HIGH HUMIDITY FABRICATION OF rGO INCORPORATED PEROVSKITE ABSORBER AND MoS_2 ELECTRODE FOR PROSPECTIVE INVERTED PSC

NUR EZYANIE BINTI SAFIE

DOCTOR OF PHILOSOPHY

2023

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

HIGH HUMIDITY FABRICATION OF rGO INCORPORATED PEROVSKITE ABSORBER AND MoS_2 ELECTRODE FOR PROSPECTIVE INVERTED PSC

Nur Ezyanie binti Safie

Doctor of Philosophy

2023

HIGH HUMIDITY FABRICATION OF rGO INCORPORATED PEROVSKITE ABSORBER AND MoS_2 ELECTRODE FOR PROSPECTIVE INVERTED PSC

NUR EZYANIE BINTI SAFIE

A thesis submitted
in fulfillment of the requirements for the degree of
Doctor of Philosophy

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2023

DECLARATION

I declare that this thesis entitled “High Humidity Fabrication of rGO Incorporated Perovskite Absorber and MoS_2 Electrode for Prospective Inverted PSC” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : 

Name : Nur Ezyanie Safie

Date : 28 September 2023

APPROVAL

I hereby declare that I have read this thesis and in my opinion, this thesis is sufficient in terms of scope and quality for the award of the Doctor of Philosophy.

Signature : 

Supervisor Name : Prof. Ir. Dr. Mohd Asyadi Azam Mohd Abid

Date : 28 September 2023

DEDICATION

This thesis is dedicated to my parents for their boundless patience in seeing me fulfil my dreams to complete the highest education degree. Finally, I thank myself for not giving up on this beautiful roller coaster route.

ABSTRACT

Methylammonium lead triiodide ($MAPbI_3$) is a perovskite material that is widely used in perovskite solar cells due to its potential for high power conversion efficiency. However, it is sensitive to humid environments, heat, oxygen and UV radiation, which can cause it to degrade and negatively affect crystal growth and the morphology of the material. This can ultimately affect the efficiency of the solar cell. Therefore, $MAPbI_3$ is typically produced at a low humidity, which requires expensive equipment. The aim of this research study is to propose a facile fabrication process for fully solution-processable inverted perovskite solar cells employing reduced graphene oxide (rGO)-based material under high humidity conditions suitable for the weather in Malaysia. Overall, the research design was divided into three phases. The aim of phase 1 is to study the influence of incorporating sulfonated rGO (srGO) into the $MAPbI_3$ absorber layer for the deposition of a high-quality thin film under open-air conditions with high relative humidity. Three different samples were prepared with different weight percentage (wt%) of srGO: 0% (T), 50% (TS B) and 15% (TS D). The morphology of the srGO-$MAPbI_3$ films was improved by the addition of srGO, resulting in fewer defects and larger perovskite grain sizes approaching micron size. In phase 2, the study aimed to determine the optimal process parameter of molybdenum disulfide (MoS_2) composite with rGO as a viable solution-processed top electrode for an effective electron-collecting electrode by taking advantage of Taguchi analysis. The results of the Taguchi analysis showed that a ratio of rGO:MoS_2 (1:1), a heating temperature of 75°C, and a heating period of 15 minutes were the optimal parameters for the electrode manufacturing process. The discovered optimal parameters were deployed to fabricate rGO:MoS_2 composite electrode that showed a promising electrical conductivity of 9.36 Ω/sq. In phase 3, the device performance of the inverted perovskite solar cells with the designated configuration of ITO/CuSCN/srGO-$MAPbI_3$/PCBM/BCP/rGO-MoS_2 was analyzed by numerical simulation with SCAPS-1D. The results proved that the device performance for the samples was affected by the addition of srGO to the absorber layer. The 15% srGO sample exhibited the highest PCE of 10.37% with Ag as the top electrode. However, when the conventional electrode was replaced with a rGO-MoS_2 composite electrode, the PCE of the same sample was improved to 13.23%, with a significant increase in FF. In summary, the findings of this research study indicate that incorporation of srGO into the $MAPbI_3$ absorber layer can improve the morphology of the srGO-$MAPbI_3$ films, resulting in fewer defects and larger perovskite grain sizes. The study also provides insight into the use of rGO-MoS_2 composite material as a workable solution-processed top electrode for an effective electron-collecting electrode, particularly in inverted configuration of perovskite solar cells. The numerical simulation results showed that the device performance of the samples could be improved by replacing Ag with rGO-MoS_2. The findings of this study could have significant implications for the growth of cost-effective, solution-processed perovskite solar cells under high relative humidity.

FABRIKASI KELEMBAPAN TINGGI PENYERAP PEROVSKIT DAN ELEKTROD MoS_2 DIPERBADANKAN rGO UNTUK PROSPEKTIF PSC TERBALIK

ABSTRAK

Metilamonium plumbum triiodida ($MAPbI_3$) adalah bahan perovskit yang banyak digunakan dalam sel suria perovskit kerana berpotensi untuk kecekapan penukaran kuasa tinggi. Walau bagaimanapun, $MAPbI_3$ sensitif terhadap persekitaran lembap, panas, oksigen dan sinaran UV, yang boleh menyebabkannya merosot dan memberi kesan negatif terhadap pertumbuhan kristal dan morfologi bahan. Keadaan ini boleh mempengaruhi kecekapan sel suria. Oleh itu, $MAPbI_3$ biasanya dihasilkan pada kelembapan rendah, yang memerlukan peralatan yang mahal. Tujuan kajian penyelidikan ini adalah untuk mencadangkan proses fabrikasi yang mudah untuk sel suria perovskit terbalik yang dapat diproses sepenuhnya menggunakan bahan berasaskan grafen oksida yang dikurangkan (rGO) dalam keadaan kelembapan tinggi yang sesuai untuk cuaca di Malaysia. Secara keseluruhan, reka bentuk penyelidikan dibahagikan kepada tiga fasa. Tujuan fasa 1 adalah untuk mengkaji pengaruh penggabungan rGO sulfonat (srGO) ke dalam lapisan penyerap $MAPbI_3$ untuk pemendapan filem nipis berkualiti tinggi dalam keadaan terbuka dengan kelembapan relatif yang tinggi. Tiga sampel berbeza disediakan dengan peratusan berat yang berbeza (wt%) srGO: 0% (T), 50% (TS B) dan 15% (TS D). Morfologi filem srGO-$MAPbI_3$ diperbaiki dengan penambahan srGO, menghasilkan ukuran butiran perovskit yang lebih besar mendekati ukuran mikron. Pada fasa 2, kajian ini bertujuan untuk menentukan parameter proses optimum bagi menghasilkan gabungan komposit antara molibdenum disulfida (MoS_2) dengan rGO sebagai elektrod teratas yang diproses untuk pengumpulan elektron yang berkesan dengan memanfaatkan kaedah analisis Taguchi. Hasil analisis Taguchi menunjukkan bahawa nisbah rGO:MoS_2 (1:1), suhu pemanasan 75°C, dan tempoh pemanasan 15 minit adalah parameter optimum untuk proses pembuatan elektrod ini. Parameter optimum yang ditemui digunakan untuk membuat elektrod komposit rGO: MoS_2 yang menunjukkan kekonduksian elektrik yang baik iaitu 9.36 Ω/meter persegi. Pada fasa 3, prestasi peranti sel suria perovskite terbalik dengan konfigurasi yang ditentukan iaitu ITO/CuSCN/srGO-$MAPbI_3$/PCBM/BCP/rGO-MoS_2 dianalisis dengan simulasi SCAPS-1D. Hasilnya membuktikan bahawa prestasi peranti untuk sampel kajian dipengaruhi oleh penambahan srGO ke lapisan penyerap $MAPbI_3$. Sampel srGO 15% menunjukkan nilai PCE tertinggi iaitu 10.37% dengan Ag sebagai elektrod teratas. Walau bagaimanapun, apabila elektrod konvensional itu digantikan dengan elektrod komposit rGO-MoS_2, PCE sampel yang sama ditingkatkan menjadi 13.23%, dengan peningkatan FF yang ketara. Ringkasnya, penemuan kajian penyelidikan ini menunjukkan bahawa penggabungan srGO ke dalam lapisan penyerap $MAPbI_3$ dapat meningkatkan morfologi filem srGO-$MAPbI_3$, mengakibatkan ukuran butiran perovskit menjadi lebih besar. Kajian ini juga memberikan gambaran mengenai penggunaan bahan komposit rGO-MoS_2 sebagai elektrod atas yang dapat dilaksanakan untuk menjadi elektrod pengumpul elektron yang berkesan, terutama dalam konfigurasi terbalik sel suria perovskit. Hasil simulasi berangka menunjukkan bahawa prestasi peranti sampel dapat ditingkatkan dengan menggantikan Ag dengan rGO-MoS_2. Penemuan kajian ini boleh memberi implikasi yang signifikan terhadap pertumbuhan sel suria perovskit yang diproses dengan kos efektif di bawah kelembapan relatif yang tinggi.

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

First and foremost, I thank and praise Allah the Almighty, my Creator, my Sustainer, for everything I have received since the beginning of my life. I want to extend my appreciation to the Universiti Teknikal Malaysia Melaka (UTeM) for providing the research platform, facilities support and UTeM Zamalah Scheme for financial assistance.

My utmost appreciation goes to my main supervisor, Prof. Ir. Dr. Mohd Asyadi 'Azam Mohd Abid, Fakulti Kejuruteraan Pembuatan, Universiti Teknikal Malaysia Melaka (UTeM), for all his support, advice, and inspiration. His constant patience in guiding and providing priceless insights will forever be remembered. Also, to my co-supervisor, Prof. Ts. Dr. Joseph Sahaya Anand Thangaraj, Fakulti Teknologi Kejuruteraan Mekanikal dan Pembuatan, Universiti Teknikal Malaysia Melaka (UTeM), who constantly supported my journey. My deep appreciation also goes to Assoc. Prof. Dr. Norasikin Ahmad Ludin, Solar Energy Research Institute, Universiti Kebangsaan Malaysia (UKM), and assistant engineers in Makmal B, Fakulti Kejuruteraan Pembuatan, Universiti Teknikal Malaysia Melaka (UTeM) for all the help and support I received from them.

Last but not least, from the bottom of my heart, gratitude to my beloved husband, Ts. Dr. Noorrezam Yusop, for his encouragement and who has been the pillar of strength in all my endeavors. My eternal love also to my daughter, Nawwal Erina Noorrezam, for her patience and understanding. I also want to thank my beloved parents and family for their endless support, love, and prayers. Finally, thank you to all the individuals, especially fellow postgraduate members who provided me with the assistance, support, and inspiration to embark on my study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

0D	-	Zero Dimensional
1D	-	One Dimensional
2D	-	Two Dimensional
3D	-	Three Dimensional
Ag	-	Silver
Al	-	Aluminium
Au	-	Gold
BCP	-	Bathocuproine
CB	-	Conduction Band
CuSCN	-	Copper Thiocyanate
CVD	-	Chemical Vapour Deposition
E_g^{opt}	-	Optical Bandgap
ETL	-	Electron Transport Layer
ETM	-	Electron Transport Material
eV	-	Electron Volt
FESEM	-	Field Emission Scanning Electron Microscopy
FF	-	Fill Factor
FTIR	-	Fourier-Transform Infrared Spectroscopy
FTO	-	Flourine-doped Tin Oxide
GO	-	Graphene Oxide
GQD	-	Graphene Quantum Dot
HOMO	-	Highest Occupied Molecular Orbital
HTL	-	Hole Transport Layer
HTM	-	Hole Transport Material
I-V	-	Current-Voltage
J_{sc}	-	Short Circuit Current Density
Li-TFSI	-	Li-bis(trifluoromethanesulfonyl)
LUMO	-	Lowest Unoccupied Molecular Orbital
mA/cm^2	-	MiliAmpere per Centimeter Square

$MAPbBr_3$	-	Methylammonium Lead Bromide
$MAPbI_3$	-	Methylammonium Lead Triiodide
MoS_2	-	Molybdenum Disulfide
n-i-p	-	Negative-Intrinsic-Positive
nm	-	Nanometer
PCBM	-	[6,6]-phenyl-C_{61}-butyric acid methyl ester
PCE	-	Power Conversion Efficiency
PEDOT:PSS	-	Poly(3,4-ethylene dioxythiophene) polystyrene sulfonate
p-i-n	-	Positive-Intrinsic-Negative
PL	-	Photoluminescence
R_{ct}	-	Charge Transfer Resistance
rGO	-	Reduced Graphene Oxide
SCAPS	-	Solar Cell Capacitance Simulator
SnO_2	-	Tin Oxide
spiro-OMeTAD	-	2,2′,7,7′-tetrakis(N,N-di-p-methoxyphenylamine)-9,9′-spirobifluorene
srGO	-	Sulfonated Reduced Graphene Oxide
TBP	-	Tert-butylpyridine
TCO	-	Transparent Conducting Oxides
TiO_2	-	Titanium Dioxide
TRPL	-	Time-Resolved Photoluminescence
UV-Vis	-	Ultraviolet-visible Spectroscopy
V	-	Voltage
VB	-	Valence Band
V_{oc}	-	Open Circuit Voltage
XRD	-	X-Ray Diffraction
ZnO	-	Zinc Oxide