Communication

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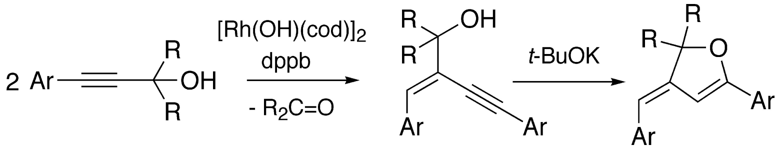

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Regio- and Stereoselective Homocoupling of γ-Arylated *tert*-Propargyl Alcohols with Liberation of a Ketone Molecule and Successive Cyclization To Produce Fluorescent Dihydrofuran Derivatives

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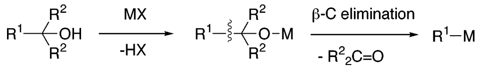
Transition metal-catalyzed alkyne coupling reactions are of genuine synthetic utility in preparing π-conjugated four-carbon compounds such as enynes.[1] Among the straightforward, practical methods leading to enynes is the dimerization of terminal alkynes, which may give rise to head-to-tail and *E*- and *Z*-tail-to-tail products, and thus, much effort has been focused on the control of the regio- and stereoselectivity.[2] In such a coupling, an alkynylmetal intermediate generated by sp C−H bond activation is involved as the key catalytic species.

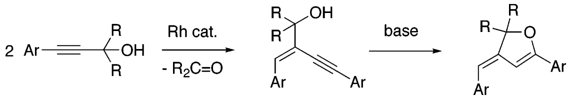
Meanwhile, catalytic processes involving C−C bond cleavage via β-carbon elimination (deinsertion) have recently attracted considerable attention since they may bring about new, useful synthetic routes in some cases.[3] Appropriately designed tertiary alcohols have been demonstrated to be suitable substrates which can undergo selective cleavage of one of the three C−C bonds to form an organometal intermediate along with a ketone (Scheme 1).

Scheme 1



As part of our study of the above processes,[4] we have undertaken the use of *tert*-propargyl alcohols in alkyne coupling. It has been found that in the presence of a rhodium catalyst, 1,1-disubstituted 3-aryl-2-propyn-1-ols undergo unprecedented unique homocoupling efficiently and regio- and stereoselectively with liberation of a ketone molecule to produce the corresponding 2-hydroxymethyl-(*E*)-enynes.[5,6] The products are readily capable of cyclizing in the presence of a base to form dihydrofuran derivatives, which exhibit relatively strong fluorescence in the solid state (Scheme 2).

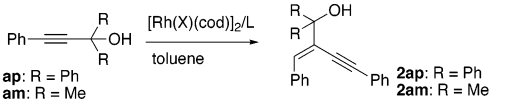
Scheme 2



When 1,1,3-triphenyl-2-propyn-1-ol (**1ap**) was heated in the presence of $[Rh(OH)(cod)]_2$ (2 mol % of Rh) and dppp (2 mol %) in refluxing toluene for 1 h, 2-[(*E*)-benzylidene]-1,1,4-triphenyl-3-butyn-1-ol (**2ap**) was formed as the single coupling product in 96% yield (85% after purification; entry 1 in Table 1). As expected, the formation of benzophenone in a quantitative yield (0.5 equiv) was detected. Among other mono- and bidentate phosphine ligands examined, dppf was fairly effective (entry 3). Reaction without any phosphine ligand was sluggish (entry 5). The use of $[RhCl(cod)]_2$ in place of the hydroxyl complex together with dppb was far less effective (entry 6), while adding Na_2CO_3 as a base enhanced the reaction to some extent (entry 7). Reaction of 2-methyl-4-phenyl-3-butyn-2-ol (**1am**) proceeded similarly. In this case, ligand effects were more significant (entries 8−14 vs 1−7).

The results for the reactions of a number of 1,1-diphenyl- and 1,1-dimethyl-3-(4-substituted-phenyl)-2-propyn-1-ols **1** in the presence of $[Rh(OH)(cod)]_2$ and dppb are shown in Scheme 3. In each reaction, the corresponding enyne **2** could be obtained with good yield. The reaction with an aliphatic alkynol 2-methyl-3-hexyn-2-ol, however, did not proceed.

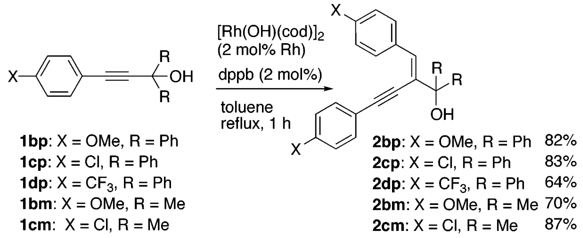
Table 1. Rhodium-Catalyzed Reaction of 1,1,3-Triphenyl-2-propyn-1-ol (**1ap**) and 2-Methyl-4-phenyl-3-butyn-2-ol (**1am**)[a]



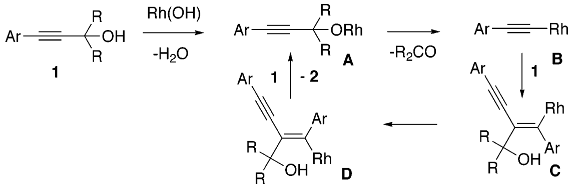
X	L	entry	% yield of **2ap**[b]	entry	% yield of **2am**[b]
OH	dppb	1	96 (85)	8	91 (81)
OH	dppp	2	80	9	52
OH	dppf	3	91	10	91
OH	PPh_3[c]	4	34	11	37
OH		5	30	12	0
Cl	dppb	6	20	13	0
Cl	dppb	7[d]	52	14[d]	14

[a] Reaction conditions: **1** (1 mmol), Rh cat. (0.01 mmol), L (0.02 mmol), in refluxing toluene (5 cm^3) under N_2. [b] GLC yield based on the amount of **1** used. Value in parentheses indicates isolated yield. [c] PPh_3 (0.04 mmol) was used. [d] Na_2CO_3 (0.1 mmol) was added.

Scheme 3



Scheme 4



A plausible mechanism for the formation of enynes **2** from alcohols **1** is illustrated in Scheme 4, in which neutral ligands are omitted. The first step involves the reaction of **1** with hydroxyrhodium(I) species to form rhodium alcoholate **A**,[7,8] and the successive β-carbon elimination with liberation of benzophenone or acetone gives alkynylrhodium **B**. Then, regioselective insertion of another molecule of **1** to the rhodium−carbon bond affords vinylrhodium **C**. Product **2** is formed after the geometrical isomerization of **C** to **D** and protonolysis by **1** with regeneration of **A**.[9] It should be noted that the reaction of alcohol **1ap** was remarkably hampered by adding 4-ethynyltoluene (1 equiv).[10] This suggests that the reaction leading to **2ap** does not involve

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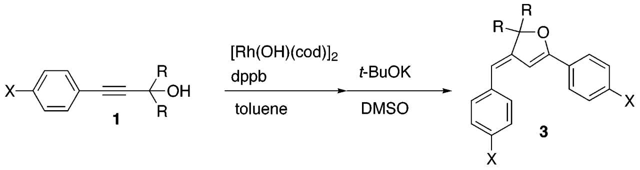
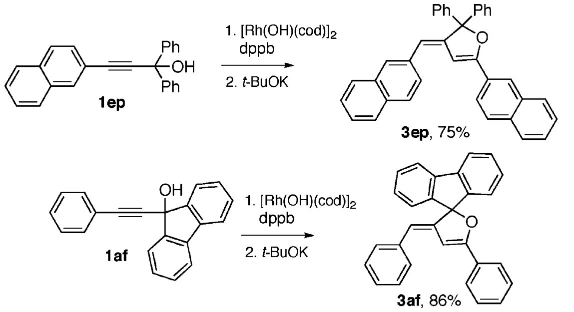
Table 2. One-Pot Synthesis of 3-Benzylidene-2,3-dihydrofrans **3**[a]



entry	**1**: X, R	**3**, % yield[b]	entry	**1**: X, R	**3**, % yield[b]
1	**1ap**: H, Ph	**3ap**, 80	5[c]	**1ap**: H, Ph	**3ap**, 71
2	**1bp**: OMe, Ph	**3bp**, 74	6	**1am**: H, Me	**3am**, 72
3	**1cp**: Cl, Ph	**3cp**, 71	7	**1bm**: OMe, Me	**3bm**, 80
4	**1dp**: CF_3, Ph	**3dp**, 70	8	**1cm**: Cl, Me	**3cm**, 70

[a] Reaction conditions: **1** (1 mmol), $[Rh(OH)(cod)]_2$ (0.01 mmol), dppb (0.02 mmol), in refluxing toluene (1.5 mL) under N_2 for 1 h. Then, *t*-BuOK (1 mmol), DMSO (5 mL), 60 °C for 1 h. [b] Isolated yield. [c] **1ap** (5 mmol) and toluene (2.5 mL) were used. The first reaction was for 2 h.

Scheme 5



ethynylbenzene as the intermediate by the simple ketone elimination of **1ap**. The regioselectivity in the insertion of **1** to **B** may be mainly due to steric reasons.[11] The geometrical isomerization of **C** to **D** may occur via a zwitterionic form.[12] The interaction of the oxygen with the metal may intervene to stabilize **D**.

Cyclization of **2** by addition of the hydroxy function to the alkyne moiety may afford the corresponding dihydrofuran derivatives, which are expected to exhibit fluorescent properties in the solid state based on the literature.[13] Since organic fluorescent solids have become increasingly important as photofunctional materials, including the components of electroluminescence (EL) devices,[14] the cyclization has also been undertaken. It has been found that a base-promoted method using *t*-BuOK[15] is effective for the present case, and the furans can be prepared by a one-pot procedure.

Sequential coupling−cyclization was carried out by heating **1** in the presence of $[Rh(OH)(cod)]_2$ and dppp in refluxing toluene for 1 h and then at 60 °C for 1 h after adding *t*-BuOK (1 equiv) and DMSO to the mixture. Thus, 5-aryl-3-[(*Z*)-(arylmethylene)]-2,2-diphenyl- and dimethylfurans (**3**) were successfully obtained (Table 2). Under the same conditions, 3-(2-naphthyl)-1,1-diphenyl-propyn-1-ol (**1ep**) and 9-(phenylethynyl)fluoren-9-ol (**1af**) gave the expected furans **3ep** and **3af**, respectively (Scheme 5). Using a 5-fold increase of **1ap** without changing the amounts of catalyst and base, the reaction proceeded smoothly (entry 5). This demonstrates high efficiency of the coupling reaction and indicates that the cyclization can occur catalytically.

Preliminary fluorescence analysis of the furans (recrystallized and powdered samples) indicated that **3ap**−**3ep** show emissions in the green to yellow−green region and are relatively more luminous than tris(8-hydroxyquinolino)aluminum (Alq_3), which is a well-known green emitter, by a factor range of 1.1−2.1 (**3ap** 1.1, **3bp** 1.8, **3cp** 1.2, **3dp** 2.1, and **3ep** 1.1; see Supporting Information).[16,17] While the factor of **3am** was 0.5, that of **3af** was very small (<0.01). These results indicate that the structure of the substituents at the nonconjugated 2-position as well as those of the conjugated aryl groups significantly affects their fluorescent efficiency, probably by changing their crystal packing mode.[18]

In summary, we have shown a new, efficient catalytic alkyne coupling; 1,1-disubstituted 3-aryl-2-propyn-1-ols undergo unique homocoupling with liberation of a ketone through β-carbon elimination to give 2-hydroxymethyl-(*E*)-enynes. The products are useful precursors of dihydrofuran derivatives that exhibit intense fluorescence in the solid state.

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Supporting Information Available: Standard experimental procedures and characterization data for new compounds. This material is available free of charge via the Internet at http://www.pubs.acs.org.

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(7) The superior efficiency of $[Rh(OH)(cod)]_2$ compared with that of $[RhCl(cod)]_2$ is considered to be due to its better ability to form the alkoxy complex. This resembles transmetalation with arylboronic acids.[8]
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(9) Alternatively, intramolecular protonolysis in the intermediate **D** followed by transalkoxylation with **1** would also take place. On the other hand, the reaction of **1ap** with the addition of D_2O (0.5 mL) gave monodeuterated **2ap** (71%), in which the vinyl hydrogen is replaced by deuterium (94% D determined by ^1H NMR). In this case, protonolysis is considered to occur directly by D_2O or via H−D exchange of the starting alcohol.
(10) The reaction occurred only to a minor extent to give 10% of **2ap** and completely stopped within 1 h. No cross-coupling with the terminal alkyne as well as its homocoupling was observed. However, the origin of the inhibiting effect is not clear at the present stage.
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(16) Interestingly, the fluorescence of compounds **3ap**−**3ep** was very weak in solution.[17] The range of quantum yield in dioxane was 0.18−2.6 × 10^{-4}.
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(18) A reviewer kindly suggested an alternative possibility for the lack of fluorescence of compound **3af**: efficient energy transfer to the fluorenyl moiety followed by nonradiative decay of the excited state. Thus, further studies are required to establish the detail of the structural effect.

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