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Visible Light Induced Bifunctional Rhodium Catalysis for Decarbonylative Coupling of Imides with Alkynes

Xiang-Ting Min, Ding-Wei Ji, Yu-Qing Guan, Shi-Yu Guo, Yan-Cheng Hu, Boshun Wan, and Qing-An Chen*

Abstract: Transition metal catalyzed decarbonylation offers a distinct synthetic strategy for new chemical bond formation. However, the π -backbonding between CO π^* orbitals and metal center d-orbitals impedes ligand dissociation to regenerate the catalyst under mild reaction conditions. Developed here is visible light induced rhodium catalysis for decarbonylative coupling of imides with alkynes under ambient conditions. Initial mechanistic studies suggest that the rhodium complex simultaneously serves as the catalytic center and photosensitizer for decarbonylation. This visible light promoted catalytic decarbonylation strategy offers new opportunities for reviewing old transformations with ligand dissociation as a rate-determining step.

Well-known ligand dissociation is a common and important step in transition metal catalysis.^[1] This fundamental step spares vacant coordination sites and simultaneously affects the steric and electronic properties on the metal center.^[2] Dissociation of the product or by-product usually either regenerates the starting catalyst or generates a species that will be converted to the starting catalyst. Conversely, transition metal reagent must be used in stoichiometric quantities instead of a catalyst.^[3] For example, Tsuji and Ohno reported the famous Tsuji-Wilkinson decarbonylation reaction of the aldehydes with stoichiometric amounts Wilkinson's complex RhCl(PPh₃)₃ (Scheme 1 a).^[4] As one of the most strongly π -accepting ligand, carbon monoxide (CO), the π -backbonding between CO and Rh impedes the ligand dissociation step to regenerate Wilkinson's catalyst under mild condition.^[5] Through a compromise approach, scientists have taken advantage of thermal dissociation (usually 110-200 °C)^[6] of CO from resting state of catalyst to facilitate the catalytic decarbonylation using various transition metals $(Rh,^{[7]} Pd,^{[8]} Ni,^{[9]} Ru,^{[10]} Pt,^{[11]} Ir^{[12]} etc.^{[6]}; Scheme 1b).$ Therefore, it is of great interest to develop mild methods for the catalytic decarbonylation.^[6]

[*] X. T. Min, D. W. Ji, Y. Q. Guan, S. Y. Guo, Dr. Y. C. Hu, Prof. Dr. B. Wan, Prof. Dr. Q. A. Chen Dalian Institute of Chemical Physics, Chinese Academy of Sciences 457 Zhongshan Road, Dalian 116023 (China) E-mail: qachen@dicp.ac.cn Homepage: http://www.lbcs.dicp.ac.cn X. T. Min, D. W. Ji University of Chinese Academy of Sciences Beijing 100049 (China)
Supporting information and the ORCID identification number(s) for

the author(s) of this article can be found under: https://doi.org/10.1002/anie.202010782.

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As an alternative approach, photochemically induced ligand dissociation has been employed for the simple metal carbonyl complexes $Cr(CO)_6$,^[13] $Fe(CO)_5$,^[13] and Ni(CO)₄,^[13] etc. under ultraviolet light irradiation. Inspired by these stoichiometric precedents in combination with growing field of photoinduced catalysis,^[14,15] we envisioned developing a catalytic decarbonylation promoted by photochemically induced CO dissociation using visible light. Herein, we demonstrated a visible light-driven bifunctional rhodium catalysis for decarbonylative coupling of imides with alkynes under mild condition (Scheme 1 c).

To verify our proposal, we chose decarbonylative coupling of imides with alkynes as model reaction (Scheme 2). Matsubara and our group have previously demonstrated that this transformation could be realized under Ni^[16] or Co^[17] catalysis (10-20 mol%) by a thermally induced approach (110-130°C). Given the unique property of Rh on decarbonvlation reactions,^[7,15g] we were curious about its performance on decarbonylative coupling of imides with alkynes. An initial investigation suggested the functional group on the nitrogen atom of imide 1 plays an important role on reaction outcomes (Scheme 2). Under thermally induced conditions (150°C), low yields (11-45%) could be obtained using pyridyl or quinolinyl as functional group. Switching to photoinduced condition (450-455 nm, 40 °C), we observed a dramatic functional group effect where only quinolinyl-substituted substrate 1c delivered the expected cross coupling product in 80% yield. These initial results indicated that the functional

a) Well-known Tsuji-Wilkinson stoichiometric decarbonylation



b) Thermal-induced catalytic decarbonylation.



c) This work: Visible-light-induced decarbonylation of imides.



Scheme 1. Transition metal catalyzed decarbonylation.

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Scheme 2. Initial investigation on thermally-induced or photoinduced Rh-catalyzed decarbonylative coupling.

group plays a bifunctional role as a directing group and as an energy transfer promoter.

To further improve the reactivity, a systematic optimization of this photo-induced cross coupling reaction was carried out (Table 1 and Table S1,S2 in the Supporting Information). After careful evaluation of the reaction conditions, isoquinolone **3ca** was formed in 90 % yield using [RhCl(C_2H_4)₂]₂ as the catalyst precursor under blue light irradiation (430–435 nm) at 40 °C (Table 1, entry 1). Control experiments confirmed the essential roles of the rhodium and the visible light (entries 2 and 3). It was found that photoreaction showed higher efficiency than thermal induced reaction (entry 4). Except for Wilkinson's catalyst RhCl(PPh₃)₃, other Rh¹ precursor, such as Rh(acac)(CO)₂, [RhCl(CO)₂]₂, [RhOH(COD)]₂ and [RhCl(COD)]₂ showed comparable reactivity (entries 5–9). Both DCE and PhCl could serve as competent solvents

Table 1:	Selected	optimization	studies.
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0 N-0 1c (0.1 mmol)	Ph [RhCl(C ₂ H ₄) ₂] ₂ (1.5 mol%) 430-435 nm, 10 W Ph Q = 8-quinolinyl 2a (1.2 equiv.) "standard condition"	Ph 3ca
Entry	Deviation from standard conditions	Yield [%] ^[a]
1	none	90 ^[b]
2	without $[RhCl(C_2H_4)_2]_2$	NR
3	40°C without light	NR
4	130°C without light	26
5	3.0 mol% Rh(acac)(CO) ₂ as catalyst	84
6	1.5 mol% [RhCl(CO) ₂] ₂ as catalyst	80
7	1.5 mol% [RhOH(COD)] ₂ as catalyst	80
8	1.5 mol% [RhCl(COD)] ₂ as catalyst	88
9	3.0 mol% RhCl(PPh3)3 as catalyst	NR
10	DCE instead of DCM	95 ^[b]
11	PhCl instead of DCM	95 ^[b]
12	380–385 nm instead of 430–435 nm	75 ^[c]
13	450–455 nm instead of 430–435 nm	79 ^[c]
14	30°C instead of 40°C	95 ^[b,c]
15	1.0 mol% [RhCl(C ₂ H ₄) ₂] ₂ as catalyst	92 ^[b,c,d]
16	$Ni(COD)_2$ 5.0 mol %	
17	Co ₂ (CO) ₈ 2.5 mol%	
18	Pd(PPh₃)₄ 5.0 mol%	

[a] Determined by ¹H NMR analysis of the crude reaction mixture.
 [b] Yield of isolated product. [c] DCE was used as solvent. [d] 36 h.

(entries 10 and 11). Further screening of wavelengths revealed that 430–435 nm was the optimal wavelengths for this protocol, may be related to the maximum absorption wavelength of rhodium intermediates (entries 12 and 13). To our delight, the decarbonalytion reaction proceeded well at 30 °C, which suggested that the light induced reaction could be carried out at room temperature (entry 14). A high yield was also obtained at lower catalyst loadings (1.0 mol%) with a prolonged reaction time (entry 15). Notably, other commonly used transition-metal catalysts for decarbonylation, such as Ni(COD)₂,^[9a–d,g] Co₂(CO)₈,^[18] Pd(PPh₃)₄,^[8] did not afford any desired product, which indicates the unique property of Rh in the photo-induced decarbonylative reactions (entries 16–18).

Considering the mild nature of the photo-induced decarbonylative coupling, a light on/off experiment was carried out to get the reactivity profile of this reaction (see Table S3 and Figure S1 for light on/off experiment). It revealed that constant irradiation was required for effective product formation by light on/off experiment. No background product formation during dark exposure supports that the current protocol does not involve a light-initiated radical chain pathway.

With the optimized conditions in hand, the generality of alkyne substrates was subsequently tested. As depicted in Scheme 3a, various symmetrical diarylacetylenes bearing either electron-withdrawing or electron-donating substituents all successfully afforded isoquinolones with moderate to excellent yields (3ca-3cf). Notably, a bromo-bearing arylalkyne could be well tolerated and delivered isoquinolone 3cb in 95% yield. Interestingly, an alkyne with a cyano functional group at the para-position of the phenyl ring was a bit sluggish in this protocol (3cd). This presumably ascribed to the coordinated ability of cyano groups to rhodium. Due to the steric hindrance of ortho-substituted diarylalkyne, isoquinolinone 3cf was isolated as a 5:1 rotamer mixture in 67% yield. To our delight, dialkyl acetylenes were also applicable under this visible light-induced rhodium catalysis conditions and led to 3cg-3ci in 63-83% yields. Encouraged by these promising results, a series of arvl-substituted terminal alkynes were further examined in this transformation. To our delight, these reactions exclusively produced isoquinolones 3cj-3cm in 28-42 % yields, which is uncommon due to the existence of a dominant [2+2+2] cycloaddition side reaction.^[19] For alkylsubstituted terminal alkynes such as acetylene, cyclohexylacetylene, 1-decyne, no product was formed under the photoinduced condition (see Scheme S1). Furthermore, unsymmetric alkynes were also suitable substrate to generate 3 cn-3 ct in moderate to high yields with acceptable regioselectivities. It is noteworthy that ethyl 3-phenylpropynoate (2u) led to 4substituted isoquinolone 3cu in 36% yield. This unique regioselectivity is probably due to electron-withdrawing ability of the ester group. No expected decarbonylative coupling was observed for alkene substrates such as phenylmaleimide, methyl cinnamate or styrene (see Scheme S1).

Next, we further investigated the scope of phthalimides (Scheme 3b). Substrate possessing methoxy group on the 6-position of quinoline ring successfully furnished the desired product **3da** in 89% yield. Symmetric phthalimides reacted



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Scheme 3. Substrate scope for photoinduced decarbonylative coupling of imides with alkynes.^[a] [a] (0.10 mmol), **2** (0.12 mmol), [RhCl(C_2H_4)₂]₂ (1.5 mol%), 40 °C, 36 h. Regiomeric ratio (rr) was determined by ¹H NMR analysis of the crude reaction mixture. Unless noted, the rr is greater than 20:1. [b] 30 °C, 18 h. [c] **2** (0.1 mmol) was used.

with 2a smoothly in this process, providing the corresponding products 3ea and 3fa in 74–92% yields. Substrate bearing *tert*-butyl group at the 4-position (1g) exhibited good reactivity via this decarbonylation process, although gave a mixture of two regioisomers 3ga and 3ga' in approximate 1:1 ratio. In the case of 3-fluorine substituted phthalimide, the product 3ha was isolated in 69% yield, together with a 5:1 regiomeric ratio. Remarkably, phthalimides having substitutents at the 3-position, such as 3-chloride and 3-alkoxy groups, all worked well to give regiospecific isoquinolones 3ia–3la in 50–81% yields. The molecular structure of 3ja was confirmed by X-ray crystallography. Of particular interest is that these reactions all exclusively occurred at the adjacent positions of the corresponding substituents, which offers an important complement for the reported C–H activation strategy in the synthesis of 5-substituted isoquinolinones.^[20]

Regarding mechanistic features, a key question is elucidating the role of visible light. First, the effect of light on the synthesis rhodium intermediate was investigated (Scheme 4a). Under light irradiation, the reaction of [RhCl- $(C_2H_4)_2$]₂ with phthalimide **1c** slowly generated a red solid precipitate which was then treated with excess pyridine to form a more stable speculative complex **Rh-1**. The subsequent purification of **Rh-1** (16-electron) gave an unexpected coordination saturated complex **Rh-2** (18-electron). The structure of **Rh-2** was fully characterized by ¹H, ¹³C NMR a) Effect of light on the synthesis of rhodium intermediate



Scheme 4. Mechanistic studies on reaction intermediate.

and HRMS (see the Supporting Information). In the absence of visible light irradiation, no red precipitate was formed and only phthalimide **1c** was recovered in 72 % yield. The UV/Vis absorption spectra of the **Rh-2** showed a strong absorbance in the region of 390–420 nm (Scheme 4b). The catalytic performance of **Rh-2** complex was evaluated for the decarbonylative coupling of imide **1c** with alkyne **2a** (Scheme 4c). No desired product was observed in the absence of light. Under light irradiation, **3ca** was obtained in 8% yield with 2.7 turn over number (TON). The low yield probably results from the different coordination environment between **Rh-2** complex and real Rh catalyst. Overall, these above results suggest that rhodium complex simultaneously serves as the catalytic center and photosensitizer for decarbonylation.

Based on the above results and literature precedents on decarbonylative reactions,^[16,17] a possible catalytic cycle is shown in Scheme 5. With the assistance of the quinoline group, the reaction is initiated from the oxidative addition of the Rh¹ species **A** into the C–N bond in the phthalimide **1** to form Rh^{III} intermediate **B**. A subsequent deinsertion of carbon monoxide cleaves the C–C bond to give Rh-complex **C**. Under visible light irradiation, it generates the excited state Rh-complex **C*** where the transfer of an electron from the π -backbonding Rh-CO orbital into an antibonding orbital decreases the bond dissociation energy of the Rh-CO bond. This leads to the subsequent CO extrusion under mild conditions to give a Rh intermediate **D** with a vacant



Scheme 5. Proposed mechanism for decarbonylative coupling.

coordination site. The coordination and migratory insertion of the alkyne 2 with D delivers a seven-membered rhodacycle E, which undergoes reductive elimination to form the isoquinolone 3 and regenerates the Rh^I catalyst A.

In summary, we have developed a visible light-induced rhodium catalysis for decarbonylative coupling of imides with alkynes under ambient conditions. The main advantages include mild conditions, good regioselectivity, and wide functional group tolerance. Initial mechanistic studies suggest that rhodium complex simultaneously serves as the catalytic center and photosensitizer for decarbonylation. This visible light promoted catalytic decarbonylation strategy offers new opportunities for reviewing old transformations with ligand dissociation as a rate-determining step.

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Conflict of interest

The authors declare no conflict of interest.

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J. F. Hartwig, Organotransition Metal Chemistry: From Bonding to Catalysis, University Science Books, Sausalito, 2010.

- [2] R. H. Crabtree, *The Organometallic Chemistry of the Transition Metals*, 6th ed., Wiley, Hoboken, **2014**.
- [3] a) M. Murakami, H. Amii, Y. Ito, *Nature* 1994, 370, 540; b) M. Murakami, H. Amii, Y. Ito, J. Am. Chem. Soc. 1996, 118, 8285; c) S. E. Havlik, J. M. Simmons, V. J. Winton, J. B. Johnson, J. Org. Chem. 2011, 76, 3588; d) T. Morioka, A. Nishizawa, T. Furukawa, M. Tobisu, N. Chatani, J. Am. Chem. Soc. 2017, 139, 1416; e) E. M. Heyboer, R. L. Johnson, M. R. Kwiatkowski, T. C. Pankratz, M. C. Yoder, K. S. DeGlopper, G. C. Ahlgrim, J. M. Dennis, J. B. Johnson, J. Org. Chem. 2020, 85, 3757.
- [4] a) J. Tsuji, K. Ohno, *Tetrahedron Lett.* 1965, *6*, 3969; b) J. Tsuji,
 K. Ohno, *Tetrahedron Lett.* 1967, *8*, 2173; c) K. Ohno, J. Tsuji, *J. Am. Chem. Soc.* 1968, *90*, 99.
- [5] a) E. J. Garcia-Suarez, K. Kahr, A. Riisager, *Rhodium Catalyzed Decarbonylation*, *Vol. 61*, Springer International, Cham, **2018**;
 b) L. Guo, M. Rueping, *Acc. Chem. Res.* **2018**, *51*, 1185;
 c) C. Liu, M. Szostak, *Org. Biomol. Chem.* **2018**, *16*, 7998.
- [6] H. Lu, T.-Y. Yu, P.-F. Xu, H. Wei, *Chem. Rev.* 2020, https://doi. org/10.1021/acs.chemrev.0c00153.
- [7] a) P. Fristrup, M. Kreis, A. Palmelund, P.-O. Norrby, R. Madsen, J. Am. Chem. Soc. 2008, 130, 5206; b) Q. Shuai, L. Yang, X. Guo, O. Baslé, C.-J. Li, J. Am. Chem. Soc. 2010, 132, 12212; c) Z.-Q. Lei, H. Li, Y. Li, X.-S. Zhang, K. Chen, X. Wang, J. Sun, Z.-J. Shi, Angew. Chem. Int. Ed. 2012, 51, 2690; Angew. Chem. 2012, 124, 2744; d) P.-H. Chen, T. Xu, G. Dong, Angew. Chem. Int. Ed. 2014, 53, 1674; Angew. Chem. 2014, 126, 1700; e) Z.-Q. Lei, F. Pan, H. Li, Y. Li, X.-S. Zhang, K. Chen, X. Wang, Y.-X. Li, J. Sun, Z.-J. Shi, J. Am. Chem. Soc. 2015, 137, 5012; f) S. K. Murphy, J.-W. Park, F. A. Cruz, V. M. Dong, Science 2015, 347, 56; g) T.-T. Zhao, W.-H. Xu, Z.-J. Zheng, P.-F. Xu, H. Wei, J. Am. Chem. Soc. 2018, 140, 586; h) G. Tan, Y. Wu, Y. Shi, J. You, Angew. Chem. Int. Ed. 2019, 58, 7440; Angew. Chem. 2019, 131, 7518.
- [8] a) G. Meng, M. Szostak, Angew. Chem. Int. Ed. 2015, 54, 14518; Angew. Chem. 2015, 127, 14726; b) Y.-Y. Meng, X.-J. Si, Y.-Y.
 Song, H.-M. Zhou, F. Xu, Chem. Commun. 2019, 55, 9507; c) S.
 Shi, M. Szostak, ACS Omega 2019, 4, 4901.
- [9] a) P. Mi, P. Liao, T. Tu, X. Bi, Chem. Eur. J. 2015, 21, 5332; b) J. Hu, Y. Zhao, J. Liu, Y. Zhang, Z. Shi, Angew. Chem. Int. Ed. 2016, 55, 8718; Angew. Chem. 2016, 128, 8860; c) X. Liu, H. Yue, J. Jia, L. Guo, M. Rueping, Chem. Eur. J. 2017, 23, 11771; d) H. Yue, L. Guo, H.-H. Liao, Y. Cai, C. Zhu, M. Rueping, Angew. Chem. Int. Ed. 2017, 56, 4282; Angew. Chem. 2017, 129, 4346; e) C. A. Malapit, J. R. Bour, C. E. Brigham, M. S. Sanford, Nature 2018, 563, 100; f) C. A. Malapit, J. R. Bour, S. R. Laursen, M. S. Sanford, J. Am. Chem. Soc. 2019, 141, 17322; g) T. Morioka, S. Nakatani, Y. Sakamoto, T. Kodama, S. Ogoshi, N. Chatani, M. Tobisu, Chem. Sci. 2019, 10, 6666.
- [10] a) D. V. Gribkov, S. J. Pastine, M. Schnürch, D. Sames, J. Am. Chem. Soc. 2007, 129, 11750; b) X. Guo, J. Wang, C.-J. Li, J. Am. Chem. Soc. 2009, 131, 15092; c) Y.-C. Yuan, R. Kamaraj, C. Bruneau, T. Labasque, T. Roisnel, R. Gramage-Doria, Org. Lett. 2017, 19, 6404.
- [11] F. Yamashita, H. Kuniyasu, J. Terao, N. Kambe, Org. Lett. 2008, 10, 101.
- [12] a) T. Iwai, T. Fujihara, Y. Tsuji, *Chem. Commun.* 2008, 6215;
 b) E. P. Olsen, R. Madsen, *Chem. Eur. J.* 2012, *18*, 16023; c) S.

Kusumoto, T. Tatsuki, K. Nozaki, Angew. Chem. Int. Ed. 2015, 54, 8458; Angew. Chem. 2015, 127, 8578.

- [13] a) E. J. Baerends, A. Rosa, Coord. Chem. Rev. 1998, 177, 97;
 b) C. Long, Photophysics of CO Loss from Simple Metal Carbonyl Complexes, Vol. 29, Springer, Heidelberg, 2010;
 c) M. A. Wright, J. A. Wright, Dalton Trans. 2016, 45, 6801.
- [14] a) C. K. Prier, D. A. Rankic, D. W. MacMillan, Chem. Rev. 2013, 113, 5322; b) A. B. Beeler, Chem. Rev. 2016, 116, 9629; c) M. D. Kärkäs, J. A. Porco, Jr., C. R. Stephenson, Chem. Rev. 2016, 116, 9683; d) D. Staveness, I. Bosque, C. R. Stephenson, Acc. Chem. Res. 2016, 49, 2295; e) Y. Wei, S. Liu, M.-M. Li, Y. Li, Y. Lan, L. Q. Lu, W. J. Xiao, J. Am. Chem. Soc. 2019, 141, 133; f) J. Zheng, W. B. Swords, H. Jung, K. L. Skubi, J. B. Kidd, G. J. Meyer, M. H. Baik, T. P. Yoon, J. Am. Chem. Soc. 2019, 141, 13625; g) Q.-Q. Zhou, Y.-Q. Zou, L.-Q. Lu, W.-J. Xiao, Angew. Chem. Int. Ed. 2019, 58, 1586; Angew. Chem. 2019, 131, 1600; h) Q. L. Zhang, Q. Xiong, M. M. Li, W. Xiong, B. Shi, Y. Lan, L. Q. Lu, W. J. Xiao, Angew. Chem. Int. Ed. 2020, 59, 14096–14100; Angew. Chem. 2020, 132, 14200–14204.
- [15] a) S. E. Creutz, K. J. Lotito, G. C. Fu, J. C. Peters, Science 2012, 338, 647; b) C. Uyeda, Y. Tan, G. C. Fu, J. C. Peters, J. Am. Chem. Soc. 2013, 135, 9548; c) D. T. Ziegler, J. Choi, J. M. Muñoz-Molina, A. C. Bissember, J. C. Peters, G. C. Fu, J. Am. Chem. Soc. 2013, 135, 13107; d) D. C. Fabry, J. Zoller, S. Raja, M. Rueping, Angew. Chem. Int. Ed. 2014, 53, 10228; Angew. Chem. 2014, 126, 10392; e) P. Gandeepan, J. Koeller, K. Korvorapun, J. Mohr, L. Ackermann, Angew. Chem. Int. Ed. 2019, 58, 9820; Angew. Chem. Int. Ed. 2019, 58, 9820; Angew. Chem. Int. Ed. 2019, 58, 9826; Angew. Chem. 2019, 131, 9931; g) J. Thongpaen, R. Manguin, V. Dorcet, T. Vives, C. Duhayon, M. Mauduit, O. Basle, Angew. Chem. Int. Ed. 2019, 58, 15244; Angew. Chem. 2019, 131, 15388.
- [16] a) Y. Kajita, S. Matsubara, T. Kurahashi, J. Am. Chem. Soc. 2008, 130, 6058; b) K. Fujiwara, T. Kurahashi, S. Matsubara, Org. Lett. 2010, 12, 4548; c) T. Shiba, T. Kurahashi, S. Matsubara, J. Am. Chem. Soc. 2013, 135, 13636.
- [17] X.-T. Min, D.-W. Ji, H. Zheng, B.-Z. Chen, Y.-C. Hu, B. Wan, Q.-A. Chen, Org. Lett. 2020, 22, 3386.
- [18] Z. Zhu, X. Li, S. Chen, P.-H. Chen, B. A. Billett, Z. Huang, G. Dong, ACS Catal. 2018, 8, 845.
- [19] a) C. Wang, X. Li, F. Wu, B. Wan, Angew. Chem. Int. Ed. 2011, 50, 7162; Angew. Chem. 2011, 123, 7300; b) M. Neumeier, U. Chakraborty, D. Schaarschmidt, V. de la Pena O'Shea, R. Perez-Ruiz, A. Jacobi von Wangelin, Angew. Chem. Int. Ed. 2020, 59, 13473–13478; Angew. Chem. 2020, 132, 13575–13580.
- [20] a) L. Grigorjeva, O. Daugulis, Angew. Chem. Int. Ed. 2014, 53, 10209; Angew. Chem. 2014, 126, 10373; b) D. Kalsi, S. Dutta, N. Barsu, M. Rueping, B. Sundararaju, ACS Catal. 2018, 8, 8115; c) S. Tang, D. Wang, Y. Liu, L. Zeng, A. Lei, Nat. Commun. 2018, 9, 798; d) P. Gandeepan, T. Muller, D. Zell, G. Cera, S. Warratz, L. Ackermann, Chem. Rev. 2019, 119, 2192.

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