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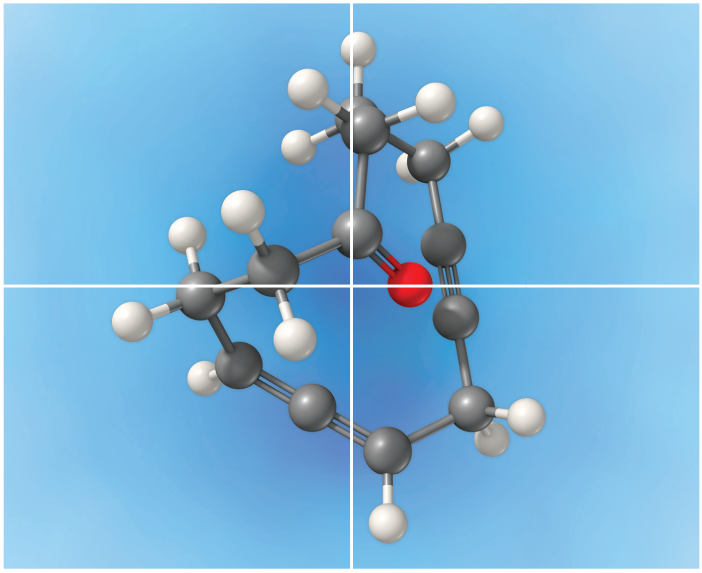

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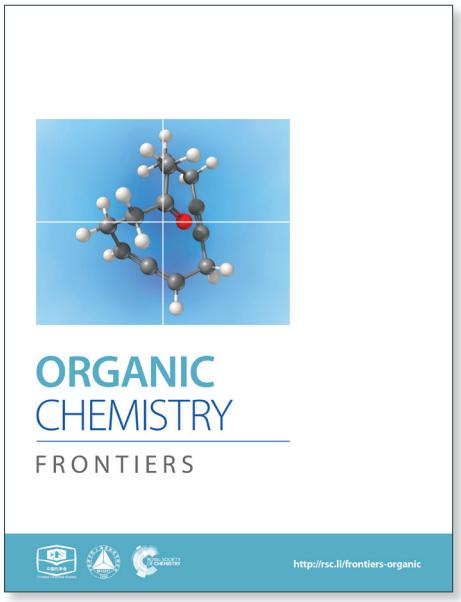

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ARTICLE

An Efficient Synthesis of *gem*-Diiodoolefins and (*E*)-iodoalkenes from Propargylic Amides with Cu(I)/Cu(III) Cycle

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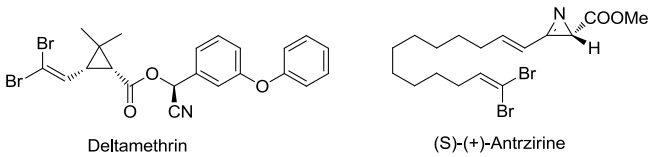
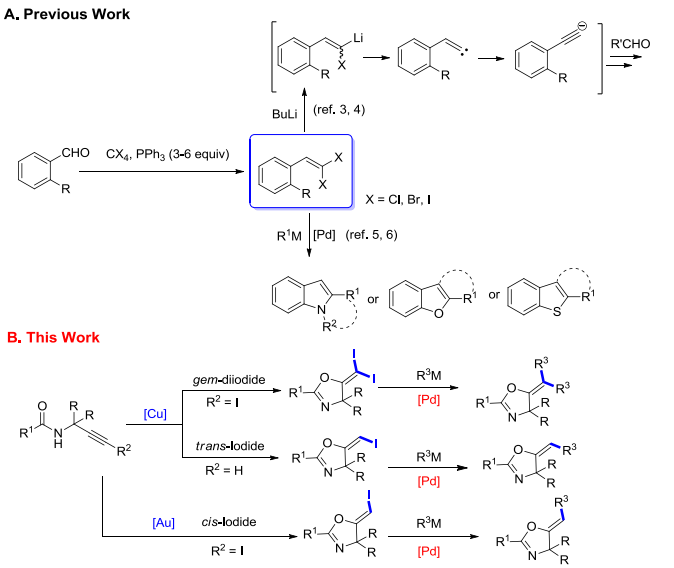
gem-Dihaloalkenes are very important building blocks widely used in organic synthesis. However the synthetic methods toward this functional group are very limited. Starting from an unexpected copper-catalyzed cyclization of propargylic amide, a new route of synthesis of *gem*-dihaloalkenes was developed. According to the plausible Cu(I)/Cu(III) catalytic cycle, another oxidative iodination protocol was developed. Through this improved method, a series of *gem*-diiodoolefins were synthesized in high yields. In addition, (*E*)-iodoalkenes could be also synthesized efficiently using the same approach, which is complementary to the gold-catalyzed reaction giving (*Z*)-iodoalkenes. These iodoolefins could be further transformed into various trisubstituted or tetrasubstituted alkenes, enynes, dienes and trienes with palladium-catalyzed coupling reactions.

1. Introduction

1,1-Dihalo-1-alkenes represent an important type of organic compounds. They exist in many bioactive natural products as well as pharmaceuticals (Scheme 1)[1]. For example, Deltamethrin[1a] products bearing a *gem*-dibromoalkene functional group, are among the most popular and widely used insecticides in the world. More importantly, 1,1-dihalo-1-alkenes are very valuable synthetic intermediates used in synthetic chemistry.[2] In the presence of base or metal reagent, 1,1-dihalo-1-alkenes went through α-elimination generating vinylidene type intermediates, the subsequent migration of H atom or alkyl group would formed alkynes (Scheme 2). Thus 1,1-dihalo-1-alkenes were widely used as alkyne equivalents, such as the well-known Corey-Fuchs reaction.[3] By using this method, Kibayashi group realized the total synthesis of Pumiliotoxins A and 225F from *gem*-dibromoalkene.[4] Recently the blossom of transition-metal catalyzed cross coupling reactions makes this *gem*-dihaolo-1-alkenes extremely useful in the synthesis of various important heterocycles (Scheme 2). For example, through the sequential intramolecular and intermolecular coupling reactions, Lautens et al developed a series of efficient methods for the construction of multisubstituted indoles, benzofurans, and benzothiophenes.[5] The Wu group developed an efficient synthetic method to polyfluoroarylpyrrolo[1,2-α]quinolines via palladium-catalyzed double arylation reactions of *gem*-dibromoalkenes.[6]



Scheme 1. Natural Products and Pharmaceuticals containing *gem*-dihaloalkenes



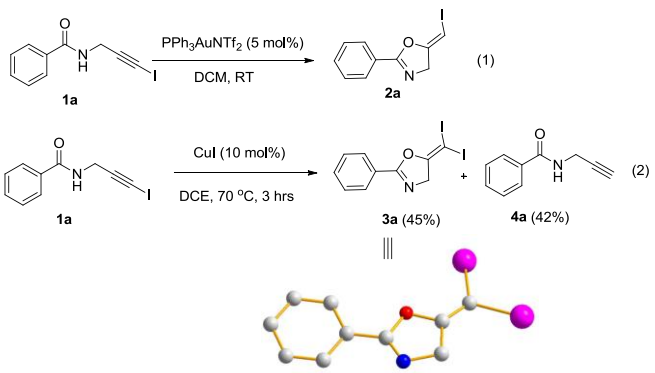
Scheme 2. Synthesis of *gem*-dihaloalkenes and their synthetic applications

1,1-Dihalo-1-alkenes are important building blocks in organic synthesis, however the synthetic methods toward this functional group are very limited. The current methods mostly focused on the Wittig type reaction between carbonyl compounds and tetrahalocarbon (Scheme 2).[7] However this protocol requires a large excess amount of triphenylphosphine (4-6 equiv), which is not ideal from the point view of atom economy and green chemistry. The development of other practical synthetic method is highly desirable. We reported herein a facile synthesis of *gem*-diiodoolefins with Cu(I)/Cu(III) catalytic cycle. Following this approach, various vinyl halide with different stereo-configurations could be easily prepared. The obtained *gem*-diiodoolefins were further transformed into tetrasubstituted olefins with palladium-catalyzed cross coupling reactions.

2. Results and discussion

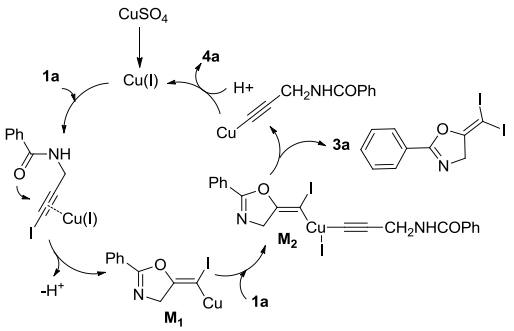
2.1. An unexpected synthesis of *gem*-diiodoalkenes from iodoalkynes with Cu(I)/Cu(III) catalytic cycle

In recent years, haloalkynes have emerged as a type of powerful and versatile building blocks widely used in organic synthesis.[8] The alkyne and halide parts, serving as two functional groups, were transformed into various functionalized alkynes and heterocycles through addition, cross coupling or cycloaddition reactions.[9] As a continuation of our research interests in Pi acid transition-metal-catalyzed reactions,[10] We studied the cyclization reaction of propargylic amide[11] **1a**. When Ph_3AuNTf_2 was used as the catalyst, the desired (*Z*)-iodoalkene **2a** was isolated in 83% yield. However this product was not stable, probably because it could isomerize into the aromatic oxazole through double bond migration (Eq. (1), Scheme 3). To our surprize, when CuI was used as the catalyst, another unknown *gem*-diiodide product **3a** was observed as the major product. Its structure was unambiguously characterized by NMR, Mass and also single crystal X-ray analysis (Eq. (2), Scheme 3). Under this condition, this product was isolated in 45% yield. However, its isolated yield is as high as 90% based on the iodine source. Through detailed analysis of the reaction mixture, the de-iodine amide **4a** was isolated in 42% yield.



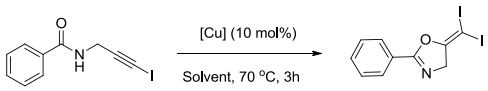
Scheme 3. Gold or Copper-catalyzed cyclization of propargylic amide

Based on these results, a plausible Cu(I)-Cu(III) catalytic cycle was proposed for this unexpected reaction (Scheme 4)[12]. Copper(I)-catalyzed intramolecular 5-exo-dig cyclization generated alkene copper intermediate $\mathbf{M_1}$. Subsequent oxidative addition with alkyne iodide **1a** would form the Cu(III) intermediate $\mathbf{M_2}$, which went through reductive elimination generating *gem*-diiodide alkene **3a** and another alkyne copper intermediate. Protonation of this intermediate would form the amide **4a** and regenerate copper(I) catalyst. It should be noted that Hu et al also observed similar mechanism in the reaction of $AgCF_3$, benzyne and alkyne iodide.[13] Also Boger and Gevorgyan demonstrated that haloalkynes could serve as an effective sources of the corresponding X^+ in their earlier reports.[14]



Scheme 4. Proposed Cu(I)-Cu(III) catalytic mechanism

Table 1. Optimization of reaction conditions[a]



Entry	Catalyst	Solvent	Yield(%)[a]
1	CuI	DCE	90
2	CuCl	DCE	86
3	CuBr	DCE	72
4	$CuPF_6(CH_3CN)_4$	DCE	50
5	IPrCuI	DCE	69
6	$Cu(acac)_2$	DCE	75
7	$CuSO_4$	DCE	95
8	$CuCl_2$	DCE	79
9	$Cu(OAc)_2$	DCE	75
10	$CuSO_4$	CH_3CN	26
11	$CuSO_4$	Dioxane	76
12	$CuSO_4$	THF	84
13	$CuSO_4$	Toluene	75
14	/	DCE	0

[a] Reaction conditions: **1a** (0.1 mmol), [Cu] (0.01 mmol) in solvent (1 mL) was stirred at 70 ℃ for 3 h. [b] Isolated yields based on iodine source.

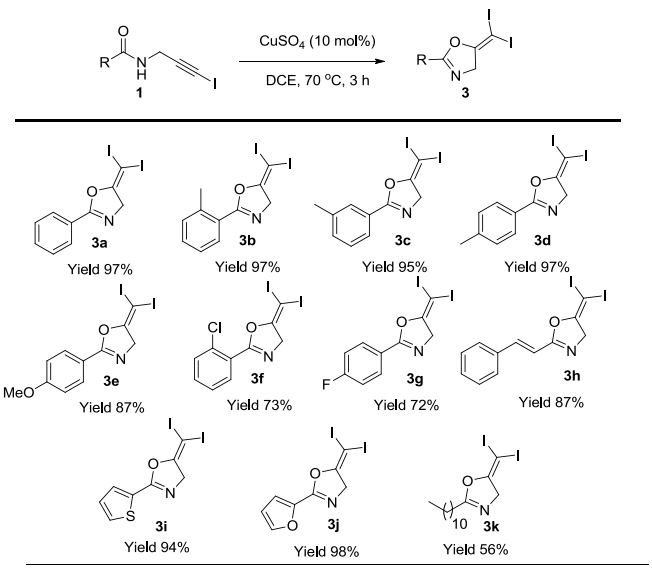
A screening of different copper catalysts indicated that this is a general reaction for all the copper salts tested (Table 1). Not only Cu(I), but also Cu(II) were also effective for this transformation. Copper(II) was probably reduced into Cu(I) to catalyze this reaction. Among all the copper catalysts, the very cheap $CuSO_4$ was the optimal choice and the target diiodide **3a**

was isolated in 95% yield in DCE solution (entry 7). Other solvents led to reduced yields (entries 10-13). Blank test showed that copper catalyst is necessary for this transformation (entry 14).

With the optimized conditions established, the substrate scope was next examined (Table 2). Different substituents at the aromatic group, including methyl, methoxyl, and halogen didn't affect the reaction (**3b**-**3g**). Styryl group, heterocycles are all tolerated in this reaction and the corresponding *gem*-diiodides were isolated in excellent yields (**3h**-**3j**). Aliphatic substrate gave the corresponding product in reduced yield (**3k**).

Then the scope of this protocol was also tested (Table 4). Similarly this reaction showed a very general scope. Different aromatic substituents, styryl group, furan or thiophene substituents, do not affect the reaction efficiency and various *gem*-diiodidealkenes were prepared in good to excellent yields with this very simple procedure (**3b**-**3k**). Substrates bearing a quarternary carbon centre also reacted very well, generating the corresponding products in excellent yields (**3l**-**3m**). All there reactions didn't require inert atmosphere. Thus such simple procedure and mild conditions make this protocol very practical in organic synthesis.

Table 2. Substrate scope[a]

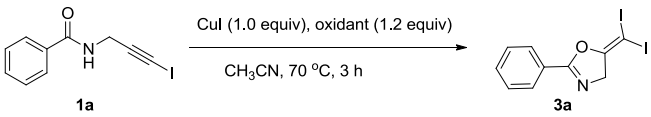


[a] Reaction conditions: **1** (0.2 mmol), $CuSO_4$ (0.02 mmol) in DCE (2 mL) was stirred at 70℃ for 3 h. Isolated yields were reported.

2.2. Improved oxidative iodination toward *gem*-diiodoalkenes

In the above transformation, the yield was almost quantitive calculated on iodine element. However, a half of the substrates were transformed into another propargylic amide **4a**. To improve this atom economy issue, we proposed another reaction pathway to mimic the previous Cu(I)/Cu(III) cycle: CuI catalyzed similar cyclization of **1a** to for $\mathbf{M_1}$.This Cu(I) intermediate $\mathbf{M_1}$ could be oxidized into a similar Cu(III) intermediate by adding another strong oxidant, which would also go through reductive elimination to form the *gem*-diiodide **3a**. Herein, CuI serve as the cyclization catalyst and also iodine source, so one equivalent of CuI is necessary. Moreover, to inhibit the oxidative addition of alkyne idodide to $\mathbf{M_1}$, the choice of oxidant is very crucial for the success of this transformation. Then a series of oxidants were test (Table 3). It was found that selectfluor was the best oxidant, leading to the target **3a** in 84% yield (entry 1). Other oxidants such as $PhI(OAc)_2$, DDQ, MCPBA, TBHP, H_2O_2 all led to reduced yields.

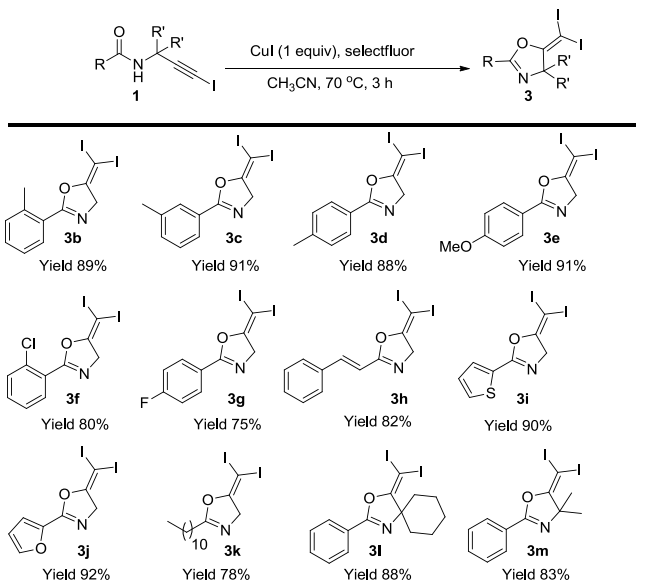
Table 3. Optimization of oxidants[a]



Entry	Oxidant (1.2equiv)	Yield(%)[b]
1	Selectfluor	84
2	$PhI(OAc)_2$	43
3	DDQ	28
4	$K_2S_2O_8$	51
5	3-Chloroperbenzoic acid	57
6	tert-butyl hydroperoxide	37
7	H_2O_2	12

[a] Reaction conditions: **1a** (0.1 mmol) , **CuI** (0.1 mmol) , Oxidant (0.12 mmol) in solvent (1 mL) was stirred at 70 ℃ for 3 h. [b] Isolated yields were reported.

Table 4. Substrate scope of the oxidative iodination reaction[a]

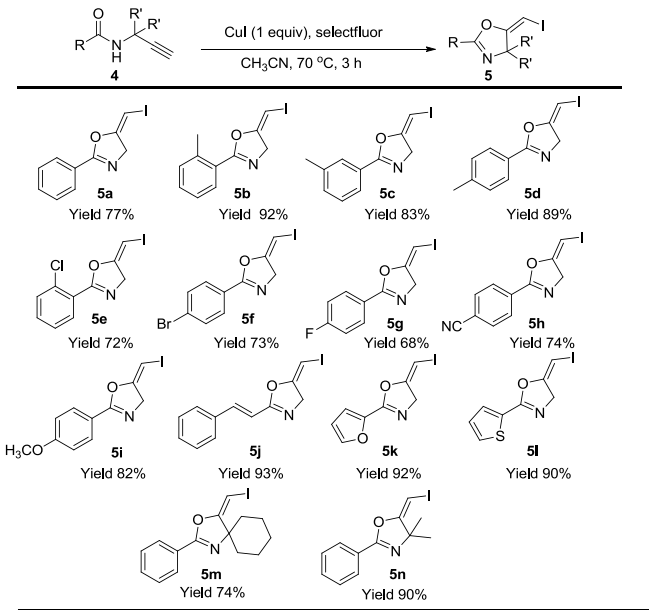


[a] Reaction conditions: **1a** (0.2 mmol), CuI (0.2 mmol), selectfluor (0.24 mmol), in CH_3CN (2 mL) was stirred at 70 ℃ for 3 h. Isolated yields were reported.

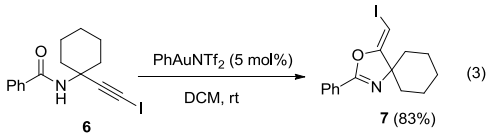
2.3. Synthesis of (*E*)-1-iodo-1-alkenes with the oxidative iodination approach

In the gold-catalyzed cyclization reaction of **1a**, the (*Z*)-alkene **2a** was observed. Similarly iodoalkyne **6** went through 5-exo-dig cyclization in the presence of $PhAuNTf_2$ catalyst, giving a stable (*Z*)-alkene **7** in 83% yield (Eq. (3)). If the current CuI mediated oxidative iodination reaction applied to the propargylic amide **4a**, the (*E*)-iodoalkene will be obtained. To our delight, this protocol works equally well on this substrate, generating the (*E*)-iodoalkene **5a** in 77% yield under standard conditions. Other substituted substrates were also worked very well and the results were summarized in Table 5. Thus both configurations of the iodoalkenes could be obtained by gold or copper catalysis, which provided different options for synthetic chemists.

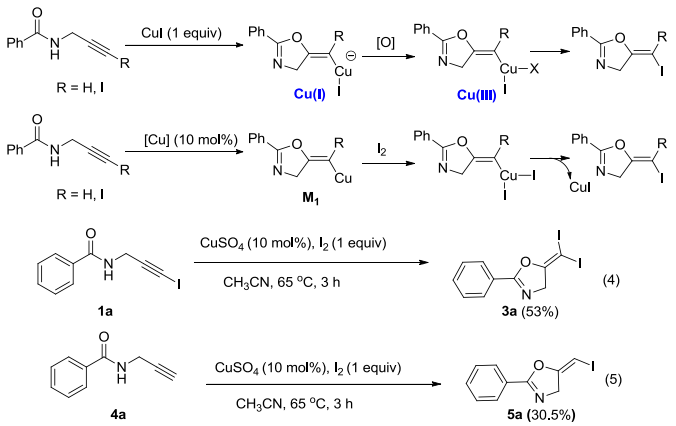
Table 5. Substrate Scope of the Synthesis of (*E*)-1-Iodo-1-alkenes[a]



[a] Reaction conditions: **1a** (0.2 mmol), CuI (0.2 mmol), selectfluor (0.24 mmol), in CH_3CN (2 mL) was stirred at 70℃ for 3 h. Isolated yields were reported



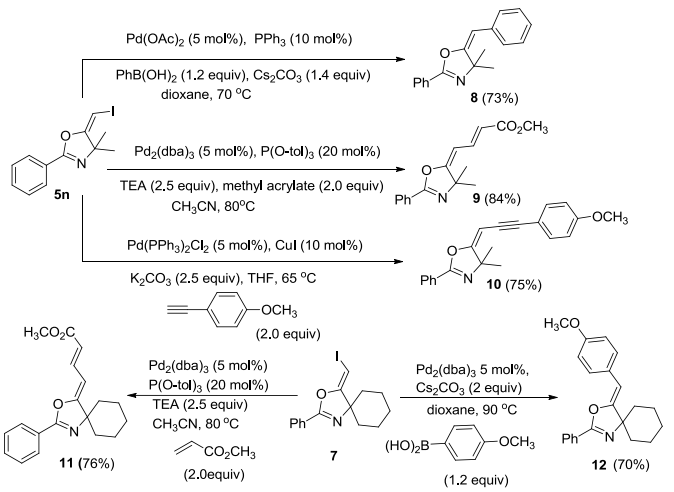
In current reaction, CuI catalyzed the first cyclization forming the Cu(I) intermediate, which was oxidized to Cu(III) intermediate. It went through reductive elimination to form final products (Scheme 5). If I_2 was used as the oxidant and also serve as iodine source, we are possible to realize this reaction with only catalytic amount of Cu(I) catalyst. We tried the reaction using one equivalent I_2 in the presence of $CuSO_4$ (10 mol%) as catalyst (eq 4, 5). The expected reactions did happen, however relatively lower yields were obtained. All these data demonstrated the viability of Cu(I)/Cu(III) catalytic cycle of this reaction.



Scheme 5. Iodination with catalytic amount of Cu(I) catalyst

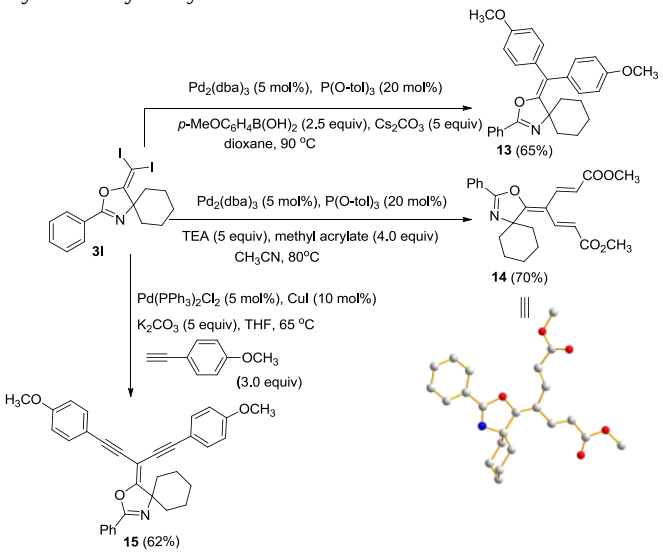
2.4. Synthesis of trisubstituted and tetrasubstituted alkenes from iodoalkenes

In the next step, we took advantage of the C-I bond to install different functional groups to construct multisubstituted alkenes. Trisubstituted and tetrasubstituted alkenes are important motif present in bioactive products and also organic functional materials. The regio and stereoselective synthesis of these molecules is still one of the most challenging subjects in organic synthesis.[15] The obtained halogen substituted alkenes serve as a perfect template for us to install different functional groups using palladium-catalyzed cross coupling reactions. Firstly we chose Suzuki reaction to install an aromatic group. As shown in Scheme 6, boronic acids coupled with (*E*)–alkene **5a** and (*Z*)-alkene **7** smoothly and afforded the expected trisubstituted alkenes **8** and **12** in good yields. The Heck reaction of (*E*)–alkene **5a** and (*Z*)-alkene **7** with methyl acrylate are also successful, giving the corresponding dienes in 84% and 76% yield. The palladium-catalyzed Sonogashira coupling reaction between **5n** and a terminal alkyne was also successful and the expected enyne product **10** was isolated in 75% yield.



Scheme 6. Synthetic transformations of *E*-iodoalkene and *Z*-iodoalkene

Then we started to investigate whether we could construct tetra-substituted alkenes from *gem*-diiodoalkenes (Scheme 7). The Suzuki reaction of diiodide **3l** and boronic acid in the presence of $Pd_2(dba)_3$ and P(*o*-tol)$_3$ afforded tetrasubstituted alkene **13** in 65% yield. The corresponding Heck reaction and Sonogashira coupling reaction of **3l** were also successful, giving the conjugated triene **14** and enyne **15** in good yields. The structures are characterized by NMR and Mass experiments, and triene **14** was further confirmed by single crystal X-ray analysis.[16]



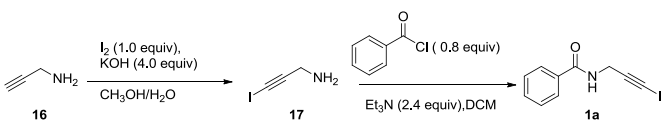
Scheme 7. Synthesis of functionalized tetrasubstituted alkenes from *gem*-diiodoalkene

3. Conclusions

In summary, started from an unexpected reaction of propargyl amide, we developed a new approach for the synthesis of *gem*-diiodoalkenes. This reaction features very simple procedure, high efficiency and broad scope. Stereoselective synthesis of (*E*) or (*Z*)-iodoalkenes could also be achieved with copper catalysis or gold catalysis. A possible Cu(I)/Cu(III) catalytic cycle was proposed. The obtained iodoalkenes were successfully used in the further palladium-catalyzed Suzuki, Heck, and Sonogoshira coupling reactions, allowing access to a wide variety of multi-subsituted alkenes, dienes, trienes and enynes.

4. Experimental section

4.1. General procedure for the synthesis of 1-iodoalkynyl amides 1a-1m.

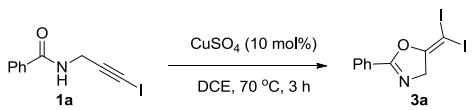


The corresponding propynylamine (10 mmol) was dissolved in MeOH (30 mL). A solution of KOH (40 mmol) in H_2O (10 mL) was prepared, cooled to 0℃, and was added to the reaction mixture. I_2 (10 mmol) was added in one portion, and the solution was stirred at room temperature overnight. The reaction mixture was extracted with CH_2Cl_2. The organic phase was washed with saturated $Na_2S_2O_3$ solution, dried over Na_2SO_4, filtered, and concentrated in vacuo to yield the crude 1-iodopropynylamine. To a cooled solution of 1-iodopropynylamine in CH_2Cl_2 (20 mL) were added triethylamine (24 mmol), chloride (8 mmol) and 4-dimethylaminopyridine (0.8 mmol), the resulting solution was allowed to reach room temperature. The reaction was stirred at room temperature for 3h. Then was diluted with water and the aqueous layer was extracted with CH_2Cl_2, and the combined organic layers were washed with satd. $NaHCO_3$ followed by water and brine, dried over Na_2SO_4 and concentrated under reduced pressure to obtain the crude 1-iodoalkynyl amides. Silica gel chromatography gave the desired 1-iodoalkynyl amides **1a-1m** in 45%-72% yields respectively.

N-(3-iodoprop-2-yn-1-yl)benzamide (1a)

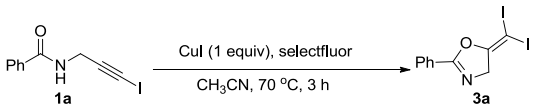
Yield:(1.91 g, 67%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.77 (d, *J* = 7.3 Hz, 2H), 7.51 (t, *J* = 7.3 Hz, 1H), 7.43 (t, *J* = 7.7 Hz, 2H), 6.32 (s, 1H), 4.40 (d, *J* = 5.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.08, 133.72, 131.81, 128.62, 127.08, 89.70, 31.64, 0.01; HRMS (ESI, m/z) calcd for $C_{10}H_8INO$ $[M+H]^+$ 285.9723, found 285.9723.

4.2. General procedure for the synthesis of *gem*-diiodoalkenes (Table 2)



Compound **1a** (0.2 mmol) was dissolved in DCE (1 mL), $CuSO_4$ (0.02 mmol) was added, the system was stirred at 70℃ for 3 h. The resulting mixture was washed with water and extracted with DCM. The organic layer was filtered on celite and evaporated under reduced pressure. Purification by flash chromatography afforded the desired product **3a** (38.95 mg, 95%).^{1}H NMR (400 MHz, DMSO-d_6) δ 7.96 (m, 2H), 7.54 (t, *J* = 7.4 Hz, 1H), 7.46, (t, *J* = 7.8 Hz, 2H), 4.61 (s, 2H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 161.39, 159.16, 132.92, 129.51, 127.92, 126.39, 61.64, -14.83. HRMS (ESI, m/z) calcd for $C_{10}H_7I_2NO$ $[M+H]^+$ 411.8690, found 411.8675.

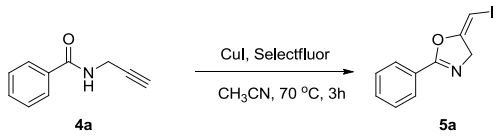
4.3. General procedure for the synthesis of *gem*-diiodoalkenes (Table 4)



Compound **1a** (0.2 mmol), CuI (0.2 mmol) and selectfluor (0.24 mmol) were dissolved in CH_3CN (2 mL). The system was stirred at 70℃ for 3 h. The resulting mixture was washed with water and extracted with DCM. The organic layer was filtered on celite and evaporated under reduced pressure. Purification

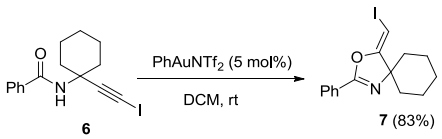
by flash chromatography afforded the desired product **3a** (69.05 mg, 84%).

4.4. General procedure for the synthesis of *(E)*-1-Iodo-1-alkenes (Table 5)



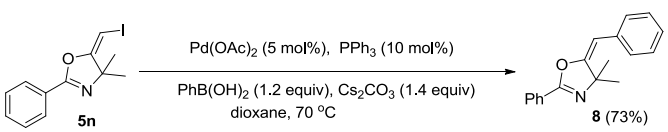
Compound 4**a** (0.2 mmol), CuI (0.2 mmol) and selectfluor (0.24 mmol) were dissolved in CH_3CN (2 mL). The system was stirred at 70℃ for 3h. The resulting mixture was washed with water and extracted with DCM. The organic layer was filtered on celite and evaporated under reduced pressure. Purification by flash chromatography afforded the desired product **5a** (43.89 mg, 77%).^{1}H NMR (400 MHz, $CDCl_3$) δ 7.96 (d, *J* = 7.5 Hz, 2H), 7.55-7.33, (m, 3H), 5.77 (t, *J* = 2.8 Hz, 1H), 4.63, (d, *J* = 3.1 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.39, 157.43, 132.27, 128.93, 127.48, 126.08, 60.44, 49.30. HRMS (ESI, m/z) calcd for $C_{10}H_8INO$ $[M+H]^+$ 285.9723, found 285.9723.

4.5. General procedure for the gold-catalyzed synthesis of *(Z)*-4-(iodomethylene)-2-phenyl-3-oxa-1-azaspiro[4.5]dec-1-ene (7)



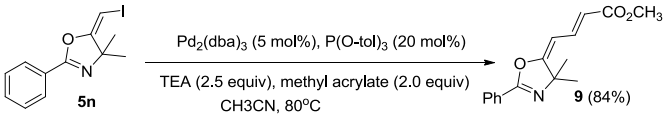
The compound **6** (1 mmol) was dissolved in DCM (10 ml) and PPh_3AuNTf_2 (0.05 mmol) was added. After stirring for 2 h at room temperature, water was added and the aqueous phase was extracted twice with DCM. After drying of the combined organic phases over Na_2SO_4, and filtration, the solvent was removed and the crude products were purified by column chromatography affording pure product **7** (0.29 g, 83%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.02 (d, *J* = 7.1 Hz, 2H), 7.51-7.42 (m, 3H), 5.05 (s, 1H), 1.89-1.52 (m, 10H) ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.38, 158.03, 131.87, 128.51, 128.37, 126.66. HRMS (ESI, m/z) calcd for $C_{15}H_{16}INO$ $[M+H]^+$ 354.0349, found 354.0346.

4.6. General procedure for the Suzuki reactions: Synthesis of *(E)*-5-benzylidene-4,4-dimethyl-2-phenyl-4,5-dihydro-oxazole (6)



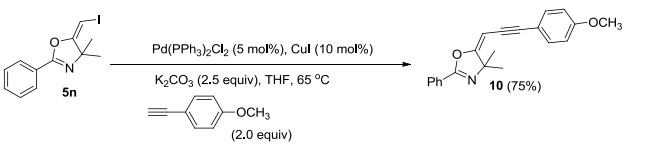
To a mixture of $Pd(OAc)_2$ (0.01 mmol), PPh_3 (0.02 mmol), Cs_2CO_3 (0.28 mmol), $PhB(OH)_2$ (0.24 mmol) in dixoane (2 ml) under N_2 atmosphere, compound **5n** (0.2 mmol) was added. The system was stirred at 70℃ overnight. The resulting mixture was washed with water and extracted with DCM. The organic layer was filtered on celite and evaporated under reduced pressure. Purification by flash chromatography afforded the desired product **8** (38.41 mg, 73%).^{1}H NMR (300 MHz, $CDCl_3$) δ 8.10-8.08 (m, 2H), 7.65, (d, *J* = 7.2Hz, 2H), 7.55-7.52 (m, 3H), 7.50-7.37, (m, 2H), 7.25-7.20 (m, 1H), 5.55 (s, 1H), 1.54 (s, 6H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 160.15, 159.36, 134.53, 131.36, 128.11, 128.04, 127.75, 127.41, 126.36, 125.66, 98.87, 70.39, 29.17. HRMS (ESI, m/z) calcd for $C_{18}H_{17}NO$ $[M+H]^+$ 264.1383, found 264.1389.

4.7. General procedure for the Heck coupling reactions: Synthesis of *(2E,4E)*-methyl 4-(4,4-dimethyl-2-phenyloxazol-5(4H)-ylidene)but-2-enoate (7)



To a mixture of $Pd_2(dba)_3$ (0.01 mmol), $P(O\text{-}tol)_3$ (0.04 mmol), compound **5n** (0.2 mmol) in CH_3CN (2 ml) under N_2 atmosphere, methyl acrylate (0.4 mmol) and Et_3N (0.5 mmol) were added. The system was stirred at 80℃ overnight. The resulting mixture was washed with water and extracted with DCM. The organic layer was filtered on celite and evaporated under reduced pressure. Purification by flash chromatography afforded the desired product **9** (45.53 mg, 84%).^{1}H NMR (400 MHz, $CDCl_3$) δ 7.96 (d, *J* = 7.3 Hz, 2H), 7.62-7.50, (m, 2H), 7.46-7.42 (m, 2H), 6.11 (d, *J* = 12.6 Hz, 1H), 5.83 (d, *J* = 15.0 Hz, 1H), 3.76 (s, 3H), 1.65 (s, 6H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 169.70, 167.16, 159.17, 138.64, 132.00, 128.58, 128.13, 126.24, 118.47, 101.13, 70.76, 51.46, 51.47, 28.55. HRMS (ESI, m/z) calcd for $C_{16}H_{17}NO_3$ $[M+H]^+$ 272.1281, found 264.1271.

4.8. General procedure for the Sonogashira coupling reactions: Synthesis of (E)-5-(3-(4-methoxyphenyl)prop-2-yn-1-ylidene)-4,4-dimethyl-2-phenyl-4,5-dihydrooxazole (8)



To a mixture of $Pd(PPh_3)_2Cl_2$ (0.01 mmol), CuI (0.02 mmol), K_2CO_3 (0.5 mmol), compound **5n** (0.2 mmol) in THF (2 mL) under N_2 atmosphere, 4-methoxyphenylacetylene (0.4 mmol) was added. The system was stirred at 65℃ overnight. The resulting mixture was washed with water and extracted with DCM. The organic layer was filtered on celite and evaporated under reduced pressure. Purification by flash chromatography afforded the desired product **10** (47.55 mg, 75%).^{1}H NMR (400 MHz, $CDCl_3$) δ 7.97 (d, *J* = 7.4 Hz, 2H), 7.53-7.49, (m, 1H), 7.44 (t, *J*= 7.6 Hz, 2H), 7.36 (d, *J* = 8.6 Hz, 2H), 6.85 (d, *J* = 8.6 Hz, 2H), 5.60 (s, 1H), 3.81 (s, 3H), 1.73 (s, 6H). 13C NMR (100 MHz, $CDCl_3$) δ 170.74, 158.88, 158.69, 131.77, 131.36, 128.03, 127.64, 125.97, 115.47, 113.56, 93.06,

84.99, 81.73, 70.67, 54.82, 25.85. HRMS (ESI, m/z) calcd for $C_{21}H_{19}NO_2$ $[M+H]^+$ 318.1489, found 318.1483.

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Electronic Supplementary Information (ESI) available: [details of any supplementary information available should be included here]. See DOI: 10.1039/b000000x/

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16 CCDC 1046596 (**3a**) and 1046597 (**14**) contain the supplementary crystallographic data for this paper. These data can be obtained free of charge from the Cambridge Crystallographic Data Centre via www.ccdc. cam.ac.uk/data_request/cif.