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Priority Communication

N-heterocyclic carbenes: novel ruthenium–alkylidene complexes

Thomas Weskamp, Florian J. Kohl, Wolfgang A. Herrmann *

Anorganisch-chemisches Institut der Technischen Universität München, Lichtenbergstaße 4, D-85747 Garching, Germany

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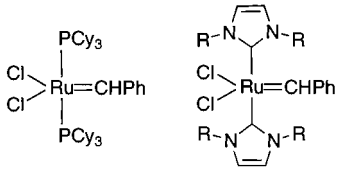
Abstract

Ruthenium-based catalysts for olefin metathesis have attained enormous attention during the past years. Recently we have shown that the application of *N*-heterocyclic carbenes extends and complements the ubiquitous phosphanes. We now report on new members of our family of ruthenium-based catalysts for olefin metathesis. The synthesis of novel mixed carbene/phosphane- and homo- and heterobimetallic rutheniumalkylidene complexes is presented. © 1999 Elsevier Science S.A. All rights reserved.

Keywords: *N*-heterocyclic carbenes; Ruthenium; Homogeneous catalysis; Olefin metathesis

1. Introduction

During the last years *N*-heterocyclic carbenes (NHC) [1–3] have been well established as alternative ligands in homogenous catalysis [4–7]. In contrast to the corresponding phosphane complexes, their high dissociation energy makes these ligands promising for chiral modifications and catalyst immobilisation. Recently, we published a novel class of complexes **2** containing NHC as well as Schrock-type carbenes [8].



1 **2**

2a: R = Cyclohexyl
2b: R = (*R*)-Phenylethyl
2c: R = (*R*)-Naphthylethyl

These compounds prove to be highly active catalysts for all kinds of olefin metathesis reactions and smoothly combine the advantages of ruthenium–alkylidene complexes $[RuCl_2(=CHR)(PR'_3)_2]$ **1** developed by Grubbs et al. [9,10] with the unique properties of NHCs.

Herein, we report on the synthesis of novel mixed NHC/phosphane as well as homo- and heterobimetallic ruthenium-alkylidene complexes.

2. Experimental

All reactions were performed with standard Schlenck techniques in an oxygen-free nitrogen atmosphere. Solvents were dried by standard methods and distilled under N_2. NMR spectra were recorded on a Jeol JNM GX 400 instrument. Elemental analyses were performed in the microanalytical laboratory of our institute.

2.1. General procedure for complexes **3**

A solution of 1.0 mmol of **1** in 100 ml of THF was treated with a solution of the appropriate 1,3-dialkylimidazolin-2-ylidene (1.2 mmol) in 20 ml of THF at −78°C. The reaction mixture was slowly warmed to room temperature. The solution was filtered and the solvent removed. The complex was dissolved in 2 ml of toluene at room temperature. Upon addition of pentane (20 ml) and cooling to −78°C, a solid was precipitated which was separated from the mother-liquid, dissolved in 2 ml of toluene and reprecipitated with pentane at −78°C.

* Corresponding author. Tel.: +49-89-28913080; fax: +49-89-28913473.

E-mail address: lit@arthur.anorg.chemie.tu-muenchen.de (W.A. Herrmann)

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2.1.1. Complex ***3a***

Yield: 80%; $C_{40}H_{63}Cl_2N_2PRu$: Calc. C 61.99, H 8.20, N 3.62; Found C 61.11; H 8.29; N 3.59. ^{1}H-NMR (CD_2Cl_2): $\delta = 20.30$ (1H, d, $^3J_{PH} = 7.4$ Hz, Ru=CH), 8.33 (2H, d, $^3J_{HH} = 7.4$ Hz, *o*-H of C_6H_5), 7.62 (1H, t, $^3J_{HH} = 7.4$ Hz, *p*-H of C_6H_5), 7.33 (2H, t, $^3J_{HH} = 7.4$ Hz, *m*-H of C_6H_5), 7.11 (1H, s, NCH), 6.92 (1H, s, NCH), 5.97 (1H, m, CH of NC_6H_{11}), 3.36 (1H, m, CH of NC_6H_{11}), 2.42 (3H, m, CH of PCy_3), 1.90–0.89 (50H, all m, CH_2 of NC_6H_{11} and PCy_3). ^{13}C-NMR (CD_2Cl_2): $\delta = 298.7$ (Ru=CH), 181.2 (d, $J_{PC} = 88$ Hz, NCN), 152.5 (*ipso*-C of C_6H_5), 130.8, 129.8, and 129.2 (*o*-C, *m*-C, and *p*-C of C_6H_5), 118.9 and 118.0 (NCH), 59.5 and 57.7 (CH of NC_6H_{11}) 33.2 (d, $J_{PC} = 17$ Hz, *ipso*-C of PCy_3), 29.9 (s, *m*-C of PCy_3), 26.8 (d, $J_{PC} =$ 3.7 Hz, *o*-C of PCy_3), 25.4 (s, *p*-C of PCy_3) 34.9, 33.3, 33.1, 28.2, 28.1, and 25.7 (CH_2 of NC_6H_{11}). ^{31}P-NMR (CD_2Cl_2): $\delta = 28.2$.

2.1.2. Complex ***3b***

Yield: 74%; $C_{44}H_{59}Cl_2N_2PRu$: Calc. C 64.53, H 7.27, N 3.42; Found C 64.58, H 7.34, N 3.44. ^{1}H-NMR (CD_2Cl_2): $\delta = 20.19$ (1H, d, $^3J_{PH} = 4.5$ Hz, Ru=CH), 7.74–7.00 (15H, all m, CH of C_6H_5), 6.83 (1H, m, NC*H*MePh), 6.73 (1H, s, NCH), 6.70 (1H, s, NCH), 2.52 (1H, m, NC*H*MePh), 2.44 (3H, m, CH of PCy_3), 2.11 (3H, d, $^3J_{HH} = 6.8$ Hz, NCH*Me*Ph), 1.82–1.12 (30H, all m, CH_2 of PCy_3)1.35 (3H, d, $^3J_{HH} = 6.8$ Hz, NCH*Me*Ph). ^{13}C-NMR (CD_2Cl_2): $\delta = 292.7$ (Ru=CH), 183.4 (d, $J_{PC} = 78$ Hz, NCN), 151.8 (*ipso*-C of C_6H_5), 140.1 and 139.5 (*ipso*-C of NCHMe*Ph*), 129.5, 128.5, 128.3, 127.9, 127.5, 127.4, 127.2, 126.6, and 126.1 (*o*-C, *m*-C, and *p*-C of C_6H_5) 119.8 and 118.4 (NCH), 57.4 and 56.2 (N*C*HMePh), 31.3(d, $J_{PC} = 17$ Hz, *ipso*-C of PCy_3), 29.0 (s, *m*-C of PCy_3), 28.9 (s, *m*-C of PCy_3), 27.2 (d, $J_{PC} = 3.7$ Hz, *o*-C of PCy_3), 27.0 (d, $J_{PC} = 3.7$ Hz, *o*-C of PCy_3), 25.8 (s, *p*-C of PCy_3) 21.7 and 20.3 (NCH*Me*Ph). ^{31}P-NMR (CD_2Cl_2): $\delta = 38.1$.

2.1.3. Complex ***3c***

Yield: 72%; $C_{52}H_{63}Cl_2N_2PRu$: Calc. C 67.95, H 6.91, N 3.05; Found C 68.09, H 7.02, N 3.04. ^{1}H-NMR (CD_2Cl_2): $\delta = 20.33$ (1H, d, $^3J_{HH} = 5.4$ Hz, Ru=CH), 8.88 (2H, d, $^3J_{HH} = 8.0$ Hz, *o*-H of C_6H_5) 7.94-6.96 (17H, all m, CH of C_6H_5),, 6.70 (1H, s, NCH), 6.61 (1H, s, NCH), 5.83 (1H, m, NC*H*MeNaph), 2.59 (1H, m, NC*H*MeNaph), 2.49 (3H, m, CH of PCy_3), 2.44 (3H, d, $^3J_{HH} = 6.8$ Hz, NCH*Me*Naph), 1.95–1.01 (30H, all m, CH_2 of PCy_3)1.54 (3H, d, $^3J_{HH} = 6.8$ Hz, NCH*Me*Naph). ^{13}C-NMR (CD_2Cl_2): $\delta = 298.4$ (Ru=CH), 184.0 (d, $J_{PC} = 87$ Hz, NCN), 152.3 (*ipso*-C of C_6H_5), 138.3 and 137.6 (*ipso*-C of NCHMe*Naph*), 134.3 – 122.9 (*o*-C, *m*-C, and *p*-C of C_6H_5, CHMe-*Naph*) 120.6 and 119.5 (NCH), 56.4 and 55.7 (N*C*H-MeNaph), 32.5(d, $J_{PC} = 17$ Hz, *ipso*-C of PCy_3), 30.1 (s, *m*-C of PCy_3), 30.0 (s, *m*-C of PCy_3), 28.1 (pseudo-t, $J_{PC} = 7.4$ Hz, *o*-C of PCy_3), 26.8 (s, *p*-C of PCy_3) 24.0 and 22.7 (NCH*Me*Naph). ^{31}P-NMR (CD_2Cl_2): $\delta =$ 31.8.

2.1.4. Complex ***3d***

A solution of 1.0 mmol of $RuCl_2(PPh_3)_2(CHPh)$ in 10 ml of THF was treated with a solution of the appropriate 1,3-dialkyl-imidazolin-2-ylidene (1.2 mmol) in 20 ml of THF at -78°C. The reaction mixture was slowly warmed to room temperature. The solution was filtered and the solvent removed. The complex was dissolved in 2 ml of toluene at room temperature. Upon addition of pentane (20 ml, a solid was precipitated which was separated from the mother-liquid, dissolved in 2 ml of toluene and reprecipitated with pentane. Yield: 70%; $C_{36}H_{41}Cl_2N_2PRu$: Calc. C 61.36, H 5.86, N 3.98; Found C 61.12, H 5.55, N 3.62. ^{1}H-NMR (CD_2Cl_2): δ 20.70 (1H, s, Ru=CH), 8.03 (2H, d, $^3J_{HH} = 7.6$ Hz, *o*-H of C_6H_5), 7.50–6.95 (20H, of which 2*m*-H and 1*p*-H of C_6H_5, 15H of PPh_3 and 2H of NCH), 1.86 (9H, s, $NCMe_3$), 1.45 (9H, s, $NCMe_3$). ^{13}C-NMR (CD_2Cl_2): δ 307.4 (br, Ru=CH), 178.3 (d, $J_{PC} = 86$ Hz, NCN), 151.5 (d, $J_{PC} = 4.5$ Hz, *ipso*-C of C_6H_5), 135.0 (m, *o*-C of PPh_3), 131.9 (m, *ipso*-C of PPh_3), 130.2 (s, *p*-C of PPh_3), 129.5, 128.6 and 128.1 (s, *o*-C, *m*-C and *p*-C of C_6H_5), 128.0 (m, *m*-C of PPh_3), 117.7 and 117.6 (NCH), 58.7 and 58.5 (N*C*Me$_3$), 30.0 and 29.5 (NC*Me*$_3$). ^{31}P-NMR (CD_2Cl_2): δ 40.7 (s, PPh_3).

2.2. General procedure for compounds ***4a–4d***

A solution of 1.0 mmol of **2a** and **3a**, respectively, in 20 ml of CH_2Cl_2 was treated with a solution of 1.0 mmol $[LMCl_2]_2$ in 10 ml of CH_2Cl_2 and stirred at room temperature. The solution was filtered and the solvent removed.

2.2.1. Compound ***4a***

Starting at **3a** and $[(p\text{-cymene})RuCl_2]_2$; reaction time: 2 h; work-up by washing with toluene/pentane (1/2). Yield: 86%; $C_{32}H_{44}Cl_4N_2Ru_2$: Calc. C 48.00, H 5.54, N 3.50; Found C 48.11; H 5.61; N 3.52. ^{1}H-NMR (CD_2Cl_2): $\delta = 21.14$ (1H, s, Ru=CH), 7.89 (2H, d, $^3J_{HH} = 7.8$ Hz, *o*-H of C_6H_5), 7.67 (1H, t, $^3J_{HH} = 7.8$ Hz, *p*-H of C_6H_5), 7.22 (2H, t, $^3J_{HH} = 7.8$ Hz, *m*-H of C_6H_5), 7.09 (1H, s, NCH), 6.65 (1H, s, NCH), 5.70 (1H, m, CH of NC_6H_{11}), 5.53, 5.50, 5.43, and 5.28 (all 1H, d, $^3J_{HH} = 5.7$ Hz, CH of *p*-cymene) 3.05 (1H, m, CH of NC_6H_{11}), 2.85 (1H, m, C*H*$(CH_3)_2$ of *p*-cymene), 2.34 (3H, s, CH_3 of *p*-cymene), 1.82-0.91 (20H, all m, CH_2 of NC_6H_{11}), 1.41 (3H, d, $^3J_{HH} = 7.0$ Hz, CH(CH_3)$_2$ of *p*-cymene), 1.27 (3H, d, $^3J_{HH} = 7.0$ Hz, CH(CH_3)$_2$ of *p*-cymene). ^{13}C-NMR (CD_2Cl_2): $\delta = 319.4$ (Ru=CH), 165.2 (NCN), 154.0 (*ipso*-C of C_6H_5), 131.4, 130.7, and 128.7 (*o*-C, *m*-C, and *p*-C of C_6H_5), 119.1 and 118.0 (NCH), 101.3, 96.8, 81.3, 80.6, 79.7, and 79.4

(*p*-cymene), 58.9 and 56.7 (CH of NC_6H_{11}), 36.0, 34.9, 31.3, 25.8, 25.4, and 22.3 (CH_2 of NC_6H_{11}), 30.8 ($CH(CH_3)_2$ of *p*-cymene), 22.2 and 21.9 ($CH(CH_3)_2$ of *p*-cymene), 18.8 (CH_3 of *p*-cymene).

2.2.2. Compound **4b**

Starting at **2a** and $[(p\text{-cymene})OsCl_2]_2$ reaction time: 3 h; work-up by flash chromatography. Yield: 32%; $C_{32}H_{44}Cl_4N_2OsRu$: Calc. C 43.14, H 4.98, N 3.15; Found C 43.31; H 5.11; N 3.13. ^{1}H-NMR (CD_2Cl_2): $\delta = 21.21$ (1H, s, Ru=CH), 7.91 (2H, d, $^3J_{HH} = 6.4$ Hz, *o*-H of C_6H_5), 7.72 (1H, t, $^3J_{HH} = 6.4$ Hz, *p*-H of C_6H_5), 7.24 (2H, t, $^3J_{HH} = 6.4$ Hz, *m*-H of C_6H_5), 7.04 (1H, s, NCH), 6.69 (1H, s, NCH), 5.70 (1H, m, CH of NC_6H_{11}), 6.08 (1H, d, $^3J_{HH} = 5.9$ Hz, CH of *p*-cymene), 5.95 (1H, d, $^3J_{HH} = 5.9$ Hz, CH of *p*-cymene) 5.75 (2H, app t, $^3J_{HH} = 5.9$ Hz, CH of *p*-cymene), 3.07 (1H, m, CH of NC_6H_{11}), 2.83 (1H, m, $CH(CH_3)_2$ of *p*-cymene), 2.34 (3H, s, CH_3 of *p*-cymene), 1.90–0.85 (20H, all m, CH_2 of NC_6H_{11}), 1.39 (3H, d, $^3J_{HH} = 6.8$ Hz, $CH(CH_3)_2$ of *p*-cymene), 1.33 (3H, d, $^3J_{HH} = 6.8$ Hz, $CH(CH_3)_2$ of *p*-cymene). ^{13}C-NMR (CD_2Cl_2): $\delta = 319.7$ (Ru=CH), 165.0 (NCN), 153.9 (*ipso*-C of C_6H_5), 131.2, 130.7, and 128.6 (*o*-C, *m*-C, and *p*-C of C_6H_5), 119.3 and 118.1 (NCH), 96.5, 91.5, 71.6, 71.4, 70.4, and 69.7 (*p*-cymene), 58.8 and 56.5 (CH of NC_6H_{11}), 35.8, 35.3, 31.2, 25.9, 25.2, and 22.7 (CH_2 of NC_6H_{11}), 31.2 ($CH(CH_3)_2$ of *p*-cymene), 22.2 and 22.1 ($CH(CH_3)_2$ of *p*-cymene), 18.7 (CH_3 of *p*-cymene).

2.2.3. Compound **4c**

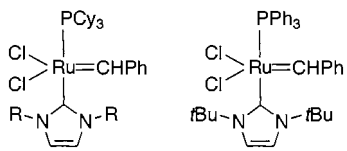
Starting at **2a** and $[Cp^*RhCl_2]_2$; reaction time: 20 min; work-up by flash chromatography. Yield: 21%; $C_{32}H_{45}Cl_4N_2RhRu$: Calc. C 47.88, H 5.65, N 3.49; Found C 47.99, H 5.70, N 3.45. ^{1}H-NMR (CD_2Cl_2): $\delta = 21.20$ (1H, s, Ru=CH), 7.95 (2H, d, $^3J_{HH} = 7.2$ Hz, *o*-H of C_6H_5), 7.67 (1H, t, $^3J_{HH} = 7.2$ Hz, *p*-H of C_6H_5), 7.25 (2H, t, $^3J_{HH} = 7.2$ Hz, *m*-H of C_6H_5), 7.09 (1H, s, NCH), 6.68 (1H, s, NCH), 6.57 (1H, m, CH of NC_6H_{11}), 2.97 (1H, m, CH of NC_6H_{11}), 1.85–0.86 (20H, all m, CH_2 of NC_6H_{11}), 1.74 (15H, s, CH_3 of Cp*). ^{13}C-NMR (CD_2Cl_2): $\delta = 319.3$ (Ru=CH), 164.4 (NCN), 153.5 (*ipso*-C of C_6H_5), 131.2, 130.4, and 128.7 (*o*-C, *m*-C, and *p*-C of C_6H_5), 118.9 and 118.3 (NCH), 94.3 (d, $J_{RhC} = 7.5$ Hz, CCH_3 of Cp*), 58.3 and 56.4 (CH of NC_6H_{11}), 35.2, 34.1, 33.3, 25.8, 22.4, 21.2 (CH_2 of NC_6H_{11}), 9.31(CH_3 of Cp*).

2.2.4. Compound **4d**

Starting at **2a** and $[Cp^*IrCl_2]_2$; reaction time: 1.5 h; work-up by flash chromatography. Yield: 25%; $C_{32}H_{45}Cl_4N_2IrRu$: Calc. C 43.05, H 5.08, N 3.14; Found C 43.19, H 5.13, N 3.05. ^{1}H-NMR (CD_2Cl_2): $\delta = 21.22$ (1H, s, Ru=CH), 7.99 (2H, d, $^3J_{HH} = 7.3$ Hz, *o*-H of C_6H_5), 7.69 (1H, t, $^3J_{HH} = 7.3$ Hz, *p*-H of C_6H_5), 7.28 (2H, t, $^3J_{HH} = 7.3$ Hz, *m*-H of C_6H_5), 7.04 (1H, s, NCH), 6.70 (1H, s, NCH), 6.65 (1H, m, CH of NC_6H_{11}), 3.03 (1H, m, CH of NC_6H_{11}), 1.84–0.88 (20H, all m, CH_2 of NC_6H_{11}), 1.70 (15H, s, CH_3 of Cp*). ^{13}C-NMR (CD_2Cl_2): $\delta = 319.9$ (Ru=CH), 165.2 (NCN), 153.7 (*ipso*-C of C_6H_5), 131.2, 130.4, and 128.7 (*o*-C, *m*-C, and *p*-C of C_6H_5), 118.5 and 118.0 (NCH), 88.0 (CCH_3 of Cp*), 59.4 and 58.0 (CH of NC_6H_{11}), 36.2, 35.8, 35.3, 26.2, 25.6, 24.2 (CH_2 of NC_6H_{11}), 9.42(CH_3 of Cp*).

3. Results and discussion

Mixed NHC/phosphane complexes **3a–3c** with any *N*-heterocyclic carbene (NHC) [1,11,12] known from **2** are accessible in excellent yields by adding 1.2 equiv. of the appropriate NHC to a solution of **1** in THF at low temperatures [13].



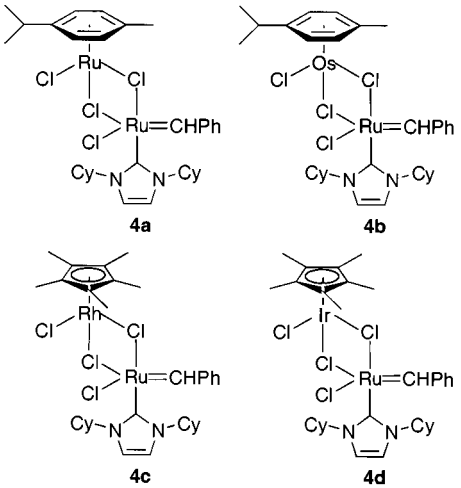
3a: R = Cyclohexyl
3b: R = (*R,R*)-Phenylethyl
3c: R = (*R,R*)-Naphthylethyl
3d

Even chiral derivatives, like **3b** and **3c** are conveniently available. In all cases, low temperature is crucial for the selectivity of the phosphane/NHC substitution. At room temperature selectivity is poor and mixtures with significant amounts of the corresponding dicarbene complexes **2** are generated. It is important to note that adding a large excess of tricyclohexylphosphane to **3a–3c** cannot reverse the reaction, clearly demonstrating the stability of the complexes as well as the stronger Lewis basicity of NHC with respect to trialkylphosphanes.

Mixing **1** and **2a** in stoichiometric amounts affords **3a** in about 15% yield after 12 h. This reaction is even observed in technical grade solvents without the exclusion of air pointing to a bimolecular mechanism for the NHC transfer rather than involvement of a free, dissociated NHC which is unlikely to survive these conditions. In contrast, no rearrangement of **3** to **1** and **2** whatsoever is observed in solution.

In the case of the corresponding triphenylphosphane/NHC complexes the steric bulk of the NHC is even more crucial, e.g. the *tert*-butyl derivative **3d** is obtained in high yields, whereas other NHCs successfully applied for the synthesis of **3a–3c** afford these NHC/PPh_3-complexes in significantly lower yields.

The increased catalytic activity of homo- and heterobimetallic ruthenium–phosphane-complexes in ROMP [14] prompted us to synthesise the corresponding NHC complexes **4a–4d**.



The differences in reactivity of the chloro-bridged organometallic precursors gives an interesting insight into the affinity of different metal fragments to NHCs. In the case of $[(p\text{-cymene})RuCl_2]_2$, **4a** can only be obtained from **3a** as starting material. Selective substitution of the phosphane ligand occurs, whereas the NHC remains untouched. Starting at **2a** reveals no conversion. In contrast, **4b**–**4d** have to be synthesised from **2a**. Starting at **3a** leads to a mixture of heterobimetallic phosphane and NHC complexes. Apparently, the decisive criterion for the reactivity is the different affinity of the NHC to the chloro-bridged compounds, which is illustrated by the reaction times for quantitative conversion: Rh(III) (20 min) > Ir(III) (1.5 h) > Os(II) (3 h) > Ru(II) (no reaction).

First applications of these catalysts in ring-opening metathesis polymerisation (ROMP) and ring-closing metathesis (RCM) show a significantly higher catalytic activity than any complexes of this type known yet. More detailed investigations are in progress.

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References

[1] A.J. Arduengo, R.L. Harlow, M. Kline, J. Am. Chem. Soc. 113 (1991) 361.
[2] H.W. Wanzlick, H.J. Schönherr, Angew. Chem. 80 (1968) 154; Angew. Chem. Int. Ed. 7 (1968) 141.
[3] K. Öfele, J. Organomet. Chem. 12 (1968) P42.
[4] W.A. Herrmann, C. Köcher, Angew. Chem. 109 (1997) 2256; Angew. Chem. Int. Ed. 36 (1997) 2162.
[5] M.G. Gardiner, W.A. Herrmann, C.-P. Reisinger, J. Schwarz, M. Spiegler, J. Organomet. Chem. 572 (1999) 239.
[6] W.A. Herrmann, M. Elison, J. Fischer, C. Köcher, G.R.J. Artus, Angew. Chem. 107 (1995) 2602; Angew. Chem. Int. Ed. 34 (1995) 2371.
[7] W.A. Herrmann, L.J. Gooßen, C. Köcher, G.R.J. Artus, Angew. Chem. 35 (1996) 2980; Angew. Chem. Int. Ed. 35 (1996) 2805.
[8] T. Weskamp, W.C. Schattenmann, M. Spiegler, W.A. Herrmann, Angew. Chem. 110 (1998) 2631; Angew. Chem. Int. Ed. 38 (1998) 2490.
[9] P. Schwab, M.B. France, J.W. Ziller, R.H. Grubbs, Angew. Chem. 107 (1995) 2179; Angew. Chem. Int. Ed. 34 (1995) 2039.
[10] P. Schwab, R.H. Grubbs, J.W. Ziller, J. Am. Chem. Soc. 118 (1996) 100.
[11] W.A. Herrmann, C. Köcher, L.J. Gooßen, G.R.J. Artus, Chem. Eur. J. 2 (1996) 1627.
[12] W.A. Herrmann, M. Elison, J. Fischer, C. Köcher, G.R.J. Artus, Chem. Eur. J. 2 (1996) 772.
[13] (a) W.A. Herrmann, W.C. Schattenmann, T. Weskamp (Hoechst R&T), DE 19815275.2, April 6, 1998. (b) W.A. Herrmann, T. Weskamp, F. J. Kohl, W.C. Schattenmann, O. Nuyken, U. Frenzel, XVIIIth ICOMC Poster B105, Munich, August 1998. (c) W.A. Herrmann, T. Weskamp, F.J. Kohl, W.C. Schattenmann, XVIIIth ICOMC Poster B106, Munich, August 1998.
[14] E.L. Dias, R.H. Grubbs, Organometalllics 17 (1998) 2758.