Catalysis Communications 29 (2012) 194–197

Contents lists available at SciVerse ScienceDirect

Catalysis Communications

journal homepage: www.elsevier.com/locate/catcom

Short Communication

$PdCl_2$-2,6-bis(1,5-diphenyl-1H-pyrazol-3-yl)pyridine catalyzed Suzuki–Miyaura cross-coupling

Qin Yang [a], Lei Wang [b], Lei Lei [a], Xue-Li Zheng [a], Hai-yan Fu [a], Mao-lin Yuan [a], Hua Chen [a], Rui-Xiang Li [a,*]

[a] Key Laboratory of Green Chemistry and Technology, Ministry of Education, College of Chemistry, Sichuan University, Chengdu, Sichuan 610064, PR China
[b] College of Chemistry and Chemical Engineering, Xuchang University, Xuchang, Henan 461000, PR China

ARTICLE INFO

Article history:
Received 11 September 2012
Received in revised form 8 October 2012
Accepted 16 October 2012
Available online 23 October 2012

Keywords:
Suzuki reactions
Palladium
Nitrogen ligand

ABSTRACT

Six multidentate nitrogen ligands, 2,6-bis(1,5-diphenyl-1H-pyrazol-3-yl)pyridine (L1), 2,6-bis(1-methyl-5-phenyl-1H-pyrazol-3-yl)pyridine (L2), 2,6-bis(1,5-dimethyl-1H-pyrazol-3-yl)pyridine (L3), 2,6-bis(5-phenyl-1H-pyrazol-3-yl)pyridine (L4), 2,6-bis(1-p-triflurophenyl-5-phenyl-1H-pyrazol-3-yl)pyridine (L5), and 2,6-bis(1-*m*-methylphenyl-5-phenyl-1H-pyrazol-3-yl)pyridine (L6) were synthesized and characterized. Their palladium complexes catalyzed Suzuki–Miyaura cross-coupling revealed that the catalytic activities of these complexes were in the order of $PdCl_2$-L5 > $PdCl_2$-L1 > $PdCl_2$-L6 > $PdCl_2$-L2 > $PdCl_2$-L3 > $PdCl_2$-L4. With a low Pd loading of 10^{-5} mol%, $PdCl_2$-L1 showed a high activity. The turnover numbers (TONs) were up to 58,000,000 for 4-bromobenzotrifluoride.

1. Introduction

The Suzuki–Miyaura cross-coupling is an extremely efficient method for carbon–carbon bond formation [1–3]. Recently, multidentate nitrogen ligands, which are easy to be synthesized, have been successfully employed in this reaction [4–11] as the appropriate electron-donating ability of nitrogen atoms in them facilitates the oxidative addition of substrates [12–14]. However their activities were generally lower than the phosphine analogues and a high catalyst loading had to be required. In fact, lots of researches also revealed that the real active species was the Pd nanoparticles in Pd catalyzed cross-coupling and various kinds of ligands played the role of stabilizing the nanoparticles in the reaction systems [15–17]. No matter what the species are, Pd complexes or nanoparticles, multidentate ligands are much more efficient in stabilizing the active Pd species than the monodentate and bidentate ligands. For example, the Pd system with the tetradentate phosphine Tedicyp showed much higher efficiency than the monophosphine or biphosphine [18]. Similarly, the tridentate azetidine [11] and tetradentate N,O ligand [7] gave higher TONs than other nitrogen-based ligands. Herein, we designed a family of multidentate N-donor ligands and employed them in a Suzuki–Miyaura reaction. Their combination with $PdCl_2$ showed high activities in the Suzuki reactions.

2. Experiment section

2.1. General information

All the chemicals received from commercial suppliers were used without further purifications unless noted. ^1H and ^{13}C NMR spectra were recorded using a 400 MHz spectrometer using TMS as the internal standard. A GC equipped with an FID detector and a 30 m × 0.32 mm × 0.25 μm SE-30 column was used to detect the reactions. Mass spectrometry was performed on a *TOF* mass analyzer using electrospray ionization (ESI) mode. Single crystal X-ray diffraction was carried at 293.15 K.

2.2. General procedure for the Suzuki reaction

Phenylbornic acid (183 mg, 1.5 mmol), KOH (84, 1.5 mmol) and aryl halides (1 mmol) were added into the reaction tube with a magnetic bar, and then dissolved in ethanol (3 mL). The EtOH solution of the desired amount of catalyst ($PdCl_2$: ligand = 1:1.2), which was formed in situ at 50 °C for 0.5 h, was injected into the reaction mixture with a syringe. After the resulting solution was stirred for the required time, it was cooled to room temperature, quenched by 3 mL water, and extracted with ethyl acetate (3 × 5 mL). The organic layer was collected and dried over $MgSO_4$. The crude products were purified by column chromatography (petroleum ether, ethyl acetate or hexane) on silica gel.

2.3. Synthesis of ligands

L1 and L4 were synthesized by the reported method [19,20]. L2, L3, L5 and L6 were synthesized by a procedure similar to that of L1.

* Corresponding author. Tel./fax: +86 28 85412904.
E-mail address: liruixiang@scu.edu.cn (R.-X. Li).

1566-7367/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.catcom.2012.10.009

To get L3, 1,1-′(pyridine-2,6-diyl)bis(butane-1,3-dione) (123 mg, 0.5 mmol) which was prepared in the reported method was dissolved in acetic acid (5 mL) in a two-necked round bottom flask. Then a 10 mL acetic acid solution of methyl hydrazine was slowly added into the solution through a funnel at room temperature. The mixture was then heated to 60 °C and stirred overnight, then cooled. A sodium carbonate solution was slowly added into the cooled solution to adjust it to neutral pH and then some white crystals were formed. The crystals were filtered, washed with water, and dried under vacuum to give L3 as white solid. Isolated yield: 53% (141 mg). Mp: 208–209 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.74 (d, J = 7.8 Hz, 2H, pyridine), 7.68–7.55 (m, 1H, pyridine), 6.75 (s, 2H, pyrazole), 3.78 (s, 6H, N-CH_3), 2.26 (s, 6H, C-CH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ 11.2 (CH_3), 36.3 (N-CH_3), 104.3 (3-pyrazole), 117.9 (3-pyridine), 136.8 (2-pyrazole), 139.7 (4-pyridine), 150.6 (4-pyrazole), 151.9 (2-pyridine). HRMS-ESI. calcd. for $C_{15}H_{18}N_5$ $(M+H)^+$ = 268.1562, found 268.1564.

For L2, L5, and L6, methylhydrazine, 4-(trifluoromethyl) phenylhydrazine and 3-(methylphenyl)hydrazinethe are treated with 3,3′-(pyridine-2,6-diyl)bis-(1-phenylpropane-1,3-dione), respectively, under similar conditions. L5 (yield of 26%): white solid. Mp: 254–256 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.15 (d, J = 8.0 Hz, 2H, pyridine), 7.92 (t, J = 7.4 Hz, 1H, pyridine), 7.63 (d, J = 8.0 Hz, 4H, phenyl), 7.58–7.44 (m, 6H, phenyl), 7.36 (d, J = 11.2 Hz, 10H, phenyl). ^{13}C NMR (100 MHz, $CDCl_3$): δ 153.2 (2-pyridine), 151.3 (3-pyrazole), 144.8 (5-pyrazole), 142.9 (4-pyridine), 137.4 (phenyl), 130.3 (phenyl), 129.1 (phenyl), 128.9 (phenyl), 128.8 (phenyl), 126.1 (phenyl), 126.1 (phenyl), 125.2 (phenyl), 124.98 (phenyl), 122.5 (3-pyridine), 108.0 (4-pyrazole). HRMS-ESI. calcd. for $C_{37}H_{24}F_6N_5$ $(M+H)^+$ = 652.1936, found 652.1953.

L6 (yield of 17%): white solid. Mp: 189–192 °C. ^{1}H NMR (400 MHz, CDCl3) δ 8.01 (d, J = 7.8 Hz, 2H,3-pyridine), 7.74 (t, J = 7.8 Hz, 1H, 2-pyridine), 7.26 (d, J = 6.8 Hz, 13H, phenyl), 7.14 (t, J = 7.7 Hz, 3H, phenyl), 7.07 (d, J = 7.5 Hz, 2H, phenyl), 7.00 (d, J = 7.8 Hz, 2H, 4-pyrazole), 2.29 (s, 6H,-CH_3). ^{13}C NMR (100 MHz, $CDCl_3$): δ 144.5 (2-pyridine), 140.1 (3-pyrazole), 139.1 (5-pyrazole), 130.7 (4-pyridine), 128.8 (phenyl), 128.6 (phenyl), 128.4 (phenyl), 128.2 (phenyl), 126.0 (phenyl), 122.6 (phenyl), 119.1 (phenyl), 106.9 (4-pyrazole), 21.3 (−CH_3). HRMS-ESI. calcd. for $C_{37}H_{29}N_5$ $(M+H)^+$ = 544.2510, found 544.2537.

L2 (yield of 67%). Mp: 216–218 °C. ^{1}H NMR (400 MHz, CDCl3) δ 7.94 (d, J = 7.8 Hz, 2H, 3-pyridine), 7.80 (t, J = 7.8 Hz, 1H, 4-pyridine), 7.60–7.34 (m, 10H, phenyl), 7.14 (s, 2H, pyrazole), 3.98 (s, 6H, N-CH_3); ^{13}C NMR (100 MHz, CDCl3) δ 37.8(−CH_3), 105.2 (4-pyrazole), 118.4 (3-pyridine), 128.5 (3-pyridine), 128.7 (phenyl), 128.8 (phenyl), 130.7 (phenyl), 137.1 (4-pyridine), 145.1 (5-pyrazole), 151.0 (3-pyrazole), 151.8 (2-pyridine). HRMS-ESI. calcd. for $C_{25}H_{22}N_5$ $(M+H)^+$ = 392.1875, found 392.1879. The structure of L2 was further identified by its single crystal structure. The single crystal was obtained by evaporation of a $CDCl_3$ solvent. The exact structure was shown in Fig. 1.

3. Result and discussion

It is well known that a ligand plays an important role in modifying the efficiency of a catalyst in a homogeneous catalysis [8]. With the six ligands in hand, the effects of the ligand structures and reaction conditions on the Suzuki–Miyaura coupling were investigated in detail.

We chose the coupling of phenylboronic acid and 4-bromoanisole as the model reaction. The effect of solvents on the reaction was firstly investigated at a low reaction temperature of 50 °C with L1 as the model ligand and KOH as the base (Table 1, entries 1–6). The reaction gave the highest yield in ethanol. The other solvents, whether they are protonic or aprotic solvents, gave lower yields. Subsequently, the effect of bases on the reaction was explored. The organic base and the weak inorganic base $NaHCO_3$ were less efficient for the reaction. By increasing the basicity of the bases, the conversion of the substrate was improved. The strong base KOH gave the highest conversion (Table 1, entries 7–10). Even if performed at room temperature, the reaction could proceed smoothly and give a yield of 58% in half an hour, which is higher than most of the N-donor catalyst systems at room temperature [7,16,21,22]. If the reaction temperature was elevated to 70 °C, the desired product can be obtained with a quantitative yield in 0.5 h. In order to shorten the reaction time in the high ratio of substrate to catalyst, 70 °C was chosen as the reaction temperature in the following reactions. KOH and ethanol were used as the optimum base and solvent, respectively.

To detect the effect of ligand structures on the reaction, the six ligands were screened under the optimum conditions. The result was shown in Scheme 1. Obviously, the existence of a phenyl ring, whenever it was on a nitrogen or carbon atom, was more favorable to improve the catalyst activity than the ligand with the methyl group. However, L3 and L4 gave unsatisfactory yields. It is supposed that methyl as an electron-donating substituent on the pyrazole resulted in the relatively low efficiency of L3. The hydrogen atom on the

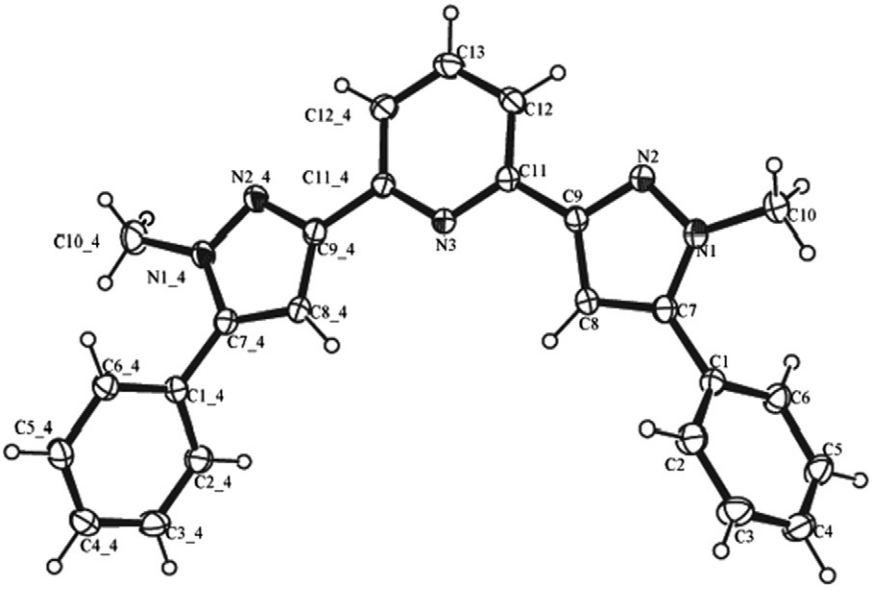
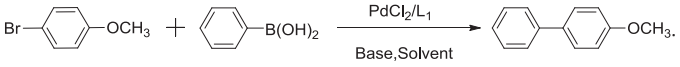


Fig. 1. ORTEP view of the molecular structure of L2.

Table 1
The effect of the base and solvent on the Suzuki–Miyaura reaction



Entry	Base	Temperature (°C)	Solvent	Yield (%)
1	KOH	50	EtOH	90
2	KOH	50	MeOH	80
3	KOH	50	i-PrOH	63
4	KOH	50	Dioxane	TRACE
5	KOH	50	DMF	TRACE
6	KOH	50	Toluene	25
7	K_2CO_3	50	EtOH	58
8	$NaHCO_3$	50	EtOH	13
9	Et_3N	50	EtOH	27
10	Pyridine	50	EtOH	Trace
11	KOH	25	EtOH	58
12	KOH	70	EtOH	100

Reaction conditions: 4-bromoanisole (1 mmol), phenylboronic acid (1.5 mmol), KOH (1.5 mmol), EtOH (3 mL), $PdCl_2$ (10^{-4} mmol), L1 (1.2×10^{-4} mmol), 0.5 h, GC yield.

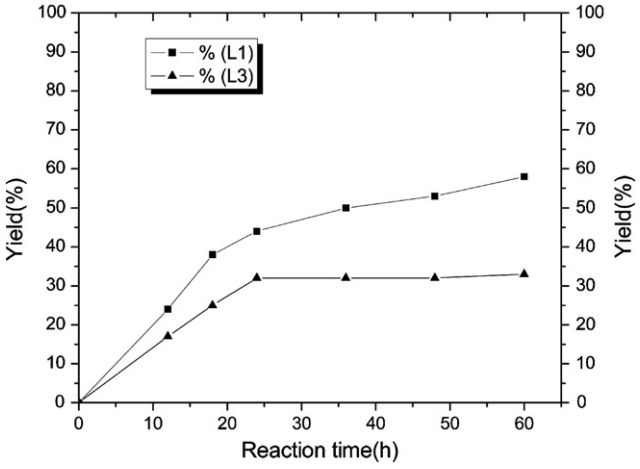
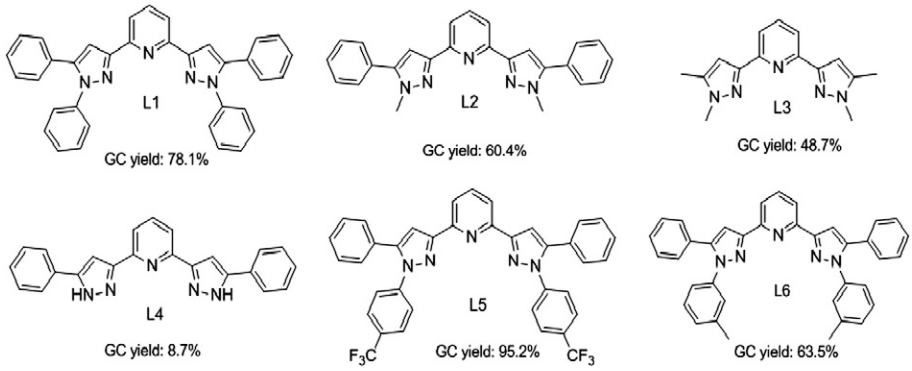


Fig. 2. The yield vs. time.

nitrogen atom of the pyrazole ring (L4) could be dissociated under the reaction condition, so L4 was transformed into an anion with a high electron density. These results indicated that methyl substituted N and high electron density in the pyrazole ring leads to the low activity of the Pd species and the conjugation between the N atom and the phenyl ring may cause the electron delocalization, which could promote the activity of the Pd species. It is well known that a bulky substituent near a coordinate atom would facilitate the reductive elimination in the catalytic cycle and the strong basicity of the coordination atom is favorable to stabilize active species and improve the catalyst activity. In this system, the conjugation structure of ligands, which may cause the electron delocalization, seemed to facilitate the active Pd species in the catalytic cycle. In order to support the suggestion, L5 with an electron-drawing substituent in the phenyl ring and L6 with an electron-donating substituent in the same phenyl ring were synthesized. It was found that the introduction of the trifluoromethyl group on the phenyl ring resulted in the increase of the yield from 78.1% to 95.2%, while the introduction of the methyl group caused the yield to decrease from 78.1% to 65.5%. The results further supported that the weak basicity of the nitrogen atom and electron delocalization were favorable in this system.

To clarify whether the weak basicity of the nitrogen atom, which is caused by electron delocalization, will promote the catalyst activity or extend the lifetime of Pd species in the catalyst system, the relationship between conversion and time (L1 and L3 as ligands) were investigated and shown in Fig. 2. The curves showed that the activity of the Pd species was dramatically decreased with the existence of the methyl group (L3) and the yield was near 32% after 24 h, while the catalytic activity with L1 as ligand can last up to 60 h in the existence of the phenyl group. It could be seen that the electron delocalization improved both the activity and lifetime of the active species. It may be due to the possibility that the electron delocalization of a ligand can keep the stability of a low-valence complex [23,24].

Owing to the low cost of the starting materials and easy synthesis of L1, we continued to use L1 as the ligand in the following research. The coupling results of various aryl halides were shown in Table 2. When the loading of Pd was 10^{-3} mol%, both the electron-deficient and electron-rich aryl bromides gave the desired products in excellent yields in 2 h (Table 2, entries 1–5). In particular, the electron-deficient aryl bromides formed the corresponding biphenyl derivatives in almost quantitative yields. Accordingly, trifluoromethyl substituted aryl bromides were selected to react with phenylboronic acid in a lower catalyst loading of 10^{-4} mol%. 3-Bromobenzotrifluoride and 4-bromobenzotrifluoride also gave products in high yields of 86% (Table 2, entry 10) and 83% (Table 2, entry 6) in 20 h, respectively. When it was performed at room temperature, 4-bromobenzotrifluoride could still give a moderate yield of 75% (Table 2, entry 8). It is identified that this catalytic system was highly efficient even at room temperature. However, it seemed that the hindrance of ortho-substitutions retarded the reaction process. When the methyl group or methoxyl group was introduced in the ortho-position of bromine, the reaction rate obviously slowed down. The loading of $PdCl_2$ had to be increased to 0.05 mol% and the reaction time had to be prolonged to 20 h, and good conversion of ortho-substituted aryl halides could be obtained (Table 2, entries 12–13). The results are similar to the reported nitrogen-based catalyst systems [6,9]. However, it has been reported that heteroaromatic compounds were the deactivated substrates due to their strong coordination ability, which can poison the catalyst [25]. A high catalyst loading (>0.1 mol%) was necessary for most of the phosphine-free catalyst systems [4,7,26,27]. In this case, for



Scheme 1. The effect of the ligands for the Suzuki reaction.

Table 2
Suzuki coupling of a variety aryl halides[a].

Entry	Substrate	S/C	t (h)	Yield (%)	Entry	Substrate	S/C	t (h)	Yield(%)
1	4-Bromoanisole	10^5	2	84 (**1a**)	10	3-Bromobenzotrifluoride	10^6	20	86 (**8a**)
2	4-Bromotoluene	10^5	2	95 (**2a**)	11	3-Bromoanisole	10^5	2	93 (**9a**)
3	4-Bromobenzaldehyde	10^5	2	96 (**3a**)	12	2-Bromotoluene	2000	20	98 (**10a**)
4	4-Bromonitrobenzene	10^5	2	97 (**4a**)	13	2-Bromoanisole	2000	20	83 (**11a**)
5	4-Bromobenzonitrile	10^5	2	78 (**5a**)	14	3-Bromopyridine	10^4	2	80 (**12a**)
6	4-Bromobenzotrifluoride	10^6	20	83 (**6a**)	15	3-Bromoquinoline	10^5	20	86 (**13a**)
7	4-Bromobenzotrifluoride	10^7	120	86 (**6a**)	16	4-Chloronitrobenzene	200	20	81[c] (**4a**)
8	4-Bromobenzotrifluoride	10^5	12	75[b] (**6a**)	17	4-Chlorobenzotrifluoride	200	20	80[c] (**6a**)
9	4-Bromoacetophenone	10^5	2	92 (**7a**)	18	4-Chloroacetophenone	200	20	81[c] (**7a**)

[a] Reaction conditions: $PdCl_2$/L1 as catalyst, aryl halide (1 mmol), phenylboronic acid (1.5 mmol), KOH (1.5 mmol), EtOH (3 mL), reaction temperature was 70 °C, isolated yield of two runs.
[b] At room temperature.
[c] 100 °C in DMF.

3-bromoquinoline, a moderate satisfactory yield of 63% could be achieved with a low Pd loading of 0.001 mol% in 2 h and the yield could increase to 86% if the reaction time was prolonged to 20 h. But for 3-bromopyridine, a poor yield of 25% was given in 2 h. By increasing $PdCl_2$ loading to 0.01 mol%, the yield was up to 80% in 2 h (Table 2, entries 14–15). As it is well known the Suzuki cross-coupling of aryl chlorides is not as easy as aryl bromides. Generally, the high catalyst loading and harsh conditions are required in order to get their corresponding coupling products [12,28]. After the reaction temperature was elevated to 100 °C, the catalytic system could catalyze the coupling of electron-deficient aryl chlorides and phenylboronic acid and gave the satisfactory yields in the presence of 0.5 mol% catalyst (Table 2, entries 16–18). It just paralleled to the reported phosphine-free catalytic systems for the Suzuki coupling of aryl chlorides [6,7,9,29]. Encouraged by the high efficiency of this optimal catalytic system, the ratio of $PdCl_2$ to the substrate was decreased to 10^{-7} mol%, and the couplings of phenylboronic acid and 4-trifluoromethyl bromobenzene were further tested. As shown in Table 2, entry 7, it afforded the corresponding substituted biphenyl in the yield of 86% and the TON is high at up to 8,600,000 and when the catalyst loading was decreased to 10^{-8} mol%, a high TON of up to 58,000,000 was obtained. This result demonstrated that the catalyst system is not only of a high activity, but also has a long lifetime. To our best knowledge, although it was not as efficient as the tetradentate phosphines Tedicyp [30] and a-Cytep [31], the $PdCl_2$/L1 system provided the highest TON in a Pd catalyzed Suzuki–Miyaura reaction with multidentate nitrogen ligands [32], for the reported highest TON was only up to 548,400 [7].

4. Conclusion

A family of polydentate nitrogen ligands with different substituents was synthesized and identified. The complexes generated by combining ligand L1 or L5 with $PdCl_2$ in situ were proved to be highly efficient for the Suzuki reactions of various aryl halides under aerobic conditions. Specially, $PdCl_2$/L1 could give a conversion of 58% even if the loading of Pd was as low as 10^{-8} mol%. We supposed that the high TON may be attributed to the long lifetime of the Pd species in the system.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (no. 21202104), and National Science Talents Fund for Research Training and Research Ability Improvement Project (j1103015).

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.catcom.2012.10.009.

References

[1] N. Miyuara, K. Yamada, A. Suzuki, Tetrahedron Letters 36 (1979) 3437.
[2] N. Miyuara, A. Suzuki, Chemical Reviews 95 (1995) 2457.
[3] A.M. Trzeciak, J.J. Ziółkowski, Coordination Chemistry Reviews 251 (2007) 1281.
[4] J.H. Li, Q.M. Zhu, Y.X. Xie, Tetrahedron 62 (2006) 10888.
[5] F. Amoroso, S. Colussi, A. Del Zotto, J. Llorca, A. Trovarelli, Catalysis Communications 12 (2011) 563.
[6] B. Puget, J.P. Roblin, D. Prim, Y. Troin, Tetrahedron Letters 49 (2008) 1706.
[7] S. Mohanty, D. Suresh, M.S. Balakrishna, J.T. Mague, Journal of Organometallic Chemistry 694 (2009) 2114.
[8] C. Nájera, J. Gil-Mono, S. Karlstrum, L.R. Falvello, Organic Letters 5 (2003) 1451.
[9] D.H. Lee, Y.H. Lee, Y. Kim, Tetrahedron 64 (2008) 7178.
[10] Y.W. Zhu, W.B. Yi, Ch Cai, Catalysis Communications 15 (2011) 118.
[11] G.A. Grasa, A.C. Hillier, S.P. Nolan, Organic Letters 3 (2001) 1077.
[12] C. Tang, F.F. Liu, D.S. Shen, T. Cheng, Z.Z. Zhou, Catalysis Letters 141 (2011) 1332.
[13] J.H. Li, W.J. Liu, Organic Letters 6 (2004) 2809.
[14] N. Marion, S.P. Nolan, Accounts of Chemical Research 41 (2008) 1440.
[15] T. Borkowski, A.M. Trzeciak, W. Bukowski, A. Bukowska, W. Tylus, L. Kępiński, Applied Catalysis A: General 378 (2010) 83.
[16] B. Tao, D.W. Boykin, Journal of Organic Chemistry 69 (2004) 4330.
[17] M.T. Reetz, E. Westermann, Angewandte Chemie International Edition 39 (2000) 165.
[18] J.C. Hierso, M. Beaupérin, P. Meunier, European Journal of Inorganic Chemistry 24 (2007) 3767.
[19] L. Wang, Q. Yang, H. Chen, R.X. Li, Inorganic Chemistry Communications 14 (2011) 1884.
[20] L. Wang, H.R. Pan, Q. Yang, H.Y. Fu, R.X. Li, Inorganic Chemistry Communications 14 (2011) 1422.
[21] F.W. Li, T.S.A. Hor, Advanced Synthesis and Catalysis 350 (2008) 2391.
[22] S. Li, Y. Lin, H. Xie, S. Zhang, J. Xu, Journal of Organic Chemistry 72 (2007) 4067.
[23] J.L. Boyer, J. Rochford, M.K. Tsai, J.T. Muckerman, E. Fujita, Coordination Chemistry Reviews 245 (2010) 309.
[24] M. Gallagher, N.L. Wieder, V.K. Dioumaev, P.J. Carroll, D.H. Berry, Organometallics 29 (2010) 591.
[25] O. Navarro, N. Marin, J.G. Mei, P. Nolan, Chemistry — A European Journal 12 (2006) 5142.
[26] S.R. Borhade, S.B. Waghmode, Tetrahedron Letters 49 (2008) 3423.
[27] A. Fihri, D. Luart, C. Len, A. Solhy, C. Chevrin, V. Polshettiwar, Dalton Transactions 40 (2011) 3116.
[28] N. Ochi, Y. Nakao, H. Sato, Y. Matano, H. Imahori, S. Sakaki, Journal of the American Chemical Society 131 (2009) 10955.
[29] C. Nájera, J. Gil-Moltó, S. Karlström, Advanced Synthesis and Catalysis 346 (2004) 1798.
[30] H. Doucet, M. Santelli, Synlett 13 (2006) 2001.
[31] E. Zaborova, J. Deschamp, D. Madec, Chemical Communications 47 (2011) 9206.
[32] V. Farina, Advanced Synthesis and Catalysis 346 (2004) 1553.