ChemComm

COMMUNICATION

View Article Online
View Journal | View Issue

Cite this: *Chem. Commun.*, 2015, **51**, 6126

Received 12th January 2015,
Accepted 24th February 2015

DOI: 10.1039/c5cc00267b

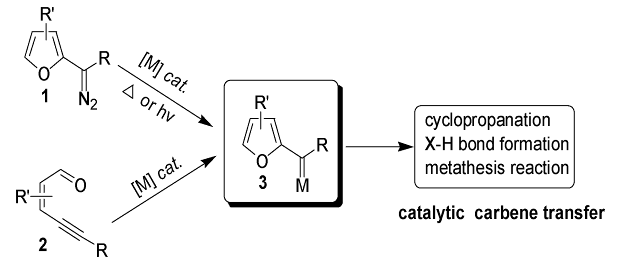
www.rsc.org/chemcomm

Access to polysubstituted indoles or benzothiophenes *via* palladium-catalyzed cross-coupling of furfural tosylhydrazones with 2-iodoanilines or 2-iodothiophenols†

Biaolin Yin,*[a] Xiaoyu Zhang,[a] Xiaoting Zhang,[a] Hui Peng,[a] Wen Zhou,[b] Bo Liu[b] and Huanfeng Jiang[a]

Palladium-catalyzed cross-coupling of furfural tosylhydrazones with 2-iodoanilines or 2-iodothiophenols produces polysubstituted indoles or benzothiophenes, respectively. The reaction proceeds through 2-furylmethylene palladium iodide intermediates, which undergo furan ring opening followed by ring closure to form indoles or benzothiophenes. This reaction will expand the synthetic applications of furfural derivatives.

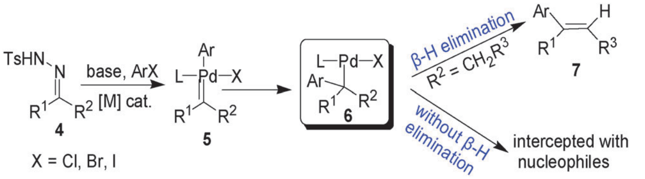
Transition-metal carbenoids are important intermediates in various transformations in organic synthesis, such as cyclopropanation and cyclopropenation, X–H insertion, and metathesis reactions.[1] In particular, the use of 2-furyl metal carbenoids **3** in catalytic carbene transfer reactions has been well explored. Carbenoids **3** can be generated by thermolysis or photolysis of 2-furyl diazoalkanes **1** (Scheme 1).[2] However, the synthesis of **1** is a formidable task owing to their explosivity and toxicity. To minimize these problems, techniques for safely handling diazoalkanes, including slow-addition techniques, are required. Carbenoids **3** can also be obtained from eneyne-ketones **2** through electrophilic activation of the alkyne group by coordination to a metal and subsequent intramolecular 5-*exo*-dig cyclization to form the furan ring.[3] However, the synthesis of precursors **2** requires multiple steps and sometimes involves the use of harsh reaction conditions. Thus, the development of simple and efficient methods for generating 2-furyl metal carbenoids and the exploration of novel pathways for efficiently transforming them to valuable molecules would expand the synthetic applications of furfural derivatives.[4,5]



Scheme 1 Generation of 2-furyl metal carbenoids **3** and their catalytic carbene transfer reactions.

Hydrazones, prepared by the reaction of an aldehyde or a ketone with hydrazine, are extensively used in organic synthesis. For example, under metal-free conditions in the presence of a base, hydrazones gradually decompose first into diazo compounds and then into carbenes which react with a variety of nucleophiles to produce X–H-insertion-like products.[6] In addition, palladium-catalyzed cross-coupling of tosylhydrazones with aryl halides is a simple, powerful method for forming C–C bonds using carbonyl compounds as the nucleophilic components without the need for a stoichiometric amount of an organometallic reagent.[7] The key step of this reaction is a migratory insertion of the aryl group into the C–Pd bond of palladium carbenes **5** to give arylmethylene palladium halides **6**, which then either undergo β-hydrogen elimination to provide olefins **7**[8] or are intercepted by a nucleophile (Scheme 2).[9]

Theoretically, base-mediated decomposition of furfural tosylhydrazones at a suitable reaction temperature could also produce furfuryl diazomethanes. Subsequent *in situ* transformation of the furfuryl diazomethanes, especially transformations involving coordination to a transition metal to form 2-furyl metal



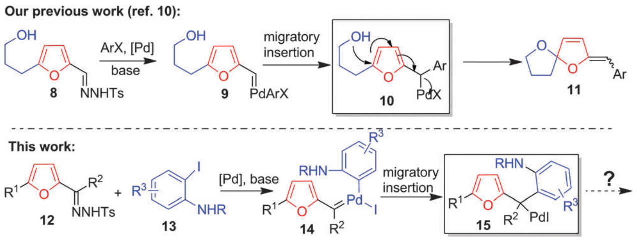
Scheme 2 Pathway for Palladium-catalyzed cross-coupling of tosylhydrazones with aryl halides.

---

[a] *School of Chemistry and Chemical Engineering, South China University of Technology, Guangzhou 510640, P. R. China. E-mail: blyin@scut.edu.cn; Fax: +86 20 8711 3735*

[b] *Guangdong Provincial Academy of Chinese Medical Sciences, Guangzhou, P. R. China 510006*

† Electronic supplementary information (ESI) available: Copies of ^{1}H NMR and ^{13}C NMR spectra of all the new compounds. See DOI: 10.1039/c5cc00267b

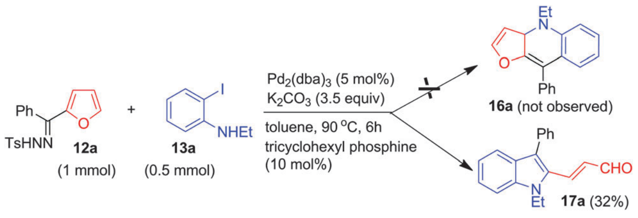


Scheme 3 Transformations of 2-furylmethylenepalladium halides.

carbenoids, which has never been reported, would be of great synthetic utility. Recently we reported that palladium-catalyzed cross-coupling of aryl halides with furfural tosylhydrazones **8** produces spiroacetal enol ethers **11** through an intramolecular nucleophilic dearomatization, involving an intermediate of 2-furylmethylenepalladium halide **10** carrying a nucleophile of the hydroxyl group in its side chain.[10] This protocol provided convenient access to exceedingly reactive 2-furylmethylene palladium halides from stable furfural hydrazones instead of from unstable 2-furylmethyl halides.[11] In the current study, we investigated the palladium-catalyzed coupling of furfural tosylhydrazones with 2-iodoanilines to afford 2-furylmethylene palladium iodides **15**, which could be transformed to various useful heterocyclic products (Scheme 3).

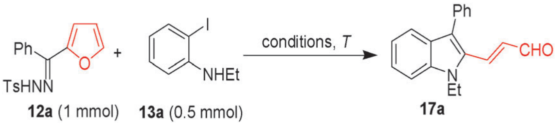
We initially studied the coupling of furfural tosylhydrazones **12a** with *N*-ethyl-2-iodoaniline (**13a**) as a model with $Pd_2(dba)_3$ as the catalyst, tricyclohexyl phosphine as the ligand, and K_2CO_3 as the base. Reaction in toluene at 90 °C for 6 h afforded no **16a**, the expected product of an intramolecular nucleophilic dearomatization pathway, but instead gave polysubstituted indole **17a** ($E/Z > 99:1$) in 32% yield (Scheme 4). This novel transformation has the potential to serve as an expedient synthetic route to polysubstituted indoles from simple furfural derivatives.[12] Therefore, we decided to optimize the reaction conditions for the formation of **17a** from **12a** and **13a**.

First, we screened various ligands while keeping the other reaction parameters fixed, that is, $Pd_2(dba)_3$ as the catalyst, K_2CO_3 as the base, toluene as the solvent, and 90 °C as the reaction temperature (Table 1, entries 1–10). Among the ligands examined, 1,1′-bis(diphenylphosphino)ferrocene (dppf) gave the highest yield of **17a** (76%, entry 5). Various solvents were then tested, and toluene was found to be the optimal one (entries 11–14). Changing the base to Cs_2CO_3, Li*Ot*Bu, Na*Ot*Bu, or NaH did not improve the yield (entries 15–18), nor did the use of other palladium catalysts, specifically $Pd(PPh_3)_4$, $Pd(PPh_3)_2Cl_2$, and $Pd(OAc)_2$ (entries 19–21). Lowering the reaction temperature to 80 °C gave a trace amount of the product along with recovered hydrazone (entry 22). Increasing the temperature to 100 °C led to a complicated mixture of products, including a relatively low yield of **17a** together with some enynal[2] (entry 23). The optimal yield was obtained with $Pd_2(dba)_3$ as the catalyst, dppf as the ligand, toluene as the solvent, and 90 °C as the reaction temperature (entry 5).



Scheme 4 Reaction of **12a** with **13a**.

Table 1 Optimization of reaction conditions for production of **17**[a]

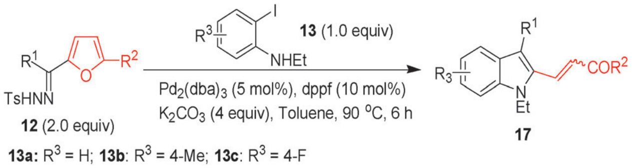


	Conditions				
Entry	Catalyst	Ligand[b]	Base	Solvent	Yield[c] (%)
1	$Pd_2(dba)_3$	PPh_3	K_2CO_3	Toluene	57
2	$Pd_2(dba)_3$	BINAP	K_2CO_3	Toluene	25
3	$Pd_2(dba)_3$	dppp	K_2CO_3	Toluene	63
4	$Pd_2(dba)_3$	dppe	K_2CO_3	Toluene	47
5	$Pd_2(dba)_3$	dppf	K_2CO_3	Toluene	76
6	$Pd_2(dba)_3$	$\mathbf{L_1}$	K_2CO_3	Toluene	54
7	$Pd_2(dba)_3$	$\mathbf{L_2}$	K_2CO_3	Toluene	32
8	$Pd_2(dba)_3$	$\mathbf{L_3}$	K_2CO_3	Toluene	Trace
9	$Pd_2(dba)_3$	$\mathbf{L_4}$	K_2CO_3	Toluene	36
10	$Pd_2(dba)_3$	$\mathbf{L_5}$	K_2CO_3	Toluene	ND
11	$Pd_2(dba)_3$	dppf	K_2CO_3	1,4-Dioxane	ND
12	$Pd_2(dba)_3$	dppf	K_2CO_3	DMF	ND
13	$Pd_2(dba)_3$	dppf	K_2CO_3	DCE	55
14	$Pd_2(dba)_3$	dppf	K_2CO_3	THF	72
15	$Pd_2(dba)_3$	dppf	Cs_2CO_3	Toluene	69
16	$Pd_2(dba)_3$	dppf	Li*Ot*Bu	Toluene	Trace
17	$Pd_2(dba)_3$	dppf	Et_3N	Toluene	NR
18	$Pd_2(dba)_3$	dppf	NaH	Toluene	Trace
19	$Pd(PPh_3)_4$	dppf	K_2CO_3	Toluene	70
20	$Pd(PPh_3)_2Cl_2$	dppf	K_2CO_3	Toluene	57
21	$Pd(OAc)_2$	dppf	K_2CO_3	Toluene	40
22[d]	$Pd_2(dba)_3$	dppf	K_2CO_3	Toluene	Trace
23[e]	$Pd_2(dba)_3$	dppf	K_2CO_3	Toluene	55

[a] Reaction conditions: unless otherwise noted, **12a** (2.0 equiv.), **13a** (1.0 equiv, 0.5 mmol), [Pd] (5.0 mol%), ligand (10 mol%), base (4.0 equiv.), T = 90 °C for 6 h. [b] $\mathbf{L_1}$ = 2-(dicyclohexylphosphino)-2′,4′,6′-tri-isopropyl-1,1′-biphenyl; $\mathbf{L_2}$ = tricyclohexylphosphine; $\mathbf{L_3}$ = tri(*p*-methoxyphenyl)phosphine; $\mathbf{L_4}$ = 4,5-bis(diphenylphospheno)-9,9-dimethylxanthene; $\mathbf{L_5}$ = 1,10-phenanthroline. [c] Yields were determined by means of ^1H NMR spectroscopy with mesitylene as an internal standard. ND = not detected; NR = no reaction. [d] T = 80 °C. [e] T = 100 °C.

With the optimized reaction conditions in hand, the substrate scope of the reaction was investigated with various substituted tosyl hydrazones **12** and 2-iodoanilines **13** (Table 2). The substituent on the furan ring clearly influenced the reaction outcome. Desired indoles **17** were obtained in moderate to good yields from reactions of **13a** and furans with R^2 fixed as hydrogen and R^1 as a phenyl group with an electron-donating substituent or an electron-neutral H atom (entries 1–4). In contrast, when R^1 was a phenyl group with an electron-withdrawing chlorine atom or NO_2 group, the corresponding indole was formed in a lower yield (60%, entry 5) or not at all (entry 6), respectively. When R^1 was an alkyl group, the reactions also proceeded well, and the corresponding indoles were produced in good yields (entries 7–10). The R^2 group could be hydrogen, Me, or a moderately electron-withdrawing amide group (entries 11 and 12), but substrate **12n**, with a more

Table 2 Synthesis of indoles **17**[a]

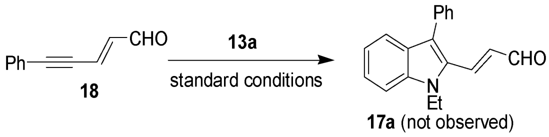


Entry	**12** (R^1, R^2)	**13**	**17** ([%][b], *E*/*Z*[c])
1	**12a** (Ph, H)	**13a**	**17a** (76, >99 : 1)
2	**12b** (4-Me-Ph, H)	**13a**	**17b** (78, 95 : 5)
3	**12c** (3,5-di-Me-Ph, H)	**13a**	**17c** (83, >99 : 1)
4	**12d** (4-MeO-Ph, H)	**13a**	**17d** (77, >99 : 1)
5	**12e** (4-Cl-Ph, H)	**13a**	**17e** (60, 97 : 3)
6	**12f** (4-NO_2-Ph, H)	**13a**	**17f** (ND)
7	**12g** (Me, H)	**13a**	**17g** (84, 98 : 2)
8	**12h** (*n*-Pr, H)	**13a**	**17h** (61, >99 : 1)
9	**12i** (*n*-Bu, H)	**13a**	**17i** (72, >99 : 1)
10	**12j** (*n*-pentyl, H)	**13a**	**17j** (86, 95 : 5)
11	**12k** (4-MeO-Ph, Me)	**13a**	**17k** (54, 75 : 25)
12	**12l** (3,5-di-Me-Ph, $CONMe_2$)	**13a**	**17l** (57, >99 : 1)
13	**12m** (4-MeO-Ph, COOMe)	**13a**	**17m** (ND)
14	**12d** (4-MeO-Ph, H)	**13b**	**17n** (54, 94 : 6)
15	**12a** (Ph, H)	**13b**	**17o** (50, 80 : 20)
16	**12g** (Me, H)	**13b**	**17p** (75, >99 : 1)
17	**12h** (*n*-Pr, H)	**13b**	**17q** (71, 96 : 4)
18	**12j** (*n*-pentyl, H)	**13b**	**17r** (78, >99 : 1)
19	**12d** (4-MeO-Ph, H)	**13c**	**17s** (67, >99 : 1)
20	**12h** (*n*-Pr, H)	**13c**	**17t** (52, >99 : 1)
21	**12j** (*n*-pentyl, H)	**13c**	**17u** (48, >99 : 1)

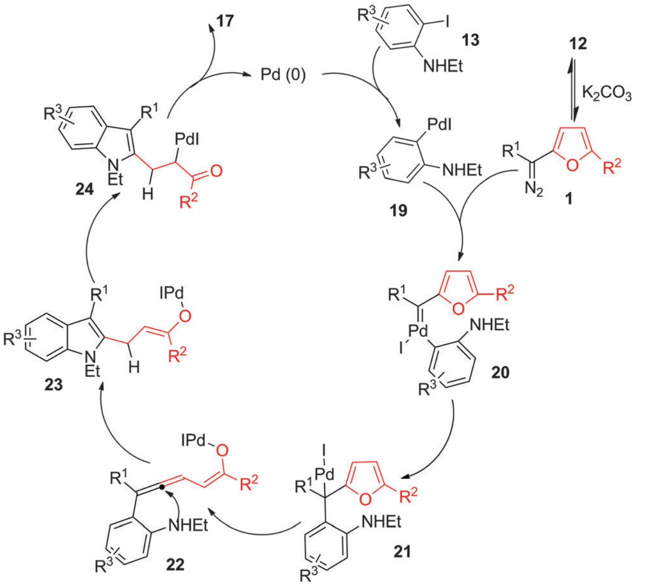
[a] All reactions were performed with 0.5 mmol of **13**. [b] Isolated yield. ND = not detected. [c] The ratios in parentheses were determined by means of ^{1}H NMR spectroscopy.

electron-withdrawing ester group, did not afford the desired product (**17n**, entry 13). We speculate that electron-withdrawing groups of R^1 and R^2 might result in the instability of 2-furylmethylenepalladium and disfavoring furan ring-opening. The R^3 on the iodoaniline could be an electron-neutral H atom (entries 1–5 and 7–13), an electron-donating methyl group (entries 14–18), or an electron-withdrawing fluorine atom (entries 19–21).

Considering the fact that the decomposition of furfuryl diazomethanes is reported to produce enynals,[2] we conducted a control reaction of enynal **18** with **13a** under standard conditions to determine whether the indole was formed *via* the Larock indole synthesis pathway (Scheme 5).[13] Because the control reaction resulted in a complicated mixture of products and none of the expected **17a** was detected, we propose that indoles **17** form by means of the pathway shown in Scheme 6. Base-mediated decomposition of **12** affords 2-furyl diazoalkane **1**, which reacts with ArPdI **19** to form palladium carbene complex **20**. Migratory insertion of the aryl group of **20** affords 2-furylmethylenepalladium iodide **21**, which might undergo concomitant β-heteroatom elimination and furan ring opening to form allene **22**.[14] Nucleophilic attack of the aniline nitrogen atom on the allene forms palladium complex **23**.[15] Palladium transfer results in intermediate **24**, and subsequent β-hydrogen elimination affords **17**.



Scheme 5 A control reaction of **18** with **13a**.

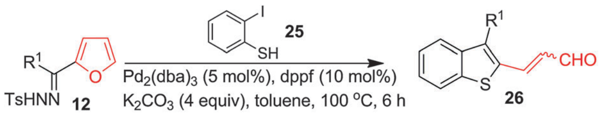


Scheme 6 Proposed mechanism for the formation of **17**.

We also investigated the utility of this protocol by synthesizing a small library of polysubstituted benzothiophenes **26** in good yields *via* coupling of 2-iodothiophene **25** with furfural tosylhydrazones **12** under similar conditions (Scheme 7).[16]

In summary, we describe an efficient palladium-catalyzed cross-coupling of readily available furfural tosylhydrazones with 2-iodoanilines or 2-iodothiophenol as a novel synthetic route to polysubstituted indoles or benzothiophenes, respectively. The reaction proceeds *via* 2-furylmethylene palladium halide intermediates, which undergo concomitant furan ring opening and ring closure to form indoles or benzothiophenes; this reaction expands the applications of sustainable furan derivatives as synthetic building blocks. Further explorations of the reaction scope, especially variation of the nucleophiles, and the use of the reaction for the synthesis of bioactive and natural products are underway in our laboratory.

This work was supported by the National Natural Science Foundation of China (No. 21272078 and 21336002), Fundamental Research Funds for the Central Universities (2014ZG0027), the Natural Science Foundation of Guangdong Province, China



26a (R^1 = Ph): 51% (*E*/*Z* > 99:1)
26b (R^1 = 4-Me-Ph): 58% (*E*/*Z* = 95:5)
26c (R^1 = 4-MeO-Ph): 61% (*E*/*Z* = 80:20)
26d (R^1 = 3,5-di-Me-Ph): 66% (*E*/*Z* > 99:1)
26e: (R^1 = 2-Me-Ph): 61% (*E*/*Z* = 96:4)
26f (R^1 = 4-Cl-Ph): 50% (*E*/*Z* = 78:22)

Scheme 7 Synthesis of benzothiophenes **26**.

(10351064101000000), and the Program for New Century Excellent Talents in Universities (NCET-12-0189).

Notes and references

1 (*a*) M. P. Doyle, M. A. McKervey and T. Ye, *Modern Catalytic Methods for Organic Synthesis with Diazo Compounds: From Cyclopropanes to Ylides*, Wiley-Interscience, New York, 1998; (*b*) F. Z. Dörwald, *Metal Carbenes in Organic Synthesis*, Wiley-VCH, Weinheim, 1999; (*c*) *Metal Carbenes in Organic Synthesis*, Topics in Organometallic Chemistry, ed. K. H. Dötz, Springer-Verlag, Berling, 2004, vol. 13; (*d*) M. P. Doyle and D. C. Forbes, *Chem. Rev.*, 1998, **98**, 911; A. Padwa and M. D. Weingarten, *Chem. Rev.*, 1996, **96**, 223; (*e*) T. Ye and M. A. McKervey, *Chem. Rev.*, 1994, **94**, 1091.

2 For reviews and selected examples, see: (*a*) L. D. Shirtcliff, S. P. McClintock and M. M. Haley, *Chem. Soc. Rev.*, 2008, **37**, 343; (*b*) R. S. Sheridan, *Chem. Rev.*, 2013, **113**, 7179; (*c*) C. R. Pharr, L. A. Kopff, B. Bennett, S. A. Reid and R. J. McMahon, *J. Am. Chem. Soc.*, 2012, **134**, 6443; (*d*) C. Röser, R. Albers and W. Sander, *Eur. J. Org. Chem.*, 2001, 269; (*e*) R. V. Hoffman and H. Shechter, *J. Am. Chem. Soc.*, 1978, **100**, 7934; (*f*) R. V. Hoffman, G. G. Orphanides and H. Shechter, *J. Am. Chem. Soc.*, 1978, **100**, 7927; (*g*) R. V. Hoffman and H. Shechter, *J. Org. Chem.*, 1974, **39**, 2939; (*h*) R. V. Hoffman and H. Shechter, *J. Am. Chem. Soc.*, 1971, **93**, 5940.

3 (*a*) M. J. González, E. López and R. Vicente, *Chem. Commun.*, 2014, **50**, 5379; (*b*) F. Hu, Y. Xia, C. Ma, Y. Zhang and J. Wang, *Org. Lett.*, 2014, **16**, 4082; (*c*) M. J. Gonzalez, L. A. Lopez and R. Vicente, *Org. Lett.*, 2014, **16**, 5780; (*d*) J. Ma, H. Jiang and S. Zhu, *Org. Lett.*, 2014, **16**, 4472; (*e*) Y. Xia, S. Qu, Q. Xiao, Z.-X. Wang, P. Qu, L. Chen, Z. Liu, L. Tian, Z. Huang, Y. Zhang and J. Wang, *J. Am. Chem. Soc.*, 2013, **135**, 13502; (*f*) J. González, J. González, C. Pérez-Calleja, L. A. López and R. Vicente, *Angew. Chem., Int. Ed.*, 2013, **52**, 5853; (*g*) M. Xu, T.-T. Ren, K.-B. Wang and C.-Y. Li, *Adv. Synth. Catal.*, 2013, **355**, 2488; (*h*) R. Vicente, J. González, L. Riesgo, J. González and L. A. López, *Angew. Chem., Int. Ed.*, 2012, **51**, 8063; (*i*) J. Barluenga, L. Riesgo, R. Vicente, L. A. López and M. Tomás, *J. Am. Chem. Soc.*, 2008, **130**, 13528; (*j*) Y. Kato, K. Miki, F. Nishino, K. Ohe and S. Uemura, *Org. Lett.*, 2003, **5**, 2619; (*k*) K. Miki, T. Yokoi, F. Nishino, Y. Kato, Y. Washitake, K. Ohe and S. Uemura, *J. Org. Chem.*, 2004, **69**, 1557; (*l*) K. Miki, Y. Washitake, K. Ohe and S. Uemura, *Angew. Chem., Int. Ed.*, 2004, **43**, 1857; (*m*) K. Miki, F. Nishino, K. Ohe and S. Uemura, *J. Am. Chem. Soc.*, 2002, **124**, 5260.

4 For reviews concerning synthetic application of furans, see: (*a*) B. H. Lipshutz, *Chem. Rev.*, 1986, **86**, 795; (*b*) F. W. Lichtenthaler, *Acc. Chem. Res.*, 2002, **35**, 728; (*c*) A. A. Rosatella, S. P. Simeonov, R. F. M. Frade and C. A. M. Afonso, *Green Chem.*, 2011, **13**, 754; (*d*) P. Gallezot, *Chem. Soc. Rev.*, 2012, **41**, 1538; (*e*) R. J. van Putten, J. C. van der Waal, E. de Jong, C. B. Rasrendra, H. J. Heeres and J. G. de Vries, *Chem. Rev.*, 2013, **113**, 1499.

5 For recent examples of furan dearomatization in our group, see: (*a*) B.-L. Yin, J.-Q. Lai, Z.-R. Zhang and H.-F. Jiang, *Adv. Synth. Catal.*, 2011, **353**, 1961; (*b*) B. Yin, G. Zeng, C. Cai, F. Ji, L. Huang, Z. Li and H. Jiang, *Org. Lett.*, 2012, **14**, 616; (*c*) B. Yin, C. Cai, G. Zeng, R. Zhang, X. Li and H. Jiang, *Org. Lett.*, 2012, **14**, 1098; (*d*) B. Yin, L. Huang, X. Wang, J. Liu and H. Jiang, *Adv. Synth. Catal.*, 2013, **355**, 370; (*e*) L. Huang, X. Zhang, J. Li, K. Ding, X. Li, W. Zheng and B. Yin, *Eur. J. Org. Chem.*, 2014, 338; (*f*) X. Zhang, L. Huang, H. Peng, F. Ji, X. Li and B. Yin, *Tetrahedron*, 2014, **70**, 5242; (*g*) B. Yin, H. Yu, Z. Li, W. Zhong and W. Gu, *Synthesis*, 2012, 3735; (*h*) H. Yu, W. Zhong, T. He, W. Gu and B. Yin, *Tetrahedron Lett.*, 2013, **54**, 1256; (*i*) B.-L. Yin, J.-Q. Lai, L. Huang, X.-Y. Zhang and F.-H. Ji, *Synthesis*, 2012, 2567.

6 For selected recent examples: (*a*) J. Barluenga, M. Tomás-Gamasa, F. Aznar and C. Valdés, *Angew. Chem., Int. Ed.*, 2010, **49**, 4993; (*b*) X. Creary, *J. Am. Chem. Soc.*, 2013, **135**, 6570; (*c*) J.-B. Liu, H. Yan and G. Lu, *Tetrahedron Lett.*, 2013, **54**, 891; (*d*) Q. Sha and Y. Wei, *Tetrahedron*, 2013, **69**, 3829; (*e*) Q. Ding, B. Cao, J. Yuan, X. Liu and Y. Peng, *Org. Biomol. Chem.*, 2011, **9**, 748; (*f*) Q. Sha and Y.-Y. Wei, *Org. Biomol. Chem.*, 2013, **11**, 5615; (*g*) H. E. Bartrum, D. C. Blakemore, C. J. Moody and C. J. Hayes, *Chem. – Eur. J.*, 2011, **17**, 9586; (*h*) A.-H. García-Muñoz, M. Tomás-Gamasa, M. C. Pérez-Aguilar, E. Cuevas-Yañez and C. Valdés, *Eur. J. Org. Chem.*, 2012, 3925.

7 Reviews: (*a*) Q. Xiao, Y. Zhang and J. Wang, *Acc. Chem. Res.*, 2013, **46**, 236; (*b*) J. Barluenga and C. Valdés, *Angew. Chem., Int. Ed.*, 2011, **50**, 7486; (*c*) X. Zhao, Y. Zhang and J. Wang, *Chem. Commun.*, 2012, **48**, 10162; (*d*) Z. Shao and H. Zhang, *Chem. Soc. Rev.*, 2012, **41**, 560; (*e*) Z. Liu and J. Wang, *J. Org. Chem.*, 2013, **78**, 10024; (*f*) Y. Xia, Y. Zhang and J. Wang, *ACS Catal.*, 2013, **3**, 2586.

8 For selected recent examples: (*a*) X. Zeng, G. Cheng, J. Shen and X. Cui, *Org. Lett.*, 2013, **15**, 3022; (*b*) Q. Xiao, B. Wang, L. Tian, Y. Yang, J. Ma, Y. Zhang, S. Chen and J. Wang, *Angew. Chem., Int. Ed.*, 2013, **52**, 9305; (*c*) L. Florentino, F. Aznar and C. Valdés, *Org. Lett.*, 2012, **14**, 2323; (*d*) J. Barluenga, N. Quiñones, M.-P. Cabal, F. Aznar and C. Valdés, *Angew. Chem., Int. Ed.*, 2011, **50**, 2350; (*e*) J. Barluenga, L. Florentino, F. Aznar and C. Valdés, *Org. Lett.*, 2011, **13**, 510; (*f*) J. Barluenga, M. Tomás-Gamasa, F. Aznar and C. Valdés, *Adv. Synth. Catal.*, 2010, **352**, 3235; (*g*) J. Barluenga, M. Escribano, F. Aznar and C. Valdés, *Angew. Chem., Int. Ed.*, 2010, **49**, 6856; (*h*) J. Barluenga, M. Tomás-Gamasa, F. Aznar and C. Valdés, *Chem. – Eur. J.*, 2010, **16**, 12801; (*i*) J. Barluenga, M. Escribano, P. Moriel, F. Aznar and C. Valdés, *Chem. – Eur. J.*, 2009, **15**, 13291; (*j*) Q. Xiao, J. Ma, Y. Yang, Y. Zhang and J. Wang, *Org. Lett.*, 2009, **11**, 4732; (*k*) J. Barluenga, M. Tomás-Gamasa, P. Moriel, F. Aznar and C. Valdés, *Chem. – Eur. J.*, 2008, **14**, 4792.

9 (*a*) R. Kudirka, S. K. J. Devine, C. S. Adams and D. L. Van Vranken, *Angew. Chem., Int. Ed.*, 2009, **48**, 3677; (*b*) L. Zhou, F. Ye, Y. Zhang and J. Wang, *J. Am. Chem. Soc.*, 2010, **132**, 13590; (*c*) A. Khanna, C. Maung, K. R. Johnson, T. T. Luong and D. L. Van Vranken, *Org. Lett.*, 2012, **14**, 3233; (*d*) P.-X. Zhou, J.-Y. Luo, L.-B. Zhao, Y.-Y. Ye and Y.-M. Liang, *Chem. Commun.*, 2013, **49**, 3254; (*e*) P.-X. Zhou, Y.-Y. Ye and Y.-M. Liang, *Org. Lett.*, 2013, **15**, 5080; (*f*) Y.-Y. Ye, P.-X. Zhou, J.-Y. Luo, M.-J. Zhong and Y.-M. Liang, *Chem. Commun.*, 2013, **49**, 10190.

10 B. Yin, X. Zhang, J. Liu, X. Li and H. Jiang, *Chem. Commun.*, 2014, **50**, 8113.

11 For related examples: (*a*) Y. Shi, P. Brenner, S. Bertsch, K. Radacki and R. D. Dewhurst, *Organometallics*, 2012, **31**, 5599; (*b*) R. D. Dewhurst, R. Muller, M. Kaupp, K. Radacki and K. Götz, *Organometallics*, 2010, **29**, 4431.

12 For recent examples concerning synthesis of indoles from orth-substituted benzylfurans under acidic conditions, see: (*a*) V. T. Abaev, A. T. Plieva, P. N. Chalikidi, M. G. Uchuskin, I. V. Trushkov and A. V. Butin, *Org. Lett.*, 2014, **16**, 4150; (*b*) M. G. Uchuskin, N. V. Molodtsova, S. A. Lysenko, V. N. Strel'nikov, I. V. Trushkov and A. V. Butin, *Eur. J. Org. Chem.*, 2014, 2508; (*c*) A. Kuznetsov, A. Makarov, A. E. Rubtsov, A. V. Butin and V. Gevorgyan, *J. Org. Chem.*, 2013, **78**, 12144; (*d*) M. G. Uchuskin, N. V. Molodtsova, V. T. Abaev, I. V. Trushkov and A. V. Butin, *Tetrahedron*, 2012, **68**, 4252; (*e*) A. V. Butin, S. K. Smirnov, F. A. Tsiunchik, M. G. Uchuskin and I. V. Trushkov, *Synthesis*, 2008, 2943; (*f*) A. V. Butin, S. K. Smirnov and I. V. Trushkov, *Tetrahedron Lett.*, 2008, **49**, 20.

13 R. C. Larock and E. K. Yum, *J. Am. Chem. Soc.*, 1991, **113**, 6689.

14 For similar elimination reactions to form allene, see: (*a*) K. Takanishi, H. Urabe and I. Kuwajima, *Tetrahedron Lett.*, 1987, **28**, 2281; (*b*) K. Isao, H. Showay, T. Toshihiko and S. Makoto, *Tetrahedron Lett.*, 1980, **21**, 3209. Other mechanisms for this step cannot be ruled out at this stage. For example, an intramolecular nucleophilic dearomatization to form a six-membered ring followed by migration of the amine group is a possibility.

15 For examples of the transformation of o-allenylaniline into indoles, see: (*a*) A. Saito, A. Kanno and Y. Hanzawa, *Angew. Chem., Int. Ed.*, 2007, **46**, 3931; (*b*) F. Inagaki, M. Mizutani, N. Kuroda and C. Mukai, *J. Org. Chem.*, 2009, **74**, 6402; (*c*) C. Mukai and Y. Takahashi, *Org. Lett.*, 2005, **7**, 5793.

16 For reviews concerning the application and synthesis of benzothiophenes, see: (*a*) *Handbook of Thiophene-Based Materials*, ed. I. F. Perepichka and D. F. Perepichka, Wiley-VCH Verlag, New York, 2009; (*b*) D. A. Horton, G. T. Bourne and M. L. Smythe, *Chem. Rev.*, 2003, **103**, 893; (*c*) T. Y. Zhang, J. O'Toole and C. S. Proctor, *Sulfur Rep.*, 1999, **22**, 1; (*d*) B. Godoi, R. F. Schumacher and G. Zeni, *Chem. Rev.*, 2011, **111**, 2937; (*e*) T. W. Lyons and M. S. Sanford, *Chem. Rev.*, 2010, **110**, 1147.