



UNIVERSITI PUTRA MALAYSIA

**PREPARATION, CHARACTERIZATION AND ELECTROMAGNETIC
INTERFERENCE SHIELDING EFFECTIVENESS OF PPY-PVA AND
PPY-CMC CONDUCTING POLYMER COMPOSITE FILMS**

H. N. M. EKRAMUL MAHMUD.

FS 2006 10

**PREPARATION, CHARACTERIZATION AND ELECTROMAGNETIC
INTERFERENCE SHIELDING EFFECTIVENESS OF PPY-PVA AND PPY-
CMC CONDUCTING POLYMER COMPOSITE FILMS**

By

H. N. M. EKRAMUL MAHMUD

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia
in Fulfilment of the Requirement for the Degree of Doctor of Philosophy**

January 2006



DEDICATION

*I look up the hills,
Where does my help come from?
My help comes from Allah, the Almighty,
The creator of heaven and earth.*

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of requirement for the degree of Doctor of Philosophy

PREPARATION, CHARACTERIZATION AND ELECTROMAGNETIC INTERFERENCE SHIELDING EFFECTIVENESS OF PPy-PVA AND PPy-CMC CONDUCTING POLYMER COMPOSITE FILMS

By

H. N. M. EKRAMUL MAHMUD

January 2006

Chairman: Professor Anuar Kassim, PhD

Faculty: Science

Polypyrrole-poly(vinyl alcohol) (PPy-PVA) and polypyrrole-carboxymethyl cellulose (PPy-CMC) conducting polymer composite films were electrochemically prepared on Indium Tin Oxide (ITO) glass electrode from an aqueous solution containing pyrrole monomer, *p*-toluene sulfonate dopant and poly(vinyl alcohol)/carboxymethyl cellulose insulating polymer. The PPy-PVA and PPy-CMC composite films prepared from different process conditions were characterized by Fourier Transform infrared (FT-IR) spectroscopy, X-ray diffraction (XRD) analysis, optical microscopy, dynamic mechanical analysis (DMA), and conductivity measurement. The highest conductivity of 64 S/cm measured at room temperature was shown by PPy-PVA composite film prepared from 0.2 M pyrrole, 0.1 M *p*-toluene sulfonate and 12×10^{-4} M PVA at 1.2 volt (vs



SCE) among all the PPY-PVA composite films produced. The PPY-CMC composite film prepared from 0.3 M pyrrole, 0.1 M *p*-toluene sulfonate and 0.03 M CMC at 1.2 volt (vs SCE) showed the highest conductivity of 38 S/cm among all the PPY-CMC composite films produced. The FT-IR study of PPY-PVA and PPY-CMC composite films shows the evidence of the incorporation of PVA and CMC in PPY structure forming PPY-PVA and PPY-CMC composite films, respectively.

The conductivity data of PPY-PVA shows that with the increase in PVA concentration in the pyrrole solution, the conductivity of the prepared PPY-PVA film is increasing up to certain level due to the increase in conjugation length and later it is decreasing with further increase in PVA concentration, which is again linked with the conjugation length decrease. This is supported by the FT-IR band intensity of $I_{C=C}/I_{C-N}$. The FT-IR study of PPY-CMC composite films shows that with the increase in CMC concentration from 0.005 M to 0.01 M, the conductivity first decreased and later with further increase in CMC concentration the conductivity showed an increasing trend and finally at 0.04 M CMC, the conductivity dropped.

The DMA results of PPY-PVA and PPY-CMC composite films show the enhanced mechanical properties of both the composite films over PPY films without PVA or CMC. The storage moduli of both the composite films were found much higher than the PPY film prepared without PVA or CMC indicating that PPY-PVA and PPY-CMC composite films are much stiffer than PPY films. The gradual decrease of storage moduli of both the composite films with the increase in temperature



ranging from 25 °C to 250 °C suggests that the composite films have got flexibility in their chains and thus the chains are soft. On the other hand, the storage modulus of PPy film only without PVA or CMC shows no decreasing tendency with the increase in temperature ranging from 25 °C to 250 °C indicating that the PPy film is very hard and have got no flexibility in its backbone chain.

The XRD results of both PPy-CMC and PPy-PVA composite films show that the films are amorphous and have got very little order. The optical micrographs of PPy-CMC and PPy-PVA show the globular surface morphology. The changes in globular surface morphology with the change in process condition of the film preparation indicates that the process parameters used to prepare the composite films have got a good influence over the surface morphology. The intense polymerization reaction has been evidenced from the surface morphology of the films.

The results of electromagnetic interference (EMI) shielding effectiveness in the microwave range of 8-12 GHz show that the highest shielding effectiveness of 45.67 dB measured in the microwave range of 8-12 GHz corresponds to the total attenuation of 99.4 % of microwave energy has been exhibited by the PPy-PVA composite film prepared from 0.2 M pyrrole, 0.1 M *p*-toluene sulfonate and 12×10^{-4} M PVA at 1.2 volt (vs SCE) among all the PPy-PVA composite films prepared. The highest shielding effectiveness of 35.7 dB measured in the microwave range corresponds to the total attenuation of 98.32 % of microwave energy has been exhibited by the PPy-CMC composite film prepared from 0.3 M

pyrrole, 0.1 M *p*-toluene sulfonate and 0.03 M CMC at 1.2 volt (vs SCE) among all the PPy-CMC composite films prepared. Thus, the promise of finding any electromagnetic interference (EMI) shielding applications in the microwave frequency range lies in PPy-PVA and PPy-CMC conducting polymer composite films.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PENYEDIAAN, PENCIRIAN DAN KEBERKESANAN LINDUNGAN
INTERFERENS ELEKTROMAGNETIK FILEM KOMPOSIT POLIMER
PENGALIR PPY-PVA DAN PPY-CMC**

Oleh

H. N. M. EKRAMUL MAHMUD

Januari 2006

Pengerusi : Professor Anuar Kassim, PhD

Fakulti : Sains

Filem komposit polimer pengalir bagi pasangan polipirol-poli(vinil alkohol) dan polipirol-karboksimetil selulosa telah disediakan melalui kaedah elektrokimia di atas elektrod kaca Indium Stanum Oksida (ITO) daripada larutan akueus yang mengandungi monomer pirol, dopan *p*-toluena sulfonat dan sebatian polimer selulosa penebat poli(vinil alkohol)/karbosimetil selulosa. Filem komposit bagi PPy-PVA dan PPy-CMC telah disediakan melalui keadaan proses yang berlainan dan langkah pencirian telah dilakukan melalui penyerapan infra merah (FT-IR), pengimbasan analisis sinar-X, mikroskopi optikal, analisis mekanikal dinamik (DMA) dan penentuan konduksian. Filem komposit PPy-PVA memberi nilai konduktiviti tertinggi iaitu 64 S/cm berbanding dengan yang lain. Filem tersebut disediakan daripada larutan pirol 0.2 M, 0.1 M *p*-toluena sulfonat dan 12×10^{-4} M PVA pada keupayaan 1.2 v (melawan SCE). Sebaliknya, filem komposit PPy-CMC

yang disediakan dengan 0.3 M pirol, 0.1 M *p*-toluena sulfonat dan 0.03 M CMC pada keupayaan 1.2 v (melawan SCE) menunjukkan nilai kekonduksian tertinggi 38 S/cm berbanding dengan yang lain. Kajian FT-IR ke atas filem komposit PPy-PVA dan PPy-CMC nyata menunjukkan kemasukan PVA dan CMC ke dalam struktur PPy berkaitan dengan pembentukan filem komposit PPy-PVA and PPy-CMC masing-masing.

Data kekonduksian, PPy-PVA menunjukkan dengan penambahan kepekatan PVA dalam larutan pirol, kekonduksian filem PPy-PVA turut bertambah ke satu paras tertentu disebabkan penambahan panjang konjugatan dan nilai kekonduksian berkurangan dengan penambahan PVA berlebihan iaitu berkaitan langsung dengan panjang konjugatan yang berkurangan. Keadaan ini disokong oleh nisbah keamatan jalur FT-IR ikatan $I_{C=C}/I_{C-N}$. Menurut kajian FT-IR bagi filem komposit menunjukkan bacaan kekonduksiannya berkurangan dengan penambahan kepekatan CMC dari 0.005 M ke 0.01 M. Dengan penambahan kepekatan CMC yang berlebihan, kekonduksian semakin bertambah sehingga mencapai 0.04 M dan seterusnya berkurang.

Keputusan DMA berkaitan dengan filem-filem komposit PPy-PVA dan PPy-CMC menunjukkan sifat mekanikal yang lebih baik berbanding dengan filem-filem tanpa komposisi PVA mahupun CMC. Moduli “puluh” bagi kedua-dua jenis filem komposit didapati jauh lebih tinggi sekiranya dibandingkan dengan filem PPy yang disediakan tanpa PVA dan CMC. Ini jelas menunjukkan bahawa filem-filem komposit PPy-PVA dan PPy-CMC adalah jauh lebih kental atau kuat berbanding

dengan filem-filem PPy. Nilai moduli “pulih” berkurangan secara beransur-ansur dengan kenaikan suhu dari 25 °C ke 250 °C bagi kedua-dua jenis komposit mencadangkan bahawa rantai filem komposit tersebut memiliki sifat fleksibiliti dan ini menyebabkan rantai tersebut lembut. Sebaliknya, nilai modulus “pulih” bagi filem PPy tanpa komposisi PVA atau CMC tidak menunjukkan sifat kecenderungan kekurangan dengan kenaikan suhu dari 25 °C ke 250 °C menunjukkan sifat keras dan tidak fleksibiliti pada pembentukan rantai utama ikatan.

Keputusan XRD menunjukkan bahawa kedua-dua filem komposit PPy-CMC dan PPy-PVA adalah bersifat amorfus dan mempunyai sedikit sifat ketertiban. Mikrografi optikal PPy-CMC dan PPy-PVA menunjukkan sifat morfologi permukaannya yang berbentuk sfera. Perubahan keadaan penyediaan turut mengubah morfologi permukaan sfera jelas menunjukkan bahawa parameter proses kajian yang digunakan mempunyai kesan untuk mempengaruhi sifat permukaannya. Jelasnya, tindak balas pempolimeran telah mempengaruhi morfologi permukaan filem-filem tersebut.

Interferen keelektromagnetan lindungan berkesan (EMI) pada julat mikrogelombang 8-12 GHz menunjukkan nilai pelindungan berkesan tertinggi pada 45.67 dB telah dihasilkan oleh filem komposit menerusi 0.2 pirol, 0.1 M *p*-toluena sulfonat dan 12×10^{-4} M PVA pada keupayaan 1.2 volt (melawan SCE) berbanding filem-filem komposit PPy-PVA yang disediakan. Nilai tertinggi bagi pelindungan berkesan (EMI) 35.7 dB ukuran pada julat mikrogelombang telah dihasilkan oleh filem komposit PPy-CMC yang disediakan daripada 0.3 M pirol,

0.1 M *p*-toluena sulfonat and 0.03 M CMC pada keupayaan 1.2 volt (melawan SCE) berbanding filem komposit PPy-CMC lain yang disediakan. Maka, sebarang aplikasi interferen keelektromagnetan lindungan berkesan boleh ditemui dalam julat frekuensi mikrogelombang filem-filem polimer komposit berkonduksian jenis PPy-PVA dan PPy-CMC.

ACKNOWLEDGMENTS

In The Name of ALLAH, The Most Merciful And Most Beneficent

All praises goes to Allah, the Lord of the universe. Only by His grace and mercy this thesis has been completed.

First and foremost, I am extra-ordinarily grateful to my supervisor Professor Anuar Kassim, PhD for his strong support, guidance and patience for the very enriching and thought provoking discussions and lectures, which helped shape the thesis. He was always there to provide everything I needed in the laboratory. I would also like to express my sincere thanks to my co-supervisors Professor Zulkarnain Zainal, PhD and Professor Wan Mahmood Mat Yunus, PhD for their guidance, support, and encouragement throughout my study period.

I am also indebted to the staff of the Department of Chemistry, Universiti Putra Malaysia, for their help and cooperation.

Special thanks are extended to my lab members Miss Masnizaayu, Mrs. Rozita Yahya, and Mr. Fariz Adzmi who helped me in every possible way providing a congenial and enthusiastic atmosphere in the laboratory. Special thanks are also extended to Mr. Mainul Hassan, Mr. Lim Chee Siong, Mr. Zahid Rezwan, Mr. Yusouf Hossain, Mr. Hamzah Haroon and Mr. Shahril Hussin for their encouragement, help and support in every aspect of my thesis. A deep



acknowledgment is also extended to Mrs Yusmawati Wan Yusof, Mrs Rusnani, Miss Yusnita Osman, and Mr. Lee Kim Yee for their assistance in analyzing the samples. I owe to Mr. Mohammad Alghoul, the PhD candidate in the department of Physics for providing the colour printing of the micrographs and some XRD spectra. Mr. Abdullah Al Mamun and Dr. Lutfur Rahman will be remembered with deep appreciation for helping me find this research project in UPM. The great help from Dr. Dedy Suhendra is highly acknowledged and will remain ever fresh in the memory.

I wish to express my deepest gratitude to my parents, brother, sisters and sister-in-law for their prayers, continuous moral support and unending encouragement. Finally, I wish to express my sincere gratitude to my beloved wife Kazi Jebunnesa Eti and my dearest and only son Shakir Mahmud for extending their moral support, encouragement, patience and understanding.



I certify that an Examination Committee met on 5th January, 2005 to conduct the final examination of H. N. M. Ekramul Mahmud on his Doctor of Philosophy thesis entitled "Preparation, Characterization and Electromagnetic Interference Shielding Effectiveness of PPY-PVA and PPY-CMC Conducting Polymer Composite Films" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Asmah Haji Yahaya, PhD

Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Abdul Halim Bin Abdullah, PhD

Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Mohd. Zaizi Bin Desa, PhD

Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Ramli Bin Hitam, PhD

Professor
Faculty of Science
Universiti Teknologi Malaysia
(External Examiner)



HASANAH M. GHAZALI, PhD
Professor / Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: **27 MAR 2006**



This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

Anuar Kassim, PhD

Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Zulkarnain Zainal, PhD

Professor
Faculty of Science
Universiti Putra Malaysia
(Member)

Wan Mahmood Mat Yunus, PhD

Professor
Faculty of Science
Universiti Putra Malaysia
(Member)



AINI IDERIS, PhD
Professor / Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: **13 APR 2006**



DECLARATION

I do hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.



H. N. M. EKRAMUL MAHMUDDate: *March 6, 2006.*

TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	vi
ACKNOWLEDGMENTS	xi
APPROVAL	xiii
DECLARATION	xv
LIST OF TABLES	xxi
LIST OF FIGURES	xxiv
 CHAPTER	
I INTRODUCTION	1
Conducting Polymers	1
History of conducting polymers	4
Background of the this research	7
Research Objectives	11
 II LITERATURE REVIEW	 13
Monomer	13
Counter ion or Dopant	14
Insulating polymer	16
Polypyrrole as a conducting polymer	17
Mechanisms of pyrrole electropolymerization	19
Polypyrrole-poly(vinyl alcohol) (PPy-PVA) and polypyrrole-carboxymethyl cellulose (PPy-CMC) composite films	26
Applications of Polypyrrole Conducting Polymers	30
Batteries	30
Polypyrrole microactuators	30
Condenser	31
Transparent loudspeakers	32
Electromagnetic interference (EMI) shielding material	32
 III MATERIALS AND METHODS	 34
Electrochemical preparation technique	34
Monomer, electrolyte and insulating polymer	34
Preparation of PPy-PVA and PPY-CMC composite films	36
Electrical Conductivity	37
Fourier transform infrared spectrometry (FT-IR)	39
X-ray diffraction (X-RD)	41



	Optical microscopy	42
	Dynamic Mechanical Analysis (DMA)	44
	Electromagnetic Interference Shielding Effectiveness	45
IV	RESULTS AND DISCUSSION	47
	Electrochemically Prepared Polypyrrole Composite Films	47
	Molecular Structure of PPy-PVA Composite Films	52
	Conductivity of PPy-PVA composite films	61
	Effect of PVA on the conductivity of PPy-PVA composite films	62
	Effect of pyrrole concentration on the conductivity of PPy-PVA films	65
	Effect of dopant concentration on the conductivity of PPy-PVA films	68
	Effect of applied voltage on the conductivity of PPy-PVA composite films	70
	Molecular Order in PPy-PVA Composite Films	72
	Effect of PVA concentration on the molecular order of PPy-PVA films	72
	Effect of pyrrole concentration on the molecular order of PPy-PVA films	79
	Effect of dopant concentration on the molecular order of PPy-PVA films	81
	Effect of applied voltage on the molecular order of PPy-PVA composite films	83
	Morphological Study of PPy-PVA Composite Films	86
	Effect of PVA concentration on the morphology of PPy-PVA composite films	86
	Comparison of morphology of PPy-PVA composite film and PPy film	91
	Effect of pyrrole concentration on the morphology of PPy-PVA films	92
	Effect of dopant concentration on the morphology of PPy-PVA films	96
	Effect of voltage on the morphology of PPy-PVA films	98
	Dynamic Mechanical Analysis (DMA) of PPy-PVA Composite Films	102
	Effect of PVA concentration on the storage modulus of PPy-PVA films	102
	Effect of PVA on the Damping Characteristic of PPy-PVA Composite Film	107
	Effect of monomer on the storage modulus of PPy-PVA composite films	110
	Effect of monomer on the damping characteristic of PPy-PVA film	112

Effect of dopant Concentration on the Storage Modulus of PPy-PVA Film	113
Effect of dopant concentration on the damping characteristic of PPy-PVA composite films	115
Effect of voltage on the storage modulus of PPy-PVA composite film	118
Effect of voltage on the damping characteristics ($\tan \delta$) of PPy-PVA films	120
Structure of PPy-CMC Composite Films	122
Conductivity of PPy-CMC Composite Films	125
Effect of CMC on the conductivity of PPy-CMC composite films	126
Effect of monomer concentration on the conductivity of PPy-CMC films	128
Effect of dopant concentration on the conductivity of PPy-CMC films	130
Effect of applied voltage on the conductivity of PPy-CMC composite films	131
Molecular Order in PPy-CMC Composite Films	133
Effect of CMC concentration on the molecular order of PPy-CMC films	133
Effect of pyrrole concentration on the molecular order of PPy-CMC films	137
Effect of dopant concentration on the molecular order of PPy-CMC films	139
Effect of applied potential on the molecular order of PPy-CMC films	141
Morphological Study of PPy-CMC Composite Films	144
Effect of CMC concentration on the morphology of PPy-CMC films	144
Comparison study of PPy-CMC composite film and PPy film	149
Effect of pyrrole concentration on the morphology of PPy-CMC composite films	152
Effect of dopant on the morphology of PPy-CMC composite films	154
Effect of applied voltage on the morphology of PPy-CMC composite films	159
Dynamic Mechanical Analysis (DMA) of PPy-CMC Composite Films	162
Effects of CMC Concentration on the Mechanical Properties of PPy-CMC Composite Film	162
Effects of CMC Concentration on the storage Modulus of PPy-CMC Composite Film	162
Effect of CMC on the Damping Characteristic of PPy-CMC Film	166



	Effect of Pyrrole Concentration on the Storage Modulus of PPy CMC Composite Films	170
	Effect of pyrrole concentration on the damping characteristic of PPy-CMC film	172
	Effect of dopant concentration on the storage modulus of PPy-CMC films	174
	Effect of Dopant Concentration on the Loss Modulus of PPy-CMC films	175
	Effect of Voltage on the Storage Modulus of PPy-CMC Composite Film	178
	Effect of Voltage on the Loss Factor ($\tan \delta$) of PPy-PVA Composite Films	179
V	POTENTIAL APPLICATION	180
	Electromagnetic Interference Shielding Effectiveness (SE) of PPy-PVA Films	180
	Effect of PVA concentration on the shielding effectiveness (SE) of PPy-PVA composite films	180
	Comparison study on shielding effectiveness between PPy film and PPy-PVA composite film	188
	Effect of pyrrole concentration on the shielding behavior of PPy-PVA films	190
	Effect of dopant concentration on the shielding behavior of Ppy-PVA films	195
	Effect of working voltage on the shielding behavior of Ppy-PVA composite films	200
	Shielding Effectiveness (SE) of Ppy-CMC Composite Films	203
	Effect of CMC concentration on the shielding effectiveness (SE) of Ppy-CMC composite films	203
	Comparison study on shielding effectiveness between PPy film and PPy-CMC composite film	210
	Effect of pyrrole concentration on the electromagnetic shielding effectiveness (SE) of Ppy-CMC composite films	212
	Effect of dopant concentration on the shielding behavior of Ppy-CMC films	218
	Effect of applied voltage on the shielding effectiveness (SE) of PPy-CMC composite films	224
VI	CONCLUSIONS	228
	Future Studies	232
	BIBLIOGRAPHY	234
	BIODATA OF THE AUTHOR	244



LIST OF TABLES

Table		Page
1.1	Conducting polymers: preparation methods and conductivities	6
2.1	Polypyrrole films with different anions	15
4.1	Physical observation of PPy-PVA composite films	48
4.2	Physical observation of PPy-CMC composite films	50
4.3	Assignments of FT-IR absorption bands of PPy-PVA composite Film, PPy film and only PVA	57
4.4	FT-IR band intensity ratio ($I_{C=C}/I_{C-N}$) of PPy-PVA films prepared from various PVA concentrations	64
4.5	FT-IR band intensity ratio ($I_{C=C}/I_{C-N}$) of PPy-PVA films prepared from various pyrrole concentration	67
4.6	FT-IR band intensity ratio ($I_{C=C}/I_{C-N}$) of PPy-PVA films prepared from various concentrations of <i>p</i> -toluene sulfonate	69
4.7	The effect of applied voltage on the conductivity of PPy-PVA film and the FT-IR band intensity ratio ($I_{C=C}/I_{C-N}$) of the films	71
4.8	X-ray diffraction data for PPy-PVA composite films prepared from various PVA concentrations	75
4.9	X-ray diffraction data for PPy-PVA composite films prepared from various PVA concentrations	79
4.10	X-ray diffraction data for PPy-PVA composite films prepared from various <i>p</i> -toluene sulfonate concentrations	81
4.11	X-ray diffraction data for PPy-PVA composite films prepared at various voltages	85
4.12	FT-IR band intensity ratio ($I_{C=C}/I_{C-N}$) of PPy-CMC composite films prepared from various concentrations of CMC	128
4.13	FT-IR band intensity ratio ($I_{C=C}/I_{C-N}$) of PPy-CMC composite films prepared from various concentrations of pyrrole	129

4.14	FT-IR band intensity ratio ($I_{C=C}/I_{C-N}$) of PPy-CMC composite films prepared from various concentrations of <i>p</i> -toluene sulfonate	131
4.15	FT-IR band intensity ratio ($I_{C=C}/I_{C-N}$) of PPy-CMC composite films prepared at various applied voltages	132
4.16	X-ray diffraction data for PPy-CMC composite films prepared from various CMC concentrations	136
4.17	X-ray diffraction data for PPy-CMC composite films prepared from various pyrrole concentrations	139
4.18	X-ray diffraction data for PPy-CMC composite films prepared from various <i>p</i> -toluene sulfonate concentrations	141
4.19	X-ray diffraction data for PPy-CMC composite films prepared from applying different voltages	143
5.1	The shielding effectiveness of PPy-PVA composite films prepared from using various concentrations of PVA	187
5.2	The shielding effectiveness of PPy-PVA composite films prepared from using various concentrations of pyrrole	195
5.3	The shielding effectiveness of PPy-PVA composite films prepared from using various concentrations of <i>p</i> -toluene sulfonate	199
5.4	The shielding effectiveness of PPy-PVA composite films prepared from applying various voltages	202
5.5	The shielding effectiveness of PPy-CMC composite films prepared from using various concentrations of CMC	209
5.6	The shielding effectiveness of PPy-CMC and PPY film	212
5.7	The shielding effectiveness of PPy-CMC composite films prepared from various concentrations of pyrrole	218
5.8	The shielding effectiveness of PPy-CMC composite films prepared from various concentrations of <i>p</i> -toluene sulfonate	223
5.9	The shielding effectiveness of PPY-CMC composite films prepared from applying various voltages	229



LIST OF FIGURES

Figure		Page
1.1	The conductivity of materials	3
2.1	Pyrrole is synthesized into polypyrrole	14
2.2	The reaction mechanism of polypyrrole film formation	23
3.1	The experimental set-up for the electrochemical preparation of PPy-PVA and PPy-CMC films	35
3.2	Circuit used for conductivity measurements	38
3.3	The current vs voltage graph for measuring the conductivity of the films	39
3.4	The X-rays beam striking the surface of crystal	41
4.1	The FT-IR spectrum of only PVA	53
4.2	The FT-IR spectrum of PPy film	54
4.3	The FT-IR spectrum of <i>p</i> -toluene sulfonate	54
4.4	The FT-IR spectrum of PPy-PVA composite film	55
4.5	FT-IR spectra of PPy-PVA composite film, PPy film, PVA and <i>p</i> -toluene sulfonate	56
4.6	Schematic representation of PPy-PVA composite film	60
4.7	Conductivity of PPy-PVA composite films versus PVA concentration used to prepare the PPy-PVA composite films	63
4.8	Conductivity of PPy-PVA composite films against pyrrole concentration	66
4.9	Conductivity of PPy-PVA composite films against different <i>p</i> -toluene sulfonate concentration	68
4.10	XRD diffractograms of PPy-PVA composite films prepared from various concentrations of PVA	74
4.11	The XRD diffractograms of PPy-PVA composite films prepared from (a) 3×10^{-4} M and (b) 12×10^{-4} M PVA	76



4.12	Schematic view on the crystalline part of polypyrrole or polyaniline in the overall amorphous structure	77
4.13	XRD diffractograms of (a) PVA (b) polypyrrole film (c) PPy-PVA composite film	78
4.14	XRD diffractograms of PPy-PVA composite films prepared from various concentrations of pyrrole	80
4.15	XRD diffractograms of PPy-PVA composite films prepared from various concentrations of <i>p</i> -toluene sulfonate	82
4.16	XRD diffractograms of PPy-PVA composite films prepared at various voltages	84
4.17	The optical micrographs of the solution side of PPy-PVA composite films produced from a) 3×10^{-4} M, b) 6×10^{-4} M, c) 9×10^{-4} M, d) 12×10^{-4} M, e) 15×10^{-4} M and f) 18×10^{-4} M PVA in the pyrrole solution	87
4.18	The optical micrographs of the electrode side of PPy-PVA composite films side of PPy-PVA composite films produced from using a) 3×10^{-4} M, b) 6×10^{-4} M, c) 9×10^{-4} M, d) 12×10^{-4} M, e) 15×10^{-4} M and f) 18×10^{-4} M PVA in the pyrrole solution	88
4.19	Optical micrographs of the solution side of (a) only PPy film and (b) PPy-PVA composite film	90
4.20	Optical micrographs of the electrode side of (a) PPy film without PVA and (b) PPy-PVA composite film	93
4.21	The optical micrographs of the solution side of PPy-PVA composite films produced from using (a) 0.1 M, (b) 0.2 M, (c) 0.3 M and (d) 0.4 M pyrrole	94
4.22	The optical micrographs of the electrode side of PPy-PVA composite films produced from using (a) 0.1 M, (b) 0.2 M, (c) 0.3 M and (d) 0.4 M pyrrole	95
4.23	The optical micrographs of the solution side of PPy-PVA composite films prepared from using (a) 0.05 M, (b) 0.2 M and (c) 0.3 M <i>p</i> -toluene sulfonate	97
4.24	The optical micrographs of the electrode side of PPy-PVA composite films prepared from using a) 0.05 M, b) 0.2 M and c) 0.3 M <i>p</i> -toluene sulfonate dopant	99

4.25	The optical micrographs of the solution side of PPy-PVA composite films prepared from using a) 0.8 volt (vs SCE) and b) 1.5 volt (vs SCE)	99
4.26	Optical micrographs of the electrode side of PPy-PVA composite films prepared from using a) 0.8 volt (vs SCE) and b) 1.5 volt (vs SCE)	101
4.27	The change of storage modulus (E') with the increase in temperature for PPy-PVA film produced from using 3×10^{-4} M PVA	103
4.28	The change of storage modulus (E') with the increase in temperature for PPy-PVA film produced from using 6×10^{-4} M PVA	106
4.29	The change of storage modulus (E') with the increase in temperature for PPy-PVA film produced from using 9×10^{-4} M PVA	108
4.30	The change of storage modulus (E') with the increase in temperature for PPy-PVA film produced from using 12×10^{-4} M PVA	110
4.31	The change of storage modulus (E') with the increase in temperature for PPy-PVA film produced from using 15×10^{-4} M PVA	111
4.32	The change of storage modulus (E') with the increase in temperature for PPy-PVA film produced from using 18×10^{-4} M PVA	113
4.33	The change in storage modulus (E') with the increase in temperature for PPy-PVA film produced from using A) 3×10^{-4} M, B) 6×10^{-4} M, C) 9×10^{-4} M, D) 12×10^{-4} M, E) 15×10^{-4} M and F) 18×10^{-4} M PVA	114
4.34	Storage moduli (E') of A) PPy film and B) PPy-PVA composite film against temperature	116
4.35	Temperature dependence of $\tan \delta$ for PPy-PVA film produced from using 3×10^{-4} M PVA	117
4.36	Temperature dependence of $\tan \delta$ for PPy-PVA film produced from using 6×10^{-4} M PVA	117
4.37	Temperature dependence of $\tan \delta$ for PPy-PVA film produced from using 9×10^{-4} M PVA	118