UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Preparation and Characterization of Polyaniline Graphene Nanoplatelets Conductive Nanocomposite for Wearable Textile Antenna

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DEDICATION

This is in memory of the sake of Allah, my Creator and messenger, Mohammed (May Allah bless and grant him), who taught us the purpose of life. I dedicate my dissertation work to my family and beloved people who have meant so much to me. A special feeling of gratitude goes to my loving parents, Keling @ Khalid Bin Che Man and Patimah Binti Seman whose words of encouragement and push for tenacity ring in my ears. Although my mother is no longer in this world, their memories continue to regulate my life. Thank you so much "Mak", I will never forget you. Thank you to my sisters Norayah and Kamariah who have never left my side and are very special. Also for my brothers Hamdan, Aziz, Hamran, Amir, Hadi, Zulhelmi and Firdaus. I am truly thankful for having you in my life. I am grateful to my friends. I will always appreciate all they have done especially for helping me develop my research skills and for being a constant source of support and encouragement during the challenges of graduate school and life. I love you all and miss you all beyond words. May Allah (SWT) grant you Jannah Firdaus. Amen.

ABSTRACT

Wearable textiles for antennas have growth significantly due to their widespread utilization in comprehensive monitoring, communication and storage systems. Traditional antennas are often bulky and susceptible to corrosion, but the integrating antenna into textiles offers a promising solution for wearable applications. This study explores the use of polyaniline (PANI) combined with graphene nanoplatelets (GNPs) at various loading (0.25 wt%, 0.50 wt%, 0.75 wt% and 1.00 wt%) to create a conductive polymer via oxidative polymerization, aimed at enhancing wireless communication function in electronics devices. Ammonium persulfate (APS) was used as an oxidizing agent in hydrochloric acid (HCl) and aniline monomers were polymerized into elongated PANI chains. Non covalent surface modification technique including π-π stacking, van der Waals forces and electrostatic interactions preserved the GNPs lattice and enhanced the electrical conductivity by charge carrier mobility, resulting in superior antenna characteristics. Screen printing techniques were employed to integrate these materials into wearable structures without compromising antenna performance. A rectangular microstrip patch antenna design, simulated with CST Microwave Studio was printed using a PANI/GNPs mixture mixed with ethylene glycol (EG) and polyvinyl pyrrolidones (PVP) for optimal ink adhesion. Morphological analysis (SEM, FESEM and TEM) showed well-distributed and connected nanoparticles facilitating continuous electron pathways. FTIR, RAMAN and XRD characterizations confirmed the presence of carboxylic acid (COOH) and amine (NH_2) groups, improved structural order and decreased crystallite size indicating enhanced charge carrier connectivity. The 0.75 wt% PANI/GNPs (treated)-DBSA sample exhibited the highest conductivity value at 22.34 S/cm. Simulation and experimental results demonstrated return loss (S_{11}) values of -23.38 dB and -20.78 dB respectively with antenna gain of 2.86 dB at 2.45 GHz and 7.01 at 2.60 GHz. The radiation pattern illustrated a dipole shape for both the E- field and H-field. The successful synthesis of PANI/GNPs with DBSA significantly enhanced electrical conductivity, leading to an optimal conductive ink formulation for microstrip patch antenna fabrication. Experimental validation confirmed improved antenna performance, which is particularly promising for flexible and lightweight WBAN application. In conclusion, PANI/GNPs-DBSA nanocomposites offer a compelling alternative to rigid, expensive materials like copper or FR4 in antenna-based telecommunication applications, paving the way for advanced wearable technology.

PENYEDIAAN DAN PENCIRIAN BAGI POLIANILIN KEPINGAN NANO GRAFIN NANOKOMPOSIT KONDUKTIF BAGI ANTENA TEKSTIL BOLEH PAKAI

ABSTRAK

Antena yang disepadukan pada tekstil boleh pakai telah menyaksikan perkembangan yang pesat disebabkan penggunaannya yang meluas dalam sistem pemantauan, komunikasi dan penyimpanan yang komprehensif. Antena tradisional selalunya besar dan terdedah kepada kakisan, tetapi antena yang disepadukan pada tekstil menawarkan penyelesaian yang berpotensi untuk kepelbagaian penggunaan. Kajian ini meneroka penggunaan polianilin (PANI) digabungkan dengan nano kepingan grafin (GNPs) dengan pelbagai pembebanan 0.25 wt%, 0.50 wt%, 0.75 wt% dan 1.00 wt% untuk mencipta polimer konduktif, melalui pempolimeran pengoksidaan untuk meningkatkan fungsi komunikasi tanpa wayar dalam peranti elektronik. Ammonium persulfate (APS) sebagai agen pengoksidaan dalam asid hidroklorik (HCl), dan monomer anilin bagi menghasilkan rantaian PANI yang tumbuh memanjang. Teknik pengubahsuaian permukaan melalui kaedah bukan kovalen termasuk susunan π-π, daya van der Waals dan interaksi elektrostatik mengekalkan kekisi GNP dan meningkatkan kekonduksian elektrik melalui mobiliti pembawa cas menghasilkan ciri antena yang unggul. Teknik percetakan skrin digunakan bagi menyepadukan bahan ini ke dalam struktur boleh pakai tanpa menjejaskan prestasi antena. Reka bentuk antena segi empat tepat bagi tampalan jalur mikro yang disimulasikan oleh CST Microwave Studio telah di cetak menggunakan campuran PANI/GNPs di campur dengan etilena glikol (EG) dan polivinil pirolidon (PVP) untuk perlekatan dakwat yang optimum. Analisis morfologi (SEM, FESEM dan TEM) menunjukkan nanozarahan yang teragih secara seragam dan saling berhubung yang memudahkan laluan berterusan bagi aliran elektron. Perincian FTIR, RAMAN dan XRD mengesahkan kehadiran kumpulan asid karboksilik (COOH) dan amina (NH2), susunan struktur yang lebih baik dan saiz kristal yang berkurangan menunjukkan sambungan pembawa cas yang dipertingkatkan. Sampel 0.75% PANI/GNPs (terawat)-DBSA mempamerkan nilai kekonduksian tertinggi pada 22.34 S/cm. Keputusan simulasi dan ujikaji menunjukkan nilai balikan pulang (S11) masing-masing adalah -23.38 dB dan -20.78 dB dengan janaan antena sebanyak 2.86 dB bagi 2.45 GHz dan 7.01 bagi 2.60 GHz. Corak radiasi menggambarkan reka bentuk dwi-kutub bagi kedua-dua medan E dan medan H. Kejayaan sintesis PANI/GNPs dengan DBSA telah meningkatkan kekonduksian elektrik dengan ketara, membawa kepada formulasi dakwat konduktif yang optimum untuk pembuatan antena tampalan jalur mikro. Ujikaji yang dijalankan telah mengesahkan prestasi antena yang lebih baik, dan amat berpotensi untuk aplikasi WBAN yang fleksibel dan ringan. Kesimpulannya, PANI/GNPs-DBSA menawarkan alternatif yang menarik kepada bahan tegar dan mahal seperti tembaga atau FR4 dalam aplikasi telekomunikasi berasaskan antena, membuka jalan untuk teknologi boleh-pakai termaju.

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LIST OF SYMBOLS AND ABBREVIATIONS

°C	-	Temperature (celcius)
2D	-	Two dimensional
Ag	-	Silver
C	-	Carbon
CPW	-	Coplanar waveguide
CST	-	Computering Simulation Technology
dB	-	Decibel
DBSA	-	Dedocylbenzene sufonic acid
EDX	-	Energy dispersive X-ray analysis
EG	-	Ethylene glycol
FTIR	-	Fourier Transform Infrared
GHz	-	Gigahertz for frequency
GNPs	-	Graphene nanoplatelets
kx	-	Magnification
N	-	Nitrogen
nm	-	nanometer
O	-	Oxygen
PANI	-	Polyaniline
PEI	-	polyethylenimine
PVP	-	Polyvinyl Pyrrolidones
RF	-	Radio Frequency
S/cm	-	Unit for Electrical conductivity (siemens per centimeter)
S_{11}	-	Reflection coefficient
SMA	-	SubMiniature version A connector
Sp^2	-	Lattice Structure
VSWR	-	Voltage Standing Wave Ratio
WBAN	-	Wireless Body Area Networks
WLAN	-	Wireless local-area network