

SINGLE STEP BIOCATALYTIC SYNTHESIS OF SEXITHIOPHENE

Subhalakshmi Nagarajan, Ramaswamy Nagarajan, Mario Cazeca,
Jayant Kumar, Ferdinando F. Bruno* & Lynne Samuelson*

Departments of Chemistry & Physics, Center for Advanced Materials,
University of Massachusetts, Lowell, MA 01854.

*Nanomaterials Science Team, U.S Army Natick Soldier Center, RDECOM,
Natick, MA 01760.

Introduction

The development of direct synthetic routes for obtaining oligomeric thiophenes, especially α -6T, continues to be of interest due numerous potential applications in nonlinear optical electroluminescent devices, photovoltaics, and in semiconductor-based components including Schottky diodes¹ and thin-film transistors² (TFTs). Among oligothiophenes, sexithiophene (α -6T), α -8T has been reported to have mobilities greater than 0.02 cm²/Vs. However, these mobilities are only attainable if the compounds are free of impurities.

α -6T has been typically synthesized by oxidatively dimerizing the trimer of thiophene, α -terthienyl (α -3T) [Terthiophene] with ferric chloride in benzene³. This method has been reported to yield a crude product that contains 2% Fe as ferrous chloride which can lead to conjugation defects through β -coupling. Another method involves coupling 2 equivalents of the 2-lithio derivative of α -3T with cupric chloride⁴. This method yields a product with much less metal impurity. However it contains chlorine and copper along with other chlorinated α -6T contaminants (as high as 25 %) that would be difficult to purify. A more recent method involves the use of ferric acetylacetonate. α -6T synthesized using this coupling reagent was found to require extensive purification which involved multiple steps such as washing with dilute HCl, water, digestion with aqueous Na₂CO₃ and a series of hot solvents of different polarities, recrystallization from mesitylene under nitrogen with hot filtration, and sublimation along a glass tube under high vacuum⁵.

Oxidoreductases such as Horseradish Peroxidase (HRP), Soybean Peroxidase (SBP) obtained from natural & renewable sources have been known to catalyze the oxidative coupling /polymerization of different monomers under benign conditions in aqueous and mixed solvent systems. In the past, HRP has been used for the polymerization of aniline⁶ and phenol⁷ in the presence of various charged macromolecular templates to yield water soluble and conducting polymers. Here we report a biocatalytic single step method for synthesizing α -6T by enzyme catalyzed coupling of terthiophene (α -3T). Both HRP and SBP can catalyze the polymerization of terthiophene to yield α -6T. The insolubility of terthiophene in aqueous media requires the use of mixed solvents and a polyelectrolyte template such as poly (styrenesulfonic acid) (PSS). The reaction can be carried out either in 50/50 acetone water system or in 60/40 water-dimethyl sulfoxide (DMSO) in the presence of PSS. The product, sexithiophene α -6T is insoluble in most common solvents and precipitates out from solution. Since the catalyst (HRP) and the unreacted monomer remain soluble, the final product can be easily separated out.

Experimental

Materials: Terthiophene and standard sexithiophene were obtained from Sigma-Aldrich Co. and were used without further purification. Peroxidase from Horseradish (activity 150-250 units/mg solid), Poly(sodium 4-styrenesulfonate) [PSS], (M_w ca. 70,000) and hydrogen peroxide (30% solution) were also obtained from Sigma-Aldrich Co. The reactions were carried out in 50/50 (v/v) mixtures of sodium phosphate buffer (pH 4.0) and acetone.

Synthesis and characterization of (α -6T)/SPS: The polymerization of terthiophene in the presence of SPS was carried out using HRP and hydrogen peroxide under ambient conditions. 15.4 mg (7.5 mM) of SPS was dissolved in 5.0 ml of sodium phosphate buffer. 18.6mg (7.5mM) of terthiophene was dissolved in 5 ml of acetone and added to the buffer solution and sonicated for 2 hours. HRP (3mg) was then added and the polymerization was initiated by the addition of 77 μ l aliquots of 0.3% H₂O₂ solution with vigorous stirring. A total of ten aliquots of the H₂O₂ solution were added at 2-minute intervals to prevent inhibition of the enzyme by the H₂O₂ solution. The reaction mixture was stirred gently for several hours and the products were characterized using a Perkin Elmer Lambda 9 UV-vis spectrometer and Perkin-Elmer LS 55

spectrofluorometer. Mass spectra were recorded using a Micromass Matrix Assisted Laser Desorption Ionization (MALDI-TOF) instrument.

Results and Discussion

Enzyme catalyzed polymerizations are known to offer many advantages over traditional chemical approaches including environmentally friendly reaction conditions and ease of synthesis. The reaction proposed here is a one step synthesis shown in **Figure 1**. PSS helps to solubilize the α -3T prior to oxidative coupling and also assists in aligning the monomer through preferred electrostatic interactions⁸ besides possibly lowering the oxidation potential of the monomer.

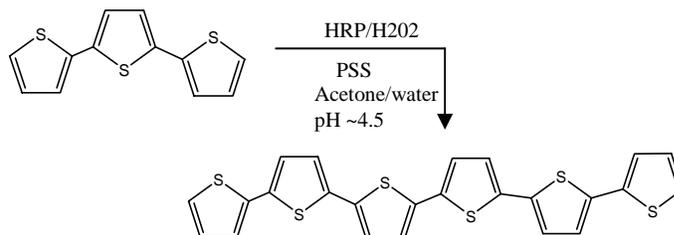


Figure 1. HRP catalyzed synthesis of sexithiophene.

The formation of sexithiophene was monitored using UV-Visible spectrometer. The UV-Visible spectrum of terthiophene in 50/50 acetone: water was obtained before the initiation of oxidative coupling reaction. The spectrum of α -3T shows a strong absorption centered around 350 nm. The spectrum obtained 4 hours after the initiation of polymerization, indicates a decrease in the intensity of this peak (monomer being consumed in the reaction). This is also accompanied by the appearance of a broad absorption band in the range of 410-500 nm due to formation of oligomeric species (α -6T) as shown in **Figure 2**.

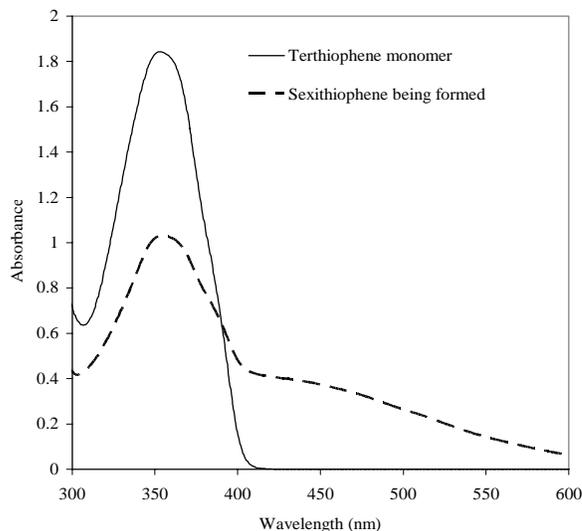


Figure 2. UV-vis spectra of Terthiophene and α -6T during the course of the reaction.

The reaction mixture was left stirring for a few more hours and subsequently left undisturbed overnight. A dark-brown precipitate of α -6T is formed after 24 hours. In order to verify the formation of α -6T, MALDI-TOF spectrum was obtained from the reaction mixture without using a matrix. MALDI-TOF indicates shows peaks at m/z values of 247.87 and 493.878 which correspond to the residual unreacted terthiophene (molar mass 248.39 g/mole) and sexithiophene (α -6T) (molar mass 494.76 g/mole) respectively. A very small peak at m/z value of 739.827 indicates that a small amount of α -9T is also formed in the reaction. The reaction mixture was then repeatedly washed with

acetone to remove any unreacted α -3T and then with water to remove PSS. The colloidal solution obtained after washing was then analyzed using MALDI-TOF. The MALDI showed only one peak at 493.62 g/mol for the α -6T and the absence of any peak for α -3T and α -9T.

The fluorescence spectra were also recorded and as seen in **Figure 3**, the fluorescence of the enzymatically synthesized α -sexithiophene closely resembles the standard α -6T. These results indicate that the enzymatic synthesis yields sexithiophene with spectral characteristics substantially similar to the standard sexithiophene

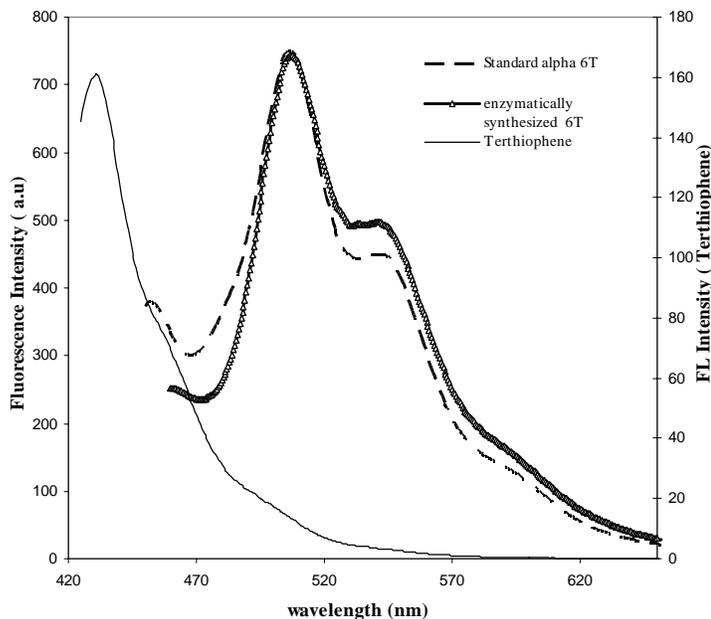


Figure 3. Fluorescence spectra of α -3T and sexithiophenes

Conclusions

α -sexithiophene has been synthesized using a single-step biocatalytic reaction using peroxidases as catalysts in mixed solvent systems. The sexithiophene formed precipitates out of solution and requires minimal purification. The enzyme mediated approach greatly simplifies synthesis and work-up procedures. Preliminary results indicate that the enzymatically synthesized α -6T exhibits properties similar to the commercially available material. The PSS helps in solubilizing the terthiophene and probably assists in changing the redox potential favorably. The role of PSS in assisting the synthesis is still currently under investigation. Further characterization of the enzymatically synthesized sexithiophene is under progress.

Acknowledgement We thank Dr. Ravi Mosurkal for help in recording the MALDI-TOF spectra and Dr. Alope Jain for helpful discussions.

References

- (1) Torsi, L.; Malitesta, C.; Sabbatini, L.; Zambonin, P. G.; Dodabalapur, A.; Katz, H. E. *Biomimetic Materials, Sensors and Systems*, **1998**, C5, 233.
- (2) Horowitz, G.; Peng, X. Z.; Fichou, D.; Garnier, F. *Journal of Molecular Electronics*, **1991**, 7, 85.
- (3) Fichou, D.; Horowitz, G. G.; Garnier, F. *Eur. Pat. Appl. EP*, **1990**, 402, 269.
- (4) Kagan, J.; Arora, S.K. *Heterocycles*, **1983**, 20, 1937.
- (5) Katz, H. E.; Torsi, L.; Dodabalapur, A. *Chem. Mater.* **1995**, 7, 2235.
- (6) Wei, L.; Cholli, A.L.; Nagarajan, R.; Kumar, J.; Tripathy, S.; Bruno, F.F.; Samuelson, L. *J. Am. Chem. Soc.* **1999**, 121, 11345.
- (7) Bruno, F. F.; Nagarajan, R.; Stenhouse, P.; Yang, Ke; Kumar, J.; Tripathy, S. K.; Samuelson, L. A. *J. Macromol. Sci., Part A – Pure and Applied Chemistry*, **2001**, A38 (12), 1417.
- (8) W. Liu, A.L. Cholli, R. Nagarajan, J. Kumar, S.K. Tripathy, F. F. Bruno and L. Samuelson, *J. Am. Chem. Soc.*, **1999**, 121, 11345.