

Preparation of Water Soluble Polythiophenes Mediated by Highly Active Zinc

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A convenient route for the preparation of water soluble polythiophenes is described. Reactions involving highly active zinc metal show unique properties, viz. tolerance of the ester group and regioselectivity to the thiophene ring. Poly [3-(ethyl-*n*-alkanoate)thiophene-2,5-diyl]s, poly [3-(*n*-carboxyalkyl)thiophene-2,5-diyl]s, and poly [3-(potassium-*n*-alkanoate)thiophene-2,5-diyl]s were easily prepared by utilizing highly active zinc.

Key Words: Water soluble, Polythiophenes, Active zinc, Polymerization

Introduction

In 1980, a very interesting material, polythiophene, was introduced into the field of polymer chemistry.¹ However, its application has remained severely limited due to its insolubility in normal organic solvents. Much efforts has been made performed to circumvent this difficulty. A major breakthrough was made by introducing an alkyl group on the 3-position of the thiophene ring, known as poly 3-alkylthiophene (P3AT).² This class of polymers has very unique properties; good solubility, processibility, and more interestingly high electroactivity. On the other hand, the introduction of an alkyl group onto the thiophene ring also resulted in other difficulties. As shown in Scheme 1, four different polymer linkages in the polymer chain could be obtained: HT-HT, HT-HH, TT-HT, and TT-HH.

It has been clearly demonstrated that the HT regioregular polymers have the improved electroconductivities, optical nonlinearity, and magnetic properties compared to the regiorandom polymers.³ Therefore, more studies have focused on the preparation of regioregular polythiophenes. This has been accomplished mostly by utilizing Zn*,⁴ the Grignard route,⁵ and the Suzuki method.⁶

A few months after since the discovery of organic-solvent-soluble poly 3-alkylthiophenes, water soluble polythiophenes were introduced by Heeger.⁷ Little work, however, has been done on these water soluble polythiophenes. These polymers

have been prepared by introducing a polar functional group, such as alkanic acid,⁸ phosphonic acid,⁹ sulfonate,^{7,8} and oxy-sulfonate,¹⁰ onto the thiophene ring.

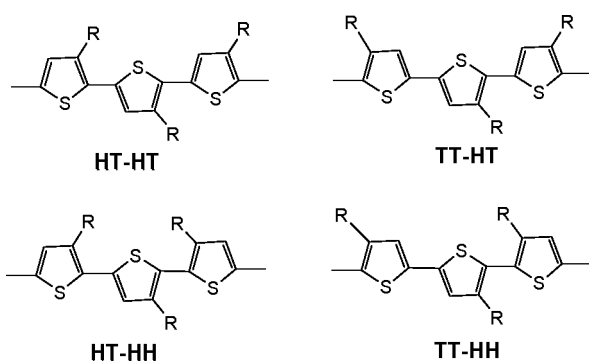
Herein, we present a new approach to the preparation of water soluble polythiophenes, mediated by highly active zinc metal (Zn*).

Results and Discussion

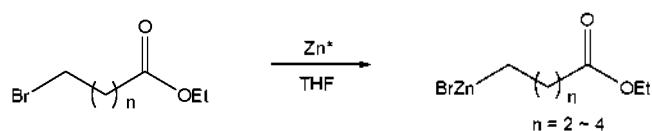
Preparation of *n*-ethoxy-*n*-oxoalkylzinc bromides(1a-1d).

Among the many organometallic reagents, organozinc has been recognized as an outstanding reagent that has a significant tolerance for some functional groups. Compared to organolithium and Grignard reagents, organozinc reagents have less reactivity toward electrophiles. Due to this big advantage, it has been widely used in organic synthesis. In this research, the unique reactivity of highly active zinc played a very important role in the preparation of the monomer as well as polymer. Scheme 2 shows a general schematic diagram for the preparation of the organozinc reagents.

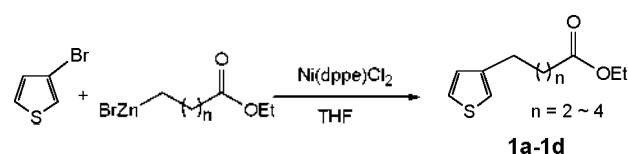
Ethyl haloalkanoates were added to the active zinc solution at rt. The Oxidative addition of active zinc was easily completed within a few hours. After allowing the solution to settled down for a few hours at rt., the supernatant was cannulated into the flask containing 3-bromothiophene in THF in the presence of Ni(dppe)Cl₂ catalyst. The coupling reaction could be performed at rt. and/or refluxing temperature. The final



Scheme 1. Four regoisomers.



Scheme 2. Preparation of organozinc reagents.



Scheme 3. Preparation of Ethyl *n*-(3-thienyl)alkanoates.

product was easily purified by either distillation or column chromatography using silica gel and heptane as the eluent. Higher yields were obtained from longer chain length substrates.

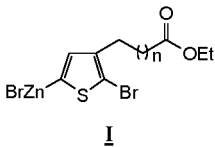
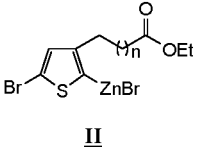
Bromination of ethyl 3-thienylalkanoates (2a-2d). Two well-known brominating agents were able to be used for the bromination of thiophene derivatives. Both of bromine and NBS in methylene chloride gave a very successfully results. All of the reactions were performed at rt within an hour, and then distilled off after a normal work-up procedure. Generally, more than 90% isolated yields were obtained and the products were pure enough (> 98%) for the polymerization.

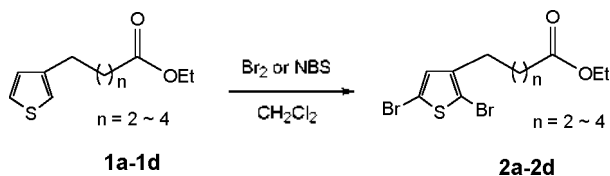
Polymerization; regio-controlled synthesis of poly[3-(ethyl-*n*-alkanoate)thiophene-2,5-diyl] (3a-3d). In 1992, Rieke and co-workers reported that the active zinc underwent direct oxidative addition to 3-alkyl-2,5-dibromothiophene chemoselectively to afford 2-(bromozincio)-5-bromothiophene quantitatively. We further examined the reactivity of highly active zinc toward dibrominated thiophene derivatives containing a functional group such as an ester group. Interestingly, both regioselectivity and tolerance toward various functionalities were observed in this reaction.

The oxidative addition of Zn* was easily carried out at 0 °C, and occurred predominantly at the 5-position of the dibrominated thiophene predominantly. The results are summarized in Table 1.

Again, Zn* has shown a good tolerance for ester group on

Table 1. Regioselectivity of active zinc

	I	II
		
		
	I	II
n = 2	80	20
n = 3	80	20
n = 4	83	17
n = 5	84	16



Scheme 4. Bromination of Ethyl *n*-(3-thienyl)alkanoates.

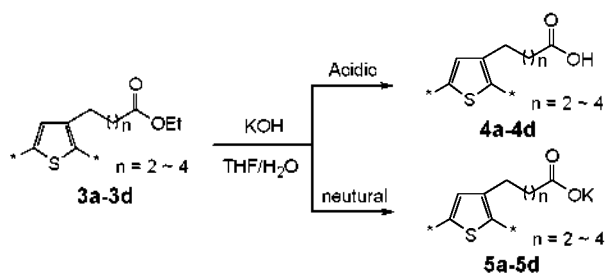
thiophene ring during the oxidative addition. Since a variety of different alkyl chain lengths are commercially available, a number of different polymers could be prepared by this methodology. It is also of interest that the ester group on the polymers can be easily converted to other functionalities.

The Polymerization of the organozinc reagents obtained above was carried out at rt. As described in previous studies,⁴ Ni(dppe)Cl₂ was the best catalyst for the polymerization of the thiophene derivatives in term of the regiochemistry of the polymer. In this study, Ni(dppe)Cl₂ was also successfully applied to the polymerization of the organozinc reagents. To complete the polymerization, the reaction mixture was stirred at rt. for 24 to 48 h. Quenching and washing with methanol gave a dark black polymer. For the analysis of molecular and regiochemistry, the polymer was further purified by Soxhlet extraction with hexanes.

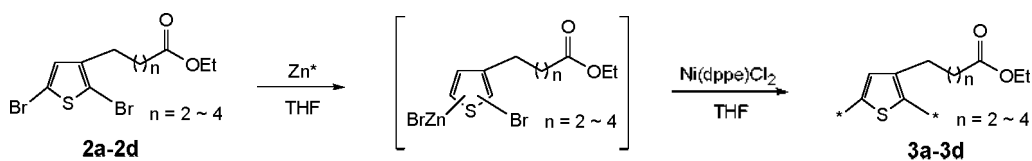
Previous reports showed that the α -methylene protons of the alkyl group could be resolved differently. Based upon the ¹H NMR study, the resulting polymers were obtained in 50 ~ 80% yields with more than 90% regioregularity. The molecular weight was determined by gel permeation chromatography (THF as eluent, polystyrene standards for calibration): Mw = 20000, PDI = 1.32.

Preparations of poly[3-(*n*-carboxyalkyl)thiophene-2,5-diyl]s, (4a-4d), and poly[3-(potassium-*n*-alkanoate)thiophene-2,5-diyl]s, (5a-5d). Due to the wide range of applications of poly 3-alkylthiophenes, many studies have focused on the usage of water soluble poly thiophenes.¹¹ Of these, poly(thiophene-3-alkanoic acid)s have been generally been used. However, a very limited number of studies have been reported on the preparation of poly(thiophene-3-alkanoic acid).^{8,12} One of these studies was performed by the Stille/CuO polymerization of an oxazoline protected monomer followed by acidic hydrolysis.¹² Herein, we would like to report a new route for the preparations of poly(thiophene-3-alkanoic acid), and poly [3-(potassium-*n*-alkanoate)thiophene-2,5-diyl], which were accomplished by utilizing 3a-3d shown above. Schematic diagrams are shown in Scheme 6.

These water soluble polymers were obtained by the basic



Scheme 6. Hydrolysis.



Scheme 5. Polymerization.

hydrolysis of the polymers **3a-3d**. A mixture of the THF solution of the polymers **3a-3d** and aqueous KOH solution was stirred at refluxing temperature overnight. Two different types of polymers were formed depending upon the work-up procedure. As described in Scheme 6, an acidic quenching after hydrolysis gave poly(thiophene-3-alkanoic acid), **4a-4d**. In order to remove any left over **3a-3d**, the resulting polymer was purified by Soxhlet extraction with chloroform. It was observed that the resulting acidic polymers **4a-4d** were not soluble in any organic solvents, but very soluble in a basic aqueous media. Even though the no NMR study of these polymers was performed, it was concluded that the same regio-regularity as the precursor might be maintained.

The use of a slightly different work-up procedure resulted in another types of polymers, corresponding potassium salts, **5a-5d**. After being hydrolyzed, the whole mixture was poured into THF affording a very sticky oily product. The oily product was solidified from the mixture of THF and methanol. Soxhlet extraction of the resulting polymer with chloroform gave the water-soluble polymer as a black solid. This procedure could be utilized for the preparation of a variety of different types of polymers containing different salts.

Conclusions

For the first time, we have developed a new practical method for the preparation of high regioregular poly[3-(ethyl-*n*-alkanoate)thiophene-2,5-diyl] (**3a-3d**). It has been accomplished by utilizing a highly active zinc and thiophene derivatives containing a functional group such as an ester group. Interestingly, a simple treatment of the resulting polymers (**3a-3d**) afforded a variety of different types of water-soluble polymers (**4a-4d**, and **5a-5d**).

Experimental Section

A representative procedure for each step is described below.

Preparation of ethyl 3-thienylhexanoate (1d). LiBr (17.4 g, 200 mmol) was placed in a 1.0 L RBF and then 200 mL of THF was added at rt. 3-Bromothiophene (24.4 g, 150 mmol) was then added into the flask. While being stirring the mixture, 6-ethoxy-6-oxohexylzinc bromide solution (0.5 M in THF, 400 mL, 200 mmol), prepared by using highly active Zinc,¹¹ was cannulated into the mixture over a period of 1.0 h. The resulting mixture was allowed to stirred at rt. overnight. After quenching with 3 M HCl solution, the mixture was extracted with ether. Standard work-up and then vacuum distillation afforded 24 g of **1d** (71%, isolated yield).

Bromination; preparation of ethyl 3-(2,5-dibromothieryl) hexanoate (2d). In a 1.0 L RBF equipped with an addition funnel, ethyl 3-thienylhexanoate, **1d**, (44 g, 180 mmol) was placed, and then 400 mL of CH₂Cl₂ was also added. Into the addition funnel, bromine (58.6 g, 360 mmol) and 40 mL of CH₂Cl₂ were added. Next, bromine solution was added slowly added to the reaction mixture while being stirred at rt. Bromination was completed in 10 min after the addition was finished. The resulting mixture was quenched with saturated

Na₂S₂O₃ solution and then the organic phase was washed with saturated NaHCO₃ solution and brine. The crude product was distilled under high vacuum pressure to afford 66 g of ethyl 3-(2,5-dibromothieryl)hexanoate as a light yellow oil (93% isolated yield).

Polymerization; preparation of poly [3-(ethylhexanoate) thiophene-2,5-diyl](3d). Highly active zinc (12 g, 180 mmol) was added into a 250 mL RBF, and then the flask was cooled down in an ice-bath. With being stirred at 0 °C, ethyl 3-(2,5-dibromothieryl)hexanoate, **3d**, (66 g, 165 mmol) was cannulated into the flask. The resulting mixture was allowed to stirred at 0 °C. The oxidative addition was completed in 1 h. The mixture was allowed to settle down and then the supernatant organozinc solution was used for the polymerization.

In a 250 mL RBF, Ni (dppe) Cl₂ (0.31 g, 0.58 mmol) was placed and then 5.0 mL of THF was added. Next, the organozinc solution prepared above was cannulated into the catalyst solution while being stirring it. After being stirred at rt for 48 h, the resulting mixture was poured into 500 mL of methanol to afford a black precipitation. The polymer was then filtered and washed with methanol. Soxhlet extraction with hexanes afforded 33 g of a black polymer.

Preparation of poly(thiophene-3-hexanoic acid)(4d). 22 g (100 mmol, based on monomer unit) of polymer was added into a 250 mL RBF, then 200 mL of THF was added to dissolve the polymer. Into the resulting deep brown solution was added KOH (6.2 g, 110 mmol) solution dissolved in 200 mL of H₂O. The resulting mixture was heated to reflux while being stirred and then cooled down to rt after being refluxed for overnight. Next, 3 M HCl solution was added into the resulting mixture. A black precipitation was obtained. The polymer was then filtered and washed with H₂O, then dried under high vacuum pressure. The resulting polymer was Soxhleted with chloroform over 24 h, then dried to give 17 g (90%, yield) of a dark black polymer.

Preparation of poly [3-(potassium-6-hexanoate)thiophene-2,5-diyl](5d). The hydrolysis of **3d** was carried out as described above. After the hydrolysis was completed, the resulting mixture was poured into THF. An oily product was obtained on the bottom of the flask. The solvent was decanted off and then the residue oily product was poured into a mixture of methanol and THF. The resulting solidified polymer was filtered and washed with methanol and then dried under high vacuum pressure affording a black powder-like polymer. An isolated yield 85% was obtained.

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