0.1	0
8	SingaCycle-A1	–	THF	0.1	16
9	SingaCycle-A3	–	THF	0.1	6
10	Pd-PEPPSI-IPr	–	DME	0.1	56
11	SingaCycle-A1	–	DME	0.1	44
12	Pd-PEPPSI-IPr	–	dioxane	0.1	2
13	Pd-PEPPSI-IPr	–	toluene	0.1	0
14	Pd-PEPPSI-IPr	–	ether	0.1	0
15	Pd-PEPPSI-IPr	5 mol%	DME	0.1	76
16	Pd-PEPPSI-IPr	5 mol%	DME	0.3	97
17	Pd-PEPPSI-IPr	5 mol%	DME	0.3	95[b]

[a] Determined by NMR using 1,1,2,2-tetrabromoethane as an internal standard. [b] 2 equiv of **2a**.

While phosphine ligands did not serve to promote the alkynylation (not shown), we were delighted to find that Pd-IPr (IPr = 1,3-bis(2,6-diisopropylphenyl)imidazol-2-ylidene) precatalysts show some catalytic activity in THF (entries 1, 2, 8, and 9).[11] The choice of IPr was found to be crucially important as other N-heterocyclic carbenes (NHCs) such as IMes (1,3-bis(2,4,6-trimethylphenyl)imidazol-2-ylidene) were inactive (entries 3–7 and Chart 2). Among the Pd-IPr precatalysts tested,

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Pd-PEPPSI-IPr and SingaCycle-A1 were selected as promising precatalysts (entries 2 and 8). In boiling 1,2-dimethoxyethane (DME), the yield was significantly improved up to 56% and 44% with Pd-PEPPSI-IPr and SingaCycle-A1, respectively (entries 10 and 11). We hence chose Pd-PEPPSI-IPr[11c–e] as the best catalyst. The reactions in dioxane, toluene, and diethyl ether were hopeless (entries 12–14). As palladium black appeared in the reaction flask, additional IPr•HCl was added to avoid the formation of catalytically inactive heterogeneous palladium black. This was indeed effective, and the yield was further increased to 76% (entry 15). A higher concentration (0.3 M for **1a**) eventually led to almost quantitative formation of **3aa** (entry 16), perhaps by facilitating transmetalation that would include a bimolecular process. We could reduce the amount of the Grignard reagent from 3 equiv to 2 equiv without a significant loss of reaction efficiency (entry 17). Notably, nickel complexes including $NiCl_2(PPh_3)(IPr)$[7f,12] and other nickel-phosphine complexes were totally ineffective (not shown) while nickel catalysis was first discovered to be effective for the cross-coupling of sulfides with Grignard reagents by Wenkert and Takei.[13]

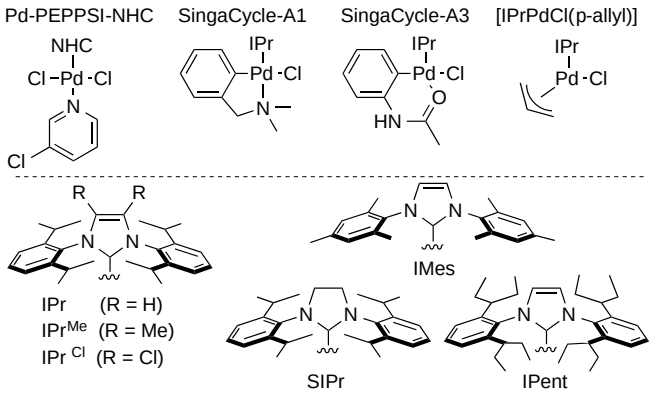


Chart 2. Palladium precatalysts in Table 1.

With these optimized conditions in hand (Table 1, entry 17), we then studied the scope and limitations of aryl sulfides in this alkynylation (Figure 1). In most cases, the reactions proceeded smoothly. An electron-donating group, *p*-methoxy, or electron-withdrawing groups such as *p*-trifluoromethyl and *p*-fluoro had little effects on the reaction efficiency, and **3da**, **3ea**, and **3fa** were obtained in excellent yields. Aryl sulfides **1g**, **1h**, and **1i** bearing triisopropylsilyloxy or acetal were compatible to be converted into **3ga**, **3ha**, and **3ia**, respectively, in high yields. Steric hindrance of methyl *o*-tolyl sulfide (**1c**) resulted in an incomplete conversion into desired **3ca**.

Heteroaryl sulfides as well as aryl sulfides also participated. Pyridyl sulfide **1k** reacted smoothly to afford **3ka** in 93% yield. We have been interested in new extended Pummerer reactions of alkenyl sulfides, and previously developed concise approaches to 2-methylsulfanylbenzo[*b*]furans[14] and -benzo[*b*]thiophenes.[15] Taking advantage of these synthetic routes, we could install a phenylethynyl group at the 2 positions of **1l**–**s** efficiently to give **3la**–**sa**. Interestingly, **1o** was alkynylated selectively at a lower temperature of 65 ˚C to yield **3oa** without touching the chloro moiety, which is of great interest from a synthetic viewpoint. With 4 equiv of Grignard reagent **2a**, twofold alkynylation of **1r** and **1s** took place to yield **3ra** and **3sa** in satisfactory yields. Benzothiophene **1q** was easily converted into the desired product **3qa** in excellent yield.

The reaction of symmetrical di-*p*-tolyl sulfide proceeded quantitatively under the otherwise same reaction conditions. The reaction of *t*-butyl *p*-tolyl sulfide afforded **3aa** in only 10% yield with 25% recovery of the starting sulfide.

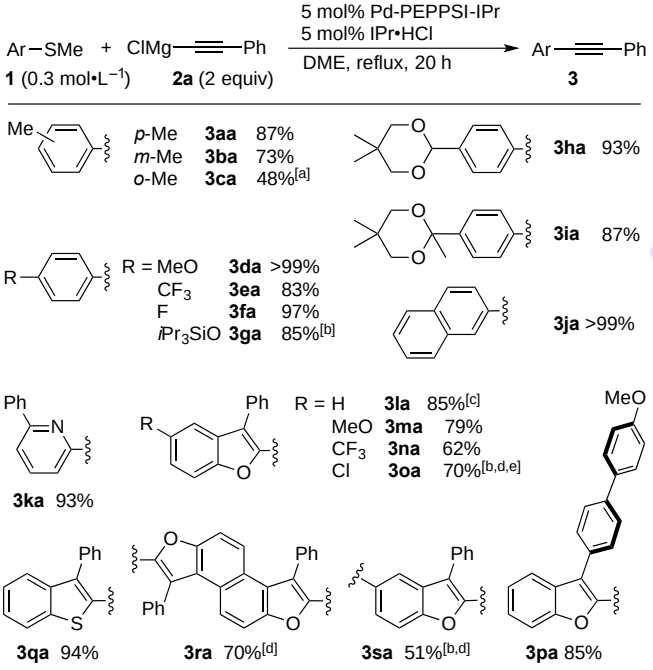


Figure 1. Scope of aryl sulfides **1**. [a] Accompanied by 30% of **1c**. [b] 10 mol% of the catalyst/IPr•HCl. [c] 2 equiv of **2a** three times. [d] 4 equiv of **2a**. [e] 65 °C.

The scope of alkynyl Grignard reagents was also investigated (Figure 2). Not only aromatic alkynyl Grignard reagents **2c**–**f** but also aliphatic ones **2b** and **2g** reacted smoothly. The highly coordinating amino group in **2d**, the reactive vinyl group in **2e**, and the triisopropylsilyl protection in **2f** were tolerated. The silyl protection of **3mf** was later removed upon treatment with K_2CO_3 (see Supporting Information).

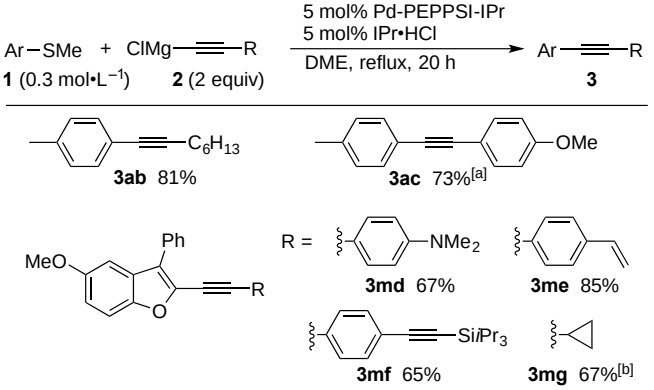
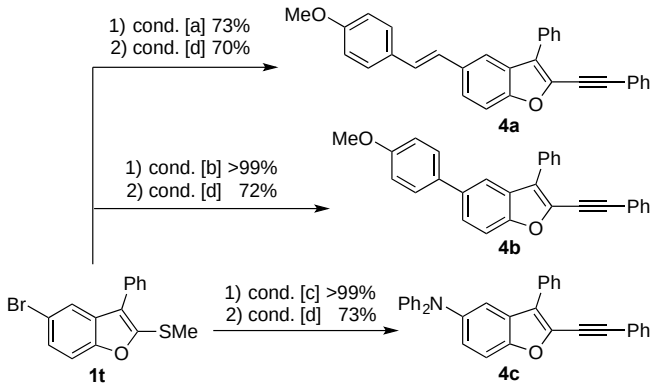


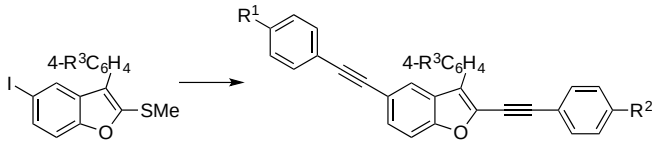
Figure 2. Scope of alkynyl Grignard reagents **2**. [a] Addition rate: 6 μL•s^{-1}. [b] 4 equiv of **2g**. 10 mol% of the catalyst/IPr•HCl.

In contrast to the methylsulfanyl-selective alkynylation of 5-chloro-2-methylsulfanylbenzofuran (**1o**) (Figure 1), the 5-bromo analogue **1t** underwent conventional cross-coupling reactions at

their 5 positions, leaving the 2-methylsulfanyl group intact (Scheme 1). The Mizoroki-Heck alkenylation, Suzuki-Miyaura coupling, and Hartwig-Buchwald amination were followed by our alkynylation at the 2 positions. In a similar fashion, the 5-iodo analogues **1u** and **1v** underwent sequences of the Sonogashira alkynylation reaction and our alkynylation to install two different alkyne units into each molecule (Scheme 2).



Scheme 1. Cross-coupling followed by alkynylation. Conditions: [a] 4-vinylanisole (2 equiv), $Pd(OAc)_2$ (10 mol%), SPhos (10 mol%), DMF/Et_3N (4:1), 100 °C; [b] 4-methoxyphenylboronic acid (2 equiv), $Pd(PPh_3)_4$ (5 mol%), K_2CO_3 (3 equiv), toluene/EtOH (1:1), 100 °C; [c] diphenylamine (1 equiv), $Pd(OAc)_2$ (5 mol%), *t*Bu_3P (10 mol%), *t*BuONa (1.2 equiv), toluene, 100 °C; [d] our standard conditions with PhC≡CMgCl.



1u R^3 = H
1v R^3 = *t*Bu

5a (R^1 = Me_2N, R^2 = *t*Bu, R^3 = H) 55% overall
5b (R^1 = Ph_2N, R^2,R^3 = *t*Bu) 65% overall
5c (R^1,R^3 = *t*Bu, R^2 = Ph_2N) 48% overall

Scheme 2. Sequential alkynylation. Conditions: $PdCl_2(PPh_3)_2$ (5 mol%), CuI (10 mol%), 4-$R^1C_6H_4C{\equiv}CH$, Et_3N (5.5 equiv), THF, 65 °C; then our standard conditions with 4-$R^2C_6H_4C{\equiv}CMgCl$.

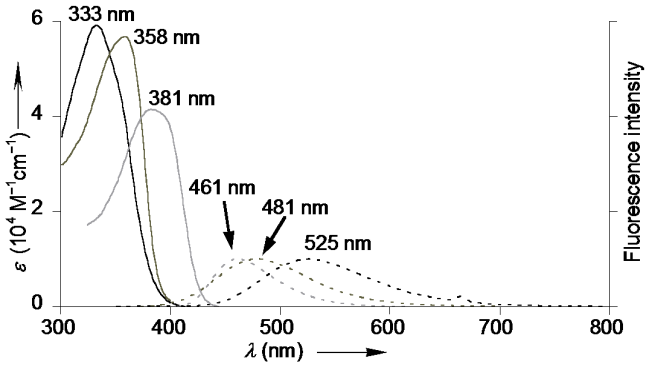
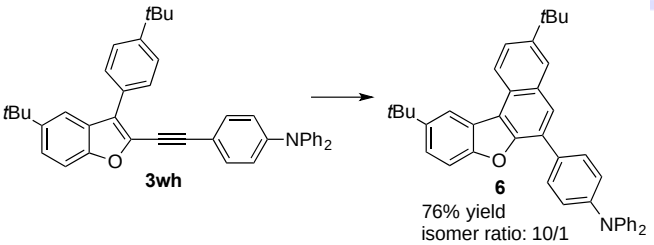


Figure 3. UV/visible absorption (solid lines) and fluorescence (dotted lines) spectra of **5a** (black), **5b** (grey), and **5c** (light grey) in CH_2Cl_2. The fluorescence spectra were obtained upon irradiation at the absorption maxima.

Connecting two π systems through an acetylene linker is a powerful tool for creating molecules of photophysical interest. This was indeed the case, and **5** showed blue-emitting property (Figure 3). The absorption spectra of **5a**, **5b**, and **5c** in CH_2Cl_2 show their absorption maxima at 333, 358, and 381 nm, respectively. The emission spectra of **5a**, **5b**, and **5c** in CH_2Cl_2 show their emission maxima at 526, 481, and 461 nm with fluorescence quantum yields of 0.369, 0.575 and 0.868, respectively. Compounds **5** generally show large Stokes shifts (11019 cm^{-1} for **5a**, 7142 cm^{-1} for **5b**, and 4555 cm^{-1} for **5c**), which indicate the intramolecular charge transfer character of photo excitation. The highest fluorescence quantum yield of **5c** would be ascribed to the more rigid structure compared with **5a** and to well-conjugated electronic interaction between the diphenylaminophenyl group and the benzofuran unit of **5c**.

With the combination of our protocol to synthesize 2-methylsulfanylbenzofuran and our alkynylation, we could thus prepare structurally peculiar 3-aryl-2-alkynylbenzofurans. These molecules can undergo $PtCl_2$-catalyzed cyclization as reported by Fürstner (Scheme 3).[16] Indeed, **3wh** was exposed to $PtCl_2$ in refluxing toluene for 12 h to give a mixture of two cyclic products in 76% yield in a ratio of 10/1. Although we initially considered the major isomer would be either the corresponding 5-*exo* or 6-*endo* cyclized product, X-ray crystallographic analysis unambiguously revealed that the major product is unexpectedly **6** (Figure 4a).[17] A plausible reaction mechanism includes 6-*endo* cyclization followed by an ensuing 1,2-aryl shift.[18] Benzonaphthofuran **6** is also fluorescent (Figure 4b), exhibiting a high fluorescence quantum yield of 0.806 with a Stokes shift of 6300 cm^{-1}. These features would originate from the rigid π-conjugated core and the intramolecular charge transfer from the diphenylaminophenyl group to the core.[19] Our alkynylation/cyclization protocol to construct a benzonaphthofuran core would be useful for developing OLED devices.[20]



Scheme 3. Pt-catalyzed cyclization accompanied by 1,2-aryl shift. Conditions: 10 mol% $PtCl_2$, toluene, reflux, 12 h.

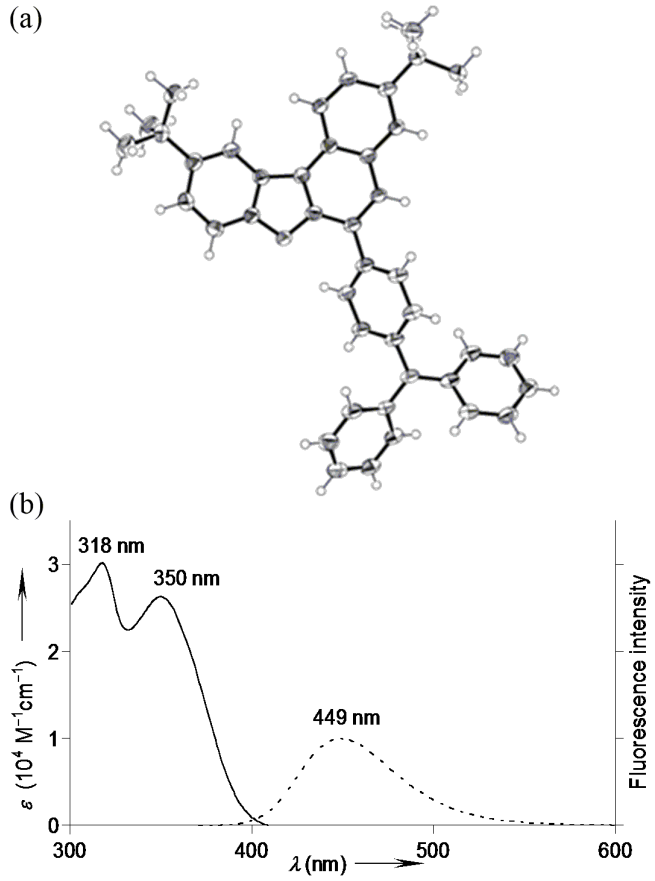


Figure 4. (a) ORTEP drawing of **6** drawn at 50% probability. (b) UV/visible absorption (solid lines) and fluorescence (dotted lines) spectra of **6** in CH_2Cl_2.

In summary, we have developed cross-coupling of aryl sulfides with alkynyl Grignard reagents in the presence of Pd-PEPPSI-IPr as a precatalyst. This alkynylation is broad in scope and is compatible with representative protecting groups, which underlines its usefulness in organic synthesis. When combined with extended Pummerer reactions developed in our laboratory, the alkynylation is apparently useful to provide fluorescent molecules. Further research to exploit organosulfur compounds for catalytic transformations are underway in our group.

Acknowledgements

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Keywords: Cross-coupling • Aryl sulfide • C–S bond cleavage • Alkyne • Palladium

[1] a) C. Nájera, R. Chinchilla, *Transition Metal-Catalyzed Alkynylation Reactions*, CRC press, **2013**; b) L. Brandsma, *Synthesis of Acetylenes, Allenes and Cumulenes: Methods and Techniques*, Elsevier: Oxford, **2004**; p 293; c) K. C. Nicolaou, P. G. Bulger, D. Sarlah, *Angew. Chem. Int. Ed.* **2005**, *44*, 4442; *Angew. Chem.* **2005**, *117*, 4516; d) E.-I. Negishi, L. Anastasia, *Chem. Rev.* **2003**, *103*, 1979; e) R. R. Tykwinski, *Angew. Chem. Int. Ed.* **2003**, *42*, 1566; *Angew. Chem.* **2003**, *115*, 1604; f) H. Doucet, J.-C. Hierso, *Angew. Chem. Int. Ed.* **2007**, *46*, 834; *Angew. Chem.* **2007**, *119*, 850.

[2] a) K. Sonogashira, Y. Tohda, N. Hagihara, *Tetrahedron Lett.* **1975**, *16*, 4467; b) R. Chinchilla, C. Nájera, *Chem. Rev.* **2007**, *107*, 874; c) K. Sonogashira, *J. Organomet. Chem.* **2002**, *653*, 46; d) K. Sonogashira, *Handbook of Organopalladium Chemistry for Organic Synthesis*, E. Negishi, A. de Meijere, Eds.; Wiley-Interscience, New York, **2002**, p.493.

[3] Reviews: a) S. R. Dubbaka, P. Vogel, *Angew. Chem. Int. Ed.* **2005**, *44*, 7674; *Angew. Chem.* **2005**, *117,* 7848; b) H. Prokopcová, C. O. Kappe, *Angew. Chem. Int. Ed.* **2008**, *47,* 3674; *Angew. Chem.* **2008**, *120,* 3732; c) H. Prokopcová, C. O. Kappe, *Angew. Chem. Int. Ed.* **2009**, *48,* 2276; *Angew. Chem.* **2009**, *121,* 2312; d) E. C. Garnier-Amblard, L. S. Liebeskind, *Boronic Acids,* 2nd ed. (Ed.: D. G. Hall), Wiely-VCH, Weinheim, **2011**, Chap. 7; e) S. G. Modha, V. P. Mehta, E. V. Van der Eycken, *Chem. Soc. Rev.* **2013**, *42*, 5042; f) L. Wang, W. He, Z. Yu, *Chem. Soc. Rev.* **2013**, *42*, 599; g) F. Pan, Z.-J. Shi, *ACS Catal.* **2014**, *4*, 280.

[4] a) L. L. Hegedus, R. W. McCabe in *Catalyst Poisoning*, Marcel Dekker, New York, **1984**; b) A. T. Hutton in *Comprehensive Coordination Chemistry*, Vol. 5 (Eds.: G. Wilkinson, R. D. Gillard, J. A. McCleverty), Pergamon, Oxford, 1984, p. 1151; c) H. Liu, X. Jiang, *Chem. Asian J.* **2013**, *8*, 2546; d) I. P. Beletskaya, V. P. Ananikov, *Chem. Rev.* **2011**, *111*, 1596; e) T. Kondo, T. Mitsudo, *Chem. Rev.* **2000**, *100*, 3205; f) C.-F. Lee, Y.-C. Liu, S. S. Badsara, *Chem. Asian J.* **2014**, *9*, 706.

[5] The bond dissociation energies of Ph–SMe, Ph–Cl, and Ph–Br were determined to be 357.3±6.3, 399.6±6.3, and 336.4±6.3 $kJmol^{-1}$, respectively: Y.-R. Luo, *Comprehensive Handbook of Chemical Bond Energies*, CRC Press, Boca Raton, **2007**. They were also measured to be 373.2±8.4, 400, and 337 $kJmol^{-1}$, respectively: K. Daasbjerg *J. Chem. Soc. Perkin Trans. 2* **1994**, *40*, 1275; S. W. Benson, *Chem. Soc. Rev.* **1978**, *78*, 23.

[6] Very recent examples: a) A. J. Eberhart, J. E. Imbriglio, D. J. Procter, *Org. Lett.* **2011**, *13*, 5882; b) L. Melzig, A. Metzger, P. Knochel, *Chem. Eur. J.* **2011**, *17*, 2948; c) S. G. Modha, J. C. Trivedi, V. P. Mehta, D. S. Ermolat’ev, E. V. Van der Eycken, *J. Org. Chem.* **2011**, *76*, 846; d) M. Koley, L. Wimmer, M. Schnürch, M. D. Mihovilovic, *Eur. J. Org. Chem.* **2011**, 1972; e) S. Dahbi, P. Bisseret, *Eur. J. Org. Chem.* **2012**, 3759; f) J. F. Hooper, R. D. Young, I. Pernik, A. S. Weller, M. C. Willis, *Chem. Sci.* **2013**, *4*, 1568; g) F. Pan, H. Wang, P.-X. Shen, J. Zhao, Z.-J. Shi, *Chem. Sci.* **2013**, *4*, 1573; h) G. S. Creech, O. Kwon, *Chem. Sci.* **2013**, *4*, 2670; i) J.-X. Liu, Y.-J. Liu, W.-T. Du, Y. Dong, J. Liu, M. Wang, *J. Org. Chem.* **2013**, *78*, 7293; j) C. I. Someya, M. Weidauer, S. Enthaler, *Catal. Lett.* **2013**, *143*, 424; k) B.-X. Du, Z.-J. Quan, Y.-X. Da, Z. Zhang, X.-C. Wang, *Adv. Synth. Catal.* **2015**, *357*, 1270.

[7] Our work: a) S. Kanemura, A. Kondoh, H. Yorimitsu, K. Oshima, *Synthesis* **2008**, 2659; b) Y. Ookubo, A. Wakamiya, H. Yorimitsu, A. Osuka, *Chem. Eur. J.* **2012**, *18*, 12690; c) K. Murakami, H. Yorimitsu, A. Osuka, *Angew. Chem. Int. Ed.* **2014**, *53*, 7510; *Angew. Chem.* **2014**, *126,* 7640; d) T. Sugahara, K. Murakami, H. Yorimitsu, A. Osuka, *Angew. Chem. Int. Ed.* **2014**, *53*, 9329; *Angew. Chem.* **2014**, *126,* 9483; e) S. Otsuka, D. Fujino, K. Murakami, H. Yorimitsu, A. Osuka, *Chem. Eur. J.* **2014**, *20*, 13146; f) A. Baralle, S. Otsuka, V. Guérin, K. Murakami, H. Yorimitsu, A. Osuka, *Synlett* **2015**, *26*, 327; g) K. Gao, H. Yorimitsu, A. Osuka, *Eur. J. Org. Chem.* **2015**, 2678; h) D. Vasu, H. Yorimitsu, A. Osuka, *Angew. Chem. Int. Ed*. **2015**, *54*, 7162; *Angew. Chem.* **2015**, *127*, 7268; i) S. Otsuka, H. Yorimitsu, A. Osuka, *Chem. Eur. J.* **2015**, *21*, 14703; j) K. Gao, H. Yorimitsu, A. Osuka, *Angew. Chem. Int. Ed*. **2016**, *55*, 4573; *Angew. Chem.* **2016**, *128*, 4649.

[8] a) V. P. Mehta, A. Sharma, E. Van der Eycken, *Org. Lett.* **2008**, *10*, 1147; b) V. P. Mehta, S. G. Modha, E. Van der Eycken, *J. Org. Chem.* **2009**, *74*, 6870; c) B. C. Shook, D. Chakravarty, P. F. Jackson, *Tetrahedron Lett.* **2009**, *50*, 1013; d) K. Lee, C. M. Counceller, J. P. Stambuli, *Org. Lett.* **2009**, *11*, 1457.

[9] a) S. Silva, B. Sylla, F. Suzenet, A. Tatibouët, A. P. Rauter, P. Rollin, *Org. Lett.* **2008**, *10*, 853; b) X. Guinchard, E. Roulland, *Org. Lett.* **2009**, *11*, 4700; c) O. V. Maltsev, A. Pöthig, L. Hintermann, *Org. Lett.* **2014**, *16*, 1282; d) Y. Wu, Y. Xing, J. Wang, Q. Sun, W. Kong, F. Suzenet, *RSC Adv.* **2015**, *5*, 48558.

[10] S. R. Dubbaka, P. Vogel, *Adv. Synth. Catal.* **2004**, *346*, 1793.

[11] For Pd-PEPPSI-NHC catalysts, see: a) C. Valente, S. Çalimsiz, K. H. Hoi, D. Mallik, M. Sayah, M. G. Organ, *Angew. Chem. Int. Ed.* **2012**, *51,* 3314; *Angew. Chem.* **2012**, *124,* 3370; b) C. Valente, M. Pompeo, M. Sayah, M. G. Organ, *Org. Process Res. Dev.* **2014**, *18*, 180; c) E. A. B. Kantchev, C. J. O'Brien, M. G. Organ, *Aldrichm. Acta* **2006**, *39*, 117. For Singacycles, see: d) G.-R. Peh, E. A. B. Kantchev, J.-C. Er, J. Y. Ying, *Chem. Eur. J.* **2010**, *16*, 4010. For [IPrPdCl(π-allyl)], see: e) N. Marion, S. P. Nolan, *Acc. Chem. Res.* **2008**, *41*, 1440.

[12] K. Matsubara, K. Ueno, Y. Shibata, *Organometallics* **2006**, *25*, 3422.

[13] a) H. Okamura, M. Miura, H. Takei, *Tetrahedron Lett.* **1979**, *20*, 43; b) H. Takei, M. Miura, H. Sugimura, H. Okamura, *Chem. Lett.* **1979**, 1447; c) E. Wenkert, T. W. Ferreira, E. L. Michelotti, *J. Chem. Soc., Chem. Commun.* **1979**, 637.

[14] a) T. Kobatake, D. Fujino, S. Yoshida, H. Yorimitsu, K. Oshima, *J. Am. Chem. Soc.* **2010**, *132*, 11838; b) K. Murakami, H. Yorimitsu, K. Oshima, *Bull. Chem. Soc. Jpn.* **2014**, *87*, 1349. Also see ref. 7b and 7c.

[15] S. Yoshida, H. Yorimitsu, K. Oshima, *Org. Lett.* **2007**, *9*, 5573.

[16] a) A. Fürstner, V. Mamane, *J. Org. Chem.* **2002**, *67*, 6264; b) V. Mamane, P. Hannen, A. Fürstner, *Chem. Eur. J.* **2004**, *10*, 4556.

[17] The structure of the minor isomer is not clear at this stage.

[18] For detailed mechanistic discussion, see Supporting Information. Only three examples of 1,2-aryl migration under platinum catalysis have been reported: a) H. Kusama, Y. Miyashita, J. Takaya, N. Iwasawa, *Org. Lett.* **2006**, *8*, 289; b) J. Takaya, S. Udagawa, H. Kusama, N. Iwasawa, *Angew. Chem. Int. Ed.* **2008**, *47*, 4906; *Angew. Chem.* **2008**, *120*, 4984; c) W. Kong, Y. Qiu, X. Zhang, C. Fu, C. Fu, S. Ma, *Adv. Synth. Catal.* **2012**, *354*, 2339.

[19] See Supporting Information for DFT calculations of **6**.

[20] S.-Y. Lee, Y.-H. Kwak, B.-W. Park, J.-W. Choi, W.-I. Choi, S.-Y. Kim, J.-Y. Lee, (Samsung Display Co. Ltd.), US 2014/0027741 A1, **2014**.

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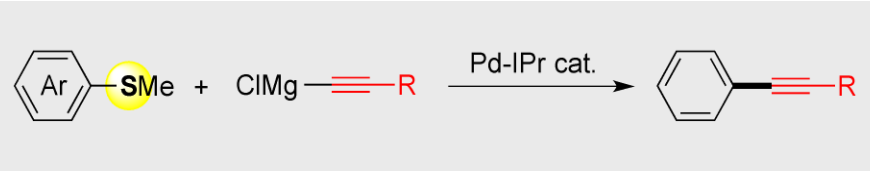
COMMUNICATION



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Pd-NHC-catalyzed Alkynylation of General Aryl Sulfides with Alkynyl Grignard Reagents

Cross-coupling reactions of unactivated aryl sulfides with alkynylmagnesium chloride afford 1-aryl-1-alkynes under palladium/*N*-heterocyclic carbene catalysis. Noteworthy is by far the widest scopes of aryl sulfides and alkynes. The alkynylation is compatible with typical protecting groups and functional groups, and is applicable to the synthesis of benzofuran-based fluorescent molecules by taking advantage of characteristic organosulfur chemistry.