DOI: 10.1002/anie.200800924

VIP **Direct Coupling**

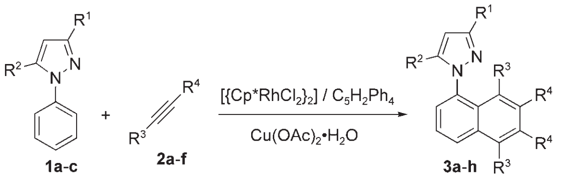
Fluorescent Naphthyl- and Anthrylazoles from the Catalytic Coupling of Phenylazoles with Internal Alkynes through the Cleavage of Multiple C−H Bonds**

Nobuyoshi Umeda, Hayato Tsurugi, Tetsuya Satoh, and Masahiro Miura**

Polycyclic aromatic and heteroaromatic compounds have attracted considerable attention because of their electrochemical and photochemical properties, and their application as π-conjugated functional materials such as organic semiconductors and luminescent materials.[1] Polyarylated derivatives with condensed aromatic cores are of particular interest because of their stability, their enhanced ability to transport charge, and their fluorescent properties in the solid-state that are brought about by the aryl groups.[2–4] Among the interesting examples is 1,3,6,8-tetraphenylpyrene, which was shown to be applicable to organic light-emitting diodes with field-effect transistor characteristics.[2] Recently, more sterically congested tetraarylpyrenes were synthesized and their solid-state emission properties were examined.[3]

Multiply arylated compounds are usually prepared by bromination of the parent aromatic compounds with subsequent cross-coupling with arylmetal reagents. Since the cross-coupling reaction is usually hampered by steric bulk, the construction of more densely arylated arenes by this method is problematic.[5] An alternative strategy includes the Diels–Alder reaction between polyarylated benzynes and cyclopentadienones.[4] This method enables the synthesis of exhaustively arylated naphthalene and anthracene units, however, the product yields are low because of steric repulsion between the bulky reagents.[6] Compared to benzyne, diarylacetylenes are more effective and readily available building blocks. Thus, transition-metal-catalyzed aromatic homologation[7] by the coupling of ArX with two alkyne molecules has been developed as an efficient and easily tunable synthetic protocol for highly substituted arenes possessing extended aromatic cores.[8] Herein, we report our new findings that phenylazoles undergo an advanced type of aromatic homologation, by the cleavage of two C−H bonds [9,10] under rhodium catalysis,[8g,h] to give (1,2,3,4-tetraarylnaphthalen-5-yl)azoles; the heterocycle functions as an effective directing group and enhances the fluorescent properties of the products (vide infra). Furthermore, similar treatment of a suitable phenylazole substrate with four equivalents of an alkyne leads to the cleavage of four C−H bonds to afford a polyarylated anthracene (1:4 coupling product) that is highly fluorescent.

In an initial attempt, 1-phenylpyrazole (**1a**) was used as a typical azole substrate for the reaction with diphenylacetylene (**2a**). The examination of different reaction conditions (see the Supporting Information) revealed that [{Cp*RhCl$_2$}$_2$]/C$_5$H$_2$Ph$_4$ (1,2,3,4-tetraphenylcyclopentadiene) and Cu(OAc)$_2$·H$_2$O are suitable choices for the catalyst and the oxidant, respectively. Thus, under optimal conditions (1 mol% [{Cp*RhCl$_2$}$_2$], 4 mol% C$_5$H$_2$Ph$_4$, 1 equiv Cu(OAc)$_2$·H$_2$O in DMF at 80 °C for 6 h under N$_2$) the 1:2 coupling product, 1-(1,2,3,4-tetraphenylnaphthalen-5-yl)pyrazole (**3a**), was obtained in 93% yield ($R^1 = R^2 = H$, $R^3 = R^4 = Ph$ in Equation (1); Table 1, entry 1).



(1)

Table 1 also summarizes the results for the coupling reactions that employed different 1-phenylpyrazoles and internal alkynes with the [{Cp*RhCl$_2$}$_2$]/C$_5$H$_2$Ph$_4$ catalyst system. The reaction of **1a** with diarylacetylenes **2b–d** proceeded efficiently to produce the corresponding 1-(1,2,3,4-tetraarylnaphthalen-5-yl)pyrazoles **3b-d** in good yields (Table 1, entries 2–4). 1-Phenyl-1-hexyne (**2e**) also reacted with **1a** to give 1-(1,4-dibutyl-2,3-diphenylnaphthalen-5-yl)pyrazole (**3e**) predominantly, along with a small amount of an unidentified isomer (Table 1, entry 5). From the reaction of 1-phenyl-1-propyne (**2f**) with **1a**, 1-(1,4-dimethyl-2,3-diphenylnaphthalen-5-yl)pyrazole (**3f**) was obtained in a moderate yield (Table 1, entry 6). 1-Phenyl-3-methylpyrazole (**1b**) and 1-phenyl-3,5-dimethylpyrazole (**1c**) underwent the coupling with **2a** in a similar manner to that of **1a** to produce the corresponding 1-naphthylpyrazoles **3g** and **3h** in good yields (Table 1, entries 7 and 8).

---

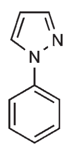
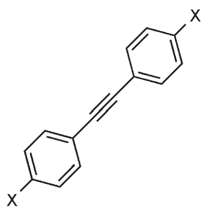
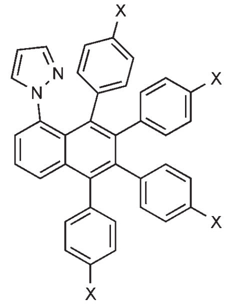
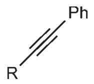
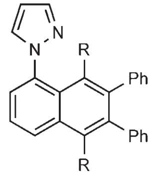
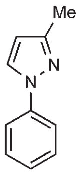
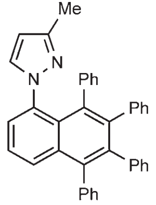
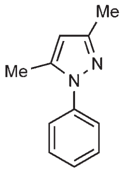
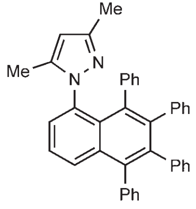
[*] N. Umeda, Dr. H. Tsurugi, Prof. Dr. T. Satoh, Prof. Dr. M. Miura
Department of Applied Chemistry
Faculty of Engineering
Osaka University
Suita, Osaka 565-0871 (Japan)
Fax: (+81) 6-6879-7362
E-mail: satoh@chem.eng.osaka-u.ac.jp
miura@chem.eng.osaka-u.ac.jp
Homepage: http://www.chem.eng.osaka-u.ac.jp/~miura-lab/index-Eng.htm

[**] We thank Prof. Dr. N. Tohnai, Osaka University, for fluorescence quantum efficiency measurements and helpful discussions. This work was partly supported by Grants-in-Aid from the Ministry of Education, Culture, Sports, Science, and Technology (Japan) and the Sumitomo Foundation.

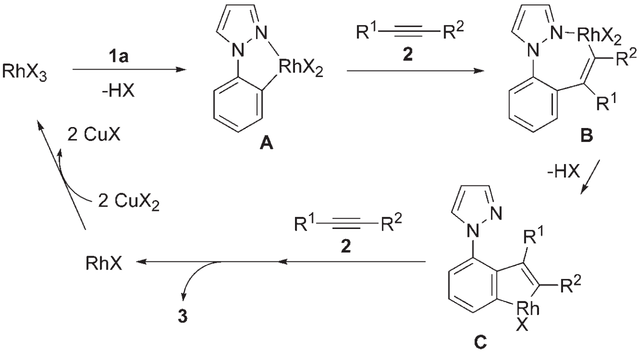
Supporting information for this article is available on the WWW under http://www.angewandte.org or from the author.

© 2008 Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim

Table 1: Reaction of 1-phenylpyrazoles **1a–c** with alkynes **2a–f**.[a]

Entry	1	2	*t* [h]	Product, Yield [%][c]
	 **1a**			
1	**1a**	**2a**: X = H	6	**3a**: X = H, 93 (93)
2		**2b**: X = Me	6	**3b**: X = Me, 80 (79)
3		**2c**: X = OMe	8	**3c**: X = OMe, (76)
4		**2d**: X = Cl	6	**3d**: X = Cl, (79)
				
5		**2e**: R = Bu	6	**3e**: R = Bu, 97 (72)[c]
6		**2f**: R = Me	6	**3f**: R = Me, 36 (20)
				
7	**1b**	**2a**	3	**3g**, 87 (87)
				
8	**1c**	**2a**	1	**3h**, 99 (97)

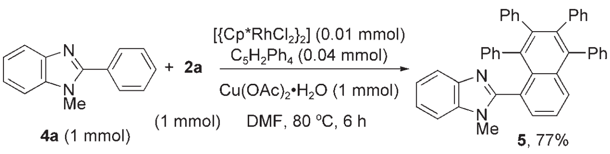
[a] Reaction conditions: **1** (1 mmol), **2** (1 mmol), [{Cp*RhCl$_2$}$_2$] (0.01 mmol), C$_5$H$_2$Ph$_4$ (0.04 mmol), Cu(OAc)$_2$·H$_2$O (1 mmol) in DMF (5 mL) at 80°C under N$_2$. [b] Yield determined by GC analysis and based on the amount of **2** used. Value in parentheses indicates yield after purification. [c] Contaminated with an isomer (**3e**:isomer = 94:6).



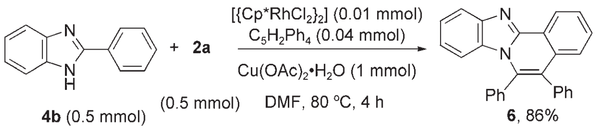
Scheme 1. Plausible mechanism for the reaction of **1a** with **2**.

A plausible mechanism for the reaction of **1a** with alkyne **2**, through directed metalation involving rhodacycle intermediates **A**–**C**,[11] is illustrated in Scheme 1 (neutral ligands are omitted). In the first step, coordination of the nitrogen atom in the 2-position of **1a** to a Rh^{III} species appears to be the key for the regioselective C–H bond cleavage.[12] Notably, the direction of the insertion of **2e** and **2f** into the Rh–Ar bonds is consistent with that in the reaction of benzoic acids.[8g]

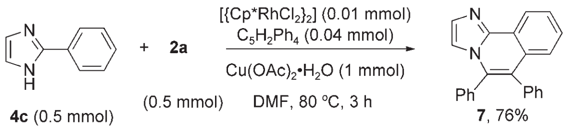
The reaction of 1-methyl-2-phenyl-1*H*-benzimidazole (**4a**) with **2a** gave 2-naphthylbenzimidazole **5** in 77% yield as expected [Eq. (2)]. In contrast, 2-phenyl-1*H*-benzimidazole (**4b**) underwent the reaction with **2a** in a 1:1 manner by the cleavage of C–H and N–H bonds to selectively produce imidazoisoquinoline **6** [Eq. (3)]. Using 2-phenyl-1*H*-imidazole (**4c**) gave a similar result to form **7** in 76% yield [Eq. (4)]. Interestingly, the less sterically demanding 2-phenylbenzoxazole (**4d**) reacted with **2a** in a 1:4 ratio to deliver 2-(1,2,3,4,5,6,7,8-octaphenylanthracen-9-yl)benzoxazole (**8**) through the activation of four C–H bonds [Eq. (5)].



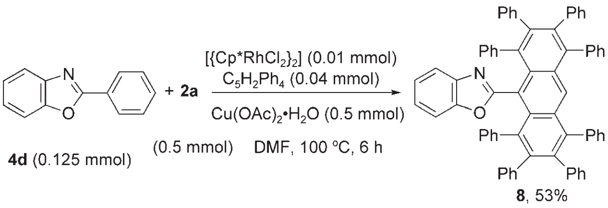
(2)



(3)



(4)



(5)

Most 1-naphthylpyrazoles **3** obtained above showed solid-state fluorescence in a range of 450–495 nm (see the Supporting Information). Notably, **3g** exhibited a relatively strong emission compared to a typical emitter, such as tris(8-hydroxyquinolino)aluminum (Alq$_3$), by a factor of 1.8 (λ_{emis} 467 nm, A versus C in Figure 1). In contrast, the parent 1,2,3,4-tetraphenylnaphthalene did not show fluorescence at all, indicating that substitution of the naphthalene core with a pyrazoyl group at the 5-position as well as four phenyl groups

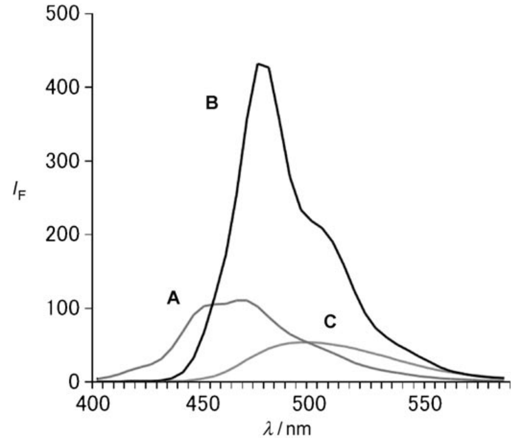


Figure 1. Fluorescence spectra of **3g** (A), **8** (B), and Alq_3 (C) in the solid state when excited at 380 nm.

is important for the flourescent properties. Interestingly, anthrylbenzoxazole **8** was found to exhibit more intense luminescence (λ_{emis} 477 nm), and the intensity was at least four times stronger than that of Alq_3 in the preliminary estimation (B versus C). Remarkably, the quantum efficiency (Φ) of the solid-state fluorescence of **8** was measured at an absolute value of 66 ± 2%.

In summary, we have demonstrated that polyarylated naphthyl- and anthrylazole derivatives can be constructed efficiently by the direct coupling of phenylazoles with internal alkynes in the presence of a rhodium catalyst and a copper oxidant. The reaction involves the cleavage of multiple C–H bonds, and some of the resulting products exhibit intense fluorescence in the solid state.

Experimental Section

General procedure for Rh-catalyzed reaction of 1-phenylpyrazoles with alkynes: 1-phenylpyrazoles **1** (1 mmol), internal alkyne **2** (1 mmol), $[Cp^*RhCl_2]_2$ (0.01 mmol, 6.2 mg), $C_5H_2Ph_4$ (0.04 mmol, 14.8 mg), $Cu(OAc)_2{\cdot}H_2O$ (1 mmol, 199 mg), dibenzyl (ca. 50 mg) as internal standard, and DMF (5 mL) were added to a 20 mL two-necked flask. The resulting mixture was stirred under N_2 at 80 °C for 1–8 h. GC and GC-MS analyses of the mixture confirmed formation of **3**. The product was isolated after chromatography on silica gel using hexane/ethyl acetate. Characterization data of products are summarized in the Supporting Information.

Received: February 26, 2008
Published online: April 16, 2008

Keywords: C–C coupling · C–H activation · fluorescent solids · homogeneous catalysis · rhodium

---

[1] Selected reviews: a) J. E. Anthony, *Angew. Chem.* **2008**, *120*, 460; *Angew. Chem. Int. Ed.* **2008**, *47*, 452; b) M. D. Watson, A. Fethtenkötter, K. Müllen, *Chem. Rev.* **2001**, *101*, 1267; c) U. Mitschke, P. Bäuerle, *J. Mater. Chem.* **2000**, *10*, 1471; d) R. G. Harvey, *Polycyclic aromatic hydrocarbons*, Wiley-VCH, Weinheim, **1996**.

[2] a) T. Oyamada, H. Sasabe, Y. Oku, N. Shimoji, C. Adachi, *Appl. Phys. Lett.* **2006**, *88*, 093514; b) T. Oyamada, H. Uchiuzou, S. Akiyama, Y. Oku, N. Shimoji, K. Matsushige, H. Sasabe, C. Adachi, *J. Appl. Phys.* **2005**, *98*, 074506; c) D. Qin, Y. Tao, *J. Appl. Phys.* **2005**, *97*, 044505; d) D. Qin, Y. Tao, *Appl. Phys. Lett.* **2005**, *86*, 113507; e) Y. Sagara, T. Mutai, I. Yoshikawa, K. Araki, *J. Am. Chem. Soc.* **2007**, *129*, 1520. See also a review: f) F. Cicoira, C. Santato, *Adv. Funct. Mater.* **2007**, *17*, 3421.

[3] J. N. Moorthy, P. Natarajan, P. Venkatakrishnan, D.-F. Huang, T. J. Chow, *Org. Lett.* **2007**, *9*, 5215.

[4] a) J. Lu, J. Zhang, X. Shen, D. M. Ho, R. A. Pascal, Jr., *J. Am. Chem. Soc.* **2002**, *124*, 8035; b) I. I. Schuster, L. Cracium, D. M. Ho, R. A. Pascal, Jr., *Tetrahedron* **2002**, *58*, 8875; c) R. A. Pascal, Jr., L. Barnett, X. Qiao, D. M. Ho, *J. Org. Chem.* **2000**, *65*, 7711; d) X. Qiao, I. Pelczer, R. A. Pascal, Jr., *Chirality* **1998**, *10*, 154; e) L. Tong, D. M. Ho, N. J. Vogelaar, C. E. Schutt, R. A. Pascal, Jr., *J. Am. Chem. Soc.* **1997**, *119*, 7291; f) L. Tong, D. M. Ho, N. J. Vogelaar, C. E. Schutt, R. A. Pascal, Jr., *Tetrahedron* **1997**, *38*, 7; g) X. Qiao, M. A. Padula, D. M. Ho, N. J. Vogelaar, C. E. Schutt, R. A. Pascal, Jr., *J. Am. Chem. Soc.* **1996**, *118*, 741. For a review on polyphenylated benzenes, see: h) M. Müller, C. Kübel, K. Müllenm, *Chem. Eur. J.* **1998**, *4*, 2099. For application to electroluminescence devices, see: i) K. Enomoto, T. Chiba, Japanese Patent JP 2005302657, **2005**; j) T. Igarashi, X. Qiu, Japanese Patent JP 2003027048, **2003**.

[5] The polyvinylation by palladium-catalyzed cross-coupling with hexa- and octabromoarenes was reported: B. Stulgies, P. Prinz, J. Magull, K. Rauch, K. Meindl, S. Rühl, A. de Meijere, *Chem. Eur. J.* **2005**, *11*, 308.

[6] The overall yield of decaphenylanthracene when prepared by using the Diels–Alder procedure was reported to be only 0.1%, whereas that of octaphenylnaphthalene was 26%. See reference [4g].

[7] a) T. Takahashi, S. Li, W. Huang, F. Kong, K. Nakajima, B. Shen, T. Ohe, K.-I. Kanno, *J. Org. Chem.* **2006**, *71*, 7967; b) T. Takahashi, Y. Li, P. Stepnicka, M. Kitamura, Y. Liu, K. Nakajima, M. Kotora, *J. Am. Chem. Soc.* **2002**, *124*, 576; c) T. Takahashi, M. Kitamura, B. Shen, K. Nakajima, *J. Am. Chem. Soc.* **2000**, *122*, 12876. Recently, polyarylated and partially fluorinated aromatics were synthesized by using the coupling of polyfluorinated aromatic substrates with 1,4-dilithio-1,2,3,4-tetraaryl-1,3-butadienes: d) S. Li, J. Xiang, X. Mei, C. Xu, *Tetrahedron Lett.* **2008**, *49*, 1690.

[8] For related naphtharene synthesis by the 1:2 coupling of ArX with internal alkynes, see: X = $CrPh_2$: a) G. M. Whitesides, W. J. Ehmann, *J. Am. Chem. Soc.* **1970**, *92*, 5625; b) W. Herwig, W. Metlesics, H. Zeiss, *J. Am. Chem. Soc.* **1959**, *81*, 6203. X = I: c) S. Kawasaki, T. Satoh, M. Miura, M. Nomura, *J. Org. Chem.* **2003**, *68*, 6836; d) G. Wu, A. L. Rheingold, S. L. Feib, R. F. Heck, *Organometallics* **1987**, *6*, 1941; e) T. Sakakibara, Y. Tanaka, T.-I. Yamasaki, *Chem. Lett.* **1986**, 797. X = COCl: f) T. Yasukawa, T. Satoh, M. Miura, M. Nomura, *J. Am. Chem. Soc.* **2002**, *124*, 12680. X = CO_2H: g) K. Ueura, T. Satoh, M. Miura, *J. Org. Chem.* **2007**, *72*, 5362. X = CR_2OH: h) T. Uto, M. Shimizu, K. Ueura, T. Tsurugi, T. Satoh, M. Miura, *J. Org. Chem.* **2008**, *73*, 298. *o*-Dihalobenzenes: i) W. Huang, X. Zhou, K.-I. Kanno, T. Takahashi, *Org. Lett.* **2004**, *6*, 2429.

[9] Selected reviews for C–H bond activation: a) D. Alberico, M. E. Scott, M. Lautens, *Chem. Rev.* **2007**, *107*, 174; b) K. Godula, D. Sames, *Science* **2006**, *312*, 67; c) C.-H. Jun, E.-A. Jo, J.-W. Park, *Eur. J. Org. Chem.* **2007**, 1869; d) B. L. Conley, W. J. Tenn III, K. J. H. Young, S. K. Ganesh, S. K. Meier, V. R. Ziatdinov, O. Mironov, J. Oxgaard, J. Gonzales, W. A. Goddard III, R. A. Periana, *J. Mol. Catal. A* **2006**, *251*, 8; e) M. Miura, T. Satoh, *Top. Organomet. Chem.* **2005**, *14*, 55; f) F. Kakiuchi, N. Chatani, *Adv. Synth. Catal.* **2003**, *345*, 1077; g) V. Ritleng, C. Sirlin, M. Pfeffer,

© 2008 Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim

Chem. Rev. **2002**, *102*, 1731; h) G. Dyker, *Angew. Chem.* **1999**, *111*, 1808; *Angew. Chem. Int. Ed.* **1999**, *38*, 1698.

[10] The coupling of benzene with alkynes by using a stoichiometric amount of Pd was reported. Naphthalene yields based on Pd were less than 20%. See reference [8e].

[11] The stoichiometric reactions of some palladacycles with alkynes to give naphthalenes were reported: a) J. Dupont, M. Pfeffer, M. A. Rotteveel, *Organometallics* **1989**, *8*, 1116; b) J. Dupont, M. Pfeffer, J.-C. Daran, J. Gouteron, *J. Chem. Soc. Dalton Trans.* **1988**, 2421; c) Reference [8d].

[12] Catalytic functionalizations involving N-directed C–H activation of 2-phenylpyrazoles have been reported. Acylation: a) T. Asaumi, T. Matsuo, T. Fukuyama, Y. Ie, F. Kakiuchi, N. Chatani, *J. Org. Chem.* **2004**, *69*, 4433; b) T. Asaumi, N. Chatani, T. Matsuo, F. Kakiuchi, S. Murai, *J. Org. Chem.* **2003**, *68*, 7538. Arylation: c) L. Ackermann, A. Althammer, R. Born, *Angew. Chem.* **2006**, *118*, 2681; *Angew. Chem. Int. Ed.* **2006**, *45*, 2619; d) D. Shabashov, O. Daugulis, *Org. Lett.* **2005**, *7*, 3657.

© 2008 Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim