

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

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DOCTOR OF PHILOSOPHY

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## **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.

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## **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.

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HIGHLY EFFICIENT AND STABLE SOLUTION  
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IRFAN AHMED

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

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## LIST OF SYMBOLS

|                 |                             |
|-----------------|-----------------------------|
| $C$             | Speed Light In Vacuum       |
| cm              | Centimetre                  |
| $C_{\mu}$       | 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               |
| $P_{\text{th}}$ | Theoretical Power           |
| $R_{\text{CT}}$ | Recombination Resistance    |
| $R_S$           | Series Resistance           |
| $R_{\text{SH}}$ | Shunt Resistance            |
| $R_T$           | Charge Transport Resistance |
| $V_{\max}$      | Maximum Voltage             |
| W               | Watt                        |
| A               | Absorption                  |
| $T_d$           | Electron Transit Time       |
| $T_n$           | Electron Lifetime           |

|                     |                                |
|---------------------|--------------------------------|
| $\varepsilon$       | Molar Extinction Coefficient   |
| $\eta$              | Photoconversion Efficiency     |
| $\eta_{\text{Cc}}$  | Electron Collection Efficiency |
| $\eta_{\text{Inj}}$ | Electron Injection Efficiency  |
| $\lambda$           | Wavelength                     |
| $\mu$               | Micrometer                     |
| $\mu_e$             | 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 <sub>2</sub> Nanorods           |
| UV-VIS-NIR      | Ultraviolet Visible near Infrared   |
| VB              | Valence Band                        |
| V <sub>oc</sub> | Open Circuit Voltage                |
| WE              | Working Electrode                   |
| XRD             | X-Ray Diffraction                   |