Tetrahedron Letters xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Tetrahedron Letters

journal homepage: www.elsevier.com/locate/tetlet

Synthesis of 2,9-dialkylated phenanthro[1,2-*b*:8,7-*b*′]dithiophenes via cross-coupling reactions and sequential Lewis acid-catalyzed regioselective cycloaromatization of epoxide

Keita Hyodo[a], Hikaru Nonobe[a], Shuhei Nishinaga[a], Yasushi Nishihara[a,b,*]

[a] *Division of Earth, Life, and Molecular Sciences, Graduate School of Natural Science and Technology, Okayama University, 3-1-1 Tsushimanaka, Kita-ku, Okayama 700-8530, Japan*
[b] *Japan Science and Technology Agency, ACT-C, 4-1-8 Honcho, Kawaguchi, Saitama 332-0012, Japan*

ARTICLE INFO

Article history:
Received 26 March 2014
Revised 26 April 2014
Accepted 9 May 2014
Available online xxxx

Keywords:
Phenacenes
Suzuki–Miyaura coupling
Negishi coupling
Boron
Zinc

ABSTRACT

Phenanthro[1,2-*b*:8,7-*b*′]dithiophene (PDT) was prepared via Suzuki–Miyaura or Negishi cross-coupling of a 2-thienylboron or -zinc compound with 1,4-dibromobenzene, followed by Lewis acid-catalyzed regioselective cycloaromatization of the epoxide. A series of 2,9-dialkylated phenanthro[1,2-*b*:8,7-*b*′]dithiophene (PDT) derivatives could also be synthesized in good yields by Suzuki–Miyaura coupling of the brominated PDT with alkylboranes by introducing linear alkyl substituents.

Organic field-effect transistors (OFETs) have attracted considerable interest as key components in future ubiquitous electronics due to advantages such as flexibility, light weight, and ease of design.[1] One particular acene-type molecule, pentacene,[2] has served as the active semiconducting layer in OFETs owing to the high field-effect mobility (μ) of 5.5 $cm^2\,V^{-1}\,s^{-1}$ that it has shown in a thin-film transistor,[3] and its state-of-the-art value of 40 cm^2 - $V^{-1}\,s^{-1}$ in single crystals.[4] However, pentacene is unstable under atmospheric conditions, and readily photodegrades owing to its relatively high HOMO energy (−5.0 eV), which arises from its extended π-conjugation.[5] Recently, a phenacene-type molecule, picene, incorporating the same number of benzene rings as pentacene, has become the focus of considerable interest because it becomes superconductive[6] with alkali-metal doping, and also shows high field-effect mobility in a transistor (1.1 $cm^2\,V^{-1}\,s^{-1}$ in a thin-film OFET).[7] Moreover, a picene-based FET is stable in air because picene has a larger energy bandgap ($E_g = 3.3$ eV) and a lower HOMO energy (−5.5 eV) than pentacene.[8] The potential utility of phenacene-type molecules makes the development of more efficient synthetic methods[9] and further improvement in their OFET properties[10–12] matters of some importance.

We have recently reported the synthesis of picenes[13] and fulminene[14] by the palladium-catalyzed Suzuki–Miyaura coupling of (*Z*)-alkenylboronates with polyhalobenzene and sequential intramolecular double cyclization via C—H activation. This protocol is also applicable to the synthesis of phenanthro[1,2-*b*:8,7-*b*′]dithiophene (PDT) by replacing the terminal phenyl rings in picene with thiophene rings, aiming at increased intermolecular π–π interactions due to the large atomic radius of sulfur, which may enhance its performance in OFETs.[15] Results showed that OFET devices fabricated with thin films of PDT formed by thermal deposition exhibited carrier mobility as large as 1.1×10^{-1} $cm^2\,V^{-1}\,s^{-1}$, and suggested that fabrication using a solution process might be possible owing to PDT's high solubility in common organic solvents.

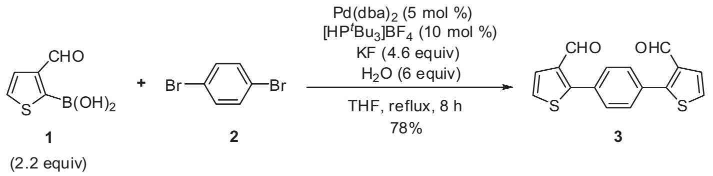
However, we found that this synthetic strategy is not suitable for the large-scale synthesis of PDT because in some cases a mixture of stereoisomers of the coupled products is formed through (*E*)/(*Z*) isomerization upon Suzuki–Miyaura coupling, leading to a lower yield of the desired products. To produce derivatives of PDT for use as organic semiconductors, a more efficient synthetic method is highly desirable. Here we report a new synthetic route to the PDT core structure using cross-coupling reactions. Furthermore, the solubility of PDT might be improved by introducing long alkyl chains, as this may induce a self-assembly process by the 'fastener effect', leading to high crystallinity in thin films. Some examples of this have already been reported in alkyl-substituted picene[16] and alkylated thienoacene.[17,18]

To explore a new synthetic route to PDT, we investigated the palladium-catalyzed Suzuki–Miyaura coupling of commercially

---

* Corresponding author. Tel./fax: +81 86 251 7855.
E-mail address: ynishiha@okayama-u.ac.jp (Y. Nishihara).

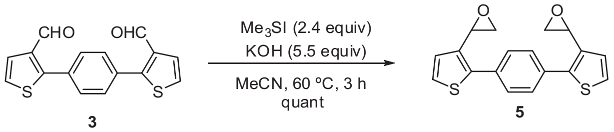
http://dx.doi.org/10.1016/j.tetlet.2014.05.035



Scheme 1.

available 3-formyl-2-thiopheneboronic acid (**1**) with 1,4-dibromobenzene (**2**) affording the corresponding coupled product **3** in 78% yield (Scheme 1).[19]

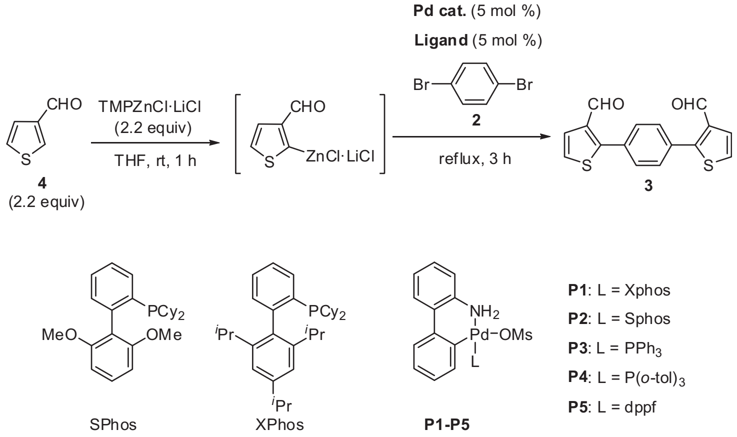
We screened various reaction conditions to develop an efficient synthetic route to **3**. The results are summarized in Table 1. To our surprise, we found that chemoselective C—H zincation across 3-formylthiophene (**4**) occurred at the 2-position (adjacent to the formyl group) of the thiophene ring, using TMPZnCl·LiCl.[20] Negishi coupling of the in situ generated 2-thienylzinc reagent with 1,4-dibromobenzene (**2**) using a catalyst system of $Pd(dba)_2$ (dba = dibenzylideneacetone) with a phosphonium salt, $[HP^tBu_3]BF_4$ used as a precursor of the phosphine ligand proceeded at reflux to furnish **3** in 65% yield (entry 1).[21] However, other palladium precursors and phosphine-based ligands including biarylphosphine (Sphos)[22] and $PdCl_2(dppf)·C_6H_6$[23] (dppf = 1,1′-bis(diphenylphosphino) ferrocene) were found to be inferior (entries 2–4). PEPPSI-IPr ((PEPPSI = pyridine-enhanced precatalyst preparation stabilization and initiation, IPr = 1,3-diisopropylimidazol-2-ylidene),[24] recently introduced by Organ, displayed a modest catalytic activity to afford **3** in 52% yield as determined by NMR (entry 5). With palladacycle precatalysts[25] utilized in the sp^2–sp^2 Negishi couplings, compound **3** was obtained in lower yields (entries 6–10).



Scheme 2.

Following this, sequential epoxidation of **3** gave the desired product **5** quantitatively (Scheme 2).[26,27] We next screened the reaction conditions of acid-mediated[28] and -catalyzed[29] Friedel–Crafts-type cycloaromatization of **5** and the results are summarized in Table 2. Attempted reactions with $MeSO_3H$ and $BF_3·OEt_2$ did not proceed, even with the addition of excess reagent. With a stoichiometric amount of $Sc(OTf)_3$, PDT (**6**) was obtained in 32% yield (entry 1). However, the catalytic variant of $Sc(OTf)_3$ was not effective (entry 2). We then explored catalytic reactions with other Lewis acids $M(OTf)_n$, but yields of **6** were insufficient (entries 3–6). To our delight, 10 mol % of $InCl_3$ was found to give better results and afforded **6** in 46% yield (entry 7). Increasing the amount of $InCl_3$ to 20 mol % improved the yield to 50% (entry 8). Varying the concentrations, we found that lower concentrations gave

Table 1
Optimization of Negishi cross-coupling of **2** with **4**



Entry	Pd cat.	Ligand	Yield[a] (%)
1[b]	$Pd(dba)_2$	$[HP^tBu_3]BF_4$	65
2[b]	$Pd(OAc)_2$	SPhos	46
3[b]	$Pd(dba)_2$	P(*o*-tol)$_3$	9
4	$PdCl_2(dppf)·C_6H_6$	—	55
5	PEPPSI·IPr	—	52
6	**P1**	—	41
7	**P2**	—	36
8	**P3**	—	15
9	**P4**	—	3
10	**P5**	—	4

[a] NMR yields based on **2**.
[b] 10 mol % of phosphine ligand was used.

Please cite this article in press as: Hyodo, K.; et al. *Tetrahedron Lett.* (2014), http://dx.doi.org/10.1016/j.tetlet.2014.05.035