

**I dedicate this thesis to my beloved
Maa & Papa**

Declaration

I hereby declare that the thesis entitled “**Development of Two-Dimensional Material and Transition Metal Oxide based nanocomposites for Direct Methanol Fuel Cell Anode Catalyst and Supercapacitor Electrode**”, being submitted to the School of Sciences, Tezpur University in partial fulfillment of the requirements for the award of the Doctor of Philosophy in Physics, is a record of original research work carried out by me. Any text, figures, theories, results or designs that are not of my own devising are appropriately referenced in order to give due credit to the original author(s). All the sources of assistance have been assigned due acknowledgement. I also declare that neither this work as a whole nor a part of it has been submitted to any other university or institute for any degree, diploma, associateship, fellowship or any other similar title or recognition.

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All help received by her from various sources have been duly acknowledged.

No part of the thesis has been submitted elsewhere for award of any other degree.

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This is to certify that the thesis entitled "*Development of Two-Dimensional Material and Transition Metal Oxide based nanocomposites for Direct Methanol Fuel Cell Anode Catalyst and Supercapacitor Electrode*" submitted by Ms. Kashmiri Baruah to Tezpur University in the Department of Physics under the School of Sciences in partial fulfilment for the award of the degree of Doctor of Philosophy in Physics, has been examined by us and found to be satisfactory.

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List of Abbreviations

Abbreviations	Meaning
FC	Fuel Cell
DAFC	Direct Alcohol Fuel Cell
HOR	Hydrogen Oxidation Reaction
ORR	Oxygen Reduction Reaction
AFC	Alkaline Fuel Cell
PEMFC	Proton exchange membrane fuel cell
SPFC	Solid Polymer Fuel Cell
SPEFC	Solid Polymer electrolyte Fuel Cell
PEFC	Polymer Electrolyte Fuel Cell
PEMFC	Polymer Electrolyte Membrane Fuel Cell
PAFC	Phosphoric Acid Fuel Cell
MCFC	Molten Carbon Fuel Cell
SOFC	Solid Oxide Fuel Cell
DMFC	Direct Methanol Fuel Cell
DEFC	Direct Ethanol Fuel Cell
AAEMFC	Alkaline Anion Exchange Membrane Fuel Cell
AEM	Anion-exchange Membrane
ADMFC	Alkaline Direct Methanol Fuel Cell
MOR	Methanol oxidation reaction
MEA	Membrane Electrode Assembly
GDL	Gas Diffusion Layers
PSSA	Polystyrene Sulfonic Acid Membrane
PFSA	Perfluorosulfonic Acid
PGMs	Pt-group metals
CL	Catalyst Layer
MPL	Microporous Layer
PTFE	Polytetrafluoroethylene
TPB	Triple Phase Boundary

EDLC	Electric double layer capacitors
TMO	Transition Metal Oxide
FESEM	Field Emission Scanning Electron Microscopy
TEM	Transmission Electron Microscopy
XRD	X-ray Diffraction
FTIR	Fourier-Transform Infrared Spectroscopy
XPS	X-ray Photoelectron Spectroscopy
BET	Brunauer-Emmett-Teller
BJH	Barret-Joyner-Halenda
EDX	Energy Dispersive X-ray
CV	Cyclic Voltammetry
CA	Chronoamperometry
EIS	Electrochemical impedance spectroscopy
GCD	Galvanostatic charge-discharge
NRP	Nanorod Pellet
DMSO	Dimethyl Sulfoxide
GCE	Glassy Carbon Electrode
MX	MXene
NW	Nanoworm
PDDA	Poly-(diallyldimethyl-ammonium chloride)
RHE	Reversible Hydrogen Electrode
CNT	Carbon Nanotube
NP	Nanoparticle
PANI	Polyaniline
SAED	Selected Area Electron Diffraction
SWCNT	Single Walled Carbon Nanotube
PVA	Polyvinyl alcohol
CPE	Constant phase element
CO ₂	Carbon dioxide
H ₂	Hydrogen
O ₂	Oxygen
N ₂	Nitrogen
CO	Carbon monoxide

CH ₃ OH	Methanol
H ₂ O	Water
H ⁺	Hydrogen ion
OH ⁻	Hydroxyl ion
MnCo ₂ O ₄	Manganese Cobaltide
CoCo ₂ O ₄	Cobalt Oxide
NiCo ₂ O ₄	Nickel Cobaltite
NiO	Nickel oxide
rGO	Reduced Graphene Oxide
C	Carbon
O	Oxygen
HF	Hydrofluoric Acid
LiF	Lithium Fluoride
HCl	Hydrochloric Acid
NH ₄ HF ₂	Ammonium Bifluoride
F ⁻	Fluoride ion
O ²⁻	Oxide ion
CoO	Cobalt (II) Oxide
Co ₂ O ₃	Cobalt (III) Oxide
CoO ₂	Cobalt (IV) Oxide
Co ₃ O ₄	Cobalt (II, III) Oxide
Ti ₃ AlCl ₂	Titanium Aluminium Chloride
Co(NO ₃) ₂ ·6H ₂ O	Cobalt (II) Nitrate Hexahydrate
NaOH	Sodium Hydroxide
Ag	Silver
AgCl	Silver Chloride
Ti	Titanium
C	Carbon
O	Oxygen
Co	Cobalt
Al	Aluminium
N	Nitrogen
F	Fluorine

Pt	Platinum
Pd	Palladium
CoOOH	Cobalt oxyhydroxide
NiOOH	Nickel oxyhydroxide
KOH	Potassium Hydroxide
Co(OH) ₂	Cobalt (II) hydroxide
Co(NO ₃) ₂ ·6H ₂ O	Cobaltous Nitrate Hexahydrate
GO	Graphene Oxide
Ni	Nickel
MoS ₂	Molybdenum disulfide
AlF ₃	Aluminium Fluoride
(NH ₄) ₃ AlF ₆	Ammonium hexafluoroaluminate
RuO ₂	Ruthenium (IV) Oxide
ZnO	Zinc Oxide
MnO ₂	Manganese dioxide

List of Symbols

Symbols	Meaning
E_p	Peak potential
E_{pa}	Anodic peak potential
E_{pc}	Cathodic peak potential
ΔE_p	Peak to peak separation
I_p	Peak current
I_{pa}	Anodic peak current
I_{pc}	Cathodic peak current
v	Scan rate
E_o	Formal potential
I_o	Exchange current density
F	Faraday constant
Γ^*	Surface coverage
Z'	Real impedance
Z''	Imaginary impedance
A	Geometric surface area
R	Gas constant
T	Absolute temperature
α	Electron transfer coefficient
k_s	Heterogeneous rate constant
Ω	Ohm
h	hour
A/g	Ampere per gram
C_{sp}	Specific Capacitance
F/g	Farad per gram
E	Energy density
P	Power density
Wh	Watt-hour
Wh/kg	Watt-hour per kilogram

I	Discharge current
ΔV	Potential window
Δt	Discharge time
R_s	Series resistance
R_{ct}	Charge transfer resistance
C_p	Faradaic capacitance
W	Warburg impedance
S	Siemens