VERTICALLY ALIGNED HIERARCHICAL NANO-ARCHITECTURES FOR HIGHLY EFFICIENT AND STABLE SOLUTION PROCESSABLE SOLAR CELLS

IRFAN AHMED

DOCTOR OF PHILOSOPHY

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy in Advanced Material.

_____

(Supervisor's Signature)

Full Name : JOSE RAJAN

Position : PROFESSOR

Date : 28 April, 2017

_____

(Co-supervisor's Signature)

Full Name : MOHD HASBI BIN AB. RAHIM

Position : ASSOCIATE PROFESSOR

Date : 28 April, 2017

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citation which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

_____

(Student's Signature)

Full Name : IRFAN AHMED

ID Number : PSM 12002

Date : 28 April, 2017

VERTICALLY ALIGNED HIERARCHICAL NANO-ARCHITECTURES FOR HIGHLY EFFICIENT AND STABLE SOLUTION PROCESSABLE SOLAR CELLS

IRFAN AHMED

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy

Faculty of Industrial Sciences and Technology
UNIVERSITI MALAYSIA PAHANG

APRIL 2017

For those who urge to know and explore the nature for the benefit of humanity.

ACKNOWLEDGEMENT

At the outset, I acknowledge Almighty Allah (SWT) for the strength granted to complete my PhD journey.

I would like to express my sincere gratitude to my supervisor Prof. Dr. Jose Rajan and Co-supervisor Assoc. Prof. Dr. Mohd Hasbi bin Ab Rahim for their continuous support during my PhD, valuable guidance, philanthropic attitude and encouragement throughout my research work. I could not have reached this stage without their support.

Thanks to Dr. Thomas brown from Centre of Hybrid and Organic Solar Energy (CHOSE), University of Rome Tor Vergata Italy, for his contribution in nanostructured solar cells and modules fabrication and testing.

I would like to thanks to the Institute of Postgraduate Studies (IPS), Universiti Malaysia Pahang for awarding me a doctoral scholarship, faculty members of FIST for their support and the technical team of the faculty for their cooperation in my lab work. To My research group members especially Azhar Fakhruddin for being so helpful and supportive to me.

My deepest gratitude to my beloved brothers (late) and my parents who have always been my mentor and supporter, my siblings for the continuous prayers, sacrifice love and support, and to my dearest wife who has been so patient throughout my study. This would have not been possible without her love and patience through these difficult years.

Irfan Ahmed

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

C	Speed Light In Vacuum
cm	Centimetre
C_{μ}	Chemical Capacitance
D	Lattice Spacing
E_g	Band Gap
F	Frequency
H	Plank's Constant
I_{max}	Maximum Current
K	Kilo
L Or D	Photoelectrode Thickness
L_n	Diffusion Length
ms	Millisecond
mV	Millivolt
P_{max}	Maximum Power
P_{th}	Theoretical Power
R_{CT}	Recombination Resistance
R_S	Series Resistance
R_{SH}	Shunt Resistance
R_T	Charge Transport Resistance
V_{max}	Maximum Voltage
W	Watt
A	Absorption
T_d	Electron Transit Time
T_n	Electron Lifetime

ε	Molar Extinction Coefficient
η	Photoconversion Efficiency
η_{Cc}	Electron Collection Efficiency
η_{Inj}	Electron Injection Efficiency
λ	Wavelength
μ	Micrometer
μ_e	Electron Mobility

LIST OF ABBREVIATIONS

1D	One Dimensional
AM	Air Mass
APCE	Absorbed Photon to Current Efficiency
CB	Conduction Band
CE	Counter Electrode
DSCs	Dye-Sensitized Solar Cells
EIS	Electrochemical Impedance Spectroscopy
EQE	External Quantum Efficiency
FESEM	Field Emission Scanning Electron Microscopy
FF	Fill Factor
FTO	Fluorine Doped Tin Oxide
FWHM	Full Width at Half Maxima
HOMO	Homo Highest Occupied Molecular Orbitals
IPCE	Incident Photon to Current Efficiency
I-V	Current-Voltage
J_{sc}	Short Circuit Current Density
LHE	Light Harvesting Efficiency
LUMO	Lowest Unoccupied Molecular Orbitals
MOS	Metal Oxide Semi-Conductor
NHE	Normal Hydrogen Electrode
NPs	Nanoparticles
NRNP	Nanorod nanoparticle
NRs	Nanorods
NRTLNPs	Nanorod thin layer nanoparticles

NSCs	Nanostructures Solar Cells
NTs	Nanotubes
NWs	Nanowires
OCVD	Open Circuit Voltage Decay
PSCs	Perovskite Solar Cells
PV	Photovoltaic
SAED	Selection Area Electron Diffraction
TEM	Transmission Electron Microscopy
TNRs	TiO_2Nanorods
UV-VIS-NIR	Ultraviolet Visible near Infrared
VB	Valence Band
V_{oc}	Open Circuit Voltage
WE	Working Electrode
XRD	X-Ray Diffraction