Conductive biodegradable film of *N*-octyloxyphenyl-*N'*-(4-methylbenzoyl)thiourea

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Abstract. Thiourea derivatives are versatile family of ligands which provides wide range of electronic properties since they consist of rigid π -systems on their structures. In this work, a new type of thiourea compound with general formula $\text{Me-C}_6\text{H}_4\text{C(O)NHC(S)NHC}_6\text{H}_4\text{-OC}_8\text{H}_{17}$ of *N'*-(4-methylbenzoyl)thiourea (MBTU) was successfully synthesised and characterized by using NMR, FTIR and UV-vis analysis. The development of new conductive biodegradable film based on MBTU has been accomplished by incorporating chitosan to the polymer-dopant system via solution-cast technique. The impedance measurement technique was employed to determine conductivity of biodegradable film. It shows that, with the addition of MBTU, the increasing of conductivity is from 10^{-9} to 10^{-8} Scm^{-1} . TNM results show that the conductivity of biodegradable film is governed by electronic conducting species. It is proven that MBTU compound exhibits promise and has great potential to be explored and used as doping system in conductive materials application in the future.

Keywords. Methylbenzoyl thiourea (MBTU); biodegradable film; electronic conductivity.

1. Introduction

Nowadays, there is a growing interest in research directed to the automation of environmental control, industrial processes and clinical analysis in the medical field. This progress has encouraged the development of materials for the recognition and sensing of highly pollutant chemical species, such as the heavy metals, which may harm the ecosystems and, in general, the human health.

In this sense, thiourea (TU) has found many applications in medicine, industry and other areas of chemistry (Yao *et al* 1992). TU and its derivatives are classical additives for the electro deposition of copper and other metals (Bolzan *et al* 2001a,b, 2002, 2003; Haseeb *et al* 2001; Lukomska and Sobkowski 2001; Kao *et al* 2004), corrosion inhibitors, vulcanization accelerators, components of fertilizers, pharmaceuticals, pesticides and herbicides (Smyth and Osteryoung 1977; Spataru and Banica 2001; World Health Organization, Geneva 2003; Spataru *et al* 2005). Thiourea system is a great candidate to construct molecular wire (molwire) as the system can act as an excellent transporter. The electron transportation through molwire assumes fundamental

importance (Li *et al* 2006) as the wire can act as the simplest electronic component for the conduction of current (Majumder *et al* 2004). Thioureas are easily synthesised by the reaction of chiral amines with isothiocyanates (Breuzard *et al* 2000) as shown in scheme 1. These compounds should display ideal characteristics such as wide concentration range, fast response time and good selectivity coefficient for many cations.

For these reasons, it has become increasingly important to investigate TU in order to utilize its application in numerous fields and related compounds. Therefore, appropriate methods for their determination in various media are worthy of development. This study deals with the synthesis of the candidate compound, namely *N*-octyloxyphenyl-*N'*-(4-methylbenzoyl)thiourea (MBTU), and characterisation and investigation of its properties so that it can be developed as a potential molecular wire which promises good electron carrier and current flow. Besides, the potential of MBTU as a dopant system by introducing a polymer, namely chitosan, in producing a conductive biodegradable film was explored. Chitosan has aroused a lot of interest in view of its applications in the industrial and biomedical sectors (Wan *et al* 2003). It is also the first natural polymer-chelating membrane and does not possess any pores. Chitosan films are homogeneous with high mechanical strength (Muzzarelli 1973). Therefore, due to these reasons, the characteristics,

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behaviour and performance of MBTU-chitosan as conductive biodegradable films in the respect of conductivity were investigated via impedance spectroscopy measurement.

2. Experimental

2.1 Materials and general methodology

All reactions were carried out under an ambient atmosphere and no special precautions were taken to exclude air or moisture during work-up. All chemicals were purchased from standard suppliers (Merck, Fisher Scientific,

R&M Marketing, Acros, Eastern Global Sdn. Bhd and Sigma Aldrich) and used as received, without further purification. ^1H (400.11 MHz) and ^{13}C (100.61 MHz) NMR spectra were recorded using Bruker Avance III 400 Spectrometer in CDCl_3 as solvent and internal standard at room temperature in the range between $\delta_{\text{H}} = 0\text{--}15$ ppm and $\delta_{\text{C}} = 0\text{--}200$ ppm, respectively. Meanwhile, infrared spectra of the synthesized compounds were recorded from KBr pellets using FT-IR Perkin Elmer 100 Spectrophotometer in the spectral range of $4000\text{--}400\text{ cm}^{-1}$. For UV-vis analysis, all compounds were recorded by Shimadzu UV-vis 1601 series in 1 cm^3 cuvette in methanolic solution. The samples that form in thin films state were then characterized via electrical impedance spectroscopy (EIS) using HIOKI 3532-50 LCR in range $50\text{ Hz--}1\text{ MHz}$ in order to investigate the conductivity.

Scheme 1. Synthesis of thiourea.

2.2 General synthesis

N-octyloxyphenyl-*N'*-(4-methylbenzoyl)thiourea (MBTU) was successfully synthesised from subsequent reactions which began with formation of the precursor compound (1). Then, the synthesis continued with the formation of compound (2) as an intermediate compound which in turn was

reacted with 4-methylbenzoyl thiocyanate to obtain the final compound (3). For compounds (1) and (2), they have been reported before in previous occasions (Hearn *et al* 2006; Seng Kue *et al* 2007; Kukut *et al* 2009; Westphal *et al* 2010; Adli *et al* 2012). However, some modifications in the synthetic work and further characterisation on the spectroscopic and analytical tasks have been carried out. Scheme 2 shows the synthetic approach applied in this study.

2.3 Synthesis of compound 1, *N*-(4-(octyloxy)phenyl)acetamide

Generally, synthesis began with the reaction between 4-hydroxy acetanilide (5.00 g, 1.0 mol), octyl bromide (6.34 g, 1.0 mol) and potassium carbonate (4.55 g, 1.0 mol) which were put at reflux with constant stirring in ca. 100 ml acetone for ca. 48 h. When adjudged completion by TLC (Hexane:CH₂Cl₂) (2:3), the reaction mixture was cooled to room temperature and taken to dryness to give brown solid compound before it was then stirred for 1 h with 50 ml of 2% sodium hydroxide to give compound (1) as white solid.

2.4 Synthesis of compound 2, 4-octyloxy aniline

Compound (1) was put at reflux for 2 h with ethanol and concentrated hydrochloric acid (50:50 ml) to give solution of 4-octyloxy aniline hydrochloride. This solution was then cooled to room temperature before being washed with water:CH₂Cl₂ (150:150 ml). After separation of the organic layer and dried over CaCl₂, the solvent was removed in vacuo to give the off-white crystalline solid of title compound (2).

2.5 Synthesis of compound 3, *N*-octyloxyphenyl-*N'*-(4-methylbenzoyl)thiourea

A suspension of 4-methylbenzoyl chloride (1.02 ml, 1.0 mol) in 50 ml acetone was added with ammonium thiocyanate (0.39 g, 1.0 mol) in 50 ml of acetone to give pale yellow solution. The solution was stirred at room temperature for ca. 4 h before 2 (1.13 g, 1.0 mol) was added. After stirring for another ca. 4 h, the colour of the solution turned from pale to bright yellow. After adjudged completion by TLC (hexane:CH₂Cl₂) (2:3), reaction mixture was cooled to room temperature and filtered. The yellow filtrate was added with 3 ice cubes and then filtered to obtain yellow precipitate. Then, yellow precipitate was recrystallized from hot methanol to afford the title compound (3).

2.6 Preparation of biodegradable film from *N*-octyloxyphenyl-*N'*-(4-methylbenzoyl)thiourea (MBTU)

According to Ahmad Khair *et al* (2006), a chitosan film has very low electrical conductivity in its actual state. Therefore, it was used as polymer host in this study to observe any changes of conductivity by addition of *N*-octyloxyphenyl-*N'*-(4-methylbenzoyl)thiourea (MBTU) which acts as ionic dopant. The biodegradable film was prepared by the solution casting technique which 2 g chitosan (Eastern Global) was dissolved in 100 ml of 1% acetic acid solution. Then, 0.4 wt.% of MBTU was added before being kept stirred continuously until complete dissolution became homogeneous. The mixture was then poured into several petri dishes and allowed to evaporate slowly at ambient temperature for film to form. The thiourea concentration for each sample and their designations are shown in table 1.

2.7 Transference number measurement (TNM)

In order to prove the proton conduction in biopolymer electrolytes (BEs) system, TNM was performed using dc polarization method (Idris *et al* 2009; Samsudin *et al* 2012) and it corresponds to ionic (t_i) or an electron (t_e) transport (Idris *et al* 2009). The dc current was monitored as a function of time on the application of fixed dc voltage (1.5 V) across the

Table 1. Composition of the samples and their designation.

Designation	Weight of chitosan (g)	Weight of dopant (wt.%)
TF0	2	0
TF1	2	0.4

Figure 1. The synthesized compounds.

sample mounted between two stainless steel electrodes under spring pressure. The ionic transference number t_i is given by the relation:

$$t_i = 1 - \frac{I_i}{I_o} = 1 - t_e. \quad (1)$$

Here I_i is the saturated proton current and I_o is initial current. If the polymer electrolytes (PEs) is purely ionic, then $t_i = 1$.

2.8 Impedance spectroscopy

In order to investigate the effect with addition of MBTU in conductivity, the impedance spectroscopy was performed. The biodegradable films were cut into small discs of 2 cm diameter and sandwiched between two stainless steel electrolytes under spring pressure. The samples were characterized via electrical impedance spectroscopy (EIS) using HIOKI 3532-50 LCR Hi-Tester interfaced to a computer in

Figure 2. (a) ^1H NMR compound (1), (b) ^1H compound (2) and (c) ^1H NMR compound (3).

a frequency range between 50 Hz and 1 MHz. The measurements were carried out at room temperature of 303 K until 353 K. The conductivity of film can be calculated from the equation:

$$\sigma = \frac{t}{R_b A}. \quad (2)$$

Here, A (cm^2) is the electrode–electrolyte contact area of the film and t its thickness. R_b is bulk resistance obtained from the complex impedance plot (Cole–Cole plot) at the intersection of the plot and the real impedance axis.

3. Results and discussion

3.1 Spectroscopic studies

Based on the ^1H NMR spectra for compounds (1)–(3) in figure 2, it shows the methyl resonance for octyl group in range of $\delta_{\text{H}} = 0.89$ – 0.92 ppm while protons for methylene group are observed in range of $\delta_{\text{H}} = 1.30$ – 1.85 ppm. For $-\text{O}-\text{CH}_2-$ in all compounds, the signals for the proton are detected in range of $\delta_{\text{H}} = 3.82$ – 4.00 ppm as three singlet resonances. Resonances for aromatic ring are observed

Table 2. ^1H NMR data for all synthesized compounds.

Compound	Moieties	Chemical shift δ_{H} (ppm)
(1)	(t, $^3J_{\text{HH}} = 7$ Hz, 3H, CH_3)	0.89
	(m, 12H, $6 \times \text{CH}_2$)	1.30–1.81
	(s, 3H, CH_3)	2.14
	(s, 2H, OCH_2)	3.91–3.95
	(pseudo-d, $^3J_{\text{HH}} = 9$ Hz, 2H, C_6H_4)	6.83–6.85
	(pseudo-d, $^3J_{\text{HH}} = 9$ Hz, 2H, C_6H_4)	7.37–7.39
	(s, 1H, NH)	7.65
(2)	(t, $^3J_{\text{HH}} = 7$ Hz, 3H, CH_3)	0.89
	(m, 12H, $6 \times \text{CH}_2$)	1.38–1.78
	(s, 2H, OCH_2)	3.82–3.85
	(pseudo-d, $^3J_{\text{HH}} = 9$ Hz, 2H, C_6H_4)	6.73–6.75
	(pseudo-d, $^3J_{\text{HH}} = 9$ Hz, 2H, C_6H_4)	7.29–7.37
	(s, 2H, NH_2)	10.78
	(s, 1H, NH)	12.46
(3)	(t, $^3J_{\text{HH}} = 7$ Hz, 3H, CH_3)	0.92
	(m, 12H, $6 \times \text{CH}_2$)	1.34–1.85
	(s, 3H, CH_3)	2.47
	(s, 2H, OCH_2)	4.00
	(pseudo-d, $^3J_{\text{HH}} = 9$ Hz, 2H, C_6H_4)	6.94–7.37
	(pseudo-d, $^3J_{\text{HH}} = 9$ Hz, 2H, C_6H_4)	7.59–7.82
	(s, 1H, NH)	9.11

Table 3. ^{13}C NMR data for all synthesized compounds in this study.

Compound	Moieties	Chemical shift δ_{C} (ppm)
(1)	(s, CH_3)	14.11
	($6 \times$ s, $6 \times \text{CH}_2$)	22.67–31.82
	(s, CH_3)	24.24
	(s, CH_2-O)	68.30
	($4 \times$ s, C_6H_4)	114.72–156.01
	(s, $\text{C}=\text{O}$)	168.54
	(s, $\text{C}=\text{S}$)	178.70
(2)	(s, CH_3)	14.10
	($6 \times$ s, $6 \times \text{CH}_2$)	22.67–31.84
	(s, CH_2-O)	68.26
	($4 \times$ s, C_6H_4)	115.31–159.14
	($2 \times$ s, CH_3)	14.09, 21.48
	($6 \times$ s, $6 \times \text{CH}_2$)	21.68–31.79
	(s, $\text{O}-\text{CH}_2$)	68.27
(3)	($8 \times$ s, C_6H_4)	114.64–157.88
	(s, $\text{C}=\text{O}$)	166.86
	(s, $\text{C}=\text{S}$)	178.70

Figure 3. (a) ^{13}C NMR compound (1), (b) ^{13}C NMR compound (2) and (c) ^{13}C NMR compound (3).

Figure 4. The IR spectrum of compound (1).

Figure 5. The IR spectrum of compound (2).

as multiplet resonances between $\delta_H = 6.73$ and 7.82 ppm due *para* substituent methyl groups and overlapping of proton signals in the aromatic rings (Küçükgülzel *et al* 2008). Protons for N–H are observed as singlet resonances in compounds (1) and (3) which can be observed at $\delta_H = 7.65$ ppm, $\delta_H = 9.11$ and $\delta_H = 12.46$ ppm, respectively. Instead, compound (2) has protons for NH_2 group which can be seen at $\delta_H = 10.78$ ppm. The 1H NMR data and chemical structures for all compounds (1)–(3) are presented in tables 2 and 3, respectively.

The ^{13}C NMR spectrum for compound (1) shows resonance of methyl group which is observed at $\delta_C = 24.24$ ppm whilst, carbon resonance for alkoxy groups in each compound (1)–(3) can be seen at $\delta_C = 21.68$ – 31.84 ppm. While the chemical shifts for $-CH_2O-$ in all compounds are observed around $\delta_C = 68.30$ ppm due to the deshielding effect in the presence of oxygen atom that withdraws certain amount of electrons from the alkyl chain (Tadjarodi *et al* 2007). Resonances of carbons for both aromatic rings in 3 are observed in range $\delta_C = 114.64$ – 157.88 ppm. Two resonances which are observed at $\delta_C = 166.86$ and $\delta_C = 178.70$ ppm are corresponded to carbons of $C=O$ and $C=S$ in compound (3). Thiocarbonyl ($C=S$) carbon corresponding to thiourea moiety can be observed at higher chemical shift $\delta_C = 180.80$ ppm (Sudha and Sathyanarayan 1984; Küçükgülzel *et al* 2008). Resonances for $C=O$ and $C=S$ are slightly deshielded to higher chemical shifts which may be due to intra-molecular hydrogen bonding of the compounds and electronegativity of oxygen and sulphur (Kavak *et al* 2000; Saeed *et al* 2002;

Del Campo *et al* 2004). ^{13}C NMR spectra for all compounds are shown in figure 3, whilst the data are shown in table 3.

From figure 4, IR spectrum of the intermediate compound (1) shows five absorption bands of interest namely $\nu(N-H)$, $\nu(C-H)$, $\nu(C=O)$, $\nu(C-N)$ and $\nu(C-O)$. Based on the spectrum, the absorption band for secondary amide N–H stretching is observed at 3260 cm^{-1} . Meanwhile, the absorption band for $C=O$ (amide) are observed at 1658 cm^{-1} , which is almost identical to the observations in the previous report on similar system (Akiyama *et al* 2008; Mureseanu *et al* 2010). Meanwhile, infrared spectrum for 2 shows four absorption bands of $\nu(N-H)$, $\nu(CH)$, $\nu(C-N)$ and $\nu(C-O)$. Apparently, from the spectrum in figure 5, there is elimination of $C=O$ amide functional group in compound. Besides, the spectrum for 2 shows broad strong absorption band of N–H at 3391 cm^{-1} which may be due to the intra-molecular hydrogen bond (Marie-Andrée *et al* 2000; Westphal *et al* 2010). The C–H alkane stretching, strong sharp absorption bands of C–N and C–O for these compounds, are observed at 2601 , 1244 and 1130 cm^{-1} , respectively. Meanwhile, the infrared spectrum for the focus compound of *N*-octyloxyphenyl-*N'*-(4-methylbenzoyl)thiourea (3) shows six absorption bands, namely $\nu(N-H)$, $\nu(C-H)$, $\nu(C=O)$, $\nu(C-O)$ and $\nu(C=S)$ as shown in figure 6. For 3, it can be concluded that there is addition of absorption band of $C=S$. The absorption band for $C=S$ in this compound is observed at 721 cm^{-1} to prove that it is a thiourea compound (Bombicz *et al* 2004; Prakash and Nirmala 2010).

Figure 6. The IR spectrum of compound (3).

Figure 7. UV-vis spectra of the synthesized compound: (a) compound (1), (b) compound (2) and (c) compound (3).

The UV-vis spectra for these synthesized compounds (1)–(3) are shown in figure 7. Electronic absorption spectrum of 1 was recorded in methanolic solution in 1 cm^3 cuvette with concentration $1 \times 10^{-4}\text{ M}$ and shows two principal bands which are expected to be contributed by C=O and Ar–O–R substructures. The absorption band of C=O chromophore is believed to take place at $\lambda_{\text{max}} = 249.60\text{ nm}$ because the formation of hydrogen bond (C=ONH) increases the bond length of C=O. Thus, smaller energy required for this transition and the absorption shows the red end of the spectrum (Madhurambal *et al* 2010). For all compounds, the absorption band of Ar–O–R is observed at $\lambda_{\text{max}} = 290.60\text{ nm}$. Meanwhile, 2 shows two principal bands which are believed to be contributed by Ar–NH₂ and Ar–O–R. Apparently, the principal absorption band for this compound was shifted to the longer wavelength and the bathochromic shift towards the end of the spectrum. This is because alkoxy group (–OR) and amine group (–NH₂) have forbidden $n\text{--}\pi^*$ (conduction band) transition and electron excitation from HOMO to LUMO transition. It is well-known, stronger donor and/or acceptor groups in the molecular framework should contribute towards the bathochromic shift at longer wavelength which may result in small energy difference between ground and excited states. (Raposo *et al* 2008). For electronic absorption spectrum 3, the transition of phenyl rings and the existence of C=O and C=S bands can be observed, which undergo $\pi\text{--}\pi^*$ transitions. The absorption bands for C=O and C=S chromophores in thiourea compound can be observed at $\lambda_{\text{max}} = 246.90$ and $\lambda_{\text{max}} = 274.00\text{ nm}$, respectively. The broad absorption band observed in the region between $\lambda_{\text{max}} = 245\text{ nm}$ and $\lambda_{\text{max}} = 325\text{ nm}$ is due to π -conjugation of the compound of phenyl rings and orbital overlapping between C=O and C=S.

3.2 Conductivity studies

Transference number measurement (TNM) was performed to correlate the diffusion phenomena to the conductivity

Figure 8. Normal polarization current vs time for sample TF1.

behaviour of chitosan doped with MBTU based conducting film system. The plot of polarized current vs time is shown in figure 8. From figure 8, it is seen that the initial total current decreases with time due to the depletion of the conducting species in the electrolyte and becomes constant in the fully depleted situation. At a steady state, the cell is polarized and current flows because of electron migration across the electrolyte and interfaces. This is because the conducting currents through an ion-blocking electrode fall rapidly with time if the electrolyte is primarily ionic. In polymer electrolytes, there are two possible mobile conducting species, i.e., ionic and electronic. From the calculations carried out, it can be found that the value of electronic transport ($t_e = 0.66$) is higher than that of ionic transport ($t_i = 0.34$) in this system.

The impedance spectra (or Cole–Cole plot) obtained on TF1 and measured at ambient temperature is shown in figure 9. The spectra show two different regions: semicircle in the high frequency and a spur in the low frequency. The appearance of semicircle can be explained by a parallel combination of resistor and capacitor. The resistor is referred to the migration of ions which occurs through the free volume of the chitosan whilst the capacitor represents its immobilization. From the initial observation, it can be concluded that the developed system in this study indeed is a conductive material (Ramya *et al* 2006). The spectra show spurs at low frequency. This is attributed to the effect of electrode polarization which is characteristic of diffusion process followed by a semicircle. It can be related to a charge transfer process with Z_i intercepts in the higher frequency range. According to Zotti *et al* (1995), due to the electron releasing property of the

Figure 9. Impedance spectra (Cole–Cole plot) for sample TF1.

alkoxy group, polythiophenes with alkoxy substituent, display the advantage of an easier dopability (and, consequently, of a higher stability of the conducting state). From the plot of negative imaginary impedance, Z_i vs real impedance, Z_r with the horizontal and vertical axes having the same scale, the bulk resistance, R_b can be obtained. Whenever R_b was difficult to obtain from the complex impedance data, the impedance data was converted into admittance data and plotted according to the admittance formalism from which $1/R_b$ may be easier to obtain (Majid and Arof 2007).

The conductivity of the samples TF0 and TF1 at ambient temperatures are illustrated in table 4 and figure 10. The conductivity depends on several factors, such as ionic or electron dopant concentration, cationic or anionic types charge carriers, the charge carriers mobility and the temperature (Raphael *et al* 2010; Samsudin *et al* 2011). It can be observed that conductivity of the sample increases with addition of MBTU in chitosan biodegradable film from 10^{-9} to 10^{-8} Scm $^{-1}$. Since MBTU is ideal to act as electron donor, it can easily dissociate with the polymer thus leading to an increase in conductivity. Therefore, it can be inferred that the conductivity with addition of MBTU is governed by electronic species conductor as proven from the TNM study.

In order to understand possible mechanism of the electron conduction with the addition MBTU in chitosan, the conductivity was investigated as a function of temperature from ambient temperature to 353 K. The log σ vs $1000/T$ plot for the samples TF0 and TF1 are shown in figure 11 and was found to be a straight line with regression value, $R^2 \sim 1$. This indicates that no phase transition occurs in the polymer matrix or domains are formed by addition of salts or ionic dopant (Avellanda *et al* 2007). Since the regression values are close to unity, this suggests that the temperature-dependent ionic conductivity for biodegradable film obeys Arrhenius behaviour (Buraidah *et al* 2009). Increase in conductivity with temperature is mainly due to increase in free volume (Miyamoto and Shibayama 1973) for the motion of electrons through the polymer backbone (chitosan). This can be understood with the emphasis that as temperature increases, the vibrational energy of segmental motion operates against the hydrostatic pressure imposed by its neighbouring atoms. Consequently, it creates a small amount of space surrounding its own volume in which vibrational motion can occur. Therefore, free volume around the polymer chain causes augmentation in mobility of electrons and hence enhances the conductivity. Due to these findings, this type of molecule

Table 4. The conductivity data of sample studied.

Sample	Thickness, t (cm)	Bulk resistant, R_b	Conductivity, σ (Scm $^{-1}$)
TF0	0.014	2.13×10^6	3.37×10^{-9}
TF1	0.013	3.36×10^5	1.25×10^{-8}

Figure 10. Conductivity against TF composition at ambient temperature.

Figure 11. Temperature dependence of ionic conductivity.

featuring MBTU can be proposed as an ideal molecular wire candidate due to its unique character of having π -conjugation system and ideal charge carriers along its molecular backbone.

4. Conclusions

A linear conjugated organic compound of $C_6H_4C(O)NHC(S)NHC_6H_4-OC_8H_{17}$, namely *N*-octyloxyphenyl-*N'*-(4-methylbenzoyl)thiourea (MBTU) has been successfully designed, prepared and characterized prior to forming biodegradable conductive thin film. The compound was spectroscopically and analytically characterized by 1H and ^{13}C NMR, FT-IR and the conductivity behaviour of the compound was investigated by using electrical impedance spectroscopy (EIS) and transference number measurement (TNM). Apparently, by addition of MBTU as dopant in chitosan, it has increased the electronic conductivity of polymer conductive films in the range of 10^{-9} to 10^{-8} Scm^{-1} . This study proves MBTU can give great promise and show good potential to be explored further as conductive biodegradable films in numerous microelectronics applications in the near future.

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