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Flexible Thin Film Solar Cells Using in the Car

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Abstract

In recent years, renewable energy technologies are being explored to meet the challenges of energy security and climate change. Solar energy is a clean and green renewable source of energy. It is an inevitable option to use photovoltaic effect to directly convert sunlight into electricity. $CuIn_{1-x}Ga_xSe_2$ (CIGS) thin films were formed from an electrodeposited $CuInSe_2$ (CIS) precursor by thermal processing in vacuum in which the film stoichiometry was adjusted by adding In, Ga and Se. The structure, composition, morphology and opto-electronic properties of the as-deposited and selenized CIS precursors were characterized by various techniques. A 17.2% CIGS based thin film solar cell was developed using the electrodeposited and processed film. The cell structure consisted of Mo/CIGS/CdS/ZnO/MgF_2. The cell parameters such as *Jsc*, *Voc*, FF and η were determined from I-V characterization of the cell. The solar electric vehicle is made using flexible thin film solar cells. With the solar cell the full charge endurance of SEV can be increased about 35% substantially compared with no solar cells.

Keywords: solar cells, thin film, flexible, lightweight, electric vehicle

1 Introduction

Industrialized nations face an uncertain energy future. Threats such as global warming and anticipated scarcity of hydrocarbon fuels present a problem to long-term planning efforts. Renewable energy has been recognized as part of a solution; wind, solar, tidal, wave, and biomass technologies are receiving steadily increasing investment, though their contribution to global energy supply remains small. Transportation systems in particular are almost exclusively powered by nonrenewable energy sources[1].

As a new and environmental vehicle, the electric vehicle has advantages of zero discharge, low noise and wide source for energy supplement[2]. In the solar car, the photovoltaic solar cell plate transforms the solar energy into electric power, then the power is stored in the batteries, and then the batteries supplies the power to the electric vehicle.

The use of flexible plastic substrates is becoming an issue of great interest in thin film solar cells technology, as they allow cost reduction in the production process by using roll-to-roll deposition systems and facilitate monolithic interconnection of the cells to produce a photovoltaic module[3,4]. Furthermore, those lightweight, reduced fragility and flexibility of the modules can reduce the storage and transportation costs. Plastic substrates solar cells can also well used in the solar car because of those characteristic[5].

One of the advantages of Cu(In, Ga)Se_2 (CIGS) solar cells is their ability to use very thin photo-absorber layers with thickness on the order of several micrometers[6]. This feature offers not only a reduction of consumption of raw materials, but also leads to a wide variety of applications of solar cells that take advantages of lightweight and flexible devices. Applications of flexible CIGS solar cells include mobile use which has a strict weight requirement as well as for use as construction materials and car roofs by application to curved surfaces. In addition to the properties of low weight and flexibility, the advantages of a low energy pay back time and strong radiation hardness of flexible CIGS solar cells are attractive[7].

Solar cars have gained the public attention through several races organized across the world including the Australian World solar Challenge, the Swiss Tour de Sol, and the GM Sunrayce[8,9]. While the entrants in these races are, for the most part, very lightweight, unsafe vehicles, the concept of a safe, practical commuting vehicle which derives its energy primarily from the sun has been little explored. While such a vehicle is expected to have very limited range (20-50 miles), the possibility of being able to drive a car to work, recharge the batteries with solar energy during the day, and drive back home at night with enough stored energy to get back to work the next day, offers a very attractive motive option. In the project described here we set out to design and fabricate flexible solar films to be used in the solar car.

Despite the significant advancement made in solar cell technology in the past decade, the purchase and installation cost of solar energy system is still not competitive in the energy industry. Ideally, mass-produced solar cells that cost \$0.06 per kilowatt-hour or less are required for solar energy to be as competitive as energy from hydrocarbon sources [3]. Because of its favorable electrical, optical, and semiconducting properties and its feasibility of large-scale fabrication, $CuInSe_2$ (CIS) or CIGS-based thin films have attracted many research interests [4]. The energy bandwidth of about 1.1 eV and absorption coefficient of $3\times10^4 cm^{-1}$ make CIS most suitable for photovoltaic applications [5].

One of the important advantages of CIGS solar cells is their ability to use very thin photo-absorber layers with a thickness on the order of several micrometers[10]. This feature offers not only a reduction of consumption of raw materials, but also leads to a wide variety of applications of thin film solar cells that take advantages of lightweight and flexible devices. Applications of flexible CIGS thin film solar cells include mobile use which has a strict weight requirement as well as for use as construction materials and car roofs by application to curved surfaces[11]. In addition to the properties of low weight and flexibility, the advantages of high efficiency and strong radiation hardness of flexible CIGS thin film solar cells are attractive.

The most commonly used substrate for rigid CIGS thin film solar cells and modules is soda-lime glass (SLG) at present[12]. For flexible CIGS cells, on the other hand, a wide variety of substrates such as stainless steel (SS), Ti, Mo, Cu, Al and polyimide (PI) have been examined to date. Among these, SS (magnetic) and Ti foils are relatively suitable and commonly used because these metal foils meet the demands required for the CIGS flexible substrate[13]. The demands on the CIGS substrate include, for example, vacuum compatibility, thermal stability, thermal expansion, chemical inertness, the ability to act as a sufficient humidity barrier, surface smoothness, cost, and weight. Using SS or Ti substrates, conversion efficiencies over 17% have been demonstrated[14].

2 Experiment

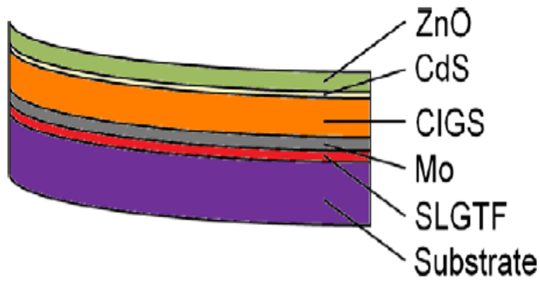

Figure 1: Schematic illustration of the device structure

Fig.1. shows the structure of the flexible CIGS thin film solar cell fabricated on zirconia sheets in this study. A 50μm thick flexible zirconia sheet was used as substrate. SLG thin films (SLGTF), one of the most familiar and inexpensive alkali-silicates consisting chiefly of Na_2O. $CaO.5SiO_2$, were used as Alkali-silacate glass thin layers (ASTL)[15]. SLGTF with a thickness of 100-120 nm were deposited by RF-magnetron sputtering on substrates prior to the deposition of the Mo back contact layer. After SLGTF deposition, 800nm thick Mo layers were deposited by sputtering. CIS, CIGS and CGS absorber layers were grown by the three-stage process. Before sputtering the CIGS film, the substrate was cleaned in de-ionized water in an ultrasonic bath.

The substrate temperature during the first stage of growth was 350℃and the temperature during the second stage and the third stage was 550℃. The [Ga] / [In + Ga] com-position ratio of the CIGS layers was about 0.4. The thickness of CIS and CIGS was about 2 μm, and the thick-ness of CGS was 1μm. The composition ratio and thick-ness were determined by electron probe microanalyzer (EPMA) measurements and scanning electron microscopy (SEM), respectively. After CIS, CIGS and CGS growth, chemical bath deposition of CdS buffer layers was performed in a water bath[16]. Highly resistive intrinsic ZnO and conductive ZnO: Al layers were then deposited by sputtering in a sputtering chamber. Finally, Al grid electrodes were formed by thermal evaporation. No anti-reflection coating was used. A completed flexible thin film solar cell fabricated on a zirconia sheet is shown in Fig. 2.

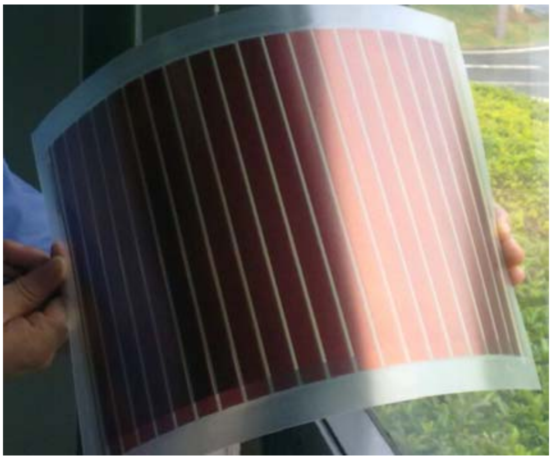

Figure 2: Picture of a solar cell fabricated on a flexible substrate

3 Results and discussion

The final configuration of photovoltaic device formed was $Mo/CuIn_{1-x}Ga_xSe_2/CdS/ZnO/MgF_2$. Once the device was formed, it was characterized by I-V measurements in which case the intensity of illumination, solar spectrum distribution and test temperature was 1000 W/m^2, AM1.5 and 25 °C, respectively. The results obtained from the I-V characterization of the solar cell are displayed in Fig. 3. which is a plot of current density (J) versus applied voltage (V) for the cell in darkness and under illumination. The cell parameters were calculated from this plot and are the following results: *Jsc* (current density) = – 26.55 mA/cm^2, *Voc* (output voltage) = 550 mV, FF (fill factor) = 67.885% and (conversion efficiency) η = 17.2%. It is indicated a high efficiency thin film solar cell which can be used in the solar electric car is developed.

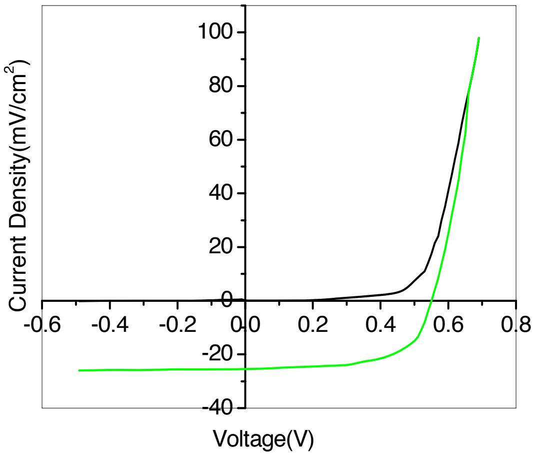

Figure 3: The j-V characteristics for CIGS thin film solar cell in dark and under illumination

The spectral response of flexible thin film solar cell under the standard test condition (1000 W/m^2, AM1.5 and 25℃) is shown in Fig. 4. It is a plot of the normalized internal quantum efficiency versus wavelength. This figure indicates that the solar cell shows considerable quantum efficiency in the longer wavelength region, where the solar spectral irradiance is much less than that in the visible region. In this way, the quantum efficiency of the thin film solar cell in the visible region is about 80%, this effect is indicative of the performance of the CIGS-based thin film solar cells.

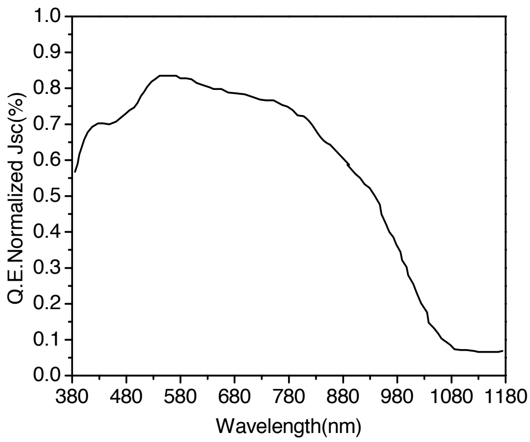

Figure 4: The spectral response for the CIGS thin film solar cell

A solar electric vehicle (SEV) shown in Fig. 5. is developed using the flexible solar cells. Flexible thin film solar cells are installed in the roof of the car. The flexible thin film solar cells are bonded with the car using 3M glue. The thickness of the thin film solar cell and 3M glue is only 3mm.

There is no clear blow-up on the top of car. It is very beautiful that SEV is installed with the solar cells. In good sunny conditions, thin film solar cells convert sunlight into electricity continuously and the electricity is stored in batteries by the controller. The full charge endurance of SEV can be increased about 35% substantially compared with no flexible thin film solar cells.

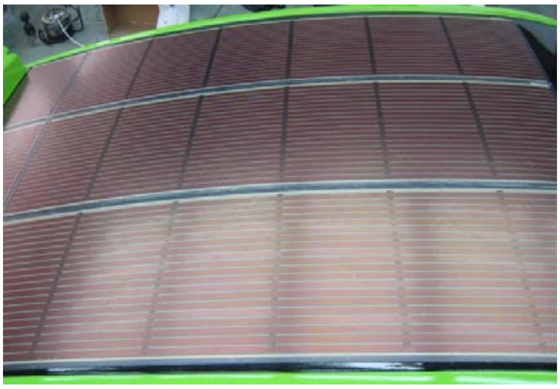

Figure 5: View of PV-assisted electric vehicle from the front side

4 Conclusion

In the paper flexible CIGS thin films were formed using a thermal processing in vacuum. According to process of developing the thin film solar cells, the film stoichiometry was adjusted by adding In, Ga and Se. The structure, composition, morph-ology and opto-electronic properties of the as-deposited and selenized CIS were characterized by various analysis techniques. A 17.2% CIGS based thin film solar cell was developed using the electrodeposited and processed film. The parameters of solar cell such as Jsc, Voc, FF and η were determined from the I-V characterization of the solar cell. Using the flexible thin film solar cells, a solar electric vehicle is developed. The full charge endurance can be increased about 35% substantially compared with no solar cells.

References

[1] J. Gould et.al., *Clean air forever? A longi-tudinal analysis of opinions about air pollution and electric vehicles*, Transportation Research Part D, ISSN: 1361-9209, 3(1998), 157-169.
[2] K. H. Jansen et.al., *Emissions impacts of plug-in hybrid electric vehicle deployment on the U.S. western grid*, Journal of Power Sources, ISSN: 0378-7753, 195 (2010), 5409-5416.
[3] M. Gloeckler et.al., *Grain-boundary recombine-tion in Cu(In,Ga)Se_2 solar cells*, Journal of Applied Physics, ISSN: 0021-8979, 98(2005), 1-10.
[4] M. E. Calixto et.al., *Cu(In,Ga)Se_2 based photo-voltaic structure by electrodeposition and processing*, Solar Energy Materials & Solar Cells, ISSN: 0927-0248, 55(1998), 83-94.
[5] R. N. Bhattacharya et.al., *15.4%$CuIn_{1-x}GaxSe_2$-based photovoltaic cells from solution-based precursor films*, Thin Solid Films, ISSN: 0040-6090, 361(2000), 396-399.
[6] S. H. Jung et.al., *Effects of Ga contents on properties of CIGS thin films and solar cells fabricated by co-evaporation technique*, Current Applied Physics, ISSN: 1567-1739, 10(2010), 990-996.
[7] J. Marlein et.al., *Analysis of electrical properties of CIGSSe and Cd-Free buffer CIGSSe solar cells*, Thin Solid Films, ISSN: 0040-6090, 517(2009), 2353-2356.
[8] S. Seyrling et.al., *$CuIn_{1-x}GaxSe_2$ photovoltaic devices for tandem solar cell application*, Thin Solid Film, ISSN: 0040-6090, 517(2009), 2411-2414.
[9] P. J. Sebastian et.al., *CIS and CIGS based photovoltaic structures developed from electrode-posited precursors*, Solar Energy Materials & Solar Cells, ISSN: 0927-0248, 59(2009), 125-135.
[10] E. Schlenker et.al., *Schottky contact analysis of photovoltaic chalcopyrite thin film absorbers*, Physics Letters A, ISSN: 0370-2693, 362(2007), 229-233.
[11] D. Y. Lee et.al., *Effect of first-stage temperature on Cu(In,Ga)Se_2 solar cells using the evaporation of binary selenide compounds*, Solar Energy Materials & Solar Cells, ISSN: 0927-0248, 75(2003), 73-79.
[12] B. Kumar et.al., *ZnxCd1-xS as a heterojunction partner for $CuIn_{1-x}GaxS_2$ thin film solar cells*, Thin Solid Films, ISSN: 0040-6090, 517(2009), 2295-2299.
[13] X. H. Tan et.al., *Effect of Na incorporated at different periods of deposition on Cu(In,Ga)Se2 films*, Appl. Opt., ISSN: 1559-128X, 49(2010), 3071-3075.
[14] M. Bar et.al., *Chemical structures of the Cu(In,Ga)Se_2/Mo and Cu(In,Ga)(S,Se)$_2$/Mo inter-faces*, Physical Review B, ISSN: 1094-1622, 78(2008), 1-8.
[15] C. Ludwig et.al., *Indium-Gallium Segregation in CuInxGa1-xSe_2: An Ab Initio-Based Monte Carlo Study*, Phys. Rev. Lett., ISSN: 0031-9007, 105(2010), 1-4.
[16] Y. Hashimoto et.al., *Chemical bath deposition of Cds buffer layer for GIGS solar cells*, Solar Energy Materials and Solar Cells, ISSN: 0927-0248, 50(1998), 71-77.

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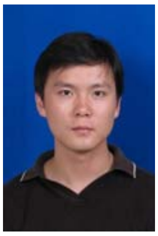

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