A Journal of the Gesellschaft Deutscher Chemiker

Angewandte International Edition

GDCh

Chemie

www.angewandte.org

Accepted Article

Title: Highly Efficient and Stereoselective Thioallylation of Alkynes: Possible Gold Redox Catalysis with No Need of a Strong Oxidant

Authors: Xiaodong Shi, Jin Wang, Shuyao Zhang, Lukasz Wojtas, Novruz Akhmedov, Hao Chen, and Chang Xu

To be cited as: *Angew. Chem. Int. Ed.* 10.1002/anie.201802540
Angew. Chem. 10.1002/ange.201802540

Link to VoR: http://dx.doi.org/10.1002/anie.201802540
http://dx.doi.org/10.1002/ange.201802540

WILEY-VCH

10.1002/anie.201802540

Angewandte Communications

Gold Redox Catalysis

DOI: 10.1002/anie.201((will be filled in by the editorial staff))

Highly Efficient and Stereoselective Thioallylation of Alkynes: Possible Gold Redox Catalysis with No Need of a Strong Oxidant

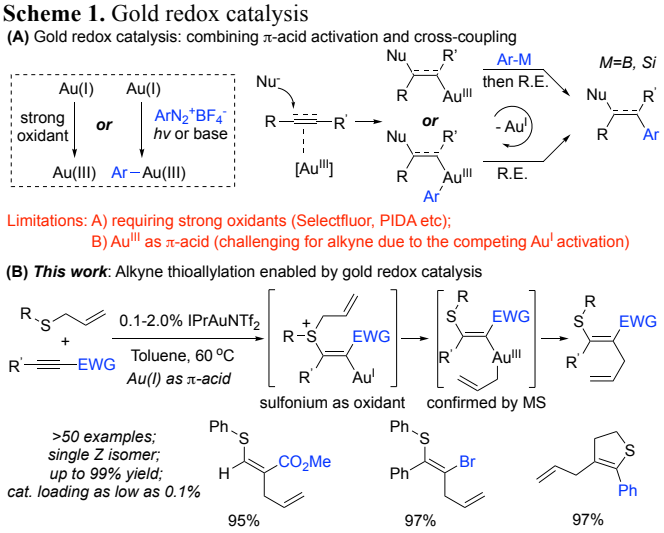
*Jin Wang,[a] Shuyao Zhang,[a] Chang Xu,[b] Lukasz Wojtas,[a] Novruz G. Akhmedov,[c] Hao Chen,[b] Xiaodong Shi[a,]**

***Abstract**: A possible gold redox-catalyzed stereoselective thioallylation of alkynes was achieved. The reaction was accomplished with high efficiency (as low as 0.1% catalyst loading, up to 99% yield) and broad substrate scope (various alkynes, inter- and intramolecular fashion). The gold(I) catalyst acts as both π-acid for alkyne activation and redox catalyst for Au(I/III) coupling, while the in-situ generated sulfonium cation functions as a mild oxidant. This novel methodology provides an exciting system for gold redox catalysis without the need of a strong oxidant.*

The past two decades have witnessed a rapid growth of homogenous gold catalysis.[1] Due to relativistic effects,[2] gold complexes exhibit superior capability in activating π-bonds in alkenes, allenes, and especially alkynes. Although the vinyl gold complex generated from gold-catalyzed nucleophilic addition to an alkyne is well-known,[3] it hasn't been of interest by the synthetic community for quite a while since rapid protodeauration is the dominant decomposition pathway in most cases. Recently, the vinyl gold complex has received more and more attention as a versatile intermediate for subsequent transformations, including halogenation,[4] radical addition[5] and transmetallation.[6]

For a long time, oxidation of Au(I) to Au(III) species is considered challenging due to the high oxidation potential (1.40 eV). The reluctance for Au(I) species to undergo oxidative addition, which is usually the entry point for metal-catalyzed cross-coupling reactions, significantly limits their synthetic applications.[7] However, recent studies have demonstrated an alternative solution of Au(I) oxidation to Au(III) by using strong oxidants such as Selectfluor or PhI(OAc)$_2$.[8] This new reaction mode thus unleashes numerous new and unique opportunities for gold catalysis. For example, the stronger Au(III) catalyst can activate alkenes towards nucleophilic attack, and the resulting alkyl-Au(III) intermediate further undergoes transmetallation and reductive elimination to yield cross-coupling product.[9] Similar Au(I/III) reactivity can also be achieved by using diazonium salt as oxidant under photochemical or basic conditions (**Scheme 1A**).[10] Overall, this new gold redox catalysis offers an effective route for alkene difunctionalization. However, two major limitations of this methodology are A) requirement of strong oxidants and B) competing reactivity between Au(I) and Au(III) cations as π-acids. As a result, only very few successful examples of alkyne difunctionalization have been reported using this methodology.[11] Thus, searching for *milder oxidants* to promote this gold redox catalysis is highly desirable.[7h] Herein, we report a successful thioallylation of alkynes under possible gold redox catalysis. A cationic Au(I) catalyst effectively promoted nucleophilic addition of allyl sulfide toward the alkyne; subsequently, the resulting vinyl gold intermediate can be oxidized by the *in-situ* generated allylsulfonium cation, providing a vinyl thioether in a stereoselective fashion. Notably, this novel thioallylation reaction is highly efficient (as low as 0.1% catalyst loading, up to 99% yield, gram scale conversions) with broad substrate scope (**Scheme 1B**). To the best of our knowledge, this is the first example of gold redox catalysis that undergoes Au(I) π-acid activation followed by vinyl-gold oxidation with a mild oxidant, which represents an innovative strategy for alkyne difunctionalization via gold redox catalysis.

Scheme 1. Gold redox catalysis



Our interest in utilizing a sulfonium cation as potential oxidant for gold redox catalysis was initiated by our recent investigation on gold-catalyzed thioalkyne activation.[12] In that work, we discovered that thioalkynes could react with allyl sulfides to form ketenedithioacetals, though in moderate yields and low *E/Z* selectivity (**Figure 1**). To investigate the key allyl transfer process from the proposed intermediate **A**, [13] we conducted the cross-over experiment by reacting thioalkyne with two different allyl sulfides.

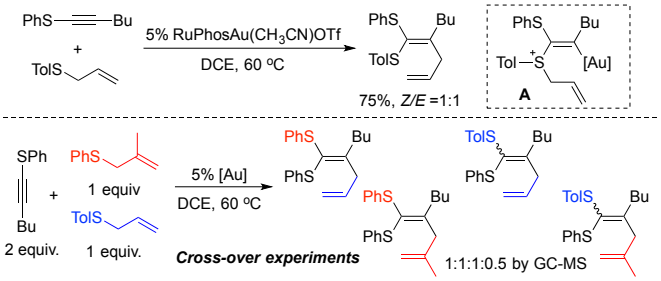


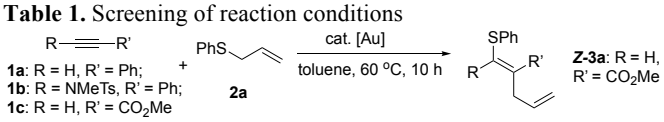
Figure 1. Intermolecular thioallylation by cross-over result

[a] Dr. J. Wang, S. Zhang, Dr. L. Wojtas, Prof. Dr. X. Shi
Department of Chemistry, University of South Florida
Tampa, FL 33620, United States
Fax: (+1) 813-974-3203
E-mail: xmshi@usf.edu
Homepage: http://xmshi.myweb.usf.edu/index.htm
[b] C. Xu, Prof. Dr. H. Chen
Department of Chemistry and Biochemistry, Ohio University
Athens, OH 45791, United States
[c] Dr. Novruz G. Akhmedov
C. Eugene Bennett Department of Chemistry, West Virginia University
Morgantown, WV 26506, United States
[**] We are grateful to NSF (CHE-1665122), NSF (CHE-1709075), NIH (1R01GM120240-01), NSFC (21228204, 21133011, 21373246 and 21522309) for financial support.

Angewandte Communications

Interestingly, significant amount of cross-over products were observed. The fact that this reaction proceeds through an intermolecular allyl transfer process is very intriguing to us. Two possible mechanisms are herein proposed. First, the allyl group attached to the sulfonium cation can form a C-C bond directly with the σ- or π-bond of the vinyl-Au(I) species to generate the thioallylation product. Alternatively, the allyl sulfonium cation can serve as a mild oxidant for vinyl-Au(I) species to generate a transient Au(III) intermediate, which delivers the same product via reductive elimination. The latter mechanism is very exciting to us because it represents a novel methodology to achieve gold redox catalysis. In order to further explore the detailed mechanism and substrate scope of this thioallylation reaction, we conducted reactions between different alkynes and allyl phenyl sulfide **2a** under various gold-catalyzed conditions. The details are shown in **Table 1**.

Table 1. Screening of reaction conditions

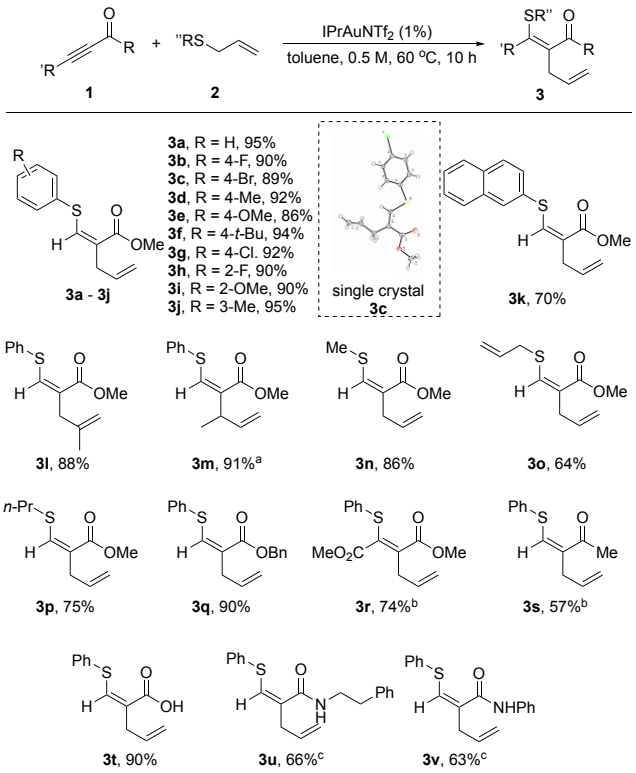


entry	alkyne	Conditions	conversion	yield of **3a** (*Z*/*E*)
1	**1a**	5% JohnPhosAuNTf$_2$	<5%	-
2	**1b**	5% JohnPhosAuNTf$_2$	100%	messy
3	**1c**	5% JohnPhosAuNTf$_2$	100%	79% (3:2)
4	**1c**	5% PPh$_3$AuNTf$_2$	100%	80% (3:2)
5	**1c**	5% RuPhosAuNTf$_2$	100%	80% (3:1)
6	**1c**	5% IPrAuNTf$_2$	100%	96% (*Z* only)
7	**1c**	5% IPrAuCl	<10%	<5%
8	**1c**	Other [Au] catalysts	<90% yields (see SI)	
9	**1c**	5% IPrAuNTf$_2$ (other solvents)	40%-90% yields (see SI)	
10	**1c**	Other metal catalysts (Ag, Cu, Fe, Pd, Rh, Ir, Zn, La, etc.)	<5% conversion (see SI)	
11	**1c**	**1% IPrAuNTf$_2$ ([c]=0.5 M, 60 °C)**	**100%**	**98% (*Z* only)**
12	**1c**	**0.1% IPrAuNTf$_2$ ([c]=2.0 M, 60 °C), 48 h, gram scale**	**100%**	**95% (*Z* only)**
13	**1c**	1% IPrAuNTf$_2$ ([c]=0.5 M, 40 °C, 48 h)	93%	88% (*Z* only)

Reaction conditions: 5% catalyst was added to a toluene solution (1 mL) of alkyne **1** (0.15 mmol) and allyl sulfide **2a** (0.1 mmol), and reaction was kept at 60 °C for 10 h. Conversion and yield were determined by ^{1}H NMR spectroscopy using dimethylsulfone as internal standard.

Under gold-catalyzed conditions (5% JohnPhosAuNTf$_2$, toluene and 60 °C), reaction of **2a** and phenylacetylene **1a** gave almost no conversion with most of the starting materials recovered, suggesting phenylacetylene was not reactive enough under these conditions. The more electron-rich ynamide **1b** gave messy reaction mixtures with no clear product identified. We then turned our attention to the carbonyl-activated alkyne propiolate **1c** due to more facile nucleophilic addition. To our delight, the thioallylation product **3a** was observed in 79% yield as a 3:2 *Z*/*E* mixture. Further screening revealed IPrAuNTf$_2$ as the optimal gold catalyst, giving product **3a** as a single isomer. The alkene geometry was later confirmed as *Z*-configuration by NMR.[14] This result suggested a possible mechanism of sulfide undergoing *trans*-addition to the gold(I)-activated alkyne, followed by subsequent allyl transfer. Toluene was optimal for this reaction, as other solvents provided inferior results. Notably, other metal catalysts including Ag, Cu, Fe, Pd, Rh, Ir, Zn and La were inactive for this reaction (see details in SI), which highlighted the unique reactivity of gold catalyst for this transformation. Finally, increasing the reaction concentration to 0.5 M gave complete conversion (10 h) and excellent yield (98%) even with only 1% catalyst loading. Further increasing the concentration to 2 M allowed a gram-scale synthesis of **3a** in excellent yield, with only 0.1% catalyst under extended reaction time (48 h). Lowering reaction temperature to 40 °C resulted in incomplete conversion. With the optimized conditions in hand, we tested the scope of this reaction. The results are summarized in **Table 2**.

Table 2. Reaction scope of carbonyl activated alkynes



Reaction conditions: 1% catalyst was added to a toluene solution (0.6 mL) of alkyne **1** (0.45 mmol) and allyl sulfide **2** (0.3 mmol), and reaction was kept at 60 °C for 10 h. [a] Starting with *trans*-crotyl phenyl sulfide. [b] 2% catalyst was used. [c] 0.3 mmol alkyne and 0.45 mmol sulfide were used.

Overall, various aryl allyl sulfides are all suitable for this reaction, giving excellent yields in all cases regardless of the substitutions on the phenyl group (**3a-3j**). Methyl-branched allyl sulfides successfully participated in this reaction, and desired products were formed as a single isomer with excellent yields (**3l** and **3m**). Notably, the structure of **3m** clearly demonstrated the exclusive S_N2' addition of vinyl gold intermediate toward allylsulfonium cation. Alkyl-substituted allyl sulfides also worked well for this transformation, providing desired products in good to excellent yields (**3n-3p**). Alkynes bearing other electron-withdrawing groups were also tested. while benzylic ester (**3q**) and carboxylic acid (**3t**) provided excellent yields, ketone (**3s**) and amides (**3u** and **3v**) were obtained with only moderate yields, presumably due to catalyst deactivation by substrate coordination. Phenyl or alkyl (Me and *n*-Bu) substituted internal propiolates gave almost no reaction even under extended reaction time (48 h), like due to the low reactivity of these internal alkynes. However, the di-ester substituted internal alkyne (dimethyl acetylenedicarboxylate) worked well, realizing **3r** in 74% yield. In addition, no sulfide conversion was observed when benzyl methyl sulfide was used, which highlighted the unique reactivity of allyl sulfides for this transformation. It's worth noting that in all cases only the *Z*-isomers were observed. The alkene geometry was ambiguously confirmed by the X-ray structure of **3c**.

To further identify if a Au(I/III) process is involved during the allyl transfer, reaction between **1c** and **2a** was monitored by mass spectrometry (**Figure 2**).

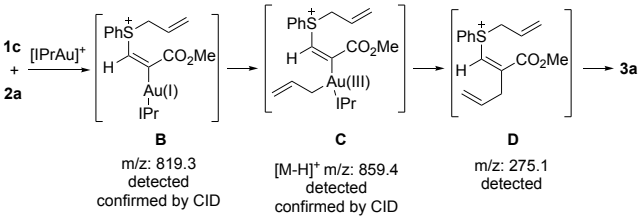
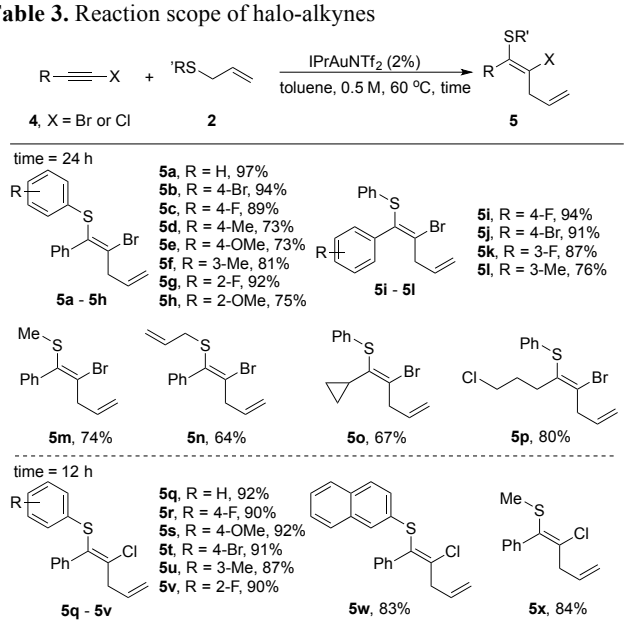


Figure 2. Mechanistic study by mass spectrometry

The ion at *m/z* = 819.3 was detected and identified as intermediate **B** based on its CID data. Importantly, the ion at *m/z* = 859.4 corresponding to Au(III) intermediate **C** ($[M-H]^+$ ion) was clearly observed, and its structure was further confirmed by CID. Intermediate **D** was also present in the mass spectrum (see detailed MS study in SI). In addition, careful interpretation of the mass data revealed another Au(III) ion at *m/z* = 735.1, which corresponds to allyl-Au(III)-SPh ion (see details in SI). In conclusion, the MS data largely supports the Au(I/III) pathway; herein, a tentative mechanism involving a vinyl gold formation (intermediate **B**) and subsequent allyl transfer to form Au(III) intermediate **C** is proposed. This mechanism was further backed up by additional MS evidences with a different gold catalyst and sulfide (see details in SI). More efforts will be made to further confirm this intriguing Au(I/III) mechanism including NMR analysis and computational study.

This novel thioallylation method provides a rapid access to highly functionalized alkenes in a stereoselective fashion. To further expand its reaction scope, several terminal alkynes with electron-deficient aromatic substitutions were tested, including C_6F_5 and 4-pyridinal substituted alkynes. Unfortunately, these substrates gave no reaction under the gold redox conditions. We then turned our attention to internal alkynes with EWG substitution. Notably, compared with NO_2, CN and CF_3 modified alkynes, halo-alkynes are easy to prepare from readily available starting materials. However, application of these compounds in synthesis are rather limited to ynamide preparation[15] and Cardiot-Chodkiewicz type coupling reaction[16]. The potential synthetic utility of halo-alkyne is somehow neglected.[17] To our great delight, halo-alkynes **4** with Br- or Cl- substitution worked well in the thioallylation with slightly increased catalyst loading (2%). The desired tetra-substituted alkenes **5** were prepared successfully in good to excellent yields as exclusive *Z*-isomers. The substrate scope is summarized in **Table 3**.

Table 3. Reaction scope of halo-alkynes

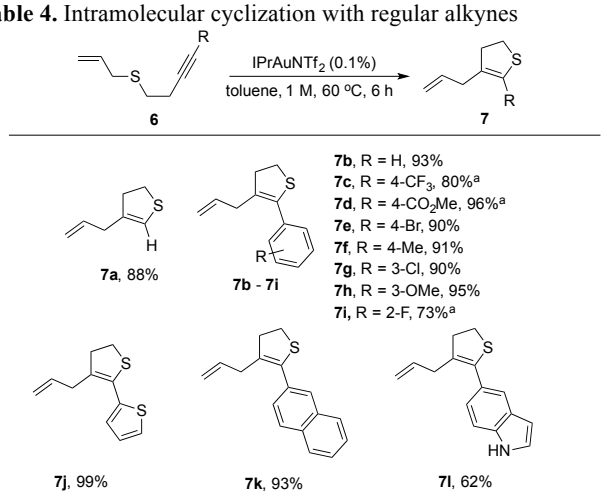


Reaction conditions: 2% catalyst was added to a toluene solution (0.4 mL) of alkyne **4** (0.3 mmol) and allyl sulfide **2** (0.2 mmol), and reaction was kept at 60 °C for 12 or 24 h.

Compared with the carbonyl-activated alkynes, reactions with halo-alkynes especially bromo-alkynes requires longer reaction time presumably due to the reduced reactivity of alkynes. Different aryl allyl sulfides gave good to excellent yields for this transformation, with either EWG or EDG substitution on arene (**5a-5h**). In general, excellent yields were obtained with EWG-substituted aryl sulfides, while EDG-substituted sulfides gave lower yields due to incomplete conversions (around 90% conv.). Similar good to excellent yields were observed with different aryl substitutions on bromo-alkynes (**5i-5l**). Alkyl substituted allyl sulfides and bromo-alkynes are all suitable substrates for this transformation as well, indicating the broad substrate scope of this transformation (**5m-5p**). Notably, no cyclopropane ring opening was observed in substrate **5o**, which ruled out the radical reaction pathway. Chloro-alkynes were also prepared and charged with the reaction conditions. As expected, superior reactivity (faster reaction) over bromo-alkynes was observed with the chloro-alkynes, giving the desired tetra-substituted vinyl chloride in excellent yields in most cases (**5q-5x**). Moreover, single alkene isomer was obtained in all cases. Comprehensive NMR analysis for **5a**, **5c** and **5p** confirmed the geometry of the alkene as exclusive *Z*-isomer similar to the carbonyl-activated alkyne substrates, which is consistent with the proposed mechanism (see details in SI). The efficient synthesis of the tetra-substituted alkenes in a stereoselective fashion greatly highlighted the unique advantage of this novel gold redox approach.

As mentioned in **Table 1**, simple internal alkynes failed to participate in this transformation, presumably due to low reactivity upon nucleophilic addition. To further extend the reaction scope to regular alkynes, we propose to facilitate this reaction in an intramolecular fashion. Alkynes **6** bearing an allyl sulfide pendant were applied to the reaction conditions. To our delight, di-hydrothiophenes **7** were obtained through a 5-*endo*-dig cyclization in excellent yields, even with catalyst loading as low as 0.1%. The scope of this reaction is summarized in **Table 4**. This intramolecular thioallylation gave excellent yield for terminal alkyne (**7a**). Good to excellent yields were obtained for aryl substituted substrates too (**7b-7i**, **7k**). Interestingly, strong EWG-substituted aryl alkynes (**7c**, **7d** and **7i**) reacted much slower, suggesting the more difficult Au(I) oxidation. Notably, heterocyclic substitutions such as thiophene and unprotected indole were also well-tolerated for this transformation (**7k**, **7m**). The ultra-low catalyst loading (TON around 1000) greatly highlighted the efficiency and practicality of this transformation.

Table 4. Intramolecular cyclization with regular alkynes



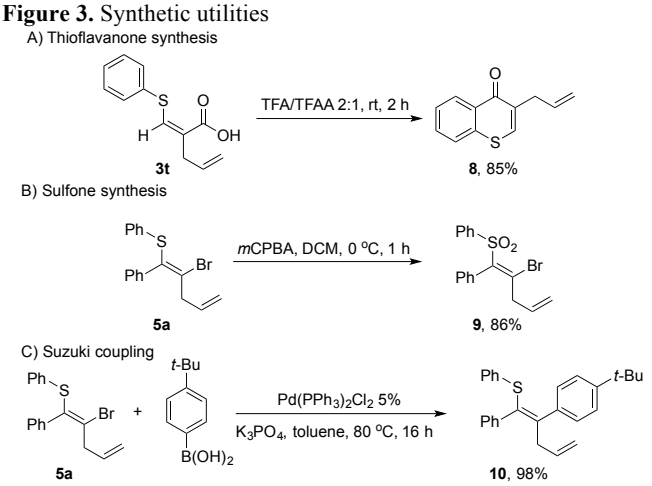
Reaction conditions: 0.1% catalyst was added to a toluene solution (0.3 mL) of alkyne **6** (0.3 mmol), and reaction was kept at 60 °C for 6 h. [a] reacted for 24 h.

To further showcase the synthetic utility of this transformation, we aimed to convert the thioallylation products into value-added synthetic intermediates. By treating with TFA/TFAA, thioflavone **8** was successfully formed from acid **3t** via a Friedel-Crafts type cyclization (**Figure 3A**). The sulfide **5a** can be efficiently converted to sulfone **9** by oxidation with *m*CPBA at 0 °C without interrupting the pendant allyl group (**Figure 3B**). The vinyl bromide motif in **5a** proved to be a useful synthetic handle for cross-coupling reactions as well, as desired Suzuki coupling product **10** was obtained in excellent yield (**Figure 3C**). These results clearly demonstrated the versatile synthetic utilities of the thioallylation substrates.

In conclusion, we have reported herein an efficient and stereoselective thioallylation of alkynes possibly enabled by gold

redox catalysis. The Au(I/III) catalytic cycle is proposed with sulfonium cation as a mild oxidant, which is confirmed by Mass Spectrometry study. This reaction displayed a broad substrate scope. Different alkynes including carbonyl-activated alkynes, halo-alkynes are well-suited for this transformation; intramolecular cyclizations proved feasible too. Subsequent transformations on thioallylation products further indicated the synthetic utility of this reaction. Detailed mechanistic study as well as expanding this mild gold redox strategy to other sulfides and alkynes are currently under investigation in our group.

Figure 3. Synthetic utilities



Keywords: gold redox catalysis · thioallylation · vinyl gold · sulfonium cation

[1] For reviews, see: a) A. S. K. Hashmi, *Gold Bull.* **2004**, 37, 51-65; b) A. Fürstner, P. Davies, *Angew. Chem. Int. Ed*. **2007**, 46, 3410-3449; c) A. S. K. Hashmi, *Chem. Rev.* **2007**, 107, 3180-3211; d) E. Jimenez-Nunez, A. M. Echavarren, *Chem. Rev.* **2008**, 108, 3326-3350; e) D. J. Gorin, B. D. Sherry, F. D. Toste, *Chem. Rev.* **2008**, 108, 3351-3378; f) R. Dorel, A. M. Echavarren, *Chem. Rev.* **2015**, 105, 9028-9072; g) A. M. Asiri, A. S. K. Hashmi, *Chem. Soc. Rev.* 2016,**45**, 4471-4503.

[2] a) D. J. Gorin, F. D. Toste, *Nature* **2007**, 446, 395-403; b) M. Pernpointner, A. S. K. Hashmi, *J. Chem. Theory Computation* **2009**, 5, 2717-2725; c) A. Leyva-Perez, A. Corma, *Angew. Chem. Int. Ed*. **2012**, 51, 614-635.

[3] Several vinyl gold species have been isolated, see: a) J. A. Akana, K. X Bhattacharyya, P. Muller, J. P. Sadighi, *J. Am. Chem. Soc.* **2007**, 129, 7736-7737; b) L.-P. Liu, B. Xu, M. S. Mashuta, G. B. Hammond, *J. Am. Chem. Soc.* **2008**, 130, 17642-17643; c) D. Weber, M. A. Tarselli, M. R. Gagne, *Angew. Chem. Int. Ed*. **2009**, 48, 5733-5736; d) A. S. K. Hashmi, A. M. Shuster, F. Rominger, *Angew. Chem. Int. Ed*. **2009**, 48, 8247-8249.

[4] a) A. Buzas, F. Gagosz, *Org. Lett.* **2006**, 8, 515-518; b) M. Yu, G. Zhang, L. Zhang, *Org. Lett.* **2007**, 9, 2147-2150; c) D. Wang, X. Ye, X. Shi, *Org. Lett.* **2010**, 12, 2088-2091; d) T. Wang, S. Shi, M. Rudolph, A. S. K. Hashmi, *Adv. Syn. Catal.* **2014**, 356, 2337-2342.

[5] H. Peng, N. G. Akhmedov, Y. Liang, N. Jiao, X. Shi, *J. Am. Chem. Soc.* **2015**, 137, 8912-8915.

[6] For Au/metal dual catalysis, see: a) J. Hirner, Y. Shi, S. Blum, *Acc. Chem. Res*. **2011**, 44, 603-613; b) A. S. K. Hashmi, C. Lothschütz, R. Dopp, M. Ackermann, J. D. B. Becker, M. Rudolph, C. Scholz, F. Rominger, *Adv. Syn. Catal.* **2012**, 354, 133-147; c) P. Garcia-Dominguez, C. Nevado, *J. Am. Chem. Soc.* **2016**, 138, 3266-3269.

[7] For examples of oxidative addition of Au(I) to alkyl halides, see: a) A. Tamaki, J. K. Kochi, *J. Organomet. Chem.* **1972**, 40, C81-C84; b) A. Tamaki, J. K. Kochi, *J. Chem. Soc., Dalton Trans.* **1973**, 23, 2620-2626; c) A. Tamaki, J. K. Kochi, *Inorg. Nucl. Chem. Lett.* **1973**, 9, 1175-1177; d) A. Tamaki, J. K. Kochi, *J. Organomet. Chem.* **1974**, 64, 411-425; e) A. Johnson, R. J. Puddephatt, *J. Organomet. Chem.* **1975**, 85, 115-121; f) M. D. Levin, F. D. Toste, *Angew. Chem. Int. Ed*. **2014**, 53, 6211-6215; g) M. S. Winston, W. J. Wolf, F. D. Toste, *J. Am. Chem. Soc.* **2014**, 136, 7777-7782.

[8] For reviews on Au(I/III) oxidative coupling, see: a) M. N. Hopkinson, A. D. Gee, V. Gouverneur, *Chem. Eur. J.* **2011**, 17, 8248-8262; b) H. A. Wegner, M. Auzias, *Angew. Chem. Int. Ed*. **2011**, 50, 8236-8247; for pioneer work reported on Au(I/III) cross-coupling, see: c) G. Zhang, Y. Peng, L. Cui, L. Zhang, *Angew. Chem. Int. Ed*. **2009**, 48, 3112-3115; d) A. S. K. Hashmi, T. D. Ramamurthi, F. Rominger, *J. Organomet. Chem.* **2009**, 694, 592-597; e) M. Pazicky, A. Loos, M. J. Ferreira, D. Serra, N. Vinokunov, F. Rominger, C. Jakel, A. S. K. Hashmi, M. Limbach, *Organometallics* **2010**, 29, 4448-4458.

[9] For early examples of Au(III)-mediated nucleophilic addition-homo-coupling sequence, see: a) A. S. K. Hashmi, M. C. Blanco, D. Fisher, J. W. Bats, *Eur. J. Org. Chem.* **2006**, 1387-1389; b) H. A. Wegner, S. Ahles, M. Neuburger, *Chem. Eur. J.* **2008**, 14, 11310-11313; c) S. Fustero, P. Bello, B. Fernandez, C. del Pozo, G. B. Hammond, *J. Org. Chem.* **2009**, 74, 7690-7696; for Au(I) catalyzed nucleophilic addition-cross-coupling sequence, see: d) G. Zhang, L. Cui, Y. Wang, L. Zhang, *J. Am. Chem. Soc.* **2010**, 132, 1474-1475; e) A. D. Melhado, W. E. Brenzovich Jr., A. D. Lacktner, F. D. Toste, *J. Am. Chem. Soc.* **2010**, 132, 8885-8887; f) W. E. Brenzovich Jr., D. Benitez, A. D. Lacktner, H. P. Shunatona, E. Tkatchouk, W. A. Goddard III, F. D. Toste, *Angew. Chem. Int. Ed*. **2010**, 49, 5519-5522.

[10] For photoredox conditions with gold catalysts and photo-active dyes, see: a) B. Sahoo, M. N. Hopkinson, F. Glorius, *J. Am. Chem. Soc.* **2013**, 135, 5505-5508; b) X. Shu, M. Zhang, Y. He, H. Frei, F. D. Toste, *J. Am. Chem. Soc.* **2014**, 136, 5844-5847; c) M. N. Hopkinson, A. Tlahuext-Aca, F. Glorius, *Acc. Chem. Res*. **2016**, 49, 2261-2272; for photoredox conditions with photo-active gold catalyst only and no additional dyes, see: d) J. Xie, S. Shi, T. Zhang, N. Mehrkens, M. Rudolph, A. S. K. Hashmi, *Angew. Chem. Int. Ed.* **2015**, 54, 6046-6050; e) J. Xie, T. Zhang, F. Chen, N. Mehrkens, F. Rominger, M. Rudolph, A. S. K. Hashmi, *Angew. Chem. Int. Ed.* **2016**, 55, 2934-2938; f) L. Huang, M. Rudolph, F. Rominger, A. S. K. Hashmi, *Angew. Chem. Int. Ed.* **2016**, 55, 4808-4813; g) J. Xie, J. Li, V. Weingand, M. Rudolph, A. S. K. Hashmi, *Chem. Eur. J.* **2016**, 22, 12646-12650; h) L. Huang, F. Rominger, M. Rudolph, A. S. K. Hashmi, *Chem. Commun.* **2016**, 52, 6435-6438; i) S. Witzel, J. Xie, M. Rudolph, A. S. K. Hashmi, *Adv. Synth. Catal.* **2017**, 359, 1522-1528; for basic conditions, see: j) R. Cai, M. Lu, E. Y. Aguilera, Y. Xi, N. G. Akmedov, J. L. Petersen, H. Chen, X. Shi, *Angew. Chem. Int. Ed.* **2015**, 54, 8772-8776; k) B. Dong, H. Peng, S. E. Motika, X. Shi, *Chem. Eur. J.* **2017**, 23, 11093-11099.

[11] For Meyer-Schuster-type rearrangement, see a) G. Zhang, Y. Peng, L. Cui, L. Zhang, *Angew. Chem. Int. Ed*. **2009**, 48, 3112-3115; b) Y. Yu, W. Yang, D. Pflasterer, A. S. K. Hashmi, *Angew. Chem. Int. Ed*. **2014**, 53, 1144-1147; c) J. Um, H. Yun, S. Shin *Org. Lett*. **2016**, 18, 484-487; d) A. Tlahuext-Aca, M. N. Hopkinson, R. A. Garza-Sanchez, F. Glorius, *Chem. Eur. J.* **2016**, 23, 5909-5913; for Sonogashira-type coupling reaction, see: e) A. Tlahuext-Aca, M. N. Hopkinson, B. Sahoo, F. Glorius, *Chem. Sci.* **2016**, 7, 89-93; for oxyarylation and aminoarylation, see: f) L. Huang, M. Rudolph, F. Rominger, A. S. K. Hashmi, *Angew. Chem. Int. Ed*. **2016**, 55, 4808-4813; g) Z. Wang, T. Tan, C. Wang, D. Yuan, T. Zhang, P. Zhu, C. Zhu, J. Zhou, L. Ye, *Chem. Commun.* **2017**, 53, 6848-6851.

[12] X. Ye, J. Wang, S. Ding, S. Hosseyni, L. Wojtas, N. G. Akhmedov, X. Shi, *Chem. Eur. J.* **2017**, 23, 10506-10510.

[13] Hashmi group reported an intramolecular oxyallylation reaction in an analogous allyl 2-ethynylphenyl ether system; a mechanism involving [3,3]-sigmatropic rearrangement was proposed, which is supported by cross-over experiment and computational study. See: a) A. S. K. Hashmi, K. Graf, M. Ackermann, F. Rominger, *ChemCatChem* **2013**, 5, 1200-1204; b) M. Ackermann, J. Bucher, M. Rappold, K. Graf, F. Rominger, A. S. K. Hashmi, *Chem. Asian J.* **2013**, 8, 1786-1794; c) L. N. dos Santos Comprido, J. E. M. N. Klein, G. Knizia, J. Kastner, A. S. K. Hashmi, *Chem. Eur. J.* **2017**, 23, 10901-10905.

[14] K. Hayakawa, Y. Kamikawaji, K. Kanematsu, *Tetrahedron. Lett.* **1982**, 23, 2171-2174.

[15] a) K. A. Dekorver, H. Li, A. G. Lohse, R. Hayashi, Z. Lu, Y. Zhang, R. P. Hsung, *Chem. Rev.* **2010**, 110, 5064-5106; b) G. Evano, A. Coste, K. Jouvin, *Angew. Chem. Int. Ed*. **2010**, 45, 2840-2859.

[16] K. S. Sindhu, A. P. Thankachan, P. S. Sajitha, G. Anikumar, *Org. Biomol. Chem*. **2015**, 13, 6891-6905.

[17] W. Wu, H. Jiang, *Acc. Chem. Res*. **2014**, 47, 2483-2504.

10.1002/anie.201802540

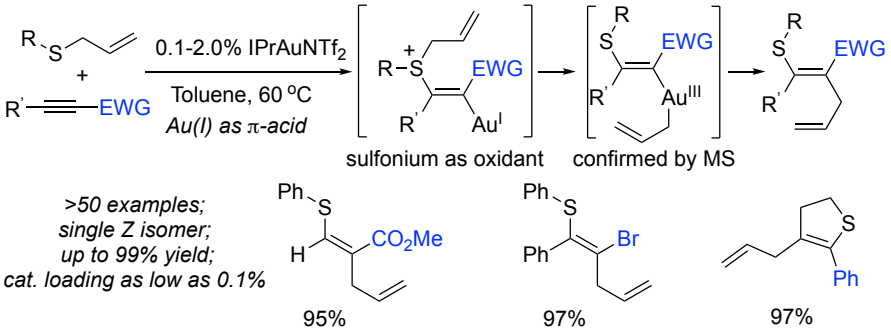
Angewandte Communications

Gold Redox Catalysis

Jin Wang,[a] Shuyao Zhang,[a] Chang Xu,[b] Lukasz Wojtas,[a] Novruz G. Akhmedov,[c] Hao Chen,[b] Xiaodong Shi[a,]*

Page 1 – Page 5

Highly Efficient and Stereoselective Thioallylation of Alkynes: Possible Gold Redox Catalysis with No Need of a Strong Oxidant



Abstract: *A possible gold redox-catalyzed stereoselective thioallylation of alkynes was achieved. The reaction was accomplished with high efficiency (as low as 0.1% catalyst loading, up to 99% yield) and broad substrate scope (various alkynes, inter- and intramolecular fashion). The gold(I) catalyst acts as both π-acid for alkyne activation and redox catalyst for Au(I/III) coupling, while the in-situ generated sulfonium cation functions as a mild oxidant. This novel methodology provides an exciting system for gold redox catalysis without the need of a strong oxidant.*