

## Synthesis of Sterically Congested Triarylamines by Palladium-Catalyzed Amination

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Keywords: Homogenous catalysis / Amination / Palladium / Cross-coupling / Steric hindrance

An efficient protocol for the palladium-catalyzed synthesis of sterically congested triarylamines from commercially available 1-chloro- or 1-bromonaphthalenes and diarylamines is described. The application of alkyllithium reagents as strong bases and a combination of Pd(OAc)<sub>2</sub> and SPhos (2-dicyclohexylphosphino-2',6'-dimethoxybiphenyl) plays a crucial role in the success of this otherwise difficult to achieve C-N

### Introduction

Triarylamines are important core motifs as structural elements for optoelectronic applications as host, transport, or emitter materials in organic light-emitting diodes (OLEDs).<sup>[1]</sup> Modern synthetic routes to triarylamines utilize well-established palladium-catalyzed Buchwald-Hartwig couplings,<sup>[2,3]</sup> copper-catalyzed Ullmann reaction,<sup>[4]</sup> and other transition-metal-mediated reactions mainly utilizing iron-<sup>[5]</sup> or nickel-based catalysts.<sup>[6]</sup> Transition-metal-free approaches are known as well.<sup>[7]</sup>

We are highly interested in the synthesis of sterically congested triarylamines bearing additional alkyl substituents in the 2-position of the aryl group, as it was demonstrated that materials based on these substrates show improved device lifetime, enhanced color coordinates, and significantly higher thermal stability than the 2-unsubstituted derivatives.<sup>[8a]</sup> Examples for privileged structures that are under heavy investigation by a variety of chemical companies are shown in Figure 1.<sup>[8b-8e]</sup> Unfortunately, for the synthesis of these sterically hindered triarylamines,<sup>[9]</sup> the standard amination protocols mentioned above deliver unsatisfactory results. A rare example for a successful synthesis of 2-substituted triarylamines was reported recently by Kuwano and co-workers. With a catalyst system comprising Pd(OAc)<sub>2</sub>/  $P(tBu)_3$ , any bromides could be coupled with a variety of bis(2-methylphenyl)amines to give the desired triarylamines in good yields.<sup>[10,11]</sup> However, we were particularly inter-

coupling reaction. A variety of secondary aromatic amines with versatile steric and electronic properties can be successfully used in this transformation to give the desired triarylamines in up to 99 % yield. The obtained products are important structural motifs in hole-transport materials for organic light-emitting diode applications.

ested in the synthesis of sterically congested triarylamines in which one of the three aryl groups was a 1-naphthyl substituent and the other two aryl groups had at least one additional substituent in the ortho position of the aromatic rings. Couplings of 1-halogenated naphthalenes with orthounsubstituted diarylamines are known (Scheme 1, a).[2f,6b,6c]



Figure 1. Representative examples of sterically congested triarylamines used as dopant or emitting materials in organic electronic devices.

However, coupling reactions between 1-halogenated naphthalenes and diarylamines bearing substituents in the 2-position seem to be challenging, as no procedure is known so far for this transformation. In this article we want

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Supporting information for this article is available on the WWW under http://dx.doi.org/10.1002/ejoc.201400046.

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(a) Recent work (ref.<sup>[2f,6b,6c]</sup>):



Scheme 1. (a) Known literature procedures for the amination of 2halonaphthalenes with unsubstituted diarylamines. (b) The present work in comparison.

to report such a reaction, which gives direct access to sterically congested triarylamines needed as materials with unique properties for OLED applications (Scheme 1, b).

#### **Results and Discussion**

Initially, we investigated the amination reaction of 1bromonaphthalene (1a) with bis(2,4-dimethylphenyl)amine (2a) by using standard Buchwald-Hartwig amination conditions. A variety of common phosphine ligands such as PPh<sub>3</sub>, RuPhos, P(o-tolyl)<sub>3</sub>, and ClP(tBu)<sub>2</sub><sup>[12]</sup> in combination with NaOtBu as a typical base gave only disappointing results, as no reasonable formation of 3a was observed (Table 1, entries 1–4). Only the SPhos<sup>[13]</sup> ligand, which was introduced by Buchwald and co-workers in 2005 for Suzuki-Miyaura couplings, gave 3a in 10% yield (Table 1, entry 5).<sup>[14]</sup> In addition to the desired product, substantial formation (15%, measured by GC) of the naphthyl ether 1tert-butoxynaphthalene was observed as a result of an undesired coupling reaction between 1-naphthtylbromide and NaOtBu. In the absence of primary and secondary amines, the formation of aryl ethers is a well-known process. Their competing formation during an amination reaction is in general negligible.

An even better yield of **3a** (30%) was observed upon using  $P(tBu)_3^{[15]}$  as a ligand (Table 1, entry 6). However, given that  $P(tBu)_3$  is air sensitive, highly flammable and pyrophoric, difficult to handle on a large scale, and subject to drastic transport regulations, the easier-to-handle, air-stable SPhos ligand was used for further optimizations instead.<sup>[16]</sup> To avoid formation of the undesired aryl ethers, other nonnucleophilic bases were investigated. Unfortunately, common phosphate, carbonate, and hydride bases were completely ineffective (Table 1, entries 7–9). Also, nitrogen-containing organic bases such as DBU and NEt<sub>3</sub> proved to be totally inefficient for this transformation (Table 1, entries 10 and 11).

Table 1. Optimization studies.

	Br HN	Pd(OAc) <sub>2</sub> (2 mol-%) ligand (4 mol-%) base solvent, 105 °C		Ň
1a 2a			3a	
Entry	Phosphine ligand	Base	Solvent	Yield [%]
1 <sup>[a]</sup>	PPh <sub>3</sub>	NaOtBu	toluene	trace
2 <sup>[a]</sup>	RuPhos	NaOtBu	toluene	0
3 <sup>[a]</sup>	$P(o-tolyl)_3$	NaOtBu	toluene	0
4 <sup>[a]</sup>	$ClP(tBu)_2$	NaOtBu	toluene	trace
5 <sup>[a]</sup>	SPhos	NaOtBu	toluene	10 <sup>[b]</sup>
6 <sup>[a]</sup>	$P(tBu)_3$	NaOtBu	toluene	30 <sup>[b]</sup>
7[c,d]	SPhos	$K_3PO_4$	xylene	trace
8 <sup>[c,d]</sup>	SPhos	$Cs_2CO_3$	xylene	trace
9 <sup>[d]</sup>	SPhos	NaH	toluene	0
10 <sup>[c]</sup>	SPhos	NEt <sub>3</sub>	toluene	0
11 <sup>[c]</sup>	SPhos	DBU	toluene	0
12 <sup>[e]</sup>	SPhos	LiHMDS	toluene	85 <sup>[f]</sup>
13 <sup>[e]</sup>	SPhos	LDA	toluene	87 <sup>[f]</sup>
14 <sup>[e]</sup>	SPhos	n-hexyllithium	toluene	92 <sup>[f]</sup>

[a] Reaction conditions: **1a** (0.455 mmol, 1.1 equiv.), **2a** (0.414 mmol, 1.0 equiv.), NaOtBu (0.538 mmol, 1.3 equiv.), solvent (4 mL), 6 h. [b] Yield determined by GC–MS. [c] Reaction conditions: **1a** (0.46 mmol), **2a** (0.683 mmol, 1.5 equiv.), base (0.68 mmol, 1.5 equiv.), solvent (5 mL), 60 h. [d] Reaction temperature was 130 °C. [e] Reaction time was 1 h. [f] Yield of isolated product. RuPhos = 2-dicyclohexylphosphino-2',6'-diisopropoxybiphenyl, SPhos = 2-dicyclohexylphosphino-2',6'-dimethoxybiphenyl, DBU = 1,8-diazabicyclo[5.4.0]undec-7-ene, LiHMDS = lithium bis(trimethylsilyl)amide, LDA = lithium diisopropylamide.

The generally accepted catalytic cycle for the Buchwald-Hartwig amination suggests an oxidative addition of Pd<sup>0</sup> into the aryl halogen bond followed by coordination of the amine. Upon coordination of the amine, its NH acidity is supposed to increase significantly. Therefore, even weak bases can deprotonate the coordinated amine. After deprotonation, the coupling product is released by reductive elimination.<sup>[17]</sup> We assume that for the coupling of bulky secondary amines and bulky aryl halogenides, the deprotonation process of the amine plays a determining role. If both the amine and the aryl moiety are coordinated to the palladium center, the key NH proton is sterically protected against deprotonation at this stage of the catalytic cycle.<sup>[18]</sup> A different approach, which would circumvent the NH-deprotonation step at the sterically congested Pd site, would be the deprotonation of the amine before entering the catalytic cycle. Secondary amines typically have  $pK_a$  values of approximately 23 in benzene.<sup>[19]</sup> NaOtBu, the strongest base we used so far  $(pK_a \approx 19)$ ,<sup>[19,20]</sup> is not strong enough to deprotonate the amine without coordinating to palladium.

Therefore, we next focused on bases with comparable or significantly higher  $pK_a$  values than those of secondary aromatic amines, in particular LiHMDS, LDA, and *n*-hexyl-lithium. To our great delight, addition of each of these bases immediately improved the yields of **3a** (Table 1, en-

tries 12–14), whereas the latter one proved to be the best base; it gave the desired product in 92% yield.<sup>[21]</sup>

With the optimized reaction parameters in hand, we next proved the general applicability of our novel amination protocol. Thus, we subsequently investigated the substrate scope of this reaction by using a variety of sterically demanding aromatic secondary amines. In addition, we successfully extended the substrate scope to 1-chloronaphth-

Table 2. Scope of the amination of 1-chloro- and 1-bromonaphthalene with various diarylamines.



[a] Extended reaction times (in parentheses) were necessary with the use of secondary amine **2f** in combination with **1b** (62 h) and **1a** (5 h).



alene **1b** as a cheap alternative to 1-bromo derivative **1a**.<sup>[22]</sup> The results of these experiments are outlined in Table 2. In general, 1-bromonaphthalene showed slightly higher reactivity than 1-chloronaphthalene. Bis(2-methylphenylamine) **2b** gave desired triarylamine **3b** in moderate yields of 48 (X = Br) and 32% (X = Cl), although the steric demand was identical to that of substrate 2a. Similar yields were observed with bis(2,3-dimethylphenyl)amine 2c to give triarylamine 3c. Mixed diarylamine 2d could also be used in this transformation to yield 3d in moderate yields of 44 (X = Cl) and 43% (X = Br). 2-Phenyl-substituted diarylamine 2e reacted smoothly to give sterically congested triarylamine **3e** in high yields of up to 71%. 1-Naphthyl- and 2-naphthylsubstituted diarylamines could be used as well, and they gave 3f and 3g in good to excellent yields of 86 and 94% (X = Br), respectively. Unfortunately, dimesitylamine did not react under these conditions (data not shown). However, less bulky diarylamines such as 2h and 2i gave corresponding triarylamines **3h** and **3i** in 99 (X = Cl) and 90% yield (X = Br), respectively. To finish our experiments, we performed the amination reaction with secondary amines with different electronic properties. Electron-rich methoxysubstituted diarylamines 2j and 2k also reacted smoothly to give desired amines **3j** and **3k** in nearly quantitative yields (up to 98%). The use of 3-trifluoromethyl-substituted diarylamine 21 resulted in the formation of 31 in good yields up to 68% (X = Br).

### Conclusions

In summary, we demonstrated synthetic access to sterically congested triarylamines through a novel Pd-catalyzed amination protocol. The key to the success of this method is initial deprotonation of the diarylamine by using alkyllithium reagents as strong bases. 1-Chloro- and 1-bromonaphthalenes were used in this transformation to give a variety of triarylamines in up to 99% yield. Detailed analysis of the properties of the materials, in particular their long-term stability in optical devices, is part of current research.

#### **Experimental Section**

**General Procedure:** Bis(2,4-dimethylphenyl)amine (**2a**; 250 mg, 1.11 mmol, 1.0 equiv.), palladium(II) acetate (4.98 mg, 0.022 mmol, 2 mol-%), and SPhos (18.22 mg, 0.044 mmol, 4 mol-%) were charged into a nitrogen-flushed vial, and the vial was sealed with a septum. After adding dry toluene (5 mL), 1-chloronaphthalene (**1b**; 0.167 mL, 1.22 mmol, 1.1 equiv.) was added dropwise to the solution, which was stirred for another few minutes. Then, *n*-hexyllithium (2.47 M in hexane, 0.58 mL, 1.442 mmol, 1.3 equiv.) was carefully added dropwise to the reaction mixture at room temperature. The mixture was then heated up to 105 °C for 2 h. After cooling down to room temperature, the mixture was diluted with water and extracted with toluene. The organic phase was washed with water, dried with MgSO<sub>4</sub>, and concentrated in vacuo. The crude residue was purified by column chromatography on silica gel (heptane/CH<sub>2</sub>Cl<sub>2</sub>, 10:1) to give **3a** (336 mg, 86%) as a colorless solid.

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**Supporting Information** (see footnote on the first page of this article): Detailed experimental procedures, characterization data, and copies of the <sup>1</sup>H NMR and <sup>13</sup>C NMR spectra of the prepared secondary amines and final products.

#### Acknowledgments

Financial support by the Deutsche Forschungsgemeinschaft (DFG) and the Fonds der Chemischen Industrie is acknowledged. S. R. gratefully acknowledges Merck KGaA for financial support.

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Received: January 10, 2014 Published Online: January 31, 2014