

## INVESTIGATION OF PALLADIUM CATALYST ON SUZUKI CROSS-COUPLING FOR SYNTHESIS OF CONJUGATED ORGANIC MOLECULES

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### ABSTRACT

*Palladium is a novel important catalyst for formation of C-C bond in Suzuki cross-coupling, aryl halide dehalogenation, and Still coupling. Here, we investigated the content of palladium catalyst including tetrakis(triphenylphosphine)palladium(0) (Pd(PPh<sub>3</sub>)<sub>4</sub>) and [1,1'-bis(diphenylphosphino)ferrocene]palladium(II) dichloride (Pd(dppf)Cl<sub>2</sub>) for the synthesis of 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) as a monomer which can be used for the synthesis of conjugated molecules.*

**Keywords:** palladium catalyst, Suzuki cross-coupling, conjugated polymer.

### TÓM TẮT

**Khảo sát xúc tác palladium trên sự ghép đôi Suzuki  
trong sự tổng hợp phân tử hữu cơ liên hợp**

*Xúc tác palladium là một loại xúc tác mới cho việc tạo thành liên kết C-C trong sự ghép đôi Suzuki, sự loại trừ halogen của halogenur aryl, và sự ghép đôi Still. Nơi đây, chúng tôi khảo sát hàm lượng và loại xúc tác palladium bao gồm tetrakis(triphenylphosphine)palladium(0) (Pd(PPh<sub>3</sub>)<sub>4</sub>) và [1,1'-bis(diphenylphosphino)ferrocene] palladium(II) dichloride (Pd(dppf)Cl<sub>2</sub>) cho sự tổng hợp 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) như là monomer hữu cơ tiếp cách, monomer này sẽ được sử dụng để tổng hợp polymer hữu cơ tiếp cách.*

**Từ khóa:** xúc tác palladium, sự ghép đôi Suzuki, polymer liên hợp.

### 1. Introduction

Over the past decades, cross-coupling arylation for the synthesis of novel monomer and conjugated polymers has emerged recently as an alternative to traditional methods of transition metal catalyzed polymerization, such as Stille, Suzuki, Negishi, and Kumada polymerizations [1-5]. In the other hand, conjugated polymers (CPs), due to their excellent optical and electronic properties, have attracted tremendous interest in the past decades from both academic and industrial fields, especially they can be used in electronic device such as polymeric solar cells (PSCs), organic light emitting diode (OLED), organic field effect transistor (OFET), electrochromic devices, and organic

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sensor.ect. Moreover they have advantage for the low cost of devices fabrication due to large areas processing, lightweight flexible substrates via solution processing [6-12]. To synthesis of these organic compounds, the cross-coupling arylation is a power tool for synthesis chemist. To date, most of conjugated molecules have been synthesized by classic Stille coupling polycondensation or Suzuki coupling polycondensation. Among catalysts using in Suzuki reaction, tetrakis(triphenylphosphine)palladium(0) ( $\text{Pd}(\text{PPh}_3)_4$ ) and [1,1'-bis(diphenylphosphino)ferrocene]palladium(II) dichloride ( $\text{Pd}(\text{dppf})\text{Cl}_2$ ) are most important catalysts for this reaction due to its high conversion.

Very recently, there has been some progress in exploring low polar or nonpolar solvents as the reaction media for synthesis of conjugated polymers. For instance, Ozawa et al. have used tetrahydrofuran (THF) instead of highly polar solvents to synthesize poly(3-hexylthiophene-2,5-diyl) (P3HT), to ensure the solubility of the resulting polymers during polymerization [13]. Herrmann's catalyst (*trans*-bis(acetato)bis[*o*-(di-*o*-tolylphosphino)benzyl]dipalladium(II)), in the presence of an appropriate ligand, was proven to be an effective catalyst in this reaction system to afford high-molecular-weight P3HT with high regioregularity (98%), whereas the reaction catalyzed with  $\text{Pd}(\text{OAc})_2$  in the same solvent was not reproducible and frequently provided low molecular weight products. Later, Leclerc et al. have utilized this reaction condition with modifications to synthesize a series conjugated polymers [14-15].

In this research, we investigated the efficiency of  $\text{Pd}(\text{PPh}_3)_4$  or  $\text{Pd}(\text{dppf})\text{Cl}_2$  as well as the content of these catalysts to synthesis of was 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) as building units toward the synthesis of conjugated organic molecules.

## 2. Experiment

### 2.1. Materials

3-Hexylthiophene was purchased from TCI (Tokyo, Japan) tetrahydrofuran (99.9%) and *N*-bromosuccinimide were purchased from Acros Organics. Tetrakis (triphenylphosphine)palladium(0)  $\text{Pd}(\text{PPh}_3)_4$  (99%), [1,1'-bis(diphenylphosphino)ferrocene]dichloropalladium  $\text{Pd}(\text{dppf})\text{Cl}_2$  (99%) and 4,4,4',4',5,5,5',5'-octamethyl-2,2'-bi-1,3,2-dioxaborolane were purchased from Sigma-Aldrich. Potassium acetate (KOAc), sodium carbonate (99%) and magnesium sulfate (98%) were purchased from Acros and used as received. Chloroform ( $\text{CHCl}_3$ , 99.5%), toluene (99.5%) and tetrahydrofuran (THF, 99%) were purchased from Fisher/Acros and dried using molecular sieves under  $\text{N}_2$ . Dichloromethane (99.8%), *n*-heptane (99%), methanol (99.8%), ethyl acetate (99%) and diethyl ether (99%) were purchased from Fisher/Acros and used as received.

## 2.2. Characterization

Thin layer chromatography (TLC) plate was used for testing reaction during the reaction time using *n*-heptane or *n*-heptane/diethyl ether (9.5/0.5, v/v) as eluent.

<sup>1</sup>H NMR spectra were recorded in deuterated chloroform (CDCl<sub>3</sub>) with TMS as an internal reference, on a Bruker AMX-300 spectrometer at a frequency of 300 MHz.

## 2.3. Synthesis of 2,5-dibromo-3-hexylthiophene

3-Hexylthiophene (5g, 29.7 mmol) and *N*-bromosuccinimide (10.59g, 59.5mmol) were added to anhydrous THF (50 mL) at 0 °C under nitrogen. The mixture was stirred at 50 °C for 2.5 h. Then, 10% aqueous Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub> was added, and the mixture was extracted with diethyl ether and dried over anhydrous MgSO<sub>4</sub>. The solvent was evaporated to obtain the crude product, which was purified by silica column chromatography (*n*-heptane as the eluent) to give pure 2,5-dibromo-3-hexylthiophene as a pale yellow oil. (7.3 g, R<sub>f</sub> = 0.8, 80%, yield).

<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>), δ (ppm): 6.77 (s, 1H), 2.50 (t, 2H), 1.54 (q, 2H), 1.30 (m, 6H), 0.89 (t, 3H).

## 2.4. General synthesis of 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) with Pd(PPh<sub>3</sub>)<sub>4</sub> (content of Pd(PPh<sub>3</sub>)<sub>4</sub>: 10 mol%, 15 mol%, 20 mol%)

2,5-dibromo-3-hexylthiophene (1.5 g, 4.6 mmol) and 4,4,4',4',5,5,5',5'-octamethyl-2,2'-bis(1,3,2-dioxaborolane) (2.34 g, 9.2 mmol) were dissolved in 45 mL of 1,4-dioxane. To this solution, 531 mg (10 mol%) of Pd(PPh<sub>3</sub>)<sub>4</sub> and 1.38 g (0.0141 mol) of KOAc were added, and the solution was bubbled by N<sub>2</sub> for 30 min. Then, the reaction was carried out at 85 °C for 24 h. After completion of the reaction, 100 mL of ethyl acetate was added for dilution and the mixture was filtered through Celite to remove the Pd catalyst. The obtained solution was washed with distilled water (2 x 100 mL) and with 10% aqueous solution of Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub> (2x100 mL). Afterward, the solution was dried over MgSO<sub>4</sub>, and the solvent was evaporated to obtain a black liquid as the crude product. The crude product was purified over silica column chromatography with *n*-heptane/diethyl ether (9.5/0.5, v/v) as eluent to obtain a yellow liquid as the pure product of 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) (R<sub>f</sub> = 0.4. 40%, yield, 10 mol% Pd(PPh<sub>3</sub>)<sub>4</sub>); 45%, yield, 15 mol% Pd(PPh<sub>3</sub>)<sub>4</sub>); 45%, yield, 20 mol% Pd(PPh<sub>3</sub>)<sub>4</sub>);

<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>), δ (ppm): 6.93 (s, 1H), 2.63 (t, 2H), 1.56 (q, 2H), 1.26 (s, 24H), 1.35 (m, 6H), 0.89 (t, 3H).

## 2.5. Synthesis of 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) with Pd(dppf)Cl<sub>2</sub> (10 mol%, 15 mol%, and 20 mol%)

2,5-dibromo-3-hexylthiophene (3 g, 9.2 mmol) and 4,4,4',4',5,5,5',5'-octamethyl-2,2'-bi-1,3,2-dioxaborolane (4.68 g, 18.4 mmol) were dissolved in 90 mL of 1,4-dioxane. To this solution, 751 mg (10 mol%) of Pd(dppf)Cl<sub>2</sub> and 2.76 g (0.0282 mol)

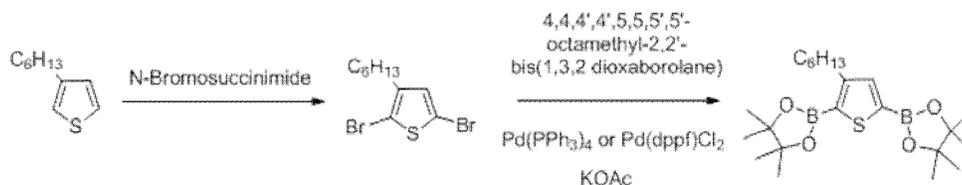
of KOAc were added, and the solution was bubbled by  $N_2$  for 30 min. Then, the reaction was carried out at 85 °C for 24 h. After completion of the reaction, 100 mL of ethyl acetate was added for dilution and the mixture was filtered through Celite to remove the Pd catalyst. The obtained solution was washed with distilled water (2 x 100 mL) and with 10% aqueous solution of  $Na_2S_2O_3$  (2 x 100 mL). Afterward, the solution was dried over  $MgSO_4$ , and the solvent was evaporated to obtain a black liquid as the crude product. The crude product was purified over silica column chromatography with *n*-heptane/diethyl ether (9.5/0.5, v/v) as eluent to obtain a yellow liquid as the pure product of 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) ( $R_f = 0.4$ , 50%, yield, 10 mol%  $Pd(dppf)Cl_2$ ); 55%, yield, 15 mol%  $Pd(dppf)Cl_2$ ; 55%, yield, 20 mol%  $Pd(dppf)Cl_2$ ).

$^1H$  NMR (300 MHz,  $CDCl_3$ ),  $\delta$  (ppm): 6.93 (s, 1H), 2.63 (t, 2H), 1.56 (q, 2H), 1.26 (s, 24H), 1.35 (m, 6H), 0.89 (t, 3H).

### 3. Results and discussion

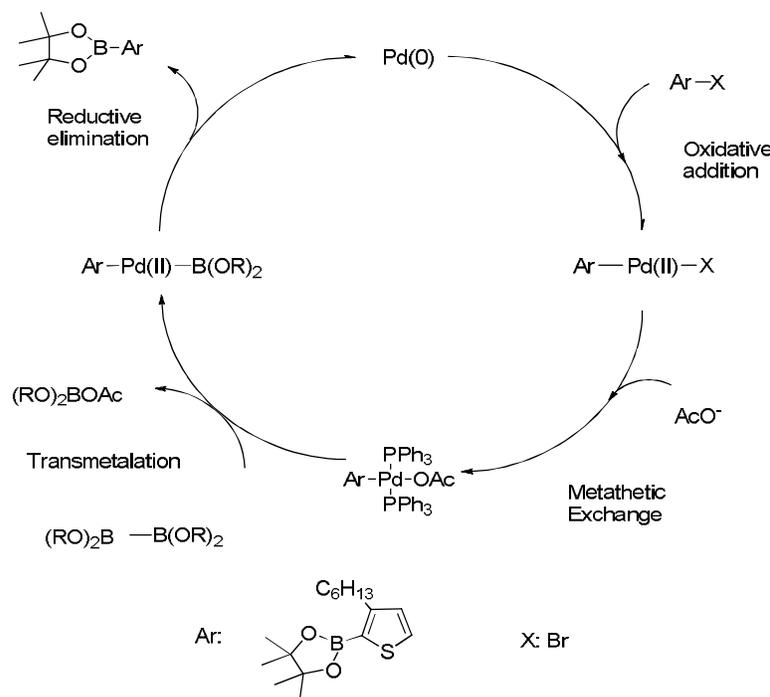
#### 3.1. Synthesis of 2,2'-(3-hexylthiophene-2,5-diyl)bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane)

The borylation of 2,5-dibromo-3-hexylthiophene with 4,4,4',4',5,5,5',5'-octamethyl-2,2'-bi-1,3,2-dioxaborolane resulting 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) using of  $Pd(PPh_3)_4$  or  $Pd(dppf)Cl_2$  as catalyst in the presence of KOAc in 1,4-dioxane media was presented in Scheme 1.



**Scheme 1.** Synthesis of 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) monomer

This mechanism resulting from a catalytic cycle that involves the oxidative addition of a heterocyclic halide compound to the palladium (0) complex to give an  $ArPd(II)X$  adduct, the transmetalation between 4,4,4',4',5,5,5',5'-octamethyl-2,2'-bi-1,3,2-dioxaborolane and  $ArPd(II)X$  to provide an  $ArPd(II)B(OR)_2$  intermediate, and the reductive elimination of desired product 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) to regenerate the  $Pd(0)$  complex. The use of KOAc is essential not only to accelerate the reaction but also to prevent the formation of biaryl by-products. The mechanism of this borylation is illustrated in Figure 1. The  $^1H$  NMR spectrum (see Figure 2) shows the chemical structure of 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane).



**Figure 1.** The borylation mechanism for synthesis of 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) using Pd(0) catalyst

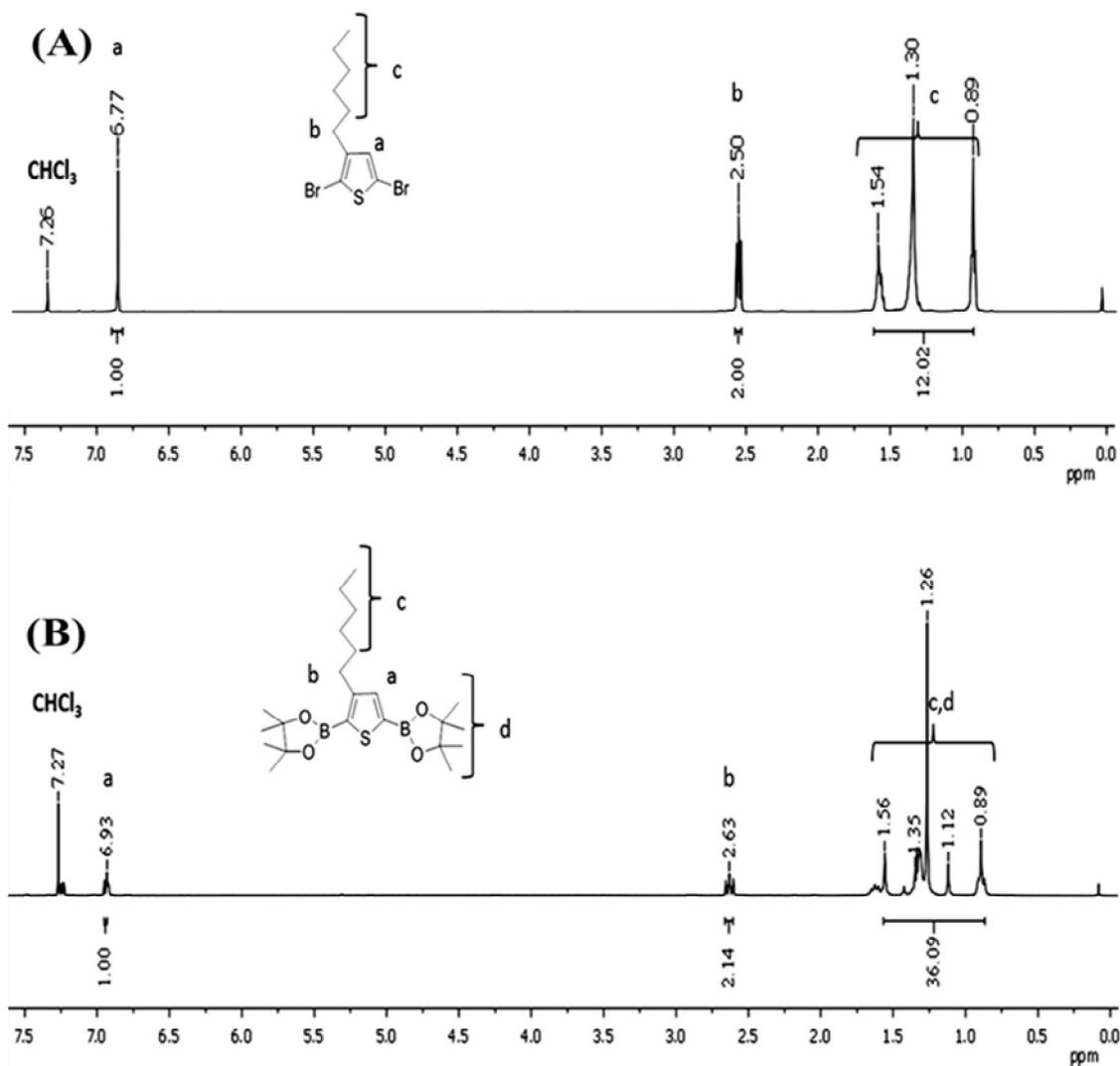
The crude product of 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) after the reaction which was purified over silica column chromatography with *n*-heptane/diethyl ether (9.5/0.5, v/v). Thin layer chromatography plates were used for checking the separation process of the product from other compounds in the reaction mixture. Moreover, The  $^1\text{H}$  NMR spectrum (see Figure 2) shows the chemical structure of 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane).

### 3.2. $^1\text{H}$ NMR of 2,5-dibromo-3-hexylthiophene and 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane)

The 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) monomer was obtained via the Suzuki cross-coupling of 2 equivalents of 4,4,4',4',5,5,5',5'-octamethyl-2,2'-bi-1,3,2-dioxaborolane and 1 equivalent of 2,5-dibromo-3-hexylthiophene by  $\text{Pd}(\text{PPh}_3)_4$  as catalyst in presence of KOAc in 1,4-dioxane. The general yield of reaction was obtained about 45%. The chemical structure of 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) monomer have been attested by  $^1\text{H}$  NMR.

Figure 2 shows the  $^1\text{H}$  NMR of 2,5-dibromo-3-hexylthiophene and 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane). The peaks of

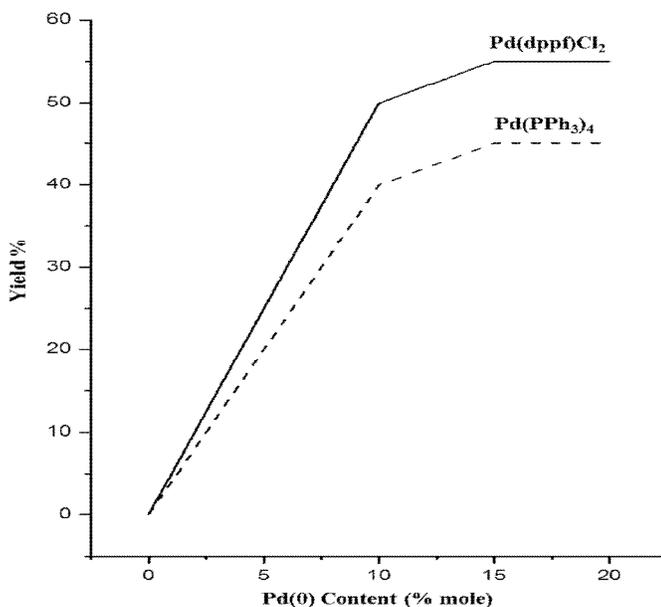
the hexyl group substituted on the thiophene, as well as the methyl peak of the boronic group in 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) monomer appear from 0.8 to 1.6 ppm which demonstrate the presence of the boronic ester. Moreover, the proton integration of hexyl groups and methyl peak of the boronic groups (peak c + d, Figure 2B) in obtained 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) monomer comparing with the peak of methine proton (peak a, Figure 2B) is approximately 35 times with that corresponding to formation in 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane).



**Figure 2.**  $^1\text{H}$  NMR of 2,5-dibromo-3-hexylthiophene (A) and 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) monomer (B)

### 3.3. Efficiency of Pd(PPh<sub>3</sub>)<sub>4</sub> or Pd(dppf)Cl<sub>2</sub> in synthesis of 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) monomer

We investigated the efficiency of catalyst content including Pd(PPh<sub>3</sub>)<sub>4</sub> and Pd(dppf)Cl<sub>2</sub> to reaction yield for obtained of 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) monomer. At the same contents of catalyst, the reaction yield using Pd(dppf)Cl<sub>2</sub> (55%, yield) is higher than those using Pd(PPh<sub>3</sub>)<sub>4</sub> catalyst. This can be explained that the transmetalation process of Pd(dppf)Cl<sub>2</sub> is more efficiently. Moreover, the highest yield of these reactions were obtained about 45% and 55% of yield for 15% mol Pd(PPh<sub>3</sub>)<sub>4</sub> or Pd(dppf)Cl<sub>2</sub> catalytic contents.



**Figure 3.** Efficiency of Pd(PPh<sub>3</sub>)<sub>4</sub> and Pd(dppf)Cl<sub>2</sub> on cross-coupling Suzuki reaction

## 4. Conclusion

In conclusion, a novel 2,2'-(3-hexylthiophene-2,5-diyl) bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolane) monomer has been successfully prepared via Suzuki cross-coupling based on palladium-catalyzed. The investigation of palladium-catalyzed exhibits that the Pd(dppf)Cl<sub>2</sub> has given a high conversion in comparison with Pd(PPh<sub>3</sub>)<sub>4</sub> as well as content of palladium-catalyzed for this kind of reaction is obtained about 15%.

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**Acknowledgement:** This research was supported by project (Code Porject : T-CNVL-2015-09) from Ho Chi Minh City University of Technology - Vietnam National University – Ho Chi Minh City, 268 Ly Thuong Kiet, District 10, Ho Chi Minh City, Viet Nam.

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(Received: 06/10/2015; Revised: 06/11/2015; Accepted: 22/12/2015)