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Palladium-Catalyzed Direct Arylation of C−H Bond To Construct Quaternary Carbon Centers: The Synthesis of Diarylfluorene

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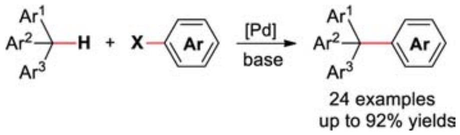
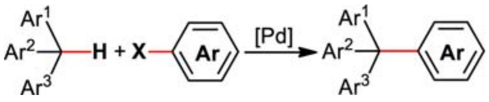
ABSTRACT



A novel Pd-catalyzed C−H functionalization reaction was developed to construct a quaternary carbon center with high yield. This reaction provides an efficient method for the synthesis of 9,9′-diarylfluorenes by direct arylation of monoarylfluorene.

Palladium-catalyzed cross-coupling reactions have become a powerful tool in organic synthesis.[1] Numerous cross-coupling systems have been applied in the preparation of pharmaceuticals, agrochemicals, and also advanced materials on both laboratory and industrial scales.[2] In those applications, C−C, C−S, C−O, and C−N bonds have been easily constructed with the help of palladium catalysts.[3] However, the construction of quaternary carbon centers via palladium catalysis has been rarely reported up to now.[4] Recently, a Pd-catalyzed construction of quaternary carbon centers from diazocompounds and carbonyl compounds has been demonstrated.[5] The conjugate addition of arylboronic acids to β-substituted cyclic enones to construct stereocenters was also reported by Lu and Stoltz respectively.[4b,6] The Stoltz group reported the formation of quaternary and tertiary stereocenters via the alkylation of enolates.[7] However, there is no report of the construction of tetraaryl quaternary carbon centers based on Pd-catalyzed cross-coupling of aryl halides with triarylmethane to date (eq 1). Herein, we demonstrate a Pd-catalyzed cross-coupling of triarylmethyl C−H bonds with aryl halides for the direct synthesis of unsymmetric diarylfluorenes.



(1)

Diarylfluorenes are widely used in semiconductors, including OLEDs, PLEDs, solar cells, fuel cells, memories, and so on.[8] Therefore, efficient preparation of 9,9-diarylfluorenes

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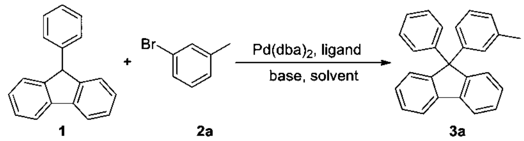
is important for both synthetic chemistry and material sciences. Diarylfluorenes with the same two aryl groups were mainly applied in OLEDs, PLEDs, and fuel cells.[8a,d] In recent years, more and more unsymmetric diarylfluorenes were utilized based on newly developed synthetic methods.[9] However, the developed methods were mainly based on Friedel−Crafts type reactions, which have many limitations on substrate scope, such as fluorenes containing electronic-poor aryl and meta-substituted aryl groups.[9b,10] These limited the further applications of diarylfluorenes in material sciences. Therefore, there is still high demand for novel and efficient synthetic methods for the access of this type of compounds.

We started our research by using compounds **1** and **2a** as the standard substrates with Pd as the catalyst to optimize the reaction conditions. First, several phosphorus ligands were investigated by using KO^{t}Bu as the base and toluene as the solvent at 100 °C (Table 1 entries 1−6). A rigid bidentate ligand dppf afforded a trace amount of the coupling product. When dppe was applied as the ligand, it also afforded a trace amount of the coupling product. However, when more labile bidentate ligand dppb was utilized, 42% of **3a** was obtained. It seemed that the more labile the bidentate ligand, the higher the yield. Therefore, 2 equiv of the monodendate ligand PPh_3 was then screened, which indeed turned out to be the most suitable ligand for this transformation and afforded the coupling product in a 95% yield. Moreover, nitrogen ligand phenanthroline gave a 64% yield of **3a** and no extra ligand provided 13% of the coupling product. Then, we tried to use a weaker base to replace KO^{t}Bu. However, the results exhibited that the weaker the base, the lower the yield (NaO^{t}Bu, 37%; NaOH, 22%; K_3PO_4, trace). We also tried to optimize the reaction temperature. However, when the reaction temperature was lowered to rt or 60 °C, only a trace amount of **3a** was observed. A temperature higher than 80 °C afforded the coupling product in an 84% yield. Solvent testing showed that other solvents could also afford the coupling product, but toluene was still the best choice for this transformation. Therefore, based on these condition screenings, the final optimized conditions included 5 mol % of [$Pd(dba)_2$], 10 mol % of PPh_3, 1.2 equiv of aryl bromide, 1.2 equiv of KO^{t}Bu in toluene at 100 °C for 8−10 h.

Table 1. Palladium Catalyzed Arylation of Monoarylfluorene[a]



entry	ligand	base	solvent	temp (°C)	yield (%)[b]
1	dppf	KO^{t}Bu	toluene	100	trace
2	dppe	KO^{t}Bu	toluene	100	trace
3	dppb	KO^{t}Bu	toluene	100	42
4	**PPh_3**	**KO^{t}Bu**	**toluene**	**100**	**95**
5	phenanthroline	KO^{t}Bu	toluene	100	64
6[c]	–	KO^{t}Bu	toluene	100	13
7	PPh_3	NaO^{t}Bu	toluene	100	37
8	PPh_3	NaOH	toluene	100	22
9	PPh_3	K_3PO_4	toluene	100	trace
10	PPh_3	KO^{t}Bu	toluene	rt	trace
11	PPh_3	KO^{t}Bu	toluene	60	trace
12	PPh_3	KO^{t}Bu	toluene	80	84
13	PPh_3	KO^{t}Bu	dioxane	100	34
14	PPh_3	KO^{t}Bu	THF	100	83
15	PPh_3	KO^{t}Bu	DMF	100	54
16	PPh_3	KO^{t}Bu	DMSO	100	44

[a] Reaction conditions: **1** (121 mg, 0.5 mmol), **2a** (102 mg, 0.6 mmol), 5 mol % $Pd(dba)_2$, 10 mol % ligand, base (0.6 mmol, 1.2 equiv). [b] Yields were determined by GC. [c] No ligand.

With the optimized reaction conditions in hand, a variety of substrates were tested. Most of the employed aryl bromides reacted smoothly with **1** under the standard conditions to afford the corresponding products in good to excellent yields (Scheme 1). C−F or C−Cl bonds were well tolerated, and the coupling products were obtained in good yields (**3b**, **3c**, **3j**, **3k**) . It was worth noting that one of the two C−Br bonds of 1,4-dibromobenzene could be well preserved by carefully controlling the ratio of the starting materials to be 1:5, which offered the opportunity for further functionalizations (**3d**). However, when the ratio was changed to 2.5:1, a good yield was easily obtained for **3h** which has been shown to be a wide-energy-gap host material for OLEDs.[11] It was shown that steric hindrance has a certain influence on the coupling reaction, and a relatively low yield was obtained (**3i**). We also extended our reaction to some bromo-heterocycles. To our delight, *N*-methyl-3-bromocarbazole gave the coupling product **3l** in 74% yield. 3-Bromopyridine was also proved to be a compatible substrate under our standard conditions, which afforded product **3e** in 65% yield. In the case of 2-bromothiophene and 3-bromothiophene, low yields were obtained (39% for **3g** and 54% for **3f**). Electron-rich aryl bromides also worked well and afforded the coupling products in good yields (**3l**, **3n**, **3o**, **3p**). *β*-Naphthalene bromide and its derivative were readily converted to the corresponding products (**3q**, **3r**) in 91% and 84% yields,

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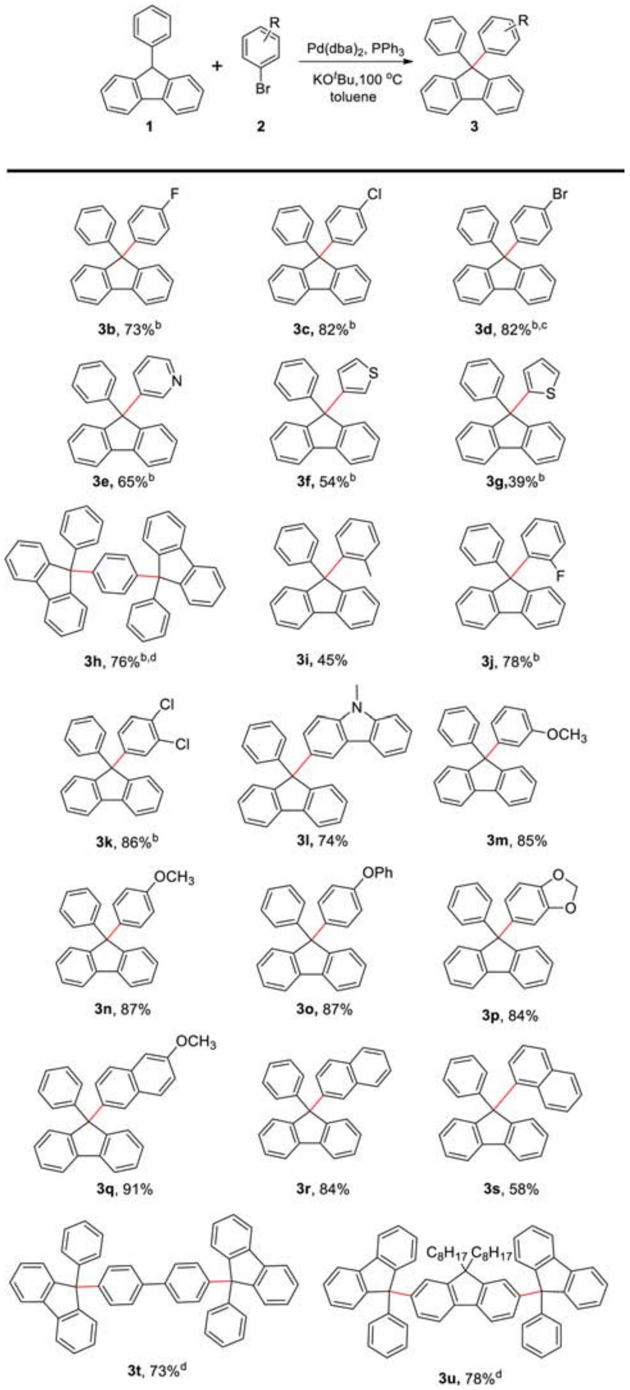
repectively. However, α-naphthalene afforded the corresponding product **3s** in a moderate yield. It was noteworthy that the difunctionalization of aryl dibromides could afford more interesting molecules in good yields which might have high potentials on host materials for OLEDs (**3t**, **3u**) .[11]

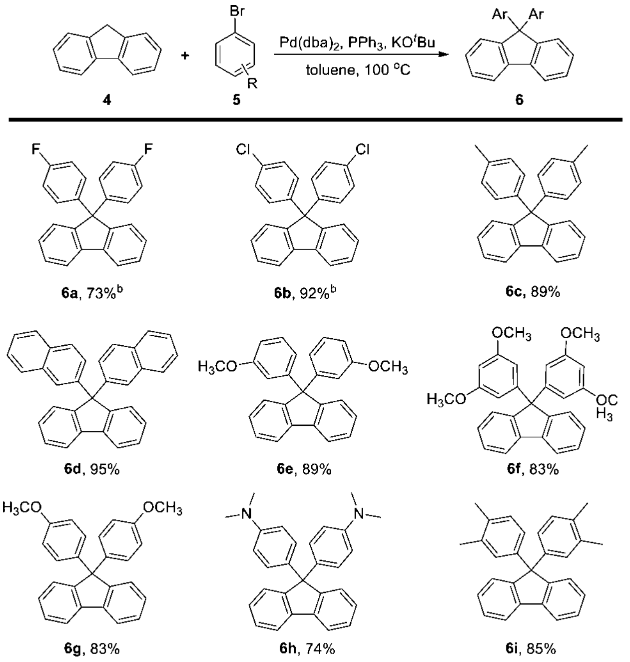
Scheme 1. Arylation of Monoarylfluorene by Different Aryl Bromides[a]



[a] Reaction conditions: **1** (0.5 mmol), **2a**–**h** (1.2 mmol), 5 mol % Pd(dba)$_2$, 10 mol % PPh$_3$, KO^{t}Bu (0.6 mmol). Isolated yield. [b] The ligand is *tert*-butyldiphenylphosphine. [c] 1,4-Dibromobenzene (2.5 mmol) is used. [d] Dibromoarenes (0.2 mmol) are used.

It has been reported that triarylmethane could be obtained via palladium catalyzed cross-coupling of diarylmethane with aryl halides.[12] Therefore, diarylfluorene could be synthesized by the one-pot reaction of fluorene with an excess amount of aryl halides in the presence of a palladium catalyst.[12a] Then, we tried the direct synthesis of diarylfluorene from fluorene with 2.4 equiv of aryl bromides. To our delight, various "symmetrical" diarylfluorenes were obtained in good to excellent yields under the standard conditions. Various functional groups, such as F, Cl, and OMe, could be well tolerated (see Scheme 2 and the Supporting Information). Multifunctionalized aryl bromides could also afford the corresponding coupling products in good yields (**6f**, **6i**). Furthermore, the present diarylation reaction was also applicable to a *β*-naphthalene bromide system, such as **5d**, which generated **6d** in 95% yield. However, negligible diarylfluorenes were observed when 2-bromotoluene, 1-bromonaphthalene, and heterocycles were employed as substrates under our standard conditions.

Scheme 2. Diarylation of Fluorene[a]



[a] Reaction conditions: **4** (0.5 mmol), **5** (1.2 mmol), 5 mol % Pd(dba)$_2$, 10 mol % PPh$_3$, KO^{t}Bu (0.6 mmol, 1.2 equiv). Isolated yield. [b] The ligand is *tert*-butyldiphenylphosphine.

In summary, we have developed an efficient Pd-catalyzed cross-coupling of triarylmethyl C–H bonds with aryl halides for the direct synthesis of unsymmetric diarylfluorenes, in which a quaternary carbon center was easily built. And fluorene was also directly diarylated. A series of diarylfluorenes, which played an important role in

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semiconductors, were smoothly obtained. Further investigation on the application of this chemistry is currently underway in our laboratory.

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Supporting Information Available. Experimental procedures, structural proofs, and spectral data for all new compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

The authors declare no competing financial interest.