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ELECTRICAL TRANSPORT AND RELATED DIELECTRIC PHENOMENA IN COCONUT-SHELL ACTIVATED CARBON

W. MOHAMAD DAUD BIN W. YUSOFF

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By

W. MOHAMAD DAUD BIN W. YUSOFF

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF SYMBOLS AND ABBREVIATIONS

ϵ	dielectric permittivity (F/m)
ϵ_o	permittivity of free space
ϵ_s	static dielectric permittivity
ϵ_∞	dielectric permittivity at very high frequency
$\epsilon(\omega)$	dielectric permittivity as a function of angular frequency
κ'	relative dielectric permittivity
κ''	loss factor
κ^*	complex dielectric permittivity
μ	micron
ρ	resistivity (ohm/cm)
σ	conductivity (mho/cm)
$\sigma(\omega)$	conductivity as a function of angular frequency
τ	relaxation time (sec)
ω	angular frequency (Hz)
ω_p	peak angular frequency
$\propto$	propotional to
Å	Angstrom unit
eV	electron volt
exp	exponential
f	frequency (Hz)

j	$= \sqrt{-1}$
k	Boltzmann constant
kHz	kilohertz
ln	natural logarithm
log	logarithm
mHz	millihertz

AC	alternating current
B	susceptance (mho)
C	capacitance (F)
C'	real part of capacitance
C''	imaginary part of capaci
C^*	complex capacitance
°C	degree Celsius
CFO	Cohen-Fritzsche-Ovshinky
CHN	carbon, hydrogen and nitrogen
DC	direct current
DVM	digital voltmeter
E	activation energy (eV)
E_c	energy at conduction band
E_F	Fermi energy
E_v	energy at valence band
FTIR	Fourier transform infrared
G	conductance (mho)
H	magnetic field (Tesla)
Hz	Hertz

I	current (ampere)
Im	immaginary part
J	current density
K	Kelvin
MHz	megahertz
NAA	neutron activation analysis
OSC	oscillator
R	resistance (ohm)
Re	real part
SEM	scanning electron micrograph
T	absolute temperature (Kelvin)
TGA	thermogravimetric analysis
UPM	University Pertanian Malaysia
UTN	Unit Tenaga Nuklear
V	voltage (volt)
X	reactance (ohm)
XRD	x-ray diffraction
Y	admittance (mho)
Y'	real part of admittance
Y''	imaginary part of admittance
Y^*	complex admittance
Z	impedance (ohm)
Z'	real part of impedance
Z''	imaginary part of impedance
Z^*	complex impedance

Subscripts

eff	effective
long	longitudinal
MW	Maxwell-Wagner
max	maximum
p	parallel
s	series
tr	transverse

Abstract of thesis submitted to the Senate of Universiti Pertanian Malaysia in fulfilment of the requirements for the degree of Doctor of Philosophy.

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Supervisors : Professor Dr. Hj. Badri bin Muhammad.
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Faculty : Faculty of Science and Environmental Studies, Universiti Pertanian Malaysia.

The electrical properties of coconut-shell activated carbon have not been thoroughly investigated and are, therefore, not well understood. In order to study these properties meaningfully, a fairly satisfactory knowledge of the structure, microstructure and composition of the material is needed.

Since the material's constitution has been little studied and dealt with in the relevant published literature, investigation of the structure and composition of the material has to be done in a comprehensive manner. The experimental investigation is divided into two categories. Firstly, the basic experimental work, which is considered important in order to provide supportive evidence to any proposed model of charge-carrier conduction and dielectric behaviour, consists of

work on x-ray diffractometry, neutron activation analysis, Fourier transform infra-red spectroscopy, scanning electron microscopy, thermoelectric power and magnetoresistance. Secondly, the main experiments consist of work on direct current conductivity and alternating current conductivity measurement.

The results of the basic experiments indicate that activated carbon prepared from coconut shells is essentially amorphous, containing many functional groups, potassium, sodium and several other trace elements. It has a highly porous microstructure. The thermopower-temperature plot obtained suggests that holes are the majority carriers below 385K while at higher temperatures electrons are the majority carriers.

The experimental results of the variation of the direct current conductivity with temperature and the dependence of the alternating current conductivity upon frequency at various fixed temperatures reveal three distinguishable regions. First, a variable-range hopping conduction mechanism operates among localised states near the Fermi level at temperatures below 200K; second, a hopping conduction mechanism occurs among localised states in the band tail for temperatures between about 200 and 385K and third, a percolation conduction mechanism is dominant at and above the mobility edge for temperatures above 385K. The graph of alternating-current conductivity versus

temperature shows that the conductivity is strongly influenced by a certain polarisation process. The results of dielectric-response measurements and the results of the equivalent-circuit analysis show that interfacial polarisation is the most probable process responsible for the observed dielectric behaviour.

Abstrak tesis yang dikemukakan kepada Senat Universiti Pertanian Malaysia bagi memenuhi syarat untuk ijazah Doktor Falsafah.

PENGANGKUTAN ELEKTRIK DAN FENOMENA DIELEKTRIK BERKAITAN DALAM KARBON AKTIF TEMPURUNG-KELAPA

Oleh

W. MOHAMAD DAUD BIN W. YUSOFF

Ogos 1991

Penyelia : Professor Dr. Hj. Badri bin Muhammad.
: Dr. Mansor bin Hashim.

Fakulti : Fakulti Sains dan Pengajian Alam Sekitar, Universiti Pertanian Malaysia.

Sifat elektrik bagi karbon aktif dari tempurung kelapa didapati tidak diselidiki secara menyeluruh, oleh yang demikian sifat tersebut tidak diketahui dengan sepenuhnya. Untuk menyelidiki sifat elektrik ini secara bermakna, sedikit sebanyak pengetahuan tentang struktur, mikrostruktur dan kandungan bahan adalah diperlukan.

Oleh kerana sifat bahan hanya sedikit sahaja diketahui dan hanya boleh diperolehi dari penerbitan ilmiah yang bersesuaian, maka penyelidikan dari segi struktur dan kandongan bahan perlu dilakukan secara menyeluruh. Penyelidikan eksperimen ini terbahagi kepada dua kategori. Pertama, eksperimen asas, yang dianggap mustahak bagi menyokong sebarang cadangan model untuk kekonduksian pembawa-cas dan sifat dielektrik; iaitu pembelauan sinar-x, analisis pengaktifan neutron, spektroskopi jelmaan

Fourier infra-merah, mikroskop elektron imbasan, kuasa termoelektrik dan magnetorintangan. Kedua, eksperimen utama yang terdiri dari pengukuran kekonduksian arus terus dan kekonduksian arus ulang alik.

Hasil eksperimen asas menunjukkan karbon aktif yang disediakan dari tempurung kelapa adalah bersifat amorfus, mengandungi banyak kumpulan berfungsi, kalium, naterium dan beberapa jumlah kecil unsur-unsur lain. Ianya juga mempunyai mikrostruktur dengan keliangan yang tinggi. Dari plot termokuasa melawan suhu didapati lohong adalah pembawa cas utama pada suhu di bawah 385K sementara pada suhu tinggi elektron adalah pembawa utama.

Hasil eksperimen perubahan kekonduksian arus terus terhadap suhu dan pergantungan kekonduksian arus ulang alik terhadap frekuensi pada beberapa suhu tertentu menunjukkan mekanisma kekonduksian dalam karbon aktif tempurung-kelapa terbahagi kepada tiga bahagian. Pertama, mekanisma kekonduksian loncatan julat-berubah berlaku di antara keadaan-keadaan tempatan yang berhampiran dengan paras Fermi pada suhu di bawah 200K; kedua, mekanisma kekonduksian loncatan berlaku di antara keadaan-keadaan tempatan dalam daerah jalur ekor untuk suhu sekitar 200 hingga 385K dan ketiga, mekanisma kekonduksian perkolasi yang menonjol pada dan bahagian atas sisi kelincahan untuk suhu melebihi 385K.

Graf kekonduksian arus ulang alik terhadap suhu menunjukkan kekonduksian sangat dipengaruhi oleh proses pengutupan tertentu. Hasil pengukuran sambutan-dielektrik dan hasil analisis litar-setara menunjukkan pengutupan antaramukaan adalah berkemungkinan besar bertanggungjawab bagi tabiat dielektrik yang diamati.

CHAPTER I

THE BASIS AND OBJECTIVES OF THIS RESEARCH

Activated carbons which are porous carbonaceous materials have been the subject of numerous laboratory investigations, particularly adsorption studies. A literature survey on the properties of activated carbon shows that the investigations were largely concerned with the materials' chemical behaviour. Only a few papers have been published on the studies on their physical properties. The latter type of study is mainly focused on the microscopic nature of electrical conduction. In addition, most of the works on the electrical properties of carbonaceous materials have been carried out on graphite, coke, carbon black and amorphous carbon thin films. Activated carbon (charcoal) prepared from biological materials such as wood, coconut shells, bamboo etc. have been the subject of still fewer electrical investigations. In this work, a material of this type will be the object for an experimental analysis.

At the outset, however, it must be stated that the research work will commence with a material whose structural details are far from clear, except for a generally accepted picture of disordered turbostratic structure (Mattson and Mark Jr., 1971).