Received: 25 December 2013

Revised: 17 February 2014

(wileyonlinelibrary.com) DOI 10.1002/aoc.3139

Pd-catalyzed desulfitative Hiyama coupling with sulfonyl chlorides

Wei Zhang^a, Fang Liu^b, Ke Li^c and Baoli Zhao^d*

Palladium-catalyzed desulfitative Hiyama cross-coupling reactions of various arylsulfonyl chlorides with aryltriethoxysilane have been achieved in good yields. The reported cross-coupling reactions are tolerant to the common functional groups regardless of electron-withdrawing or electron-donating, making these transformations attractive alternatives to the traditional cross-coupling approaches. Copyright © 2014 John Wiley & Sons, Ltd.

Additional supporting information may be found in the online version of this article at the publisher's web-site.

Keywords: Pd-catalyzed; desulfitative coupling; Hiyama cross-coupling; arylsulfonyl chloride

Introduction

Arylsulfonyl chlorides are inexpensive and readily available compounds. They have been used for many years in industry for the manufacture of drugs, pesticides, dyes, polymers, etc.^[1,2] However, the application of arylsulfonyl chlorides in transition metal-catalyzed C—C bond-forming reactions was obscured until 1988. The first job using arylsulfonyl chlorides as reagents in Pd-catalyzed Heck-type cross-coupling reactions was reported by Kasahara and Miura.^[3–6] Development came to a standstill for more than 10 years until Vogel's series of achievement were published from 2003.^[7]

Arylsulfonyl chlorides have been demonstrated as a class of electrophilic reagents in Pd-catalyzed desulfitative C—C cross-coupling reactions since then. Many types of coupling reaction, such as Negishi,^[8] Stille,^[9–11] Suzuki,^[12] Heck,^[13] Sonogashira,^[14–16] homocoupling^[17,18] and carbonylation^[19] have been well developed. However, it has not been extended to Pd-catalyzed C—C bond formation with organosilanes (Hiyama cross-coupling; Fig. 1). Hiyama reaction has drawn increasing attention as one of the useful synthetic methods for the construction of asymmetrical biaryls.^[20–23] Organosilanes are very stable, low toxicity^[24,25] and the leaving silicon group can be converted to harmless SiO₂ by incineration,^[26,27] which has made this method attractive from an environmentally friendly point of view. We report here a new application to arylsulfonyl chlorides in Hiyama-type cross-coupling under mild conditions without ligands.^[28]

Results and Discussion

We initiated our investigation on the model reaction of *p*-methylphenylsulfonyl chloride with phenyltrimethoxysilane to optimize the cross-coupling conditions. To our delight, the desulfitative cross-coupling took place in the presence of Pd₂ (dba)₃ (3 mol%) and TBAF.3H₂O (*n*-tetrabutylammonium fluoride) (1 equiv.) in DMSO under N₂ with a yield of 52% (Table 1, entry 1). We then investigated the influence of solvents on reaction activity. The optimization results are shown in Table 1. The yields obtained in other polar aprotic solvents like DMF, DMA and NMP were also 47–59% (Table 1, entries 2–4). Ether solvents such as 1,4-dioxane and THF have been tested, and no better results were obtained (Table 1, entries 5 and 6). Acetonitrile was coped with the cross-coupling; however, toluene inhibited its activity (Table 1, entries 7 and 8). Subsequently, we further considered the application of component solvent. We chose the DMF (which showed the best in solvent selection) to mix with the other solvent. To our delight, the mixture displayed an obvious effect to the cross-coupling reaction (69–75%) (Table 1, entries 9–11) and solvent consisting of DMF and CH₃CN (volume ratio 1:1) was shown to be best (Table 1, entry 12). Finally, we adjusted the constitution of DMF and CH₃CN in the range of 9:1 to 1:9 (Table 1, entries 13–20). A volume ratio of 1:4 (DMF vs. CH₃CN) was chosen for the following optimization (Table 1, entry 19).

As shown in Table 2, the effects of catalysts and additives were investigated. We tested various Pd catalysts for this desulfinative coupling reaction by using DMF/CH₃CN (1:4) as the solvent and TBAF.3H₂O as the additive. Among palladium catalysts explored, Pd(dppf)Cl₂, PdCl₂(PPh₃)₂ and PdCl₂(CH₃CN)₂ afforded the desired biphenyl with 45%, 39% and 49% yields (Table 2, entries 1–3). Although Pd(OAc)₂ and PdCl₂ afforded the same or a higher yield of the desired product (Table 2, entries 4 and 5), the Pd(0) catalysts showed better catalytic activities. The screening of non-valent palladium catalysts, such as Pd(PPh₃)₄, Pd(dba)₂ and Pd₂(dba)₃, provided 4-methyl-1,1'-biphenyl in 87%, 83% and 91% yield,

- a Department of Chemistry and Chemical Engineering, Xinxiang University, Xinxiang, Henan Province 453003, People's Republic of China
- b Life Science Research Center, Hebei North University, Zhangjiakou, Hebei Province 075000, People's Republic of China
- c Jiaozuo City Environmental Protection Bureau, Jiaozuo, Henan Province 453003, People's Republic of China
- d Institute of Applied Chemistry and Department of Chemistry, Shaoxing University, Shaoxing, Zhejiang Province 312000, People's Republic of China

^{*} Correspondence to: Baoli Zhao, Institute of Applied Chemistry and Department of Chemistry, Shaoxing University, Shaoxing, Zhejiang Province 312000, People's Republic of China. E-mail: babygarfield@126.com





Figure 1. Arylsulfonyl chlorides in Pd-catalyzed coupling.

respectively (Table 2, entries 6–8). No product was formed in the presence of heterogeneous Pd/C catalyst(Table 2, entry 9). Thus $Pd_2(dba)_3$ was selected for further optimization. Subsequently, we started to investigate a variety of additives (fluorochemical) to favor the removal of silicon groups. Intriguingly, when TBAF.3H₂O was used as the additive, it gave a 91% yield of biphenyls, whereas the use of TBAF (1 M in THF) and TBAF (75% water) gave less than 20% of the product (Table 2, entries 10 and 11). Furthermore, the reaction did not proceed well when carried out with other additives, such as NaF, KF and CsF (Table 2, entries 12–14).

Hence the scope of the direct desulfinative coupling with arylsulfonyl chloride was explored by using 5 mol% Pd₂(dba)₃ as the catalyst and TBAF as the additive in DMF/CH₃CN at 100°C under nitrogen. As summarized in Table 3, the palladium-catalyzed desulfinative coupling of phenyltriethoxysilane was successfully extended to various arylsulfonyl chloride substrates with different substituents at the *para*, *meta* or *ortho* position of the aromatic ring, and the desired biaryls were obtained in moderate to good yields. The reaction could tolerate a range of functional groups at the *para* position with coupling occurring in the presence of methoxy group, acetyl group and nitro group (Table 3,



entries 1–5). The ability to incorporate chloro and bromo substituents makes this reaction particularly attractive for transition metal-catalyzed coupling reactions (Table 3, entries 6 and 7).

| Table 1. Solvent selection of Pd-catalyzed cross-coupling | | | | | |
|--|--------------------|------------------------|-------|-------------------------------|------------------------|
| $\begin{array}{c} Pd_2(db)_3\\ TBAF\cdot3H_2O\\ SO_2CI & Si(OMe)_3 & Solvent\\ & & 100^{\circ}C, N_2 \\ & & & & & & \\ \end{array}$ | | | | | |
| Entry | Solvent | Yield (%) ^b | Entry | Solvent | Yield (%) ^b |
| 1 | DMSO | 52 | 11 | DMF/1,4-dioxane (1:1) | 73 |
| 2 | DMF | 59 | 12 | DMF/ CH ₃ CN (1:1) | 79 |
| 3 | DMA | 56 | 13 | DMF/ CH ₃ CN (9:1) | 74 |
| 4 | NMP | 40 | 14 | DMF/ CH ₃ CN (4:1) | 79 |
| 5 | 1,4-Dioxane | 46 | 15 | DMF/ CH ₃ CN (3:1) | 76 |
| 6 | THF | 48 | 16 | DMF/ CH ₃ CN (2:1) | 81 |
| 7 | CH ₃ CN | 50 | 17 | DMF/ CH ₃ CN (1:2) | 85 |
| 8 | Toluene | _ | 18 | DMF/ CH ₃ CN (1:3) | 81 |
| 9 | DMF/DMSO (1:1) | 69 | 19 | DMF/ CH ₃ CN (1:4) | 91 |
| 10 | DMF/THF (1:1) | 75 | 20 | DMF/ CH ₃ CN (1:9) | 87 |

^aReaction conditions: *p*-methylphenylsulfonyl chloride (0.5 mmol), phenyltriethoxysilane (0.5 mmol), Pd₂(dba)₃ (3 mol%), TBAF.3H₂O (0.5 mmol), solvent (1.0 ml) at 100°C for 3 h unless otherwise indicated.

^bIsolated cross-coupling yield; the v/v ratio of solvents shown in parentheses.



^blsolated cross-coupling yield; v/v ratio of solvents is shown

in parentheses.

However, the site-diverse groups on the phenyl ring of arylsilane would slightly decrease the reaction efficiency (Table 3, entries 8 and 9). After a broad scope of arylsulfonyl chloride was established, we were particularly interested in extending the arylation to arylsilane derivatives. 4- Methoxy, 4-chloro, 4-bromo, 4-nitro and 4-*tert*-butyl could be coupled with good efficiency (Table 3, entries 12–17). Importantly, naphthalene groups were also applicable to these reaction conditions in moderate to good yield, no matter whether naphthalene-sulfonyl chloride or trimethoxy(naphthalen-2-yl)silane (Table 3, entries 10, 11, 20, 21).

A plausible mechanism is outlined in Fig. 2. Step (i) involves the oxidative addition of arylsulfonyl chloride to the Pd(0) forms the Pd(II) intermediate A. In step (ii), the intermediate A produces intermediate B with concomitant loss of SO₂ in the presence of palladium catalysts at a higher temperature, the exchange of arylsilane with intermediate B in step (iii) to afford intermediate C by the assistance of TBAF and, in step (iv), the reductive elimination from the Pd(II) complex affords the biaryl and regenerates Pd(0).



Figure 2. Possible mechanism.

Conclusion

We disclose here the first cross-coupling of arylsulfonyl chloride with aryltrimethoxysilane to afford biaryl products. The Pd(0)catalyzed Hiyama-type reaction proceeded smoothly in DMF/ CH₃CN under N₂. This transformation was efficient via desulfitative course with the assistance of TBAF·3H₂O.

References

- R. T. Morrison, R. N. Boyd, Organic Chemistry, 5th edn, A. Bacon, Boston, MA, 1987.
- [2] Kirk-Othmer Concise Encyclopedia of Chemical Technology, Wiley-VCH, New York, 1985.
- [3] A. Kasahara, T. Izumi, N. Kudou, H. Azami, S. Yamamato, Chem. Ind. 1988, 51.
- [4] A. Kasahara, T. Izumi, K. Miyamoto, T. Sakai, Chem. Ind. 1989, 192.
- [5] M. Miura, H. Hashimoto, K. Itoh, M. Nomura, *Tetrahedron Lett.* 1989, 30, 975.
- [6] M. Miura, H. Hashimoto, K. Itoh, M. Nomura, J. Chem. Soc. Perkin Trans.1 1990, 8, 2207.
- [7] For review of arylsulfonyl chloride in Pd-catalyzed cross-coupling, see S. R. Dubbaka, P. Vogel, Angew. Chem. Int. Ed. 2005, 44, 7674.
- [8] S. R. Dubbaka, P. Vogel, Tetrahedron Lett. 2006, 47, 3345.
- [9] S. R. Dubbaka, P. Vogel, J. Am. Chem. Soc. 2003, 125, 15292.
- [10] S. R. Dubbaka, P. Steunenberg, P. Vogel, Synlett 2004, 1235.
- [11] S. S. Labadie, J. Org. Chem. **1989**, 54, 2496.
- [12] S. R. Dubbaka, P. Vogel, Org. Lett. 2004, 6, 95.
- [13] S. R. Dubbaka, P. Vogel, Chem. Eur. J. 2005, 11, 2633.
- [14] S. R. Dubbaka, P. Vogel, Adv. Synth. Catal. 2004, 346, 1793.
- [15] V. P. W. Bohm, W. A. Herrmann, Eur. J. Org. Chem. 2000, 3679.
- [16] A. Soheili, J. Albaneze-Walker, J. A. Murry, P. G. Dormer, D. L. Hughes, Org. Lett. 2003, 5, 4191.
- [17] T. Kashiwabara, M. Tanaka, Tetrahedron Lett. 2005, 46, 7125.
- [18] M. Miura, H. Hashimoto, K. Itoh, M. Nomura, Chem. Lett. 1990, 459.
- [19] M. Miura, K. Itoh, M. Nomura, Chem. Lett. **1989**, 77.
- [20] S. E. Denmark, M. H. Ober, Aldrichim. Acta 2003, 36, 76.
- [21] S. E. Denmark, J. H.-C. Liu, Angew. Chem. Int. Ed. 2010, 49, 2.
- [22] S. E. Denmark, C. S. Regens, Acc. Chem. Res. 2008, 41, 1486.
- [23] Y. Nakao, T. Hiyama, Chem. Soc. Rev. 2011, 40, 4893.
- [24] R. G. Franzen, Tetrahedron 2000, 56, 685.
- [25] E. C. Ashby, J. Laemmle, H. M. Neumann, Acc. Chem. Res. 1974, 7, 272.
- [26] H. E. Elsayed-Ali, E. Waldbusser, US Patent 200400767552004.
- [27] E. R. Boller, US Patent 35089131970.
- [28] K. Cheng, S. Hu, B. Zhao, X. M. Zhang, C. Qi, J. Org. Chem. 2013, 78, 5022.

Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's web-site.