Iron-catalysed Mizoroki–Heck reaction using 2,2′-diamino-6,6′-dimethylbiphenyl as the ligand

Xiu-Ren Wang and Fan Chen*

College of Chemistry and Materials Engineering, Wenzhou University, Chashan University Town, Wenzhou, Zhejiang Province 325035, P. R. China

$FeCl_3{\cdot}6H_2O$-catalysed Mizoroki–Heck reactions of aryl iodides with methyl acrylate have been achieved by using 2,2′-diamino-6,6′-dimethylbiphenyl as the ligand and $NaHCO_3$ as the base in DMF and H_2O. It was found that an appropriate amount of H_2O is essential for high yields in these reactions.

Keywords: Mizoroki–Heck reaction, iron catalysis, H_2O, 2,2′-diamino-6,6′-dimethylbiphenyl, aryl iodides, methyl acrylate

Transition-metal catalysed cross-coupling reactions are versatile methods for carbon-carbon bond formation.[1–3] Among them, the Mizoroki–Heck reaction is one of the most important methods for the vinylation of aromatic compounds.[4–10] Traditionally, the combination of palladium and a phosphine-based ligand is a good catalyst for this reaction.[11–14] Because of the high cost of palladium salts and the air-sensitivity and toxicity of phosphine-based ligands, alternative metals as well as ligands have been developed.[15–25] In the past few years, iron salts, as one of the most inexpensive and environmentally friendly salts on the earth, have been proved to be efficient catalysts for carbon–carbon and carbon–heteroatom bond formation.[26–43] Recently, Shao, Lu and co-workers found that 2,2′-diamino-6,6′-dimethylbiphenyl (**L**), as a non-phosphine compound, is a good ligand in the transition metal catalysed carbon-carbon bond formation reactions.[44,45] An iron catalysed Mizoroki–Heck reaction using 80 mol% of proline or picolinic acid as the ligand has been reported.[46] In this laboratory, we have found that **L** is also a good ligand in the $FeCl_3{\cdot}6H_2O$-catalysed Mizoroki–Heck reactions of aryl iodides with methyl acrylate. We now report these results in detail.

Initial investigations were carried out using 1-chloro-4-iodobenzene (**1a**, 0.5 mmol) and methyl acrylate (**2a**, 0.6 mmol) as the reactants, a combination of Fe_2O_3 (10 mol%) and **L** (20 mol%) as the catalyst, $KHCO_3$ (2.0 equiv.) as the base and DMF (1.0 mL) as the solvent at 135 °C for 24 h (Table 1). Preliminary results showed that the amount of H_2O affected the reaction dramatically. When 0–2.0 equiv. of H_2O was introduced in the reaction system, none of the desired product **3a** was obtained (Table 1, entries 1–3). Careful investigations showed that 8.0 equiv. of H_2O gave the best result and the corresponding coupling product **3a** was obtained in 72% yield (Table 1, entry 6). When the amount of H_2O was increased to 20.0 equiv., the yield was drastically decreased to 26% (Table 1, entry 8). Next, some other iron salts as $FeCl_3{\cdot}6H_2O$, $FeCl_2{\cdot}4H_2O$, Fe_3O_4 and $FeCl_3$ were screened and the best result was obtained in the presence of $FeCl_3{\cdot}6H_2O$ (Table 1, entry 9) (Note the amount of H_2O added was tuned so that the total amount present was 8.0 equiv.) Finally, screening for the base showed that $NaHCO_3$ was most effective and product **3a** can be obtained in 92% yield (Table 1, entry 16).

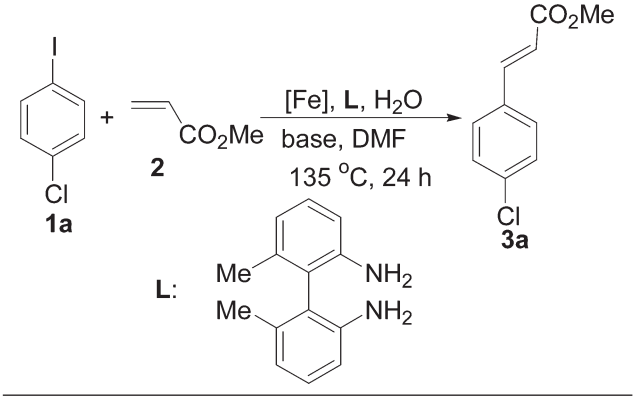
Therefore, the optimised reaction conditions were established as: using the combination of $FeCl_3{\cdot}6H_2O$ (10 mol%) and **L** (20 mol%) as the catalyst, $NaHCO_3$ (2.0 equiv.) as the base, DMF (1.0 mL) as the solvent in the presence of 7.4 equiv. H_2O at 135 °C for 24 h.[47]

To exclude the possibility that trace copper salts were effective in this reaction, copper powder (10 mol%) and copper compounds (10 mol%) – CuI, CuO, $CuCl_2{\cdot}2H_2O$, CuCl and CuBr were also investigated instead of $FeCl_3{\cdot}6H_2O$, and it was found that these showed no activity for the Mizoroki–Heck reaction of 1-chloro-4-iodobenzene **1a** with methyl acrylate **2**.

With the optimal reaction conditions in hand, we next explored the generality of the reaction with a set of aryl iodides. We were pleased to find out that all reactions proceeded smoothly to give the desired coupling products **3** in good to high yields (Table 2). It seems that substituents on the *ortho*-position on the phenyl ring of the iodides **1** have some effect on the reaction. For example, 2-iodotoluene **1e** and 1-bromo-2-iodobenzene **1h** only gave the corresponding products **3e** and **3h** in 53 and 60% yields, respectively (Table 2, entries 4 and 7). However, 2-methoxy group on the phenyl ring of iodide **1k** has less effect on the reaction and product **3k** was obtained in 85% yield (Table 2, entry 10).

In conclusion, we have found that 2,2′-diamino-6,6′-dimethylbiphenyl (**L**) is an efficient ligand in the $FeCl_3{\cdot}6H_2O$-catalysed Mizoroki–Heck reaction of aryl iodides with methyl

Table 1 Optimisation for the reaction of **1a** with **2**

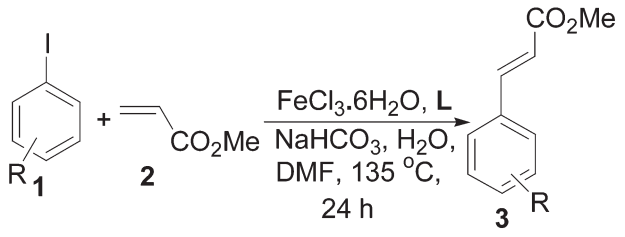


Entry[a]	H_2O (equiv)	[Fe]	Base	Yield/%[b]
1	—	Fe_2O_3	$KHCO_3$	—
2	1.2	Fe_2O_3	$KHCO_3$	—
3	2.0	Fe_2O_3	$KHCO_3$	trace
4	4.0	Fe_2O_3	$KHCO_3$	15
5	6.0	Fe_2O_3	$KHCO_3$	69
6	8.0	Fe_2O_3	$KHCO_3$	72
7	10.0	Fe_2O_3	$KHCO_3$	61
8	20.0	Fe_2O_3	$KHCO_3$	26
9	7.4	$FeCl_3{\cdot}6H_2O$	$KHCO_3$	90
10	7.6	$FeCl_2{\cdot}4H_2O$	$KHCO_3$	81
11	8.0	Fe_3O_4	$KHCO_3$	74
12	8.0	$FeCl_3$	$KHCO_3$	79
13	7.4	$FeCl_3{\cdot}6H_2O$	K_2CO_3	43
14	7.4	$FeCl_3{\cdot}6H_2O$	AcOK	72
15	7.4	$FeCl_3{\cdot}6H_2O$	Na_2CO_3	85
16	7.4	$FeCl_3{\cdot}6H_2O$	$NaHCO_3$	92

[a] All reactions were carried out using **1a** (0.5 mmol), **2** (0.6 mmol), [Fe] (10 mol%), **L** (20 mol%), base (2.0 equiv), DMF (1.0 mL), H_2O (3.7 mmol), 24 h.
[b] Isolated yields.

* Correspondent. E-mail: chenfancn@126.com

Table 2 Iron catalysed aryl iodides with methyl acrylate



Entry[a]	**1** (R)	Yield/%[b]
1	**1b** (4-MeO)	**3b**, 96
2	**1c** (H)	**3c**, 94
3	**1d** (4-Me)	**3d**, 97
4	**1e** (2-Me)	**3e**, 53
5	**1f** (3-Me)	**3f**, 92
6	**1g** (4-CO_2Et)	**3g**, 83
7	**1h** (2-Br)	**3h**, 60
8	**1i** (4-F)	**3i**, 81
9	**1j** (3,5-Me_2)	**3j**, 94
10	**1k** (2-MeO)	**3k**, 85
11	**1l** (4-Ac)	**3l**, 93

[a] All reactions were carried out using **1** (0.5 mmol), **2** (0.6 mmol), $FeCl_3{\cdot}6H_2O$ (10 mol %), **L** (20 mol %), $NaHCO_3$ (2.0 equiv), H_2O (7.4 equiv), DMF (1.0 mL) at 135 °C for 24 h.
[b] Isolated yields.

acrylate in DMF at 135 °C. Though the mechanism for this reaction is not clear at this stage, it was found that an appropriate amount of H_2O plays an important role in this reaction. Efforts are underway to elucidate the reaction mechanism and to find more applications for this catalytic system in organic synthesis.

Experimental

^{1}H and ^{13}C NMR spectra were recorded on a Bruker Avance-300 or 500 MHz spectrometer for solution in $CDCl_3$ with tetramethylsilane (TMS) as an internal standard; *J*-values are in Hz. Flash column chromatography was carried out using Huanghai 300–400 mesh silica gel at increased pressure.

Iron-catalysed Mizoroki–Heck reaction of aryl iodides with methyl acrylate; general procedure

Under a N_2 atmosphere, in a dry Schlenk tube were placed the corresponding iodide **1** (0.5 mmol), $FeCl_3{\cdot}6H_2O$ (10 mol%), $NaHCO_3$ (2.0 equiv.), **L** (20 mol%), degassed DMF (1.0 mL) and methyl acrylate **2** (0.6 mmol). Finally, H_2O (3.7 mmol) was added. Then, the septum was replaced by a sealed condenser pipe, and the reaction vessel was placed in an oil bath at 135 ^{0}C for 24 h. After cooling to room temperature, the mixture was diluted with ethyl acetate (20 mL), and washed with saturated brine (15 mL). The organic phase was then dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The residue was purified by flash chromatography on silica gel to give the pure products.

3-(4-Chlorophenyl)acrylic acid methyl ester (**3a**):[47] Rf = 0.6 (petroleum ether/ethyl acetate = 20:1, v/v). Chromatography solvent petroleum ether/ethyl acetate = 100/1. ^{1}H NMR (300 MHz, $CDCl_3$, TMS) δ 7.63 (d, *J* = 16.0 Hz, 1H), 7.44 (d, *J* = 8.5 Hz, 2H, Ar), 7.35 (d, *J* = 8.5 Hz, 2H, Ar), 6.40 (d, *J* = 16.0 Hz, 1H), 3.80 (s, 3H, OMe). ^{13}C NMR (75 MHz, $CDCl_3$) δ 167.1, 143.3, 136.1, 132.8, 129.2, 129.1, 118.3, 51.7.

3-(4-Methoxyphenyl)acrylic acid methyl ester (**3b**):[47] Rf = 0.4 (petroleum ether/ethyl acetate = 20:1, v/v). Chromatography solvent: petroleum ether/ethyl acetate = 50/1. ^{1}H NMR (300 MHz, $CDCl_3$, TMS) δ 7.65 (d, *J* = 16.0 Hz, 1H), 7.48 (d, *J* = 8.6 Hz, 2H, Ar), 6.90 (d, *J* = 8.6 Hz, 2H, Ar), 6.31 (d, *J* = 16.0 Hz, 1H), 3.83 (s, 3H, OMe), 3.79 (s, 3H, OMe). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.6, 161.3, 144.4, 129.6, 127.0, 115.2, 114.2, 55.3, 51.5.

3-Phenylacrylic acid methyl ester (**3c**):[47] Rf = 0.6 (petroleum ether/ethyl acetate = 20:1, v/v). Chromatography solvent: petroleum ether/ethyl acetate = 100/1. ^{1}H NMR (300 MHz, $CDCl_3$, TMS) δ 7.70 (d, *J* = 16.0 Hz, 1H), 7.54–7.51 (m, 2H, Ar), 7.39–7.37 (m, 3H, Ar), 6.45 (d, *J* = 16.0 Hz, 1H), 3.80 (s, 3H, OMe). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.3, 144.8, 134.3, 130.2, 128.8, 128.0, 117.8, 51.6.

3-(4-Methylphenyl)acrylic acid methyl ester (**3d**):[47] Rf = 0.6 (petroleum ether/ethyl acetate = 20:1, v/v). Chromatography solvent: petroleum ether/ethyl acetate = 100/1. ^{1}H NMR (300 MHz, $CDCl_3$, TMS) δ 7.66 (d, *J* = 16.0 Hz, 1H), 7.40 (d, *J* = 8.0 Hz, 2H, Ar), 7.17 (d, *J* = 8.0 Hz, 2H, Ar), 6.39 (d, *J* = 16.0 Hz, 1H), 3.79 (s, 3H, OMe), 2.35 (s, 3H, Me). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.5, 144.8, 140.59, 131.5, 129.5, 128.0, 116.5, 51.5, 21.3.

3-(2-methylphenyl)acrylic acid methyl ester (**3e**):[47] Rf = 0.6 (petroleum ether/ethyl acetate = 20:1, v/v). Chromatography solvent: petroleum ether/ethyl acetate = 100/1. ^{1}H NMR (300 MHz, $CDCl_3$, TMS) δ 7.98 (d, *J* = 15.9 Hz, 1H), 7.54 (d, *J* = 7.2 Hz, 1H, Ar), 7.30–7.18 (m, 3H, Ar), 6.36 (d, *J* = 15.9 Hz, 1H), 3.81 (s, 3H, OMe), 2.44 (s, 3H, Me). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.5, 142.5, 137.6, 133.3, 130.7, 130.0, 126.3, 126.3, 118.7, 51.7, 19.8.

3-(3-Methylphenyl)acrylic acid methyl ester (**3f**):[47] Rf = 0.6 (petroleum ether/ethyl acetate = 20:1, v/v). Chromatography solvent: petroleum ether/ethyl acetate = 100/1. ^{1}H NMR (300 MHz, $CDCl_3$, TMS) δ 7.66 (d, *J* = 16.0 Hz, 1H), 7.32–7.19 (m, 4H, Ar), 6.42 (d, *J* = 16.0 Hz, 1H), 3.79 (s, 3H, OMe), 2.36 (s, 3H, Me). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.4, 145.0, 138.4, 134.2, 131.1, 128.7, 128.6, 125.2, 117.4, 51.6, 21.2.

4-(2-Methoxycarbonylvinyl)benzoic acid ethyl ester (**3g**):[48] Rf = 0.4 (petroleum ether/ethyl acetate = 20:1, v/v). Chromatography solvent: petroleum ether/ethyl acetate = 50/1. ^{1}H NMR (300 MHz, $CDCl_3$, TMS) δ 8.05 (d, *J* = 8.3 Hz, 2H, Ar), 7.71 (d, *J* = 16.1 Hz, 1H), 7.58 (d, *J* = 8.3 Hz, 2H, Ar), 6.52 (d, *J* = 16.1 Hz, 1H), 4.39 (q, *J* = 7.1 Hz, 2H), 3.82 (s, 3H, OMe), 1.40 (t, *J* = 7.1 Hz, 3H, Me). ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.9, 165.9, 143.4, 138.4, 131.7, 130.0, 127.8, 120.0, 61.1, 51. 8, 14.2.

3-(2-Bromophenyl)acrylic acid methyl ester (**3h**):[49] Rf = 0.6 (petroleum ether/ethyl acetate = 20:1, v/v). Chromatography solvent: petroleum ether/ethyl acetate = 100/1. ^{1}H NMR (300 MHz, $CDCl_3$, TMS) δ 8.05 (d, *J* = 16.0 Hz, 1H), 7.62–7.58 (m, 2H, Ar), 7.32–7.22 (m, 2H, Ar), 6.39 (d, *J* = 16.0 Hz, 1H), 3.82 (s, 3H, OMe). ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.74, 143.10, 134.39, 133.36, 131.15, 127.69, 127.65, 125.25, 120.59, 51.79.

3-(4-Fluorophenyl)acrylic acid methyl ester (**3i**):[48] Rf = 0.6 (petroleum ether/ethyl acetate = 20:1, v/v). Chromatography solvent: petroleum ether/ethyl acetate = 100/1. ^{1}H NMR (300 MHz, $CDCl_3$, TMS) δ 7.66 (d, *J* = 16.0 Hz, 1H), 7.54–7.49 (m, 2H, Ar), 7.08 (t, *J* = 8.6 Hz, 2H, Ar), 6.37 (d, *J* = 16.0 Hz, 1H), 3.81 (s, 3H, OMe). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.2, 163.9 (d, $J_{C\text{-}F}$ = 249.8 Hz), 143.5, 130.6 (d, $J_{C\text{-}F}$ = 3.3 Hz), 129.9 (d, $J_{C\text{-}F}$ = 8.4 Hz), 117.5 (d, $J_{C\text{-}F}$ = 2.3 Hz), 116.0 (d, $J_{C\text{-}F}$ = 21.8 Hz), 51.7.

3-(3,5-Dimethylphenyl)acrylic acid methyl ester (**3j**):[48] Rf = 0.6 (petroleum ether/ethyl acetate = 20:1, v/v). Chromatography solvent: petroleum ether/ethyl acetate = 100/1. ^{1}H NMR (300 MHz, $CDCl_3$, TMS) δ 7.64 (d, *J* = 16.0 Hz, 1H), 7.14 (s, 2H, Ar), 7.02 (s, 1H, Ar), 6.41 (d, *J* = 16.0 Hz, 1H), 3.79 (s, 3H, OMe), 2.32 (s, 6H, 2Me). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.5, 145.2, 138.3, 134.3, 132.0, 125.9, 117.3, 51.6, 21.1.

3-(2-Methoxyphenyl)acrylic acid methyl ester (**3k**):[50] Rf = 0.4 (petroleum ether/ethyl acetate = 20:1, v/v). Chromatography solvent: petroleum ether/ethyl acetate = 50/1. ^{1}H NMR (300 MHz, $CDCl_3$, TMS) δ 8.01 (d, *J* = 16.2 Hz, 1H), 7.52–7.49 (m, 1H, Ar), 7.37–7.32 (m, 1H, Ar), 6.98–6.89 (m, 2H, Ar), 6.53 (d, *J* = 16.2 Hz, 1H), 3.87 (s, 3H, OMe), 3.80 (s, 3H, OMe). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.8, 158.3, 140.2, 131.41, 128.82, 123.3, 120.6, 118.2, 111.1, 55.4, 51.5.

3-(4-Acetylphenyl)acrylic acid methyl ester (**3l**):[48] Rf = 0.2 (petroleum ether/ethyl acetate = 20:1, v/v). Chromatography solvent: petroleum ether/ethyl acetate = 30/1. ^{1}H NMR (300 MHz, $CDCl_3$, TMS) δ 7.98 (d, *J* = 8.3 Hz, 2H, Ar), 7.72 (d, *J* = 16.1 Hz, 1H), 7.61 (d, *J* = 8.3 Hz, 2H, Ar), 6.54 (d, *J* = 16.1 Hz, 1H), 3.83 (s, 3H, OMe), 2.63 (s, 3H, Me). ^{13}C NMR (125 MHz, $CDCl_3$) δ 197.2, 166.9, 143.3, 138.7, 138.0, 128.82, 128.1, 120.3, 51.9, 26.6.

Financial support from the Science and Technology Department of Zhejiang Province is greatly acknowledged.

Received 18 September 2010; accepted 21 October 2010
Paper 1000361 doi: 10.3184/030823410X12906997367352
Published online: 23 December 2010

References

1 B.M. Trost, *Science*, 1991, **234**, 1471.
2 J. Tsuji, *Palladium reagents and catalysis: innovations in organic synthesis;* Wiley: New York, 1995.
3 E. Negishi and A. de Meijere (eds), *Handbook of organopalladium chemistry for organic synthesis,* John Wiley & Sons, New York, 2002.
4 R.F. Heck, *J. Am. Chem. Soc.*, 1968, **90**, 5518.
5 A. de Meijere and F.E. Meyer, *Angew. Chem. Int. Ed. Engl.*, 1994, **33**, 2379.
6 W. Cabri and I. Candiani, *Acc. Chem. Res.*, 1995, **28**, 2.
7 G.T. Crisp, *Chem. Soc. Rev.*, 1998, **27**, 427.
8 J.P. Genet and M. Savignac, *J. Organomet. Chem.*, 1999, **576**, 305.
9 I.P. Beletskaya and A.V. Cheprakov, *Chem. Rev.*, 2000, **100**, 3009.
10 C. Amatore and A. Jutand, *J. Organomet. Chem.*, 1999, **576**, 254.
11 U. Christmann and R. Vilar, *Angew. Chem. Int. Ed.*, 2005, **44**, 366.
12 A. Zapf and M. Beller, *Chem. Commun.*, 2005, 431.
13 S. Dez-González and S.P. Nolan, *Top. Organomet. Chem.*, 2007, **21**, 47.
14 M. Beller and C. Bolm, *Transition metals for organic synthesis*, 2nd edn, Wiley: New York, 2004, pp. 271.
15 S. Oi, K. Sakai and Y. Inoue, *Org. Lett.*, 2005, **7**, 4009.
16 J. Yorke, L. Wan, A. Xia and W. Zheng, *Tetrahedron Lett.*, 2007, **48**, 8843.
17 K. Inamoto, J.I. Kuroda, K. Hiroya, Y. Noda, M. Watanabe and T. Sakamoto, *Organometallics*, 2006, **25**, 3095.
18 H. Yorimitsu and K. Oshima, *Pure Appl. Chem.*, 2006, **78**, 441.
19 P. Zhou, Y.G. Li, P.P. Sun, J.H. Zhou and J.C. Bao, *Chem. Commun.*, 2007, 1418.
20 V. Calò, A. Nacci, A. Monopoli, E. Leva and N. Cioffi, *Org. Lett.*, 2005, **7**, 617.
21 V. Declerck, J. Martinez and F. Lamaty, *Synlett*, 2006, 3029.
22 X. Cui, J. Li, Z.-P. Zhang, Y. Fu, L. Liu and Q.-X. Guo, *J. Org. Chem.*, 2007, **72**, 9342.
23 X.M. Zhang, Z.X. Xi, A.L. Liu and W.Z. Chen, *Organometallics*, 2008, **27**, 4401.
24 V. Monyoya, J. Pons, V. Branchadell, J. Garcia-Antón, X. Solans, M. Font-Bardia and J. Ros, *Organometallics*, 2008, **27**, 1084.
25 Y.Q. Cai, Y. Lu, M.Y. He and Q.X. Wan, *Catal. Commun.*, 2008, **9**, 1209.
26 A. Fürstner and R. Martin, *Chem. Lett.*, 2005, **34**, 624.
27 C. Bolm, J. Legros, J. Le Paih and L. Zani, *Chem. Rev.*, 2004, **104**, 6217.
28 B.D. Sherry and A. Fürstner, *Acc. Chem. Res.*, 2008, **41**, 1500.
29 A. Correa, O. García Mancheño and C. Bolm, *Chem. Soc. Rev.*, 2008, **37**, 1108.
30 S. Enthaler, K. Junge and M. Beller, *Angew. Chem. Int. Ed.*, 2008, **47**, 3317.
31 O. Garcia Mancheno and C. Bolm, *Iron catalysis in organic chemistry*; ed. B. Plietker, Wiley-VCH: New York, 2008, p.109.
32 A.A.O. Sarhan and C. Bolm, *Chem. Soc. Rev.*, 2009, **38**, 2730.
33 C. Bolm, *Nat. Chem.*, 2009, **1**, 420.
34 K.M. Driller, H. Klein, R. Jackstell and M. Beller, *Angew. Chem. Int. Ed.*, 2009, **48**, 6041.
35 A. Fürstner, *Angew. Chem. Int. Ed.*, 2009, **48**, 1364.
36 J.C. Mao, G.L. Xie, J.M. Zhan, Q.Q. Hua and D.Q. Shi, *Adv. Synth. Catal.*, 2009, **351**, 1268.
37 X. Xie, X.B. Xu, H.F. Li, X.L. Xu, J.Y. Yang and Y.Z. Li, *Adv. Synth. Catal.*, 2009, **351**, 1263.
38 Y.C. Teo, *Adv. Synth. Catal.*, 2009, **351**, 720.
39 W. Liu, H. Cao and A.W. Lei, *Angew. Chem., Int. Ed.*, 2010, **49**, 2004.
40 T. Hata, R. Bannai, M. Otsuki and H. Urabe, *Org. Lett.*, 2010, **12**, 1012.
41 S. Maiti, S. Biswas and U. Jana, *J. Org. Chem.*, 2010, **75**, 1674.
42 T. Hatakeyama, N. Nakagawa and M. Nakamura, *Org. Lett.*, 2009, **11**, 4496.
43 Y.-Z. Li, B.-J. Li, X.-Y. Lu, S. Lin and Z.-J. Shi, *Angew. Chem. Int. Ed.*, 2009, **48**, 3817.
44 J.-M. Lu, H. Ma, S.-S. Li, D. Ma and L.-X. Shao, *Tetrahedron*, 2010, **66**, 5185.
45 Y.-M. Ye, B.-B. Wang, D. Ma, L.-X. Shao and J.-M. Lu, *Cat. Lett.*, 2010, DOI: 10.1007/s10562-010-0418-9.
46 R. Loska, C.M. Rao Volla and P. Vogel, *Adv. Synth. Catal.*, 2008, **350**, 2859.
47 J.W. Ruan, X.M. Li, O. Saidi and J.L. Xiao, *J. Am. Chem. Soc.*, 2008, **130**, 2424.
48 C.F. Yao, H.G. Li, H.H. Wu, Y.M. Liu and P. Wu, *Catal. Commun.*, 2009, **10**, 1099.
49 F.X. Felpin, E. Fouquet and C. Zakri, *Adv. Synth. Catal.*, 2008, **350**, 2559.
50 A. El-Batta, C.C. Jiang, W. Zhao, R. Anness, A.L. Cooksy and M. Bergdahl, *J. Org. Chem.*, 2007, **72**, 5244.