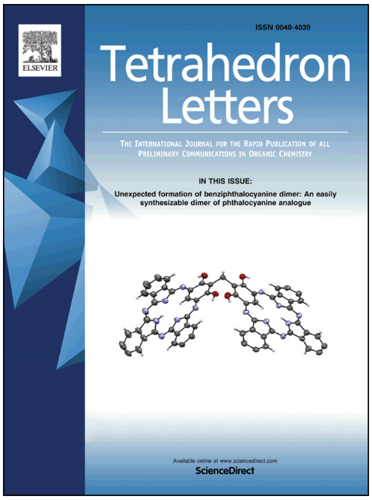

Carbon-carbon bond forming reactions *via* Pd-catalyzed detellurative homocoupling of diorganyl tellurides

Shaozhong Zhang, Lalitha Kolluru, Souseelya K Vedula, Drew Whippie, Jin Jin

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Graphical Abstract

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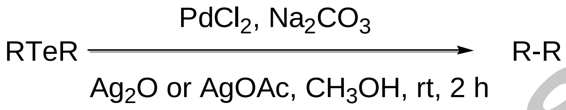
Shaozhong Zhang, Lalitha Kolluru, Souseelya Keerthi Vedula, Drew Whippie and Jin Jin*
Department of Chemistry, Western Illinois University, Macomb, IL 61455



$$\mathrm{RTeR} \xrightarrow[\mathrm{Ag_2O\ or\ AgOAc,\ CH_3OH,\ rt,\ 2\ h}]{\mathrm{PdCl_2,\ Na_2CO_3}} \mathrm{R{-}R}$$

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Carbon-carbon bond forming reactions *via* Pd-catalyzed detellurative homocoupling of diorganyl tellurides

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Department of Chemistry, Western Illinois University, Macomb, IL 61455

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ABSTRACT

A simple and highly efficient method for the constructions of Csp-Csp, Csp^2-Csp^2 and Csp^3-Csp^3 bonds is reported. The symmetrical diaryl tellurides undergo detellurative homocouplings to afford symmetrical biaryl products. The reactions are carried out at ambient temperature using $PdCl_2$ as a catalyst in the presence of Ag_2O and Na_2CO_3. Similarly, the detellurative homocouplings of dibenzyl telluride and bis(phenylethynyl)telluride give bibenzyl and the conjugated diyne, respectively.

Introduction

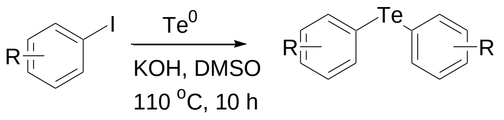
Organotellurium compounds have attracted more attentions in recent years due to their important roles in organic synthesis and biological activities.[1] They have been used instead of halogens as electrophilic partners in some palladium-catalyzed cross-coupling reactions such as Heck reaction,[2] Negishi coupling[3] and Suzuki coupling.[4] Carbon-carbon bond formation is involved in all areas of organic chemistry since the skeleton of all organic molecules is made of carbon-carbon bonds. The formation of aryl-aryl bond is one of the most important targets in organic synthesis. The biaryl scaffold is a core component occurring in natural products,[5] pharmaceuticals,[6] agrochemicals[7] and many biologically important molecules.[8] Many biaryl compounds have been reported to possess activities like antibiotic,[9] anti-inflammatory,[10] antihypertensive,[11] anticancer,[12] antidiabetic,[13] etc. The synthesis of symmetrical biaryls has been traditionally achieved by Ullmann reaction.[14] Other methods include using metal-catalyzed homocoupling of aryl halides,[15] aryl boronic acids,[16] aryl Grignard reagents,[17] methoxyarenes[18] and aryl diazonium salts.[19]

As reported by Bergman in 1970s, diaryltellurium dichlorides are detellurated by treatment with degassed Raney nickel in diglyme at reflux, giving the corresponding biaryls.[20] Since then, there have been more reports on detelluration of organotellurium compounds.[21] For example, it was reported by Barton that palladium(0) converts symmetrical and unsymmetrical tellurides into coupled compounds.[21] The drawback of these methods is the necessity of more than a stoichiometric amount of the required metal or the requirement of harsh condition such as high temperature. Further reports describe the use of the $Ni(PEt_3)_4$ system in the presence of phosphines as a successful catalyst for the detelluration of organotellurides and ditellurides.[22]

Here we report a very simple method for the synthesis of symmetrical biaryl compounds *via* the detellurative homocoupling of symmetrical diaryl tellurides. The reactions are promoted by a catalytic amount of $PdCl_2$ without using any ligands and occur at room temperature with good yields. The use of tellurium agents here is advantageous compared to the usual previously described methods because of the mildness of the experimental conditions.

Conjugated diynes or dienes are also important structures and useful building blocks in organic synthesis.[23] They have been found to exist widely in nature and possess special biological activities.[24] In addition, conjugated diynes have also been found to be crucial in material science.[25] Therefore we also explored the detelluration reactions on bis(ethynyl)telluride and bis(vinyl)telluride. In order to examine whether the reaction will occur on dialkyl tellurides, we synthesized dibenzyl telluride as well and performed the detelluration reaction on it.

We recently reported a method to prepare symmetrical diaryl tellurides in a catalyst-free condition using Te^0 as the chalcogen source in the presence of KOH, which is shown in Scheme 1.[26]



R = H, *p*-CH_3, *m*-CH_3, *p*-Cl, *p*-OCH_3, naphthyl, *o*-OCH_3, *m*-OCH_3, *p*-F, *p*-OCF_3, *p*-*t*-butyl, *o*-OCF_3, *p*-Br, 2,4-dimethyl

Scheme 1. Synthesis of symmetrical diaryl tellurides

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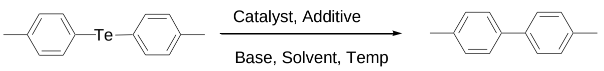
* Corresponding author. Tel.: +1-309-298-2261; fax: +1-309-298-2180; e-mail: j-jin@wiu.edu

The diaryl tellurides synthesized above would then be used as the substrates for the detellurative coupling reactions to form symmetrical biaryls. In order to find the optimal conditions, we selected bis(*p*-tolyl)telluride as a model substrate (Table 1). A variety of conditions were screened such as catalyst, additive, base, solvent and reaction temperature. Among the four catalysts screened, we found $PdCl_2$ was the optimal catalyst for the detellurative coupling reaction (Table 1, entry 1-4). Subsequently, Na_2CO_3 was found to be a more proper base when compared to Et_3N (Table 1, entry 2 and 5). Several kinds of solvents such as CH_3OH, DMSO and CH_3CN were also examined, and CH_3OH was the optimal solvent for this reaction (Table 1, entry 5-7). The oxidant additive is also critical in this reaction. We found the detelluration reaction did not proceed at all in the absence of Ag_2O or AgOAc as the additive (Table 1, entry 10). Furthermore, when the reaction temperature was lowered from 65 ^{o}C to the ambient temperature with either Ag_2O or AgOAc as the additive, the same yields were obtained as that at higher temperature (Table 1, entry 5, 8 and 9). Based on these results, the optimal conditions for the detellurative coupling of diaryl tellurides involved the use of 10 mol% of $PdCl_2$ as catalyst, Ag_2O or AgOAc as additive, Na_2CO_3 as base in CH_3OH at room temperature for 2 hours in ambient air.

Table 1: Optimization of detellurative coupling reactions[a]



1

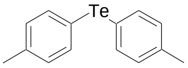
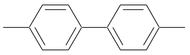
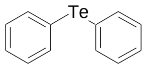
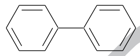
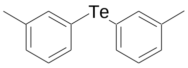
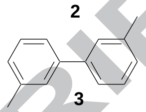
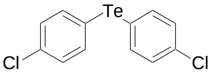
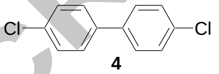
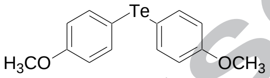
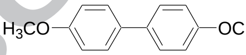
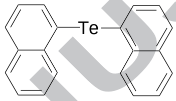
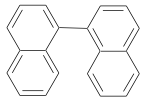
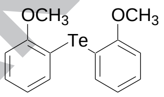
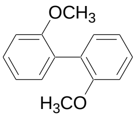
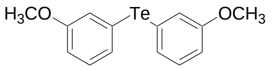
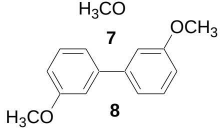
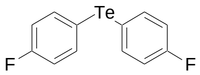
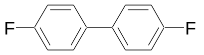
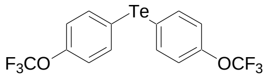
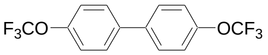
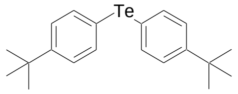
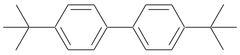
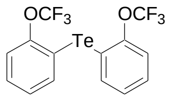
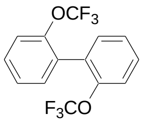
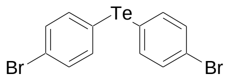
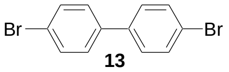
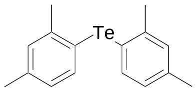
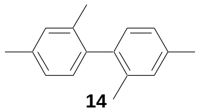
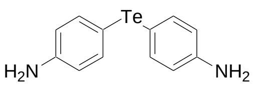
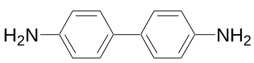
Entry	Catalyst	Additive	Base	Solvent	Temp (^{o}C)	Yield[b] (%)
1	$Pd(OAc)_2$	Ag_2O	Et_3N	CH_3OH	65	20
2	$PdCl_2$	Ag_2O	Et_3N	CH_3OH	65	50
3	CuI	Ag_2O	Et_3N	CH_3OH	65	0
4	$NiSO_4$	Ag_2O	Et_3N	CH_3OH	65	0
5	$PdCl_2$	Ag_2O	Na_2CO_3	CH_3OH	65	95
6	$PdCl_2$	Ag_2O	Na_2CO_3	DMSO	65	60
7	$PdCl_2$	Ag_2O	Na_2CO_3	CH_3CN	65	20
8	**$PdCl_2$**	**Ag_2O**	**Na_2CO_3**	**CH_3OH**	**rt**	**95**
9	**$PdCl_2$**	**AgOAc**	**Na_2CO_3**	**CH_3OH**	**rt**	**95**
10	$PdCl_2$	—	Na_2CO_3	CH_3OH	65	0

[a] Reaction conditions: bis(*p*-toly)telluride (1 equiv.), catalyst (10 mol %), additive (2 equiv.), base (2 equiv.), solvent (3 mL), under air, 2 h.
[b] Isolated yield.

With the optimal conditions for the detelluration reaction in hand, a series of parent precursors of symmetrical diaryl tellurides were conveniently prepared in high yields using the approach mentioned in Scheme 1. Subsequently, the detellurative coupling reactions were performed on these diaryl tellurides (Table 2). The reactions proceeded nicely with electron-withdrawing and most electron-donating substituents at ortho, meta or para position in the biaryl architecture. However, it should be pointed out that when bis(*p*-aminophenyl)telluride was used as the substrate, the desired biaryl product **15** was not obtained (Table 2, entry 15). An unidentified product was resulted probably due to the coordination reaction between N and Pd. All other symmetrical biaryl products (**1**-**14**) were successfully prepared by the detellurative coupling approach in

Table 2: Synthesis of symmetrical biaryls by detelluration of diaryl tellurides[a]

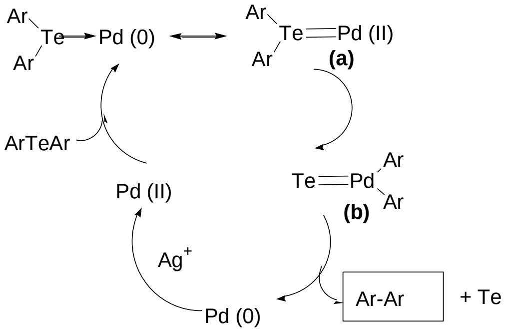
$$\text{ArTeAr} \xrightarrow[\text{Ag}_2\text{O, CH}_3\text{OH, rt 2h}]{\text{PdCl}_2\text{, Na}_2\text{CO}_3} \text{Ar-Ar}$$

Entry	Diaryl tellurides (ArTeAr)	Biaryls (Ar-Ar)	Yield (%)[b]
1		 **1**	95
2		 **2**	92
3		 **3**	80
4		 **4**	92
5		 **5**	90
6		 **6**	89
7		 **7**	80
8		 **8**	75
9		 **9**	85
10		 **10**	72
11		 **11**	75
12		 **12**	74
13		 **13**	83
14		 **14**	60
15		 **15**	0

[a] Reaction conditions: diaryl telluride (1 mmol), $PdCl_2$ (0.1 mmol), Ag_2O (2 mmol), Na_2CO_3 (2 mmol), CH_3OH (3 mL), rt, 2 h.
[b] Isolated yield.

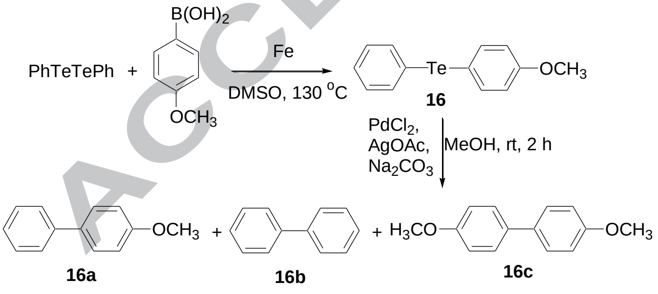
good yields,[27] as summarized in Table 2. All of the synthesized products were characterized by ^{1}H, ^{13}C NMR and Mass spectroscopy.

According to a previous report,[21] the catalytic cycle for the detellurative coupling of symmetrical diary tellurides involves the formation of a telluride-palladium (II) complex **(a)** which further undergoes a double aryl migration affording another palladium complex **(b)**, as shown in Scheme 2**.** Reductive elimination of complex **(b)** leads to the formation of biaryl compound (Ar-Ar) along with Pd(0) and elemental tellurium. Pd(0) is later oxidized by Ag$^+$ ions to Pd(II) thus completing the catalytic cycle.



Scheme 2: Possible mechanism for the formation of symmetrical biaryls

Next, in order to examine if this approach is also applicable for the synthesis of unsymmetrical biaryls, we synthesized an unsymmetrical diaryl telluride (4-methoxyphenyl phenyl telluride, **16**) according to the literature method[28] and proceeded the detelluration reaction on it. However, the desired detellurative coupling product (4-methoxybiphenyl, **16a**) was obtained together with the formation of the other two symmetrical biaryl by-products (**16b** and **16c**) in a ratio of 3:5:2, as shown in Scheme 3. Therefore we conclude this methodology is not ideal for the synthesis of unsymmetrical biaryl products.



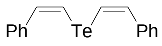
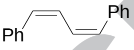
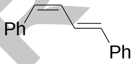
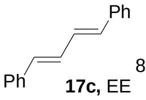
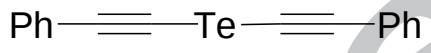
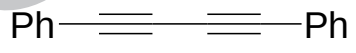
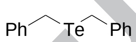
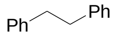
(16a: 16b: 16c = 3:5:2)

Scheme 3: Detelluration reaction of unsymmetrical diaryl telluride

Finally, we tried to explore whether the detellurative homocoupling approach would apply to other diorganyl tellurides such as bis(vinyl), bis(alkynyl) and dialkyl tellurides. Therefore, (Z,Z)-bis(phenylethenyl)telluride **17**, bis(phenylethynyl)telluride **18**, and dibenzyl telluride **19** were prepared according to the literature methods.[29] The detellurative homocoupling reactions were carried out thereafter. To our surprise, instead of retaining the original ZZ configuration of the precursor **17**, a mixture of ZZ, ZE and EE isomers (17a, 17b and 17c) was formed altogether for the detelluration of (Z,Z)-bis(phenylethenyl)telluride, **17** at a ratio of 1:6:3, as determined by ^{1}H NMR spectroscopy. However, the detellurative coupling of **18** and **19** proceeded nicely to afford the corresponding conjugated diyne **18a** and bibenzyl **19a** in high yields, as shown in Table 3.

Table 3: Detelluration of other diorganyl tellurides

$$\text{RTeR} \xrightarrow[\text{AgOAc, CH}_3\text{OH, rt}]{\text{PdCl}_2\text{, Na}_2\text{CO}_3} \text{R-R}$$

Entry	Diaryl tellurides	Biaryls	Yield (%)
1	 **17**	 **17a,** ZZ  **17b,** ZE  **17c,** EE (17a: 17b: 17c = 1:6:3)	84
2	 **18**	 **18a**	90
3	 **19**	 **19a**	90

Conclusions

In summary, we demonstrated a simple method for carbon-carbon bond forming reactions. The detellurative homocouplings of symmetrical diaryl tellurides provide biaryl compounds. The reaction requires only a catalytic amount of palladium catalyst and completes efficiently at room temperature. Similarly, the detellurative homocouplings of other diorganyl tellurides such as dibenzyl telluride and bis(phenylethynyl)telluride afford the corresponding bibenzyl and the conjugated diyne, respectively.

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Supplementary data

Full experimental details and spectroscopic data of all compounds, ^{1}H and ^{13}C NMR, HRMS data can be found. Supplementary data associated with this article can be found.

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27. *General experimental procedure for biaryl (**1-14**) synthesis:* A mixture of diaryl telluride ArTeAr (1 mmol), $PdCl_2$ (0.02 g, 0.1 mmol), Na_2CO_3 (0.21 g, 2 mmol) and Ag_2O (0.46 g, 2 mmol) (or AgOAc (0.33g, 2 mmol)) in CH_3OH (3 mL) was stirred at room temperature for 2 h. The progress of the reaction was monitored by TLC. After the completion of reaction, the dark precipitate formed was filtered off. The reaction mixture was diluted with CH_2Cl_2 (20 mL) and the organic layer was washed with saturated NH_4Cl (10 mL) and water (2 x 10 mL), dried over anhyd. Na_2SO_4, and concentrated under vacuum. The crude product was purified by silica column chromatography.

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Highlights of the work

- A simple method for the constructions of Csp-Csp, Csp^2-Csp^2 and Csp^3-Csp^3 bonds by detellurative homocoupling reactions.
- The detellurative homocouplings of symmetrical diaryl tellurides provide biaryl compounds.
- The detelluration of other diorganyl tellurides such as dibenzyl telluride and bis(ethynyl)tellurides give the corresponding bibenzyl and the conjugated diyne, respectively.
- The reactions require only a catalytic amount of $PdCl_2$, which is readily available and low cost.
- The reactions complete efficiently at room temperature in ambient air within 2 hours.