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Highly active ruthenium-based catalyst for metathesis of cyano-contained olefins

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Abstract—Ruthenium benzylidene complex (H_2IMes)(2-CH_3–C_5H_4N)(Cl)$_2$Ru=CHPh [H_2IMes = 1,3-bis(2,6-dimethylphenyl)-4,5-dihydroimidazol-2-ylidene] (**4**), which introduced *ortho* substituted pyridine as dissociating ligand to weaken Ru–N bond and accelerate initiation through steric hindrance, was prepared by the reaction of (H_2IMes)(PPh_3)(Cl)$_2$Ru=CHPh (**1**) with 2-methylpyridine and proved to exhibit enhanced catalytic activity for cyano-contained olefin metathesis.

In the last decades, olefin metathesis has become a most powerful tool for the formation of carbon–carbon bonds and has proved to be extremely useful in organic synthesis facilitated by the development of highly active ruthenium carbene catalysts.[1] Compared to molybdenum alkylidene catalysts,[2] ruthenium-based metathesis catalysts exhibit remarkable air and water stability, significant functional group tolerance, and thus have gained major attention.[3] However, many substrates containing cyano or/and strong base functional groups remained challenging because of their proneness to deactivate or destroy such catalysts.[4]

Two resolutions to this problem have been developed. Firstly, employment of exquisite fast-initiating catalyst, such as Hoveyda–Grubbs type ruthenium alkylidene complexes,[5] bispyridine complexes,[6] and bis(3-bromopyridine) complexes.[7] Previous studies suggested that catalyst efficiency during cyano-contained olefin metathesis are related to dissociation rates of ligands.[8] Catalysts bearing those easily dissociated ligands could initiate fast, consequently, showed enhanced catalytic activity. Secondly, introduction of appropriate additives to disable the functional groups' coordination to the catalytically active center and maintain intrinsic catalyst efficiency.[9]

Activity of metathesis catalysts, which mainly depends on the rates of initiation and rebinding of the dissociated ligands, could be improved by properly tuning the nature of the dissociating ligands. In pyridine derivative complexes, tuning the electronics of the pyridine ligand by substitution of pyridine with 3-bromopyridine has resulted in the successful development of an excellent catalyst capable of performing acrylonitrile CM with high efficiency.[7] Our efforts focused on steric tuning of pyridine ligand in catalyst design and using it for cyano-contained olefin metathesis.

In this work, *ortho* substituted pyridine was chosen as dissociating ligand. Although electron-sufficient, it is speculated that *ortho* methyl group would weaken coordination of pyridine to ruthenium atom because of steric hindrance. Therefore, it would accelerate the dissociation and/or slow rebinding of pyridine ligand. According to a protocol used to obtain similar complexes **2** and **3**, 2-methylpyridine ruthenium benzylidene complex **4** was prepared by reaction of complex **1** with larger excess of 2-methylpyridine (~100 equiv) for 12 h (Scheme 1). The product was isolated in 84% yield and characterized by detailed spectroscopic studies.[10] 2,4-Dimethylpyridine ruthenium benzylidene complex **5** was easily accessible relative to complex **4**.[10] Unfortunately, reactions of complex **1** or **2** with 2,6-dimethylpyridine or 2-bromopyridine failed to yield corresponding complex, which might result from excessively weakening coordination ability of pyridine ligand. Although bispyridine complexes were considered to form preferentially to monopyridine complexes, X-ray crystallography of complex **2**[11] and ^{1}H NMR, MS analysis of complexes **2**–**5** obviously showed monopyridine coordination in our study.

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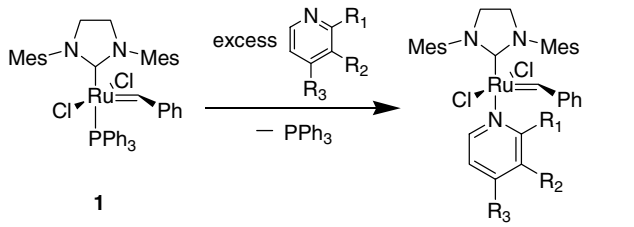
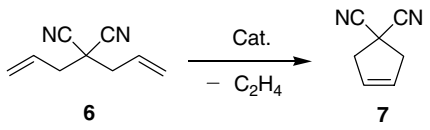


Scheme 1. Preparation of pyridine-ligated metathesis catalysts. Mes = 2,6-dimethylphenyl.

Initiation rates of catalysts **2**–**4** were measured qualitatively by tandem mass spectroscopy.[12] When the samples were delivered to the ionization source in CH_2Cl_2/CH_3CN solutions and the collision cone voltage was 3 V, $[M-Cl+CH_3CN]^+$ cation was found as base peak for complexes **2**, **3**. However, under the same conditions, an evident peak (*m*/*z* 586.9) was detected for complex **4**, which was attributed to $[M-Cl-py+2CH_3CN]^+$ species. The difference might be explained by different lability of the dissociated ligands. That is to say, the pyridine dissociation of **4** was carried out more easily than that of **2** and**3**, therefore catalyst **4** initiated faster than catalysts **2** and **3**, which implied higher catalytic activity of complex **4** for the above-mentioned challenging substrates.

Diallylmalononitrile was chosen to evaluate catalytic ability of complexes **1**–**5** to mediate RCM reaction of cyano-contained substrate (Scheme 2, Table 1).[13] Complex **1** showed low conversion even with high catalyst load mainly because of its relatively slow initiation. Compared with modest conversion for complex **2**, complex **4** exhibited higher and faster performance on diallylmalononitrile RCM with relatively low catalyst load. Importantly, even though catalyst load reached to 0.2 mol %, 96% conversion could be obtained in 1 h. Complexes **3** and **5** also showed good performance although inferiority to complex **4**.

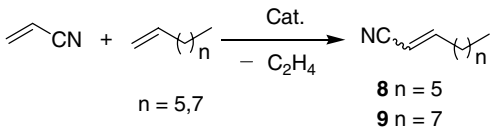


Scheme 2. RCM reaction of diallylmalononitrile.

Table 1. RCM reaction of diallylmalononitrile catalyzed by **1**–**5**[a]

Entry	Catalyst	Cat. (mol %)	Time (h)	Conversion[b] (%)
1	**1**	5	12	44
2	**2**	1	1	70
3	**3**	0.5	1	95
4	**4**	0.5	<0.5	99
5	**4**	0.2	1	96
6	**5**	0.5	1	93
7	**5**	0.2	1	90

[a] 0.1 M diallylmalononitrile in CH_2Cl_2, 40 °C.
[b] Conversion was determined by GC and confirmed by ^1H NMR.



Scheme 3. CM reaction of acrylonitrile with α-olefins.

Table 2. CM reaction of acrylonitrile with α-olefins catalyzed by **2**–**5**[a]

Entry	Catalyst	*n*	Yield[b] (%)	*E*/*Z*[c]
1	**2**	5	56	1:3.2
2	**3**	5	75	1:2.1
3	**4**	5	81	1:2.8
4	**5**	5	70	1:3.0
5	**2**	7	67	1:3.0
6	**3**	7	83	1:1.9
7	**4**	7	95	1:2.9
8	**5**	7	76	1:3.0

[a] 0.1 M acrylonitrile (1.0 equiv) in CH_2Cl_2, α-olefins (2.0 equiv), catalyst (2 mol %), 40 °C, 12 h.
[b] Isolated yield.
[c] Ratios determined by means of ^1H NMR spectroscopy.

Complexes **2**–**5** were also tested for their capability to conduct CM reaction between acrylonitrile and α-olefins (Scheme 3, Table 2).[14] Under the same conditions, the cross-metathesis products were formed in 67%, 83%, 95% and 76% yield when acrylonitrile and 1-decene were treated with catalysts **2**, **3**, **4** and **5**, respectively. Interestingly, when 1-octene was employed, lower yields were obtained. In cross-metathesis products *Z* selectivity was preferential to *E* selectivity which could be probably ascribed to the kinetically controlled process. Complex **4** still showed the highest catalytic efficiency, presumably because dissociation of stereo-hindered 2-methylpyridine was rapid and/or rebinding of it was slow. The electron-donating effect of *para* methyl group probably caused relatively slow dissociation and/or rapid rebinding of 2,4-dimethylpyridine. Complex **5** only provided modest yield compared with complex **4**.

In conclusion, we have shown that steric tuning of dissociating ligand resulted in a novel catalyst which exhibited high catalytic activity for RCM reaction of diallylmalononitrile and CM reaction of acrylonitrile with terminal olefins. New complex $(H_2IMes)(2\text{-}CH_3\text{–}C_5H_4N)(Cl)_2Ru{=}CHPh$ offers an alternative catalyst to perform metathesis reaction of cyano-containing olefins.

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References and notes

1. (a) Chauvin, Y. *Angew. Chem., Int. Ed.* **2006**, *45*, 3740–3747; (b) Schrock, R. R. *Angew. Chem., Int. Ed.* **2006**, *45*, 3748–3759; (c) Grubbs, R. H. *Angew. Chem., Int. Ed.*

2006, *45*, 3760–3765; (d) Astruc, D. *New J. Chem.* **2005**, *29*, 42–56.
2. (a) Schrock, R. R.; Murdzek, J. S.; Bazan, G. C.; Robbins, J.; Dimane, M.; O'Regan, M. B. *J. Am. Chem. Soc.* **1990**, *112*, 3875–3886; (b) Bazan, G. C.; Khosravi, E.; Schrock, R. R.; Feast, W. J.; Gibson, V. C.; O'Regan, M. B.; Thomas, J. K.; Davis, W. M. *J. Am. Chem. Soc.* **1990**, *112*, 8378–8387; (c) Bazan, G. C.; Oskan, J. H.; Cho, H. N.; Park, Y.; Schrock, R. R. *J. Am. Chem. Soc.* **1991**, *113*, 6899–6907.
3. (a) Grubbs, R. H. *Tetrahedron* **2004**, *60*, 7117–7140; (b) Trnak, T. M.; Grubbs, R. H. *Acc. Chem. Res.* **2001**, *34*, 18–29; (c) Schwab, P.; Grubbs, R. H.; Ziller, J. W. *J. Am. Chem. Soc.* **1996**, *118*, 100–110; (d) Scholl, M.; Ding, S.; Lee, C. W.; Grubbs, R. H. *Org. Lett.* **1999**, *1*, 953–956.
4. (a) Hoveyda, H. R.; Vézina, M. *Org. Lett.* **2005**, *7*, 2113–2116; (b) BouzBouz, S.; Simmons, R.; Cossy, J. *Org. Lett.* **2004**, *6*, 3465–3467; (c) Cossy, J.; BouzBouz, S.; Hoveyda, A. H. *J. Organomet. Chem.* **2001**, *634*, 216–221.
5. (a) Garber, S. B.; Kingsbury, J. S.; Gray, B. L.; Hoveyda, A. H. *J. Am. Chem. Soc.* **2000**, *122*, 8168–8179; (b) Wakamatsu, H.; Blechert, S. *Angew. Chem., Int. Ed.* **2002**, *41*, 2403–2405; (c) Michrowska, A.; Bujok, R.; Harutyunyan, S.; Sashuk, V.; Dolgonos, G.; Grela, K. *J. Am. Chem. Soc.* **2004**, *126*, 9318–9325.
6. (a) Sanford, M. S.; Love, J. A.; Grubbs, R. H. *Organometallics* **2001**, *20*, 5314–5318; (b) Love, J. A.; Sanford, M. S.; Day, M. W.; Grubbs, R. H. *J. Am. Chem. Soc.* **2003**, *125*, 10103–10109.
7. Love, J. A.; Morgan, J. P.; Trnak, T. M.; Grubbs, R. H. *Angew. Chem., Int. Ed.* **2002**, *41*, 4035–4037.
8. (a) Sanford, M. S.; Ulman, M.; Grubbs, R. H. *J. Am. Chem. Soc.* **2001**, *123*, 749–750; (b) Sanford, M. S.; Love, J. A.; Grubbs, R. H. *J. Am. Chem. Soc.* **2001**, *123*, 6543–6554.
9. Yang, Q.; Xiao, W.-J.; Yu, Z.-K. *Org. Lett.* **2005**, *7*, 871–874.
10. 2-Methylpyridine (6.0 mL, 60.8 mmol) was added to complex **1** (0.50 g, 0.62 mmol) in a 150 mL Schlenk flask, no additional solvent was required. The reaction was stirred at room temperature for 12 h during which time a color change from reddish brown to green was observed. Room temperature hexane (100 mL) was added and a green solid precipitated. The flask was sealed under nitrogen and stood at 0 °C overnight. The green precipitate was filtered, washed with 4 × 10 mL hexane and dried in vacuo to afford **4** as a green powder (0.33 g, 84% yield). ^{1}H NMR (400 MHz, $CDCl_3$): δ 19.64 (s, 1H, Ru=C*H*Ph), 8.49 (br s, 1H, pyridine), 8.01 (br s, 1H, pyridine), 7.57–7.02 (multiple peaks, 7H, pyridine, *ortho* C*H*, *para* C*H*, *meta* C*H*), 6.82 (br s, 4H, 2,6-dimethylphenyl aromatic C*H*), 6.55 (br s, 2H, 2,6-dimethylphenyl aromatic C*H*), 4.16 (s, 2H, NCH_2CH_2N), 3.95 (s, 2H, NCH_2CH_2N), 2.76 (br s, 9H, pyridine CH_3, *ortho* CH_3), 2.25 (s, 6H, *ortho* CH_3). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 312.64 (m, Ru=*C*HPh), 218.09 (s, Ru–*C*(N)$_2$), 159.53, 151.74, 151.34, 140.53, 139.08, 137.94, 137.75, 137.28, 136.59, 130.91, 130.33, 129.35, 128.99, 128.76, 128.67, 128.33, 128.04, 127.80, 127.62, 126.49, 125.17, 121.32, 120.93, 51.76, 50.85, 31.58, 20.34, 18.41. Elemental analyses calcd for $C_{32}H_{35}Cl_2N_3Ru{\cdot}0.2CHCl_3$: C, 58.82; H, 5.40; N, 6.39. Found: C, 58.83; H, 5.43; N, 6.43. Similar procedure gives complex **5** as a green powder (89% yield). ^{1}H NMR (400 MHz, $CDCl_3$): δ 19.61 (s, 1H, Ru=C*H*Ph), 7.99 (br s, 1H, pyridine), 7.57–6.38 (multiple peaks, 13H, pyridine, *ortho* C*H*, *para* C*H*, *meta* C*H*, 2,6-dimethylphenyl aromatic C*H*), 4.16 (s, 2H, NCH_2CH_2N), 3.95 (s, 2H, NCH_2CH_2N), 2.75 (br s, 9H, pyridine CH_3, *ortho* CH_3), 2.24 (s, 6H, *ortho* CH_3), 2.12 (s, 3H, pyridine CH_3). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 312.49 (m, Ru=*C*HPh), 218.38 (s, Ru–*C*(N)$_2$), 158.75, 151.24, 148.08, 140.46, 139.07, 137.86, 130.80, 130.15, 129.23, 128.89, 128.69, 128.53, 128.20, 126.01, 122.41, 51.63, 50.71, 31.51, 21.48, 20.45, 18.34. Elemental analyses calcd for $C_{33}H_{37}Cl_2N_3Ru{\cdot}0.1CHCl_3$: C, 60.27; H, 5.67; N, 6.37. Found: C, 60.10; H, 5.66; N, 6.37.
11. Crystal structure data for **2**: $C_{32}H_{34}Cl_5N_3Ru$ ($C_{31}H_{33}Cl_2N_3Ru{\cdot}CHCl_3$), $M_r = 738.94$ (619.59·119.35), triclinic, space group: $P-1$, $a = 10.1262(2)$, $b = 11.0684(2)$, $c = 14.8361(2)$ Å, $\alpha = 96.5600(10)$, $\beta = 94.6810(10)$, $\gamma = 92.1950(10)$, $V = 1644.54(5)$ Å^3, $Z = 2$, $F(000) = 752$, $D_c = 1.492$ g cm^{-3}, $R = 0.0432$, $R_w = 0.1058$. CCDC-635304 contains the supplementary crystallographic data for this letter. These data can be obtained free of charge from The Director, CCDC, 12 Union Road, Cambridge, CB21EZ, UK (Fax: +44-1233-336-033; e-mail: deposit@ccdc.cam.ac.uk or http://www.ccdc.cam.ac.uk).
12. For MS studies on ruthenium catalysts and ruthenium catalyzed olefin metathesis reactions or tandem mass spectroscopy in the gas phase, see: (a) Adlhart, C.; Hinderling, C.; Baumann, H.; Chen, P. *J. Am. Chem. Soc.* **2000**, *122*, 8204–8214; (b) Adlhart, C.; Chen, P. *Angew. Chem., Int. Ed.* **2002**, *41*, 4484–4487; (c) Chen, P. *Angew. Chem., Int. Ed.* **2003**, *42*, 2832–2847; (d) Chen, P.; Chisholm, M. H.; Gallucci, J. C.; Zhang, X.-Y.; Zhou, Z.-P. *Inorg. Chem.* **2005**, *44*, 2588–2595.
13. General procedure for ring-closing metathesis. In a typical experiment, catalyst **4** (2.5 mg, 3.9 μmol) and diallylmalononitrile (117 mg, 0.8 mmol) were weighed to a dried, two-necked flask equipped with a reflux condenser, 8 mL solvent was then added. The resulting mixture was stirred under the certain condition. After reaction was completed, the mixture was filtered through a short pad of silica gel, and the solvent was removed in vacuo. Conversion was measured by GC-FID and confirmed by NMR. Compound **6**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.90 (ddt, 2H, $J = 7.2$, 10.4, 16.8 Hz), 5.45 (dd, 2H, $J = 0.8$, 10.4 Hz), 5.41 (dd, 2H, $J = 0.8$, 16.8 Hz), 2.69 (d, 4H, $J = 7.2$ Hz); HRMS (EI), *m*/*z*: $[M]^+$, calculated for $C_9H_{10}N_2$: 146.0844; found, 146.0851. Compound **7**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.81 (s, 2H), 3.22 (s, 2H); HRMS (EI), *m*/*z*: $[M]^+$, calculated for $C_7H_6N_2$: 118.0531; found, 118.0532.
14. General procedure for cross-metathesis reaction of acrylonitrile with α-olefins. In a typical experiment, catalyst **4** (16.4 mg, 25.9 μmol) was weighed to a dried, two-necked flask equipped with a reflux condenser, 1-octene (290 mg, 2.6 mmol) and acrylonitrile (67 mg, 1.3 mmol) in CH_2Cl_2 (13 mL) were then added. The resulting mixture was stirred under the specified condition. After reaction was completed, the mixture was filtered through a short pad of silica gel, and the solvent was removed in vacuo. The crude mixture was purified by chromatography on silica gel yielding the product (140 mg, 81%), *E*/*Z* ratio was determined by means of ^{1}H NMR spectroscopy as 1:2.8. Compound **8**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.69 (dt, 1H, $J = 6.8$, 16.4 Hz, trans), 6.47 (dt, 1H, $J = 7.6$, 10.8 Hz, *cis*), 5.30 (d, 1H, $J = 16.4$ Hz, trans), 5.28 (d, 1H, $J = 10.8$ Hz, cis), 2.39 (q, 2H, $J = 7.6$ Hz, cis), 2.19 (q, 2H, $J = 6.8$ Hz, trans), 1.26–1.31 (m, 8H), 0.86 (t, $J = 6.8$ Hz, 3H). Compound **9**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.71 (dt, 1H, $J = 6.8$, 16.4 Hz, trans), 6.49 (dt, 1H, $J = 7.6$, 10.8 Hz, cis), 5.32 (d, 1H, $J = 16.4$ Hz, trans), 5.30 (d, 1H, $J = 10.8$ Hz, cis), 2.42 (q, 2H, $J = 7.6$ Hz, cis), 2.22 (q, 2H, $J = 6.8$ Hz, trans), 1.26–1.31 (m, 12H), 0.89 (t, $J = 6.8$ Hz, 3H).