UNIVERSITI PUTRA MALAYSIA

EFFICIENCY ENHANCEMENT OF COPPER INDIUM GALLIUM DI-SELENIDE THIN FILM SOLAR CELL USING OPTIMIZED MATERIAL PROPERTIES

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FK 2014 13

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By

NIMA KHOSHSIRAT

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

May 2014

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DEDICATIONS

I dedicate my dissertation work to my loving parents. I cannot find words to express my gratitude to them whose words of encouragement and push for tenacity ring in my ears.

I also dedicate this dissertation to my wife for her supports, care and kindness. And finally I want to dedicate this work and give special thanks to all who have been the wind beneath my wings.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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April 2014

Chair: Nurul Amziah Md Yunus, Ph.D.

Faculty: Engineering

The Copper Indium Gallium di-Selenide (CIGS) thin film solar cells are studied in this research. The interest in Cu(In_{1-x}, Ga_x)Se_2 thin-film solar cells has increased significantly due to its promising characteristics for high performance and low cost. The cell structure consists of a substrate that is made of glass and layers of back contact, CIGS absorber, buffer, window layer and front contact. The material that was used as the buffer layer in this study is the Indium Sulfide as an alternative to the conventional toxic material, Cadmium Sulfide. The geometrical, electrical and optical properties of each layer can affect the cell performance and efficiency. The objective of the research is to find and propose the optimum thickness and electro-optical properties of absorber, buffer and window layer. The electro-optical parameters that are studied in this project are the energy band gap (E_g), electron affinity (χ_e), light absorption coefficient (α) and doping density. In this project the performance of (CIGS) thin film solar cell has been numerically simulated using the simulation program called SCAPS-1D. The simulation started on a baseline model that was proposed by Gloeckler et al. This is the most valid model of CIGS thin film solar cell that serves an excellent starting point for more specific and more complete simulations. The Gloeckler model contains the initial values for the material properties of each layer. These values were used as the simulation starting points. Since the material that are used in a CIGS thin film solar cells all are compound semiconductors, their properties are the function of their composition. In the other words, the electro optical properties of the compound semiconductor materials can be tuned in a specific range. Accordingly, in this study first the major material properties of

each layer were extracted in a range from valid references which experimentally studied the electro-optical features of the materials. This made the present research as an empirical study which is based on values that are experimentally measured. It is important to be mentioned that in some cases interpolation was done by curve fitting technique to reach to some unknown values of material properties. Then the numerical simulations are performed by varying the geometrical, electrical and optical properties for each layer in the extracted range. The effects of these variations on cell performance were investigated and data analyses were done in order to find the optimum ranges for layers properties. Resulting optimized cell shows 20.16% efficiency with the V_{oc}=0.762 V; J_{sc}=32.28 mA/cm^2; FF=81.99%. This is comparable with the highest reported efficiency for a laboratory scale CIGS/In_2S_3/i-ZnO/ZnO:Al solar cell that is 16.4% and V_{oc}=0.665 V; J_{sc}=31.5 mA/cm^2; FF=78%. At the last step the best reported CIGS/In_2S_3/i-ZnO/ZnO:Al cell in the literature was simulated to find the value of its absorber and window layer band gap. The simulation result is in a good agreement with the reported experimental study results. The obtained optimized material properties can be used in fabrication of the cell with optimized and desired features and give faster input to the fabrication process.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Sarjana Sains

PENINGKATAN KECEKAPAN FILEM NIPIS SEL SURIA KUPRUM INDIUM GALIUM DI-SELENIDA MENGGUNAKAN SIFAT-SIFAT BAHAN DIOPTIMUMKAN

Oleh

NIMA KHOSHSIRAT

April 2014

Pengerusi: Nurul Amziah Md Yunus, Ph.D.

Fakulti: Kejuruteraan

Filem nipis sel suria Kuprum Indium Galium di-Selenida (CIGS) diselidiki dalam kajian ini. Kepentingan filem nipis sel suria Cu $(In_{1-x}, Ga_x)Se_2$ telah meningkat dengan ketara kerana ciri-cirinya menjanjikan prestasi tinggi dan berkos rendah. Struktur sel terdiri daripada substrat yang diperbuat daripada kaca dan lapisan penghubung belakang, penyerap CIGS, penampan, lapisan tingkap dan penghubung depan. Bahan yang telah digunakan sebagai lapisan penampan dalam kajian ini adalah Indium Sulfida sebagai alternatif kepada bahan toksik konvensional, Kadmium Sulfida. Geometri, sifat elektrik dan optik setiap lapisan boleh memberi kesan terhadap prestasi dan kecekapan sel. Objektif kajian ini adalah untuk mencari dan mencadangkan ketebalan optimum dan ciri-ciri elektro-optik penyerap, penampan dan lapisan tingkap. Parameter elektro-optik dikaji dalam projek ini adalah jurang jalur tenaga (E_g), afiniti elektron (χ_e), pekali penyerapan cahaya (α) dan ketumpatan pendopan. Dalam projek ini prestasi filem nipis sel suria CIGS telah menggunakan program simulasi yang dipanggil SCAPS-1D. Simulasi ini bermula dengan model asas yang dicadangkan oleh Gloeckler et al. Ini adalah model yang paling sah bagi filem nipis sel suria CIGS yang berfungsi pada titik permulaan yang sangat baik untuk penyelakuan yang lebih khusus dan lebih lengkap. Model Gloeckler mengandungi nilai awal untuk sifat-sifat setiap lapisan bahan. Nilai-nilai ini telah digunakan sebagai mata permulaan simulasi. Oleh kerana bahan yang digunakan dalam filem nipis sel suria CIGS kesemuanya merupakan semikonduktor sebatian, maka sifat-sifat mereka adalah berfungsikan komposisi mereka. Dalam kata lain, sifat-sifat elektro-optik daripada bahan semikonduktor sebatian boleh ditala dalam julat tertentu. Oleh itu, dalam kajian ini, pertama sifat-sifat bahan utama setiap julat lapisan dipetik daripada rujukan yang sah melalui kajian eksperimen ciri-ciri elektro-optik bahan tersebut. Ini membuat kajian yang dijalankan sebagai

satu kajian empirikal yang berasaskan nilai-nilai yang diukur secara eksperimen. Adalah penting untuk menyebut bahawa dalam beberapa kes, interpolasi telah dilakukan oleh teknik pemasangan lengkung untuk sampai ke nilai-nilai sifat bahan yang tidak diketahui. Kemudian simulasi berangka dilakukan dengan mengubah sifat-sifat geometri, elektrik dan optik untuk setiap lapisan dalam julat yang diekstrak. Kesan perubahan setiap lapisan kepada prestasi sel telah diselidiki dan analisis data telah dilakukan untuk mencari julat optimum ciri-ciri lapisan. Keputusan sel yang telah dioptimumkan menunjukkan kecekapan 20.16% dengan V_{oc}= 0.762 V; J_{sc}=32.28 mA/cm^2; FF=81.99%. Ini adalah setanding dengan kecekapan paling tinggi yang dilaporkan untuk skala makmal sel suria CIGS/In_2S_3/i-ZnO/ZnO:Al iaitu 16.4% dan V_{oc}= 0.665 V; J_{sc}=31.5 mA/cm^2; FF=78%. Pada langkah terakhir sel CIGS/In_2S_3/i-ZnO/ZnO:Al terbaik yang dilaporkan dalam kesusasteraan telah disimulasi untuk mencari nilai-nilai jurang penyerap dan lapisan tetingkap itu. Keputusan simulasi adalah dalam perjanjian yang baik dengan hasil kajian eksperimen yang dilaporkan. Keputusan yang diperolehi boleh digunakan dalam fabrikasi sel dengan ciri-ciri optimum yang dikehendaki dan memberi input lebih cepat untuk proses fabrikasi.

ACKNOWLEDGEMENTS

First of all, I would like to thank my committee members who were more than generous with their expertise and precious time. A special thanks to Dr. Nurul Amziah Md Yunus, my committee chairman for her countless hours of reflecting, reading, encouraging, and most of all patience throughout the entire process. I would like to thank Associate Prof. Dr. Mohd Nizar Hamidon, Dr. Suhaidi Shafie and professor Nowshad Amin for agreeing to be on my committee and their unfailing support.

Finally I would like to gratefully and sincerely acknowledge and thank Professor Marc Burgelman and the Electronics and Information Systems (ELIS) department, University of Gent, Belgium for providing the opportunity to use SCAPS simulation software.

I certify that a Thesis Examination Committee has met on (**21 April 2014**) to conduct the final examination of **Nima Khoshsirat** on his (or her) thesis entitled "**Efficiency enhancement of Copper Indium Gallium Diselenide thin film solar cell using optimized material properties**" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the **Master of Science**.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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