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## COMMUNICATION

# A straightforward access to photochromic diarylethene derivatives *via* palladium-catalysed direct heteroarylation of 1,2-dichloroperfluorocyclopentene†

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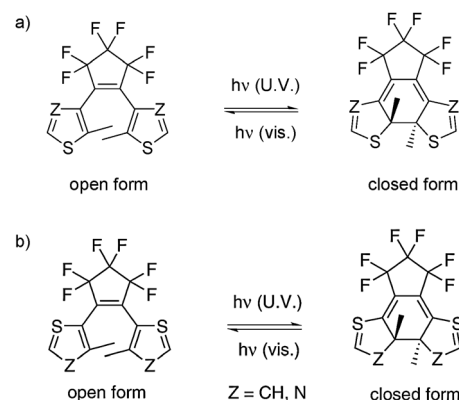
A novel and efficient palladium-catalysed direct di-heteroarylation of 1,2-dichloroperfluorocyclopentene with a variety of heteroarenes is reported, giving rise to 1,2-di(heteroaryl)perfluorocyclopentene photochromic compounds. The reaction proceeds with thiazoles, thiophenes or furan derivatives and tolerates various substituents.

The palladium-catalysed direct arylation or vinylation of heteroaromatics has recently emerged as a very powerful method for the preparation of substituted heteroaromatics.<sup>1–5</sup> However, there are still limitations for these reactions in terms of substrate scope. If the coupling of various *aryl* halides<sup>5</sup> with heteroarenes has been largely described, on the other hand, the coupling of *vinyl* halides and especially *vinyl chlorides* has attracted much less attention.<sup>6</sup>

Research in design and preparation of photoswitchable molecules such as diarylethene containing heterocyclic rings (DAE) has been driven by their potential applications in optical data storages and molecular switches.<sup>7</sup> The chemistry of photochromic DAE derivatives, in which the two heteroaryl rings are connected to the ethene bridge at the C3-thienyl or C4-thiazolyl position has been widely developed (Scheme 1a).<sup>7</sup> By contrast, the design of DAE derivatives incorporating bis(2-thienyl)ethene and bis(5-thiazolyl)ethene fragments, whose photochromic and optical properties are different from the former species, has been much less explored (Scheme 1b).<sup>8</sup>

DAE derivatives are generally prepared in two steps *via* lithiation of thiophenes or thiazoles and requires the use of the toxic and volatile octafluorocyclopentene C<sub>5</sub>F<sub>8</sub>.<sup>7,8</sup> Therefore, to overcome these limitations, a straightforward and selective method for the synthesis of 1,2-di(heteroaryl)perfluorocyclopentenes is highly desirable.

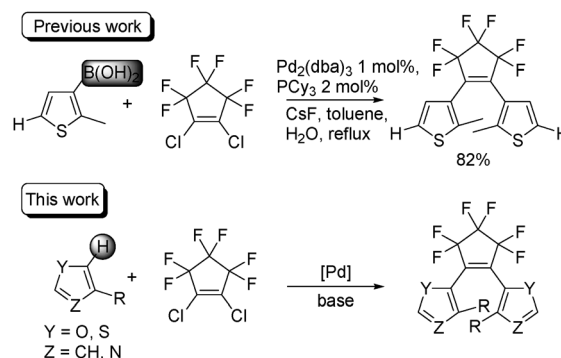
Very recently, it has been reported that dithienylperfluorocyclopentene can be easily obtained in high yield by



**Scheme 1** Photochromism of (a) 3-thienyl/4-thiazolyl and (b) 2-thienyl/5-thiazolyl containing DAE derivatives.

Suzuki–Miyaura cross-coupling (Scheme 2, top).<sup>9</sup> Based on this result, and also on our results on palladium-catalysed direct arylation or vinylation of heteroaromatics,<sup>2,6a</sup> we decided to investigate the synthesis of 1,2-di(heteroaryl)perfluorocyclopentenes *via* the direct coupling of 1,2-dichloroperfluorocyclopentene with various heteroarenes (Scheme 2, bottom).

The palladium-catalysed direct heteroarylation for access to 1,2-di(heteroaryl)perfluorocyclopentenes would present considerable advantages. It would allow us to reduce the number of steps to prepare these compounds. In addition, such couplings



**Scheme 2**

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† Electronic supplementary information (ESI) available: Procedures; NMR data; additional absorption data and UV-visible spectra for compounds **2**, **3a**, **4**, **6** and **12**. See DOI: 10.1039/c2cc37046h

are expected to present a better functional group tolerance, which would allow a straightforward modification of the nature of the substituents and hence of the photochromic properties of the resulting 1,2-di(heteroaryl)perfluorocyclopentene derivatives.

We now report (i) conditions for the palladium-catalysed direct coupling of heteroaromatics with 1,2-dichloroperfluorocyclopentene (ii) the synthesis of a variety of new DAE derivatives and preliminary studies on their photochromic properties (iii) that this coupling method tolerates several useful functional groups.

Keeping in mind the reaction conditions employed for the direct arylation of heteroaromatics in our previous works,<sup>2,6a</sup> we initially examined the influence of the nature of the solvent for the coupling of 1,2-dichloroperfluorocyclopentene with 2-*i*-butylthiazole (Table 1). We observed that, the use of 5 mol% Pd(OAc)<sub>2</sub> as the palladium source, 5 mol% PCy<sub>3</sub> as the ligand, DMAc as the solvent using KOAc as a base and Bu<sub>4</sub>NBr as an additive at 150 °C did not result in the formation of the target product **1a** (Table 1, entry 1). Similar results were obtained at 130 °C using either PCy<sub>3</sub> or dppb as the ligands and cyclopentyl methyl ether (CPME) as the solvent (Table 1, entries 2 and 3). On the other hand, the use of CPME as the solvent for this reaction, using 10 mol% Pd(OAc)<sub>2</sub> as the palladium source and 10 mol% PCy<sub>3</sub> as the ligand at 130 or 120 °C, without addition of Bu<sub>4</sub>NBr, afforded cleanly the desired product **1a** in 74% yield (Table 1, entry 4). Surprisingly, no trace of the mono-heteroarylated product **1b** was detected under these conditions. We had previously observed that CPME promotes the palladium-catalysed direct arylations in high yields with some heteroaromatic derivatives.<sup>10</sup> This solvent presents several advantageous features such as limited miscibility in water and low formation of peroxides.<sup>11</sup> A slightly lower reaction temperature of 120 °C allowed the increase of the yield in **1a** to 91% (Table 1, entry 5). It should be noted that the use of 5 mol%

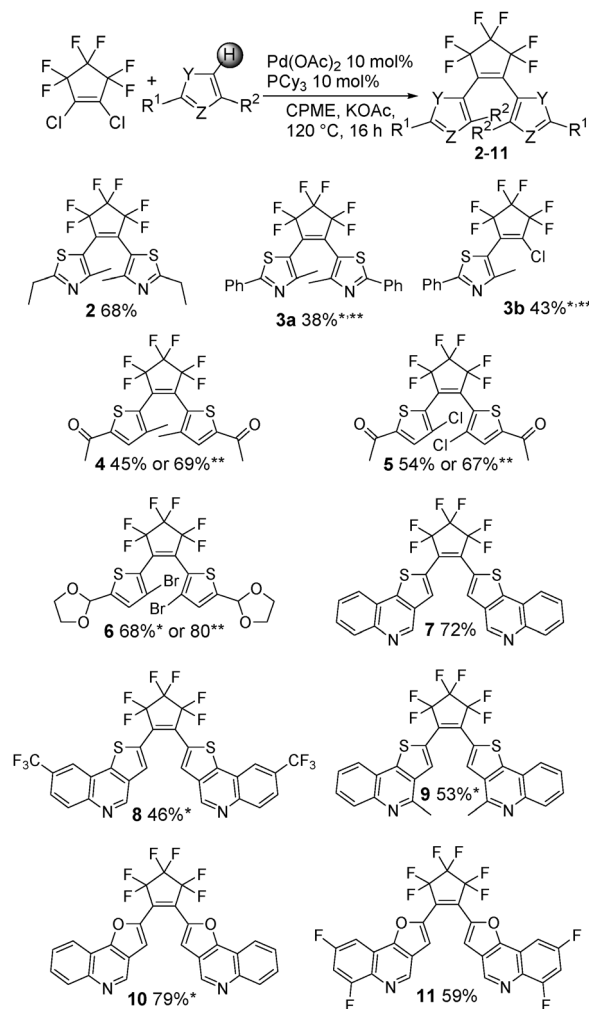
PdCl(C<sub>3</sub>H<sub>5</sub>)(dppb) as the catalyst also produces **1a** in high yield, whereas the use of 5 mol% Pd(OAc)<sub>2</sub> in the absence of phosphine ligand was completely ineffective (Table 1, entries 7 and 8).

The scope of this reaction was examined using various heteroarenes (Scheme 3). A good yield of 68% in **2** was obtained by coupling of 1,2-dichloroperfluorocyclopentene with 2-ethyl-4-methylthiazole. By using a 1 : 1 ratio of these reactants, the formation of a mixture of the mono-heteroarylated cyclopentene and **2** in a 4 : 1 ratio was observed by GC/MS. However, under these conditions, 48% of the 1,2-dichloroperfluorocyclopentene was recovered unreacted. A lower yield in **3a** was obtained from 2-phenyl-4-methylthiazole due to the formation of a mixture of the mono- and di-heteroarylated alkenes **3a** and **3b** in a 38 : 43 ratio after 24 h. Then, the reactivity of several thiophene derivatives was examined. From 2-acetyl-4-methylthiophene, **4** was obtained in 69% yield using 5 mol% PdCl(C<sub>3</sub>H<sub>5</sub>)(dppb) as the catalyst. No significant formation of the mono-heteroarylated product was formed. Next, in order to obtain building blocks allowing a simple access to a variety of di(heteroarylated)perfluorocyclopentenones, we employed 2-acetyl-4-chlorothiophene as the reactant. The desired

**Table 1** Influence of the reaction conditions for palladium-catalysed direct coupling of 1,2-dichloroperfluorocyclopentene with 2-*i*-butylthiazole

Entry	Catalyst (mol%)	Temp./ °C	Solvent	Bu <sub>4</sub> NBr	Ratio 1a : 1b	Yield (%)
1	Pd(OAc) <sub>2</sub> /PCy <sub>3</sub> (10)	150	DMAc	1 equiv.	nd	0
2	Pd(OAc) <sub>2</sub> /PCy <sub>3</sub> (10)	130	CPME	1 equiv.	nd	0
3	Pd(OAc) <sub>2</sub> /dppb (10)	130	CPME	1 equiv.	nd	0
4	Pd(OAc) <sub>2</sub> /PCy <sub>3</sub> (10)	130	CPME	—	100 : 0	74
5	Pd(OAc) <sub>2</sub> /PCy <sub>3</sub> (10)	120	CPME	—	100 : 0	91 (82)
6	Pd(OAc) <sub>2</sub> /PCy <sub>3</sub> (5)	120	CPME	—	100 : 0	59
7	Pd(OAc) <sub>2</sub> (5)	120	CPME	—	Nd	0
8	PdCl(C <sub>3</sub> H <sub>5</sub> )(dppb) (5)	120	CPME	—	97 : 3	90 (80)

Conditions: catalyst: [Pd], 2-*i*-butylthiazole (1.5 mmol), 1,2-dichloroperfluorocyclopentene (0.5 mmol), KOAc (1.5 mmol), under argon, 16 h, GC and NMR yields. Yields in parentheses are isolated. CPME: cyclopentyl methyl ether.



\*: Reaction time 24 h

\*\*: 5 mol% PdCl(C<sub>3</sub>H<sub>5</sub>)(dppb) as the catalyst

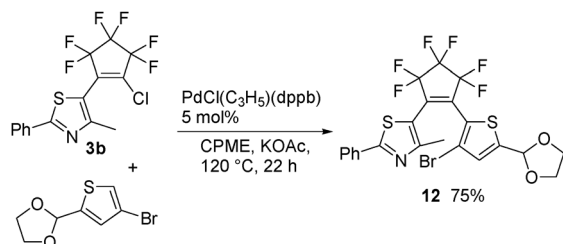
**Scheme 3** Palladium-catalysed direct coupling of heteroaromatics with 1,2-dichloroperfluorocyclopentene: substrate scope.

product **5** was obtained in 67% yield. Interestingly, in the course of this reaction no cleavage of the C–Cl bond on thiophene was observed. Then, we employed a 2-formyl-4-bromothiophene protected as an acetal. The target compound **6** was isolated in 80% yield, again without cleavage of the C–Br bond of thiophene. Finally, the reactivity of three thienoquinolines and two fluoroquinolines was examined. The desired products **7–11** were obtained in 46–79% yields.

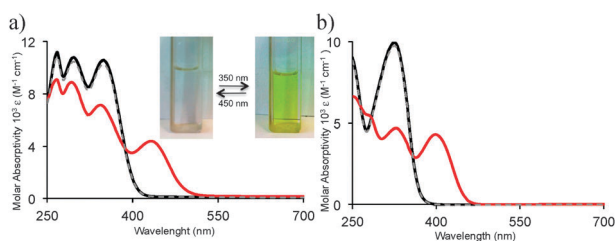
As the synthesis of the mono-heteroarylated alkene **3b** was possible, we attempt to synthesize a 1,2-di(heteroaryl)perfluorocyclopentene derivative bearing two different heteroaryl units. From **3b** and protected 2-formyl-4-bromothiophene, **12** was obtained in 75% yield (Scheme 4).

The photochromic behaviour of compounds **2**, **3a**, **4**, **6** and **12** has been monitored by UV-visible absorption (Fig. 1, Fig. S1 and Table S2 (see ESI†)). The thienyl- and the thiazolyl-based compounds **6** and **2** were used as representative examples. Fig. 1 shows their absorption spectral changes in dichloromethane upon light irradiation. The initial solution of **6** was colorless with an intense absorption band in the UV region ( $\lambda_{\text{max}} = 346 \text{ nm}$ ) (Fig. 1a). Upon UV irradiation ( $\lambda = 350 \text{ nm}$ ), the solution turned yellow with a concomitant decrease of the bands in the UV and the appearance of a new band in the visible ( $\lambda_{\text{max}} = 430 \text{ nm}$ ). The  $^1\text{H}$  NMR spectrum displayed two new singlets at 5.93 and 5.77, upfield shifted by *ca.* 0.3 ppm, which are assigned to the thiophene protons. These features are consistent with the formation of the closed form,<sup>8a</sup> with a photocyclization conversion of 83%. The thiazole derivative **2** shows a similar photochromic behaviour under the same conditions (Fig. 1b). For both compounds **6** and **2**, the yellow color of the solution was easily bleached with visible light irradiation ( $\lambda = 450 \text{ nm}$ ) with the initial spectrum being fully recovered (Fig. 1), indicating the fully reversible closed-to-open photoisomerization.

In summary, we have demonstrated that when appropriate reaction conditions are employed, the palladium-catalysed direct coupling of various heteroarenes with 1,2-dichloroperfluorocyclopentene proceeds in moderate to high yields. This route



**Scheme 4** Palladium-catalysed synthesis of unsymmetric DAE **12**.



**Fig. 1** UV-visible absorption spectra of the open form (black line), photostationary state after UV irradiation at 350 nm (red line) and after irradiation at 450 nm (dashed grey line) of (a) **6** and (b) **2**.

offers a fast and direct access to symmetric and unsymmetric 1, 2-di(heteroaryl)perfluorocyclopentenes. This protocol is applicable to a range of functions, including reactive ones, on the heteroarene. Such functional group tolerance allows the easy modification of the electronic structure of such derivatives, a strategy enabling the tuning of their optical and photochromic properties. Moreover, due to its higher boiling point, the handling of 1,2-dichloroperfluorocyclopentene is more convenient than octafluorocyclopentene. For these reasons, this process should give a more economically viable and environmentally attractive access to several 1, 2-di(heteroaryl)perfluorocyclopentenes.

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