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Site-Selective Monotitanation of Dialkynylpyridines and Its Application for Preparation of Highly Fluorescent π-Conjugated Oligomers

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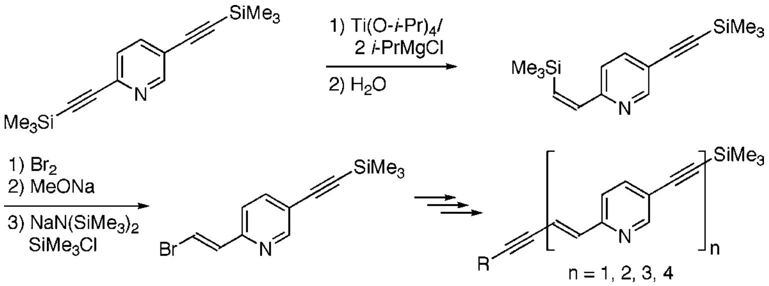
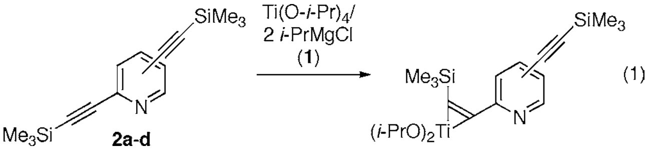
ABSTRACT



Reaction of Ti(O-*i*-Pr)$_4$/2*i*-PrMgCl reagent with 2,*n*-bis[(trimethylsilyl)ethynyl]pyridines, where *n* is 3, 4, 5, and 6, or with 3,4-bis[(trimethylsilyl)-ethynyl]pyridines, proceeded with excellent site-selectivity to afford the corresponding monotitanated complex. Synthetic application of the reaction was demonstrated by an efficient preparation of π-conjugated oligomers having pyridine and enyne units alternately, which possess intense blue fluorescence emission.

Recently, we reported the preparation of acetylene−titanium alkoxide complexes from acetylenes and Ti(O-*i*-Pr)$_4$/2*i*-PrMgCl reagent (**1**),[1] which are versatile and economical intermediates for the preparation of various olefins.[2] Herein, we report the site-selective monotitanation of dialkynylpyridines **2** with **1** and its synthetic application.

First, we carried out the reaction of **1** with 2,*n*-bis[(trimethylsilyl)ethynyl]pyridines where *n* is 3, 4, 5, and 6, **2a**−**d**, and found that the reaction occurred in a highly site-selective manner at the acetylene moiety connected at the 2-position rather than at the 3-, 4-, or 5-position, respectively, as shown in eq 1: another possible monotitanated product, the site isomer, was not detected in all cases.[3]



(1)

These results prompted us to consider that the site-selectivity of the reaction might be explained by assuming the coordination of the pyridine N-atom to the titanium, which placed the triple bond at the 2-position nearer the

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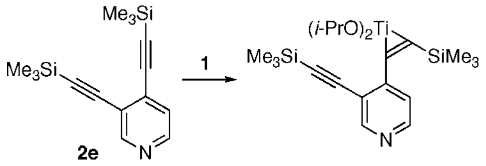
[1] (a) Harada, K.; Urabe, H.; Sato, F. *Tetrahedron Lett.* **1995**, *36*, 3203−3206. (b) Urabe, H.; Suzuki, D.; Sato, F. *Org. Synth.* **2003**, *80*, 120−128.

[2] (a) Sato, F.; Urabe, H.; Okamoto, S. *Chem. Rev.* **2000**, *100*, 2835−2886. (b) Sato, F.; Okamoto, S. *Adv. Synth. Catal.* **2001**, *343*, 759−784. (c) Sato. F.; Urabe, H. In *Titamiun and Zirconium in Organic Synthesis*; Marek, I., Ed.; Wiley-VCH: Weinheim, 2002; pp 319−354.

[3] The resulting titanium complex was confirmed by hydrolysis and comparing the product with an authentic sample, respectively. For details, see the Supporting Information.

10.1021/ol048316p CCC: $27.50

titanium than at the 3-, 4-, or 5-position, and thus, it was easier to react with **1**. However, the reaction of **1** with 3,4-bis[(trimethylsilyl)ethynyl]pyridine **2e** also proceeded with almost complete site-selectivity at the acetylene group bonded at the 4-position as shown in eq 2, not supporting our assumption.[3]



(2)

Although a precise explanation of the site-selectivity of the reaction of **1** with **2** needs further study, it seems to be controlled by electronic factors. As the electron-deficient acetylenic bond is more reactive to the electron-rich low-valent titanium complex,[4] the origin of these site-selections apparently can be explained by assuming the coordination of the pyridine N-atom to the titanium or magnesium salts in the reaction medium which makes the acetylenic moiety bonded at the 2- and 4-position in compound **2** more electron-deficient than that bonded at the 3- or 5-position due to the resonancing effect as shown in Figure 1.[5] Thus, the 2,3-, 2,5-, and 3,4-bis[(trimethylsilyl)ethynyl]pyridines reacted with **1** preferentially at the 2- or 4-position, respectively, while the selective reaction of 2,4-bis[(trimethylsilyl)-ethynyl]pyridines at the 2-position might be explained by the fact that acetylenic bond at the 2-position is more electron-deficient since it is situated nearer the electron-withdrawing N-atom.

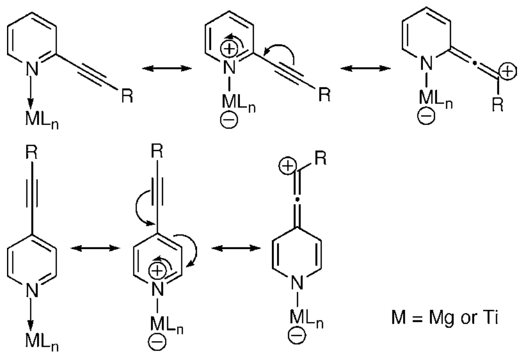
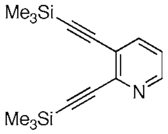
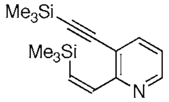
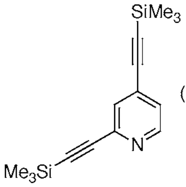
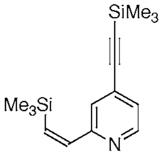
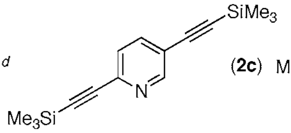
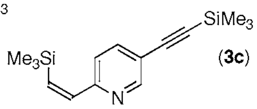
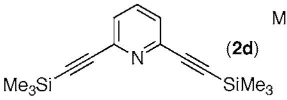
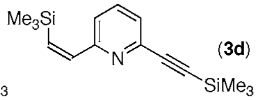
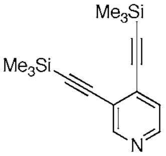
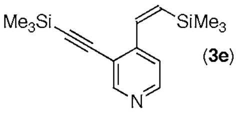
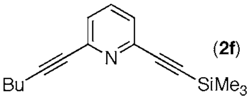
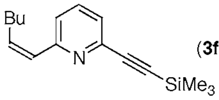
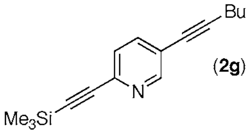
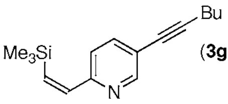
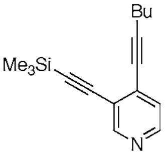
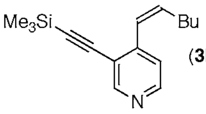


Figure 1. Resonance structure of the complex of alkylnylpyridines with ML_n (M = Mg or Ti).

Table 1 summarizes the results of hydrolysis after the reaction of **1** with **2a**−**e** and, in addition, **2f**−**h** which have two different alkynyl groups. It can be seen from Table 1 that the site-selectivity of the reaction is not affected by an alkynyl substituent. Thus, although the alkynyl moiety having an alkyl group reacts preferentially with **1** rather than that bearing a trimethylsilyl substituent as is exemplified by the reaction of **2f** (entry 6), **2g**, having trimethylsilyl- and alkylethynyl groups, reacted with the alkynyl group at the 2-position exclusively, though it has a trimethylsilyl substituent, to furnish **3g** (entry 7).

Table 1. Hydrolysis Result after Monotitanation of **2** with **1** Affording **3**[a]

entry	substrate **2**		product **3**		yield (%)[b]
1		(**2a**)		(**3a**)	84
2		(**2b**)		(**3b**)	80
3[c,d]		(**2c**)		(**3c**)	88 (93)
4[e]		(**2d**)		(**3d**)	90
5[f]		(**2e**)		(**3e**)	79
6[g]		(**2f**)		(**3f**)	70[h]
7		(**2g**)		(**3g**)	74
8[i]		(**2h**)		(**3h**)	83

[a] The reaction was carried out using 1.0 equiv of **1** in Et_2O at −50 °C for 2 h unless otherwise indicated. The titanium reagent **1** was generated from 1.0 equiv of Ti(O-*i*-Pr)$_4$ and 2.2 equiv of *i*-PrMgCl. [b] Isolated yield. NMR yield is given in parentheses. [c] Use of 2.0 equiv of **1** gave 52 and 45% yield (NMR) of **3c** and 2,5-bis[(trimethylsilyl)ethenyl]pyridine, respectively. [d] Deuteriolysis gave the corresponding **3c**-d_2 with 99% *d*-content. [e] 1.1 equiv of **1** was used. Use of 2.0 equiv of **1** gave, after 1 h reaction, 90 and 10% yield of **3d** and 2,6-bis[(trimethylsilyl)ethenyl]pyridine, respectively. [f] 2.0 equiv of **1** was used; see ref 6. [g] Reaction conditions: 2.0 equiv of **1**, 1 h reaction. Use of 1.0 equiv of **1** afforded 57% yield (NMR) of **3f**. [h] The site-isomer, 2-(1-hexynyl)-6-[(trimethylsilyl)ethenyl]pyridine, was also produced in 16% yield. [i] 2.0 equiv of **1** was used; see ref 6.

It should also be noted that further reaction of the resulting monotitanated product generated in situ with **1** is slow under

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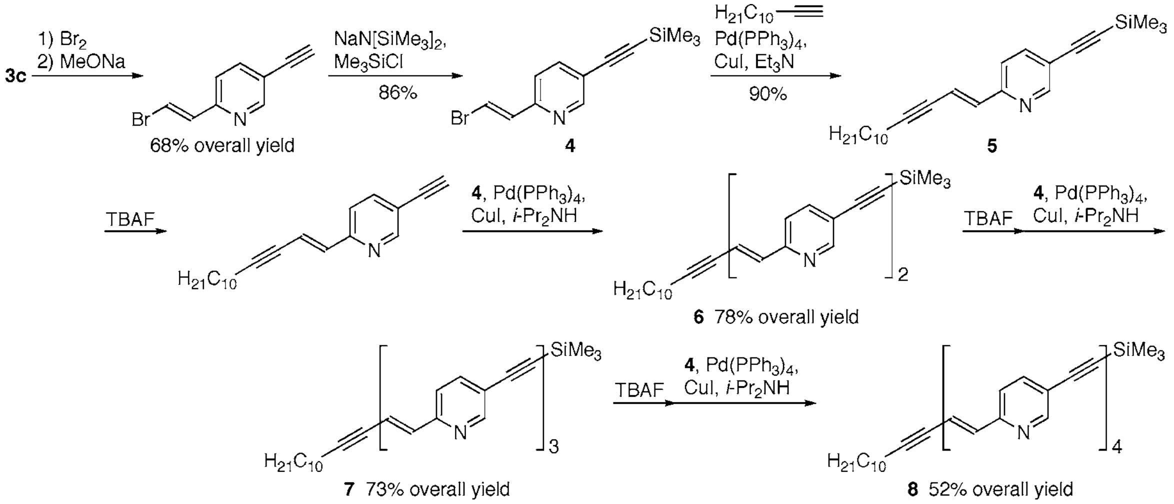
(4) Delas C.; Urabe, H.; Sato, F. *Chem. Commun.* **2002**, 272−273.

(5) Lin. C.-Y.; Chuang, L.-C.; Yang, Y.-F.; Lin, C.-L.; Kao, H.-C.; Wang, W.-J. *Dalton Trans.* **2004**, 456−462.

Scheme 1



the reaction conditions; thus, in every case, the corresponding bis-titanated product was produced in less than 1% yield if any, as far as equivalent of **1** was used (see footnotes c and e in Table 1).

From a synthetic point of view, easy entry to pyridine derivatives having trimethylsilylethynyl and β-trimethylsilylethenyl functional groups, such as **3a**−**e**, is especially noteworthy because both of these groups are versatile and the starting bis[(trimethylsilyl)ethynyl]pyridines **2a**−**e** can be readily prepared in bulk from commercially available or easily accessible corresponding dihalopyridine or its equivalent by Sonogashira coupling reaction with 1-ethynyltrimethylsilane.[7] The synthetic application of **3a**−**e**, therefore, was our next concern.

In 1990, Friend, Holmes, and co-workers showed that poly(*p*-phenylenevinylene) (PPV) works as an organic light-emitting diode (OLED).[8] Since this report concerning the evolution of OLEDs, π-conjugated polymers and oligomers related to PPV have attracted much interest as advanced materials for electronic and photonic applications including use as potential materials for OLEDs in both academic and industrial research laboratories.[9] These related compounds thus far synthesized include those having, instead of the ethenyl group, other unsaturated moieties such as ethynyl, dienyl, or diynyl moiety and/or those having an aromatic moiety other than phenyl such as a pyridyl, thienyl, or pyrrolyl group. In relation to our recent interest in preparing π-conjugated oligomers using building-block methodology,[10] herein we report an efficient and practical method for synthesizing monodisperse oligomers having alternately a pyridine ring and an enyne unit starting with **3c** and also report their optical properties.[11]

Thus, as shown in Scheme 1, the trimethylsilylethenyl moiety in **3c** was readily converted to the bromovinyl group by successive treatment with Br_2 and MeONa providing, after silylation again, **4** in 58% overall yield. Sonogashira coupling reaction of **4** with 1-dodecyne provided **5** in 90% yield, which can be regarded as a monomer of a π-conjugated compound having a pyridine ring and an enyne unit. Starting with **5**, the oligomers having alternately a pyridine ring and an enyne unit, such as dimer **6**, trimer **7**, and tetramer **8**, were prepared in good overall yield, respectively, according to the procedure shown in Scheme 1 which is characterized by repeated use of **4** as a building block and use of the Sonogashira coupling reaction as the key carbon-elongation reaction.[10]

The electronic absorption and fluorescene spectra of the oligomers **5**−**8** thus prepared are summarized in Table 2. It can be seen from Table 2 that both the longest wavelength absorption maxima λ_{max} and the emission maxima are

Table 2. Electronic Absorption and Emission Data of **5**−**8**[a]

	absorption λ_{max}[b] (nm)	emission	
oligomers	(ϵ[c] ($M^{-1}cm^{-1}$))	λ_{max}[d] (nm)	Φ_F[e]
monomer **5**	327 (37 100)	369	<0.01
dimer **6**	367 (66 300)	406	0.77
trimer **7**	391 (86 400)	433	0.82
tetramer **8**	398 (108 700)	444	0.80

[a] Spectra were recorded at room temperature in $CHCl_3$. [b] Longest wavelength absorption maximum. [c] Molar extinction coefficient. [d] Fluorescence emission maximum. [e] Fluorescence quantum yield, determined by using quinine sulfate ($\Phi_F = 0.577$) as reference compound.

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(6) As the substrate **2e** and the resulting monotitanated product **3e** were inseparable by column chromatography, we used 2 equiv of **1** to consume completely **2e**. In this case, 3,4-bis[(trimethylsilyl)ethenyl]pyridine was also obtained, but the yield was less than 10%, which could be separated easily by column chromatography. A similar tendency was observed for **2h**.

(7) For details, see the Supporting Information.

(8) Burroughes, J. H.; Bradley, D. D. C.; Brown, A. R.; Marks, R. N.; Mackay K.; Friend, R. H.; Burns, P. L.; Holmes, A. B. *Nature* **1990**, *347*, 539−541.

(9) For reviews, see: (a) Greiner, A. *Polym. Adv. Technol.* **1998**, *9*, 371−389. (b) Kraft, A.; Grimsdale, A. C.; Holmes, A. B. *Angew. Chem., Int. Ed.* **1998**, *37*, 402−428. (c) Martin R. E.; Diederich, F. *Angew. Chem., Int. Ed. Engl.* **1999**, *38*, 1350−1377. (d) Mitschke, U.; Bäuerle, P. *J. Mater. Chem.* **2000**, *10*, 1471−1507.

bathochromically shifted with increasing conjugation length as expected.[9] Although monomer **5** shows very weak fluorescence, the oligomers **6**, **7**, and **8** display intense fluorescence emission having quantum yield of around $\Phi_F = 0.80$, with the highest yield, 0.82, being measured for the trimer **7**.

Synthesis of oligomers corresponding to **5**−**8** started with **3a**, **3b**, **3d**, and **3e** instead of **3c** according to the procedure shown in Scheme 1, and investigation of the oligomers **6**−**8** as OLEDs is now in progress in our group.

Acknowledgment. We gratefully thank Mr. Yoichiro Wada of this institute for measurement of the fluorescence quantum yield.

Supporting Information Available: Experimental procedures, spectroscopic data, and physical properties of **2**−**8** and structural determination of **3a**−**c**,**e**. This material is available free of charge via the Internet at http://pubs.acs.org.

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(10) (a) Takayama, Y.; Delas, C.; Muraoka, K.; Sato, F. *Org. Lett.* **2003**, *5*, 365−368. (b) Takayama, Y.; Delas, C.; Muraoka, K.; Uemura, M.; Sato, F. *J. Am. Chem. Soc.* **2003**, *125*, 14163−14167. (c) Nakano, Y.; Ishizuka, K.; Muraoka, K.; Ohtani, H.; Takayama, Y.; Sato, F. *Org. Lett.* **2004**, *6*, 2373−2376.

(11) Synthesis and properties of poly(phenyleneethynylenevinylene)s were reported, see: Venkatesan, D.; Yoneda, M.; Ueda, M. *React. Func. Polym.* **1996**, *30*, 341−352.