C–C Bond Cleavage

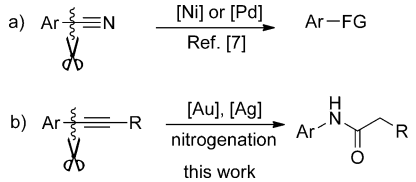
DOI: 10.1002/anie.201303376

Selective C_{sp^2}–C_{sp} Bond Cleavage: The Nitrogenation of Alkynes to Amides**

*Chong Qin, Peng Feng, Yang Ou, Tao Shen, Teng Wang, and Ning Jiao**

Chemical bond cleavage is a fundamental process in organic transformation.[1] Compared to traditional C–X (X = halogen), C–M (M = metal), and C–Y (Y = O, N, S, P) bond cleavage, C–H[2] and C–C[3] bond cleavage and thus associated transformations are much more challenging owing to the unreactivity and ubiquity of these bonds. Although there has been significant developments in this area in the recent decades, there is still scope for the discovery of novel reactions through direct C–H or C–C functionalization.

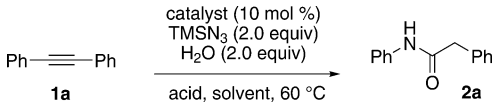
Owing to the inertness of C–C bonds and competing C–H activation, examples of C–C bond activation are much less common, with the exception of strained C–C bonds.[4,5] For C–C bond cleavage of unstrained molecules, special driving forces such as chelation assistants are required to generate stable intermediates.[6] Among the reported C–C σ-bond cleavages, a notable achievement is transition-metal-mediated cleavage of C_{sp^2}–C_{sp} bonds, in which strong C–C σ-bonds can be cleaved without the aid of ring strain or extra coordinating groups. Despite significant developments, C_{sp^2}–C_{sp} bond cleavages are mostly restricted to aryl–cyano bonds (Scheme 1 a).[7] In comparison, catalytic aryl–alkyne C_{sp^2}–C_{sp} bond cleavage has rarely been reported. Herein, we report the first direct C_{sp^2}–C_{sp} bond functionalization of alkynes through a nitrogenation process to amides, which is one of the most important organic functional groups in natural products and pharmaceuticals[8] (Scheme 1 b).



Scheme 1. Transition-metal-catalyzed cleavage of C_{sp^2}–C_{sp} bonds. FG = functional group.

Initially, we examined the transformation of 1,2-diphenylethyne (**1a**) to *N*,2-diphenylacetamide (**2a**) in the presence of TFA and $TMSN_3$, as a nitrogen source,[9] in DCE (Table 1). A screen of transition metal catalysts showed that $[PPh_3AuCl]/Ag_2CO_3$ was more efficient than $AuCl_3$, $PtCl_4$, and other metal salts (Table 1, entries 1–5). A better yield was obtained with $[PPh_3AuCl]/Ag(CF_3CO_2)$, thus indicating that the active gold catalytic species should be $PPh_3Au(CF_3CO_2)$ (see the Sup-

Table 1: Direct transformation of 1,2-diphenylethyne **1a** to amide **2a**.[a]



1a **2a**

Entry	Catalyst	Acid	Solvent	Yield of **2a** [%][b]
1	$AuCl_3$	TFA	DCE	0
2	$PtCl_4$	TFA	DCE	0
3	$[PPh_3AuCl]/Ag_2CO_3$	TFA	DCE	52
4	$Cu(OAc)_2$	TFA	DCE	0
5	$CoCl_2$	TFA	DCE	13
6	–	TFA	DCE	0
7	$[PPh_3AuCl]$	TFA	DCE	9
8	Ag_2CO_3	TFA	DCE	0
9	PPh_3AuCl/Ag_2CO_3	–	DCE	< 5
10	$[PPh_3AuCl]/Ag_2CO_3$	TfOH	DCE	15
11	$[PPh_3AuCl]/Ag_2CO_3$	$H(NTf)_2$	DCE	10
12	$[PPh_3AuCl]/Ag_2CO_3$	HOAc	DCE	< 5
13	$[PPh_3AuCl]/Ag_2CO_3$	–	TFA	45
14	$[PPh_3AuCl]/Ag_2CO_3$	TFA	PhCl	31
15	$[PPh_3AuCl]/Ag_2CO_3$	TFA	HOAc	15
16[c]	$[PPh_3AuCl]/Ag_2CO_3$	TFA	DCE	72
17[c,d]	$[PPh_3AuCl]/Ag_2CO_3$	TFA	DCE	89
18[c]	[XPhosAuCl]/Ag_2CO_3	TFA	DCE	43
19[c]	[JohnPhosAuCl]/Ag_2CO_3	TFA	DCE	35
20[c]	[IPrAuCl]/Ag_2CO_3	TFA	DCE	52
21[c]	[IMesAuCl]/Ag_2CO_3	TFA	DCE	41
22[c]	$[(4\text{-}CF_3C_6H_4)PAuCl]/Ag_2CO_3$	TFA	DCE	66

[a] Reaction conditions: **1a** (0.5 mmol), catalyst (0.05 mmol), $TMSN_3$ (1.0 mmol), H_2O (1.0 mmol), acid (200 μL) in solvent (2 mL), stirred at 60 °C. [b] Yield of the isolated product. [c] Two portions of $TMSN_3$ (0.5 mmol each time) were added, once every 2 h. [d] $[PPh_3AuCl]$ (20 mol %) and Ag_2CO_3 (20 mol %) were used. DCE = 1,2-dichloroethane, IMes = 1,3-di(2,4,6-trimethylphenyl)imidazolin-2-ylidene, IPr = *N*,*N*′-bis(2,6-(diisopropyl)phenyl)imidazol-2-ylidene, JohnPhos = 2-(di-*tert*-butylphosphino)biphenyl, Tf = trifluoromethanesulfonyl, TFA = Trifluoroacetic acid, TMS = trimethylsilyl, Xphos = 2-dicyclohexylphosphino-2′,4′,6′-triisopropylbiphenyl.

[*] C. Qin, P. Feng, Y. Ou, T. Shen, T. Wang, Dr. N. Jiao
State Key Laboratory of Natural and Biomimetic Drugs
School of Pharmaceutical Sciences, Peking University
Xue Yuan Rd. 38, Beijing 100191 (China)
E-mail: jiaoning@bjmu.edu.cn
Homepage: http://sklnbd.bjmu.edu.cn/index.html
Dr. N. Jiao
State Key Laboratory of Organometallic Chemistry
Chinese Academy of Sciences, Shanghai 200032 (China)

[**] Financial support from the National Basic Research Program of China (973 Program) (Grant No. 2009CB825300), the National Science Foundation of China (No. 21172006), and the Ph.D. Programs Foundation of the Ministry of Education of China (No. 20120001110013) are greatly appreciated. We thank Yizhi Yuan for reproducing the results of **4f** and **4i** in Table 3.

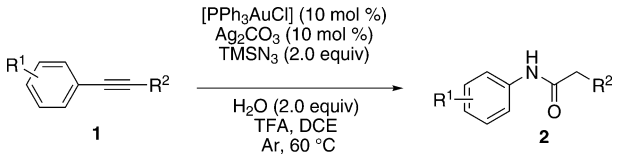
Supporting information for this article is available on the WWW under http://dx.doi.org/10.1002/anie.201303376.

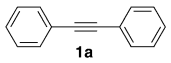
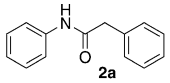
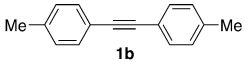
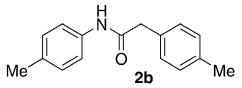
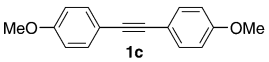
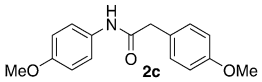
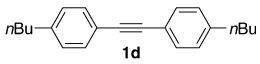
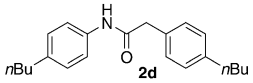
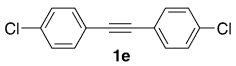
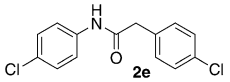
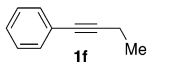
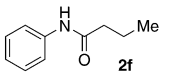
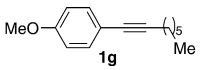
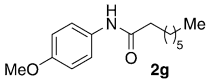
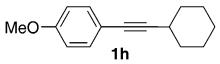
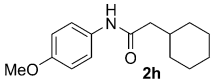
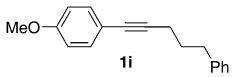
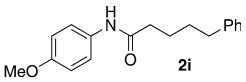
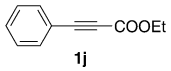
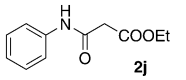
porting Information, Table S1, entry 8). However, considering the cost, we choose to use Ag_2CO_3 as co-catalyst. Control experiments indicated that [PPh_3AuCl] is essential for this transformation (Table 1, entry 6). In contrast to the Au catalyst, when the Ag catalyst was used alone this amide formation did not occur. Besides, only a trace amount of desired product was detected when the reaction was performed in the absence of TFA (Table 1, entry 9). Reactions in which either HOTf, $HN(Tf)_2$, or HOAc were used as an acid additive did not give good results (Table 1, entries 10–12). We also investigated the use of PhCl and HOAc as the solvent. However, this resulted in low yields (Table 1, entries 13–15). The reactivity of other gold catalysts with different ligands (XPhos, JohnPhos, IPr, IMes, $(4\text{-}CF_3C_6H_4)_3P$) were also investigated. Unfortunately, these catalysts gave poor results (entries 18–22). After extensive screening on other parameters (see the Supporting Information, Table S1), the optimum reaction conditions were determined as: alkynes (0.5 mmol, 1.0 equiv), [PPh_3AuCl] (10 mol%), Ag_2CO_3 (10 mol%), $TMSN_3$ (2.0 equiv, added in two portions), H_2O (2.0 equiv), TFA (200 μL), DCE (2 mL), 60 °C.

The scope of the substrates were investigated under the optimized conditions (Table 2). A variety of 1,2-diarylethynes were found to be compatible with this protocol. Substituted *N*,2-diphenylacetamides were generated through the cleavage of C_{sp}–C_{sp^2} bonds of diarylethynes. Reactions of diarylethynes bearing electron-donating substituents (Me, OMe, and *n*Bu) on the aryl ring afforded the desired products **2b**, **2c**, and **2d**, respectively, in moderate yields (74%, 42%, and 56%, respectively). When diarylethynes with both electron-rich and electron-poor aromatic substituents were employed, the azide anion preferred to add at the electron-rich side of the alkynes, thus leading to a low regioselectivity (see the Supporting Information). Significantly, in addition to diarylethynes, alkyl-substituted phenylethynes, such as but-1-yn-1-ylbenzene (**1f**), 1-methoxy-4-(oct-1-yn-1-yl)benzene (**1g**), 1-(cyclohexylethynyl)-4-methoxybenzene (**1h**), and 1-methoxy-4-(5-phenylpent-1-yn-1-yl)benzene (**1i**) also gave the desired amide products through highly selective C_{sp^2}–C_{sp} bond cleavage (Table 2, entries 6–9). The possible amide products from C_{sp^3}–C_{sp} bond cleavage were not detected in these cases. Unfortunately, electron-deficient internal alkyne ethyl 3-phenylpropiolate (**1j**) did not react under these conditions.

When the reactions of terminal alkynes were tested under the optimized conditions, the reaction of **3a** in TFA produced the desired amide **4a** in 70% yield (Table 3, entry 1). Based on this result, TFA was chosen as the solvent for the reaction of terminal alkynes. A variety of phenylethynes were converted into the desired products in modest to good yields (up to 93%, Table 3). Various substituents, including electron-donating groups, such as methyl (**4c** and **4k**), methoxy (**4b**, **4j** and **4l**), *tert*-butyl (**4g**), and phenyl (**4h**), and electron-withdrawing groups, such as fluoride (**4d** and **4m**), carboxyl (**4i**), were tolerated at the *meta*, *ortho*, and *para* positions of the aromatic ring. Halogens were tolerated on the aromatic ring (**4d**, **4e**, **4f**, **4j**, and **4m**), thus offering an opportunity for further cross-coupling, and facilitating the expedient synthesis of complex compounds. Notably, the carboxylic acid group of

Table 2: Direct transformation of diaryl alkynes **1** to amides **2**.[a]



Entry	Alkynes **1**	Amides **2**	Yield [%][b]
1			72
2			74
3			42
4			56
5			67
6[c]			35
7			43
8[d]			44
9[d]			47
10			0

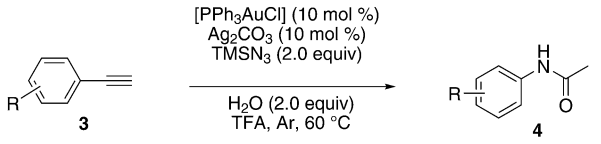
[a] Reaction conditions: **1** (0.5 mmol), [PPh_3AuCl] (0.05 mmol), Ag_2CO_3 (0.05 mmol), $TMSN_3$ (1.0 mmol), H_2O (1.0 mmol), TFA (200 μL) in DCE (2 mL), stirred at 60 °C. [b] Yield of the isolated product. [c] HOTf (5.2 mmol) was used instead of TFA. [d] 0.5 mmol $TMSN_3$ was used.

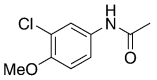
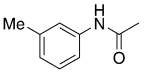
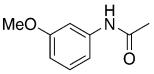
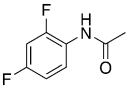
N-phenylacetamide **4i** was also tolerated in this transformation (Table 3, entry 9).

To elucidate the mechanism, possible intermediates were investigated. As ketones were detected as a by-product in this reaction, we assumed that one possible pathway is a tandem process involving gold-catalyzed hydration of alkynes to ketones[10] and a subsequent Schmidt reaction.[11] To verify this possibility, the reaction of **1a** in the absence of $TMSN_3$ was studied, and 1,2-diphenylethanone (**5**) was indeed obtained in 73% yield (Scheme 2a). However, **5** failed to be converted into **2a** under the standard reaction conditions (Scheme 2b). Thus, ketones are probably not a key intermediate in this transformation.

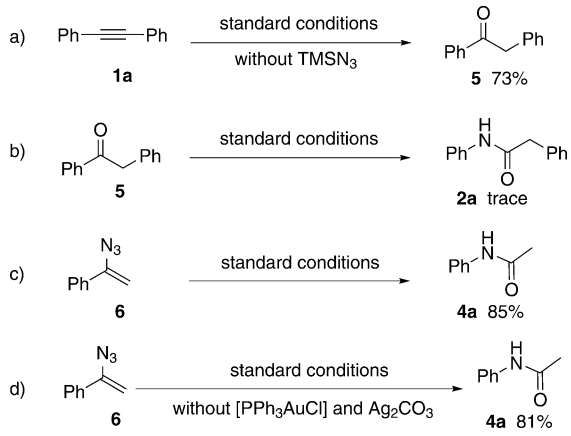
Gold catalysts are one of the most effective catalysts for electrophilic activation of alkynes toward a variety of nucleophiles.[12] In a simplified form, nucleophilic attack on

Table 3: Direct transformation of phenylacetylenes **3** to acetanilides **4**.



Entry	Product		Yield [%][b]
1	R = H	**4a**	70
2	R = OMe	**4b**	78
3	R = Me	**4c**	52
4	R = F	**4d**	81
5	R = Cl	**4e**	92
6	R = Br	**4f**	93
7	R = *t*Bu	**4g**	66
8	R = Ph	**4h**	69
9	R = COOH	**4i**	52
10		**4j**	72
11		**4k**	59
12		**4l**	55
13		**4m**	69

[a] Reaction conditions: **1** (0.5 mmol), [PPh_3AuCl] (0.05 mmol), Ag_2CO_3 (0.05 mmol), $TNSN_3$ (1.0 mmol), H_2O (1.0 mmol), TFA (2 mL), stirred at 60 °C.[b] Yield of the isolated product.



Scheme 2. Mechanistic studies and control experiments.

the gold-activated alkyne proceeds to give *trans* alkenyl gold complexes as intermediates.[13] Therefore, it seems reasonable that a gold-catalyzed nucleophilic attack by an azide anion occurs in the initial stage of this transformation. To obtain data to support mechanism, (1-azidovinyl)benzene **6** was synthesized and subjected to the standard reaction conditions (Scheme 2c); as expected, **4a** (85% yield) was obtained. Notably, in the absence of [PPh_3AuCl] and Ag_2CO_3, **6** was converted into **4a** in a 81% yield (Scheme 2d). Moreover, the reactions in the absence of either [PPh_3AuCl] or Ag_2CO_3 gave 83% and 84% yield of **4a,** respectively (see the Supporting Information). All these results indicate that gold and silver salts are not involved in the second step.

To further explore the reaction mechanism, the progress of the reaction of phenylacetylene was monitored by ^1H NMR spectroscopy (Figure 1). The signal corresponding to the

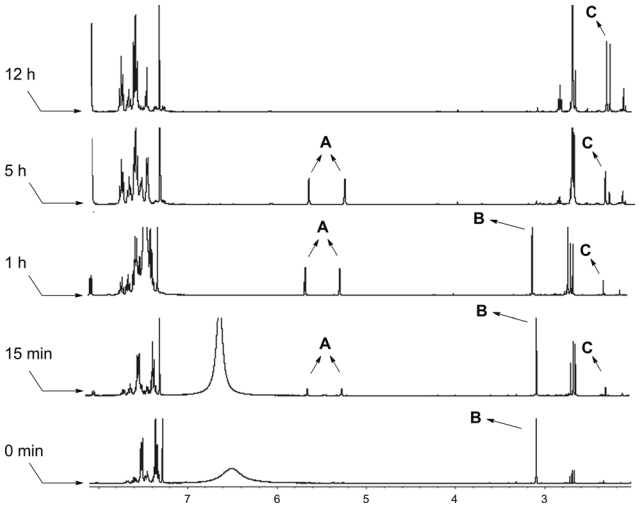
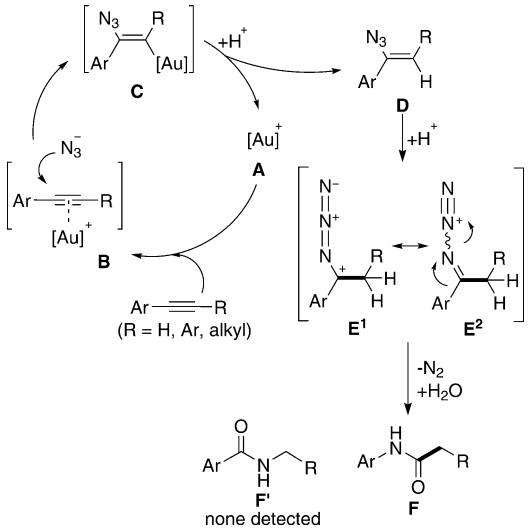


Figure 1. Reaction monitoring by NMR spectroscopy. A = olefinic hydrogen in **6**. B = alkynyl hydrogen in **3a**. C = methyl group in **4a**.

olefinic hydrogen in (1-azidovinyl)benzene (**6**; $\delta = 5.63$ and 5.25, $J = 3.2$ Hz in $CDCl_3$) appeared at 15 min after the reaction started. This signal became strong at the early stage and disappeared by the end of the reaction. The consumption of **3a** and production of **4a** were also observed in the spectrum as the reaction proceeded. These results strongly indicate that azidoethene is an intermediate of this transformation.

On the basis of the above results, a proposed mechanism is illustrated in Scheme 3. Initially, alkyne is activated by



Scheme 3. Proposed mechanism.

cationic gold(I) **A** generated in situ from [PPh_3AuCl] and Ag_2CO_3.[14] Subsequent attack of intermediate **B** by an azide anion produces complexe **C**. The protolysis of **C** produces alkenyl azide **D**. Further protonation of **D** forms resonance azide cations $\mathbf{E^1}$ and $\mathbf{E^2}$, which could transform to amide **F** through an acid-catalyzed rearrangement process.[15] It should be noted that the electrophiles Au^+ and H^+ add preferentially at the less substituted carbon atoms of the unsaturated C–C triple and double bonds, respectively, (in intermediates **B** and **D**) in accordance with Markovnikov's rule.[16] In the rearrangement step, the migratory aptitude of aryl groups is higher than that of alkyl groups. These two facts lead to the high regioselectivity of this transformation, and result in no formation of the regioisomer of amide product **F′**.

In summary, we have demonstrated a direct C–C functionalization of aryl-substituted alkynes to amides under mild reaction conditions. This method offers a novel application of alkynes in organic synthesis. A nitrogenation process is achieved by the highly selective C_{sp^2}–C_{sp} bond cleavage of substituted alkynes. The mechanistic insights into this novel transformation may promote the discovery of other reactions involving C–C bond cleavage. Further studies into the reaction mechanism and applications of this protocol are ongoing in our group.

Received: April 21, 2013
Revised: May 28, 2013
Published online: June 26, 2013

Keywords: alkynes · amides · C–C bond cleavage · gold · rearrangement

[1] M. B. Smith, J. March in *March's Advanced Organic Chemistry: Reactions, Mechanisms, and Structure*, Wiley, Hoboken, NJ, **2007**.

[2] For some recent reviews of C–H activation, see: a) D. A. Colby, R. G. Bergman, J. A. Ellman, *Chem. Rev.* **2010**, *110*, 624; b) C.-L. Sun, B.-J. Li, Z.-J. Shi, *Chem. Rev.* **2011**, *111*, 1293; c) T. W. Lyons, M. S. Sanford, *Chem. Rev.* **2010**, *110*, 1147; d) C. S. Yeung, V. M. Dong, *Chem. Rev.* **2011**, *111*, 1215; e) J. Le Bras, J. Muzart, *Chem. Rev.* **2011**, *111*, 1170; f) L. Ackermann, *Chem. Rev.* **2011**, *111*, 1315; g) G. E. Dobereiner, R. H. Crabtree, *Chem. Rev.* **2010**, *110*, 681.

[3] For reviews on C–C cleavage, see: a) R. H. Crabtree, *Chem. Rev.* **1985**, *85*, 245; b) B. Rybtchinski, D. Milstein, *Angew. Chem.* **1999**, *111*, 918; *Angew. Chem. Int. Ed.* **1999**, *38*, 870; c) C.-H. Jun, *Chem. Soc. Rev.* **2004**, *33*, 610; d) M. Tobisu, N. Chatani, *Chem. Soc. Rev.* **2008**, *37*, 300.

[4] For some reviews, see: a) P. Binger, U. Schuchardt, *Chem. Ber.* **1981**, *114*, 3313; b) A. Brandi, A. Goti, *Chem. Rev.* **1998**, *98*, 589; c) I. Nakamura, Y. Yamamoto, *Adv. Synth. Catal.* **2002**, *344*, 111; d) A. Brandi, S. Cicchi, F. M. Cordero, A. Goti, *Chem. Rev.* **2003**, *103*, 1213; e) W. R. Dolbier, Jr., M. A. Battiste, *Chem. Rev.* **2003**, *103*, 1071; f) A. Sekiguchi, V. Y. Lee, *Chem. Rev.* **2003**, *103*, 1429; g) R. Walsh, *Chem. Soc. Rev.* **2005**, *34*, 714; h) Z.-B. Zhu, Y. Wei, M. Shi, *Chem. Soc. Rev.* **2011**, *40*, 5534; i) B.-L. Lu, L. Dai, M. Shi, *Chem. Soc. Rev.* **2012**, *41*, 3318.

[5] For selected recent examples, see: a) T. Ohmura, H. Taniguchi, Y. Kondo, M. Suginome, *J. Am. Chem. Soc.* **2007**, *129*, 3518; b) T. Matsuda, M. Shigeno, M. Murakami, *J. Am. Chem. Soc.* **2007**, *129*, 12086; c) C. Winter, N. Krause, *Angew. Chem.* **2009**, *121*, 2497; *Angew. Chem. Int. Ed.* **2009**, *48*, 2460; d) T. Seiser, O. A. Roth, N. Cramer, *Angew. Chem.* **2009**, *121*, 6438; *Angew. Chem. Int. Ed.* **2009**, *48*, 6320; e) T. Seiser, N. Cramer, *J. Am. Chem. Soc.* **2010**, *132*, 5340; f) T. Seiser, N. Cramer, *Chem. Eur. J.* **2010**, *16*, 3383; g) T. Wang, C.-H. Wang, J. Zhang, *Chem. Commun.* **2011**, *47*, 5578; h) L. Zhou, F. Ye, Y. Zhang, J. Wang, *Org. Lett.* **2012**, *14*, 922; i) B.-L. Lu, M. Shi, *Angew. Chem.* **2011**, *123*, 12233; *Angew. Chem. Int. Ed.* **2011**, *50*, 12027.

[6] a) C.-H. Jun, H. Lee, *J. Am. Chem. Soc.* **1999**, *121*, 880; b) N. Chatani, Y. Ie, F. Kakiuchi, S. Murai, *J. Am. Chem. Soc.* **1999**, *121*, 8645; c) C.-H. Jun, D.-Y. Lee, H. Lee, J.-B. Hong, *Angew. Chem.* **2000**, *112*, 3214; *Angew. Chem. Int. Ed.* **2000**, *39*, 3070; d) C.-H. Jun, C. W. Moon, D.-Y. Lee, *Chem. Eur. J.* **2002**, *8*, 2422; e) Y. J. Park, J.-W. Park, C.-H. Jun, *Acc. Chem. Res.* **2008**, *41*, 222; f) H. Li, Y. Li, X.-S. Zhang, K. Chen, X. Wang, Z.-J. Shi, *J. Am. Chem. Soc.* **2011**, *133*, 15244; g) Z.-Q. Lei, H. Li, Y. Li, X.-S. Zhang, K. Chen, X. Wang, J. Sun, Z.-J. Shi, *Angew. Chem.* **2012**, *124*, 2744; *Angew. Chem. Int. Ed.* **2012**, *51*, 2690; h) J. Wang, B. Liu, H. Zhao, J. Wang, *Organometallics* **2012**, *31*, 8598; i) J. Wang, W. Chen, S. Zuo, L. Liu, X. Zhang, J. Wang, *Angew. Chem.* **2012**, *124*, 12500; *Angew. Chem. Int. Ed.* **2012**, *51*, 12334; j) J. P. Lutz, C. M. Rathbun, S. M. Stevenson, B. M. Powell, T. S. Boman, C. E. Baxter, J. M. Zona, J. B. Johnson, *J. Am. Chem. Soc.* **2012**, *134*, 715.

[7] a) M. Tobisu, Y. Kita, N. Chatani, *J. Am. Chem. Soc.* **2006**, *128*, 8152; b) Y. Nakao, A. Yada, S. Ebata, T. Hiyama, *J. Am. Chem. Soc.* **2007**, *129*, 2428; c) F. L. Taw, A. H. Mueller, R. G. Bergman, M. Brookhart, *J. Am. Chem. Soc.* **2003**, *125*, 9808; d) M. Tobisu, R. Nakamura, Y. Kita, N. Chatani, *J. Am. Chem. Soc.* **2009**, *131*, 3174; e) D.-G. Yu, M. Yu, B.-T. Guan, B.-J. Li, Y. Zheng, Z.-H. Wu, Z.-J. Shi, *Org. Lett.* **2009**, *11*, 3374; f) M. R. Grochowski, T. Li, W. W. Brennessel, W. D. Jones, *J. Am. Chem. Soc.* **2010**, *132*, 12412; g) K. Nakai, T. Kurahashi, S. Matsubara, *J. Am. Chem. Soc.* **2011**, *133*, 11066; h) M. R. Grochowski, J. Morris, W. W. Brennessel, W. D. Jones, *Organometallics* **2011**, *30*, 5604; i) M. Tobisu, H. Kinuta, Y. Kita, E. Remond, N. Chatani, *J. Am. Chem. Soc.* **2012**, *134*, 115.

[8] For recent reviews on amide synthesis, see: a) E. Valeur, M. Bradley, *Chem. Soc. Rev.* **2009**, *38*, 606; b) C. L. Allen, J. M. J. Williams, *Chem. Soc. Rev.* **2011**, *40*, 3405; c) A. J. A. Watson, J. M. J. Williams, *Science* **2010**, *329*, 635; d) K. Ekoue-Kovi, C. Wolf, *Chem. Eur. J.* **2008**, *14*, 6302.

[9] For some selected recent examples on the reaction of azide compounds, see: a) Y.-F. Wang, K. K. Toh, J.-Y. Lee, S. Chiba, *Angew. Chem.* **2011**, *123*, 6049; *Angew. Chem. Int. Ed.* **2011**, *50*, 5927; b) Y.-F. Wang, K. K. Toh, E. P. J. Ng, S. Chiba, *J. Am. Chem. Soc.* **2011**, *133*, 6411; c) B. J. Stokes, S. Liu, T. G. Driver, *J. Am. Chem. Soc.* **2011**, *133*, 4702; d) Q. Nguyen, K. Sun, T. G. Driver, *J. Am. Chem. Soc.* **2012**, *134*, 7262; e) J. Y. Kim, S. H. Park, J. Ryu, S. H. Cho, S. H. Kim, S. Chang, *J. Am. Chem. Soc.* **2012**, *134*, 9110; f) J. Ryu, K. Shin, S. H. Park, J. Y. Kim, S. Chang, *Angew. Chem.* **2012**, *124*, 10042; *Angew. Chem. Int. Ed.* **2012**, *51*, 9904; g) Z.-Y. Yan, Y. Xiao, L. Zhang, *Angew. Chem.* **2012**, *124*, 8752; *Angew. Chem. Int. Ed.* **2012**, *51*, 8624; h) B. Lu, Y. Luo, L. Liu, L. Ye, Y. Wang, L. Zhang, *Angew. Chem.* **2011**, *123*, 8508; *Angew. Chem. Int. Ed.* **2011**, *50*, 8358; i) H. Lu, H. Jiang, L. Wojtas, X. P. Zhang, *Angew. Chem.* **2010**, *122*, 10390; *Angew. Chem. Int. Ed.* **2010**, *49*, 10192; j) W. Yao, L. Pan, Y. Zhang, G. Wang, X. Wang, C. Ma, *Angew. Chem.* **2010**, *122*, 9396; *Angew. Chem. Int. Ed.* **2010**, *49*, 9210; k) K. Weidner, A. Giroult, P. Panchaud, P. Renaud, *J. Am. Chem. Soc.* **2010**, *132*, 17511; l) I. Cano, E. Álvarez, M. C. Nicasio, P. J. Peréz, *J. Am. Chem. Soc.* **2011**, *133*, 191; m) S. Zhang, J. Zhao, W.-X. Zhang, Z. Xi, *Org. Lett.* **2011**, *13*, 1626; n) J. Wang, J. Wang, Y. Zhu, P. Lu, Y. Wang, *Chem. Commun.* **2011**, *47*, 3275; o) Z. Chen, C. Ye, L. Gao, J. Wu, *Chem. Commun.* **2011**, *47*, 5623; p) C. Qin, W. Zhou, F. Chen, Y. Ou, N. Jiao, *Angew. Chem.* **2011**, *123*, 12803; *Angew. Chem. Int. Ed.* **2011**, *50*, 12595; q) T. Bach, B. Schlummer, K. Harms, *Chem. Commun.* **2000**, 287; r) T. Miura, T. Biyajima, T.

Fujii, M. Murakami, *J. Am. Chem. Soc.* **2012**, *134*, 194; s) C. Qin, N. Jiao, *J. Am. Chem. Soc.* **2010**, *132*, 15893; t) C. Tang, N. Jiao, *J. Am. Chem. Soc.* **2012**, *134*, 18924; u) T. Wang, W. Zhou, H. Yin, J.-A. Ma, N. Jiao, *Angew. Chem.* **2012**, *124*, 10981; *Angew. Chem. Int. Ed.* **2012**, *51*, 10823; v) D. Lubriks, I. Sokolovs, E. Suna, *J. Am. Chem. Soc.* **2012**, *134*, 15436; w) T. Miura, Y. Funakoshi, M. Morimoto, T. Biyajima, M. Murakami, *J. Am. Chem. Soc.* **2012**, *134*, 17440; x) M. Zibinsky, V. V. Fokin, *Angew. Chem.* **2013**, *125*, 1547; *Angew. Chem. Int. Ed.* **2013**, *52*, 1507; y) D. J. Gorin, N. R. Davis, F. D. Toste, *J. Am. Chem. Soc.* **2005**, *127*, 11260; z) K. Hiroya, S. Matsumoto, M. Ashikawa, K. Ogiwara, T. Sakamoto, *Org. Lett.* **2006**, *8*, 5349.

[10] a) X. Jin, T. Oishi, K. Yamaguchi, N. Mizuno, *Chem. Eur. J.* **2011**, *17*, 1261; b) S. Gaillard, J. Bosson, R. S. Ramón, P. Nun, A. M. Z. Slawin, S. P. Nolan, *Chem. Eur. J.* **2010**, *16*, 13729; c) A. Leyva, A. Leyva, *J. Org. Chem.* **2009**, *74*, 2067.

[11] a) K. F. Z. Schmidt, *Angew. Chem.* **1923**, *36*, 511; b) S. Lang, J. A. Murphy, *Chem. Soc. Rev.* **2006**, *35*, 146.

[12] For reviews on gold-catalyzed activation of alkynes, see: a) S. Ma, S. Yu, Z. Gu, *Angew. Chem.* **2006**, *118*, 206; *Angew. Chem. Int. Ed.* **2006**, *45*, 200; b) A. S. K. Hashmi, *Chem. Rev.* **2007**, *107*, 3180; c) N. Marion, S. P. Nolan, *Chem. Soc. Rev.* **2008**, *37*, 1776; d) E. Jiménez-Núñez, A. M. Echavarren, *Chem. Rev.* **2008**, *108*, 3326; e) M. N. Hopkinson, A. D. Gee, V. Gouverneur, *Chem. Eur. J.* **2011**, *17*, 8248; f) H. A. Wegner, M. Auzias, *Angew. Chem.* **2011**, *123*, 8386; *Angew. Chem. Int. Ed.* **2011**, *50*, 8236; g) Y. Yamamoto, I. D. Gridnev, N. T. Patil, T. Jin, *Chem. Commun.* **2009**, 5075; h) E. Jiménez-Núñez, A. M. Echavarren, *Chem. Commun.* **2007**, 333; i) D. J. Gorin, B. D. Sherry, F. D. Toste, *Chem. Rev.* **2008**, *108*, 3351.

[13] For some selected examples, see: a) H.-S. Yeom, J.-E. Lee, S. Shin, *Angew. Chem.* **2008**, *120*, 7148; *Angew. Chem. Int. Ed.* **2008**, *47*, 7040; b) P. W. Davies, S. J.-C. Albrecht, *Angew. Chem.* **2009**, *121*, 8522; *Angew. Chem. Int. Ed.* **2009**, *48*, 8372; c) N. D. Shapiro, F. D. Toste, *J. Am. Chem. Soc.* **2007**, *129*, 4160; d) A. M. Jadhav, S. Bhunia, H.-Y. Liao, R.-S. Liu, *J. Am. Chem. Soc.* **2011**, *133*, 1769; e) Y. Wang, K. Ji, S. Lan, L. Zhang, *Angew. Chem.* **2012**, *124*, 1951; *Angew. Chem. Int. Ed.* **2012**, *51*, 1915; f) Y. Luo, K. Ji, Y. Li, L. Zhang, *J. Am. Chem. Soc.* **2012**, *134*, 17412; g) D. Qian, J. Zhang, *Chem. Commun.* **2012**, *48*, 7082; h) M. Zhang, J. Zhang, *Chem. Commun.* **2012**, *48*, 6399; i) D. Wang, X. Ye, X. Shi, *Org. Lett.* **2010**, *12*, 2088; j) D. Wang, R. Cai, S. Sharma, J. Jirak, S. K. Thummanapelli, N. G. Akhmedov, H. Zhang, X. Liu, J. L. Petersen, X. Shi, *J. Am. Chem. Soc.* **2012**, *134*, 9012.

[14] D. V. Partyka, J. B. Updegraff III, M. Zeller, A. D. Hunter, T. G. Gray, *Organometallics* **2007**, *26*, 183.

[15] a) R. D. Bach, G. J. Wolber, *J. Org. Chem.* **1982**, *47*, 239; b) A. Hassner, E. S. Ferdinandi, R. J. Isbister, *J. Am. Chem. Soc.* **1970**, *92*, 1672.

[16] M. Beller, J. Seayad, A. Tillack, H. Jiao, *Angew. Chem.* **2004**, *116*, 3448; *Angew. Chem. Int. Ed.* **2004**, *43*, 3368.

