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World Best Level Efficiency from An Engineered Novel SLG/ Mo/p-$Cu_2ZnSn(Al)Se_4$/n-CdS/i-ZnO/Al:ZnO/Al Compound Semiconductor Hetero-Junction Thin Film Solar Cells

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Abstract

Molybdenum (Mo) metal seed layer deposited on soda lime glass (SLG) substrate and then Mo thick metal layer deposited on Mo seed layer. Then the Copper zinc tin aluminum selenide p-$Cu_2ZnSn(Al)Se_4$ (CZTAS) thin film was fabricated on molybdenum (Mo) thin film layer. For making p-n junction a n-CdS thin films fabricated on p-CZTAS layer using chemical bath deposition method. The surface morphology of total device structure was investigated by Scanning electron microscopy (SEM). The observed world best level efficiency and its note worthy results are presented and discussed in this research work.

Keywords: World Best Efficiency, p-$Cu_2ZnSn(Al)Se_4$, n-CdS Layer, Thin Film, Solar Cells

Introduction

Copper Indium Gallium diselenide p-$Cu_2InGaSe_2$ (p-CIGS) is one of the important direct band gap I-III-VI2 thin film compound semiconductor absorber material which composed of copper, indium, gallium, and selenium elements. Optics band gap of CIGS absorber thin film compound can modify from 1 eV to 1.6 eV by fine tuning of gallium and Indium elemental composition. Very high photo-voltaic energy conversion efficiency (□) of p-CIGS solar cell based opto-electronic devices has been widely issued and implemented for the last decades in worldwide solar power market. The p-CIGS thin film solar power devices have proved superior laboratory scale photoconversion efficiency (□) over 18% to 21%. A successful implementation of plant scale level with several megawatt power conversions also proved for the past several years [1-7]. But still a deep research is ongoing to reach the estimated theoretical efficiency limitation through many ways, such as ultra fine tuning of In and Ga ratio jointly,suitable n-type buffer layer with suitable modifications, molybdenum (Mo) back metal contact surface texturing and controlling the sodium participation from soda lime base glass (SLG) substrate, ultra-thin continuous Molybdenum diselenide ($MoSe_2$) quasi-ohmic layer formation through selenium flux and heat treatment controlling during selenization processing.

Especially the CIGS thin film solar cells have demonstrated very high solar power conversion efficiencies and in more recent years it exceeds □ = 21% in laboratory scale (CIGS solar cell active area of 0.45 cm^2 to 0.5 cm^2) and 13% to 16% in case of small sub-module level or small area mini-module size and was reported by many worldwide industries. Thin film solar cells have been enormously investigated for low-cost manufacturing for renewable energy sources. Particularly, $Cu(In,Ga)Se_2$ (CIGS) thin film solar cells are being importantly addressed for present market opening, including possibilities of $Cu_2ZnSn(S,Se)_4$ (CZTSSe) solar cells being issued for further reduction of manufacturing cost by use of earth abundant materials. Fundamentally, fabrication of the quaternary thin film solar cells depends on platform technologies. For the fabrication of platform technologies, there are several available methods such as vacuum-based, electrochemical, and other solution-based depositions [8-13].Similar to CIGS solar cells the CZTS thin film solar cells also reached more than 10% photo conversion efficiency in recent years. But still CZTS solar cells efficiency not reached the level of CIGS solar cells performance.

In this regard, in the present work a high quality p-$Cu_2ZnSn(Al)Se_4$ thin film absorber layer fabricated with well packed large grain boundary. Its surface morphology cross-section view was investigated. Then the complete device structure SLG/Mo/p-$Cu_2ZnSn(Al)Se_4$/n-CdS/i-ZnO/Al:ZnO/Al was successfully fabricated and its photovoltaic conversion efficiency was measured using 3-A Newport solar simulator (US Brand) and Vacuum solar simulator (Japan Brand) for results reliability conformation.

Experimental

Initially a thin soda lime glass (SLG) base bottom substrate was taken and cleaned using acetone using ultrasonic bath. Then well cleaned SLG glass substrate was dried using Nitrogen gas for 1 to 2 minutes. Next this SLG glass substrate was inserted inside ethanol (or) methanol solution and cleaned using ultrasonic bath. Further this SLG glass cleaned using pure water ultrasonic bath. After wards this well cleaned SLG glass substrates were kept at a constant temperature oven at 60 to 70° C for completely removing water molecules and other unwanted solution droplets. After this complete cleaning process we utilized SLG glass substrate for Mo metal back bottom electrode fabrication.

Mo metal back electrode fabricated on well cleaned soda-lime glass (SLG) substrates using two stage sputtering process. Initially a Mo seed layer of 100 nm were grown on SLG glass substrate to increase adhesion between SLG glass surface and Mo metal layer and this seed layer can act as a base layer for thick Mo metal layer fabrication. Both Mo seed layer and thick Mo thin film layer fabricated using sputtering method with predetermined experimental conditions under vacuum conditions. After wards this SLG/Mo layer well cleaned using acetone, ethanol and water with help of ultrasonic bath cleaner. Then dried in Nitrogen gas atmosphere and then dried in air atmosphere. Further this prepared SLG/MO layer kept inside constant temperature oven at 60 to 70° C.

Next a well packed p-type p-$Cu_2ZnSn(Al)Se_4$ thin film absorber layer was fabricated using the following prefixed experimental conditions. A thick p-$Cu_2ZnSn(Al)Se_4$ absorber layer was deposited on the well cleaned SLG/Mo-coated substrates through a programmable robotic arm controlled automatic sputtering method. After the sample cool down to room temperature, then the fabricated SLG/Mo/p- $Cu_2ZnSn(Al)Se_4$ layers taken out from sputtering chamber to avoid oxidation and atmospheric gas contamination due to the sample high surface temperature.

Using chemical bath deposition (CBD) method an n-CdS thin film layer separately fabricated on well grown SLG/Mo/p- $Cu_2ZnSn(Al)Se_4$ structure to complete p-n junction. The n-CdS was fabricated on p- $Cu_2ZnSn(Al)Se_4$ layer using the same chemical bath concentration of 0.068 M thiourea, and 0.97 M ammonium hydroxide solution and only cadmium sulfate concentration is 0.0014 M.

Further a resistive intrinsic Zinc oxide (ZnO) layer with 50 nm thickness was fabricated using sputtering method on both SLG/Mo/p-$Cu_2ZnSn(Al)Se_4$/n-CdS structure. After that a 500 nm thick Aluminum doped ZnO (Al:ZnO) transparent conducting layer was fabricated using sputtering. Then a 1 µm thick Aluminum (Al) metal grid pattern was fabricated on the fabricated structures to complete the solar cell device. So the completed CZTAS solar cell structure finally becomes SLG/Mo/p-CZTAS/n-CdS/i-ZnO/Al:ZnO/Al. The completed solar cell surface morphology and I-V measurements were derived and its merit points exhibited in the following discussion.

Results and Discussion

Surface Morphology of p-CZTAS/n-CdS Junction

Figure (1) showed the SLG/Mo/p-CIGS/n-CdS p-n junction stacked layers for reference solar cell device sample. Figure (2) showed the SLG/Mo thin film stack SEM surface morphology cross view image. From this we can understand the perfect vertical grain growth arrangement in Mo thin film metal layer on SLG glass substrate throughout whole sample. Figure (3) shows the SEM cross-section image of our present fabricated SLG/Mo/p-CZTAS/n-CdS p-n junction stacked layers. One can easily identify well aligned p-CZTAS with very large grain boundary. The SEM cross-section view clearly shows the grown p-type CZTAS layer have very high packing density and well adhered with Mo back metal electrode. At the bottom of p- CZTAS layer one can see Mo metal stacked layer with vertically aligned morphology. Grain packing density of metal electrode Mo also very high and was well textured on SLG glass substrate surface. The SEM investigation on the fabricated p- CZTAS/n-CdS showed more clear morphology stack cross-section image. The present smooth surface cross stack morphology will lead to achieve high photo-conversion efficiency.

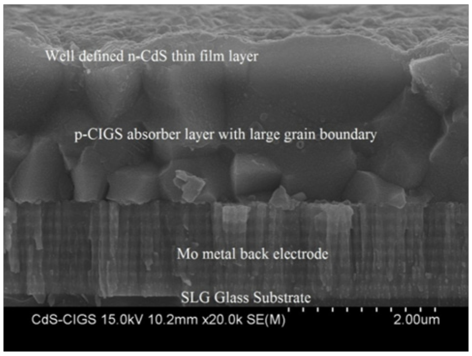

Figure 1 The SEM cross-section view of our fabricated SLG/Mo/p-CIGS/n-CdS thin film p-n junction stacked multi layers

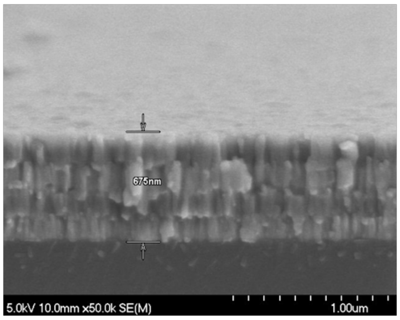

Figure 2 The SEM cross-section view of our fabricated SLG/Mo/stacked multi layers metal electrode

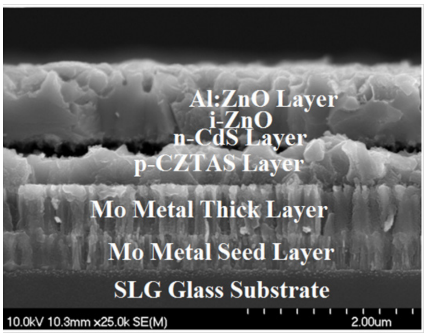

Figure 3 The SEM cross-section view of our fabricated SLG/Mo/p- CZTAS/n-CdS thin film p-n hetero junction stacked layers

Solar Cell Efficiency Measurement

Current-voltage (I-V) measurement was taken for SLG/Mo/p-CZTAS/n-CdS/i-ZnO/Al:ZnO/Al device at standard 1 sun condition with in a small active area of 0.45 cm2 using 3A-class Newport solar simulator (USA) and Vacuum solar simulator (Japan) instrument. Before I-V measurement the fabricated device gently cleaned using nitrogen gas to remove dust and unwanted loosely bounded particles. Figure (4) shows the SLG/Mo/p-CZTAS/n-CdS/i-ZnO/Al:ZnO/Al solar cell photo voltaic performance and the obtained parameters are as follows Open circuit voltage (Voc): 0.66 V; Short circuit current density (Jsc): 48.26 mA/cm2; Fill factor (FF): 60% and the photo conversion efficiency (): 19 %.

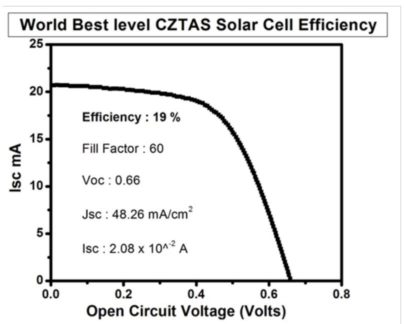

Figure 4 SLG/Mo/p-CZTAS/n-CdS/i-ZnO/Al:ZnO/Al solar cell photo voltaic performance

This present obtained result showed there are more room available to increase CZTAS compound thin film based solar cell efficiency. One can also extend this p-CZTAS/n-CdZnS layer and p-CZTAS/n-ZnS and many other p-n hetero junction combination formation works compound semiconductor thin film solar cells fabrication. This current limitation is almost a world best level when compared with worldwide photovoltaic single cells photo conversion current and its semiconductor quantum limitation.

Conclusions

The SEM cross-view showed the fabricated SLG/Mo stack layers and SLG/Mo/p-CZTAS/n-CdS multi layer stacks and has very clear and well defined p-n junction stack. Both the Mo metal back contact seed layer and positive terminal back electrode aligned vertically on SLG glass substrate surface. The measured solar cell power conversion efficiency of SLG/Mo/p-CZTAS/n-CdS/i-ZnO/Al:ZnO/Al solar cell photo voltaic performance (□: 19 %). Further work suggestion for worldwide researchers (1) Double p-type layer grading works, (2) Dual n-type layer for electron transport controlling, (3) Various metal sandwich top metal grid pattern, (4) Dark Glow material implantation in p-type absorber layers and inside p-n junction, (5) phosphor plasmonic materials implantation in solar cells and micro / nano scribed thin film solar cells energy sources for micro robotics and nano robotic machines.

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References

1. Reinhard, P. et al. Review of progress toward 20% efficiency flexible cigs solar cells and manufacturing issues of solar modules. In Photovoltaic Specialists Conference (PVSC), Volume 2, 2012 IEEE 38th, 1–9 (IEEE, 2012).
2. A. Chiril, P. Reinhard, F. Pianezzi, P. Bloesch, A. Uhl, C. Fella, L. Kranz, D. Keller, C. Gretener, H. Hagendorfer, D. Jaeger, R. Erni, S. Nishiwaki, S. Buecheler, and A. Tiwari, Nat. Mater. 12, 1107-1111 (2013).
3. Jackson, P. et al. Effects of heavy alkali elements in Cu (In,Ga)Se2solar cells with efficiencies up to 22.6%. physica status solidi (RRL)-Rapid Research Letters 10, 583–586 (2016).
4. A. Chirila, S. Buecheler, F. Pianezzi, P. Bloesch, C. Gretener,A. Uhl, C. Fella, L. Kranz, J. Perrenoud, S. Seyrling,R. Verma, S. Nishiwaki, Y. E. Romanyuk, G. Bilger, and A. Tiwari, Nat. Mater. 10, 857-861 (2011).
5. Chirilă, A. et al. Potassium-induced surface modification of Cu(In,Ga)Se2 thin films for high-efficiency solar cells. Nat. Mater.12, 1107–11 (2013).
6. Narazaki, A. et al. Femtosecond Laser Scribing of Cu(In,Ga)Se2Thin-Film Solar Cell. J. Laser Micro Nanoeng. 11, 130–136 (2016).
7. P. Jackson, D. Hariskos, E. Lotter, S. Paetel, R. Wuerz,R. Menner, W. Wischmann, and M. Powalla, Prog. Photovoltaics 19, 894-897 (2011).
8. H. Katagiri, K. Saitoh, T. Washio, H. Shinohara, T. Kurumadani, S. Miyajima, Solar Energy Materials & Solar Cells 65, 141-148, (2001).
9. K. Jimbo, R. Kimura, T. Kamimura, S. Yamada,W. S. Maw, H. Araki, K. Oishi, H. Katagiri, Thin Solid Films 515, 5997–5999, (2007).

10. Hironori Katagiri, Thin Solid Films 480-481,426-432, (2005).
11. H. Katagiri, K. Jimbo, S. Yamada, T. Kamimura, W. Maw, T. Fukano, T. Ito, and T. Motohiro, Appl. Phys. Express 1, 041201 (2008).
12. H. Katagiri, K. Jimbo, W. Maw, K. Oishi, M. Yamazaki, H. Araki, and A. Takeuchi, Thin Solid Films 517, 2455-2460 (2009).
13. M. Friedlmeier, N. Wieser, T. Walter, H. Dittrich, H.-W.Schock, Proceedings ofthe 14th European Conference of Photovoltaic Solar Energy Conference andExhibition, Belford, 1997, p. 1242.