

Fabrication of Light weight Flexible CIGS solar Cells for Space Power Applications

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ABSTRACT

A novel, non-vacuum and a patented process developed by ISET for manufacturing terrestrial CIGS solar cells was successfully applied to fabricate CIGS solar cells on flexible 50 μm thick Mo foil for space power applications. Solar cells of area 5.0 cm^2 were fabricated with their AM0 efficiency approaching 9.0% with an estimated power density of 250 watts/kg. With further improvements it is possible to fabricate CIGS solar cells with AM0 efficiencies approaching 13%. This process can be used to fabricate low cost, light-weight CIGS solar cells on a variety of flexible substrates much lighter than Mo foil to achieve power densities approaching 1.0 kW/kg.

INTRODUCTION

Rapidly growing business of wireless communication and information transmission will require a large number of satellites to be launched in the next few years. All of these satellites require *low cost, light-weight* and preferably *flexible* solar modules to power them. The most important criteria for these modules are low cost, high specific power density and excellent radiation hardness. CIGS solar cells have been known to be robust against the radiation damage (1,2), however, the other attributes of low cost and light weight depend on the process and the type of substrate used in the fabrication of these solar cells. We at ISET have developed a unique, non-vacuum and a low cost process for the fabrication of thin film CIGS solar cells. This process is described in detail in another publication of this proceedings volume (3). The basic approach of ISET's process is to use water based inks made using nano-particles of mixed oxides of Cu, In and Ga to deposit precursor coatings in which the ratio Cu/(In +Ga) is fixed molecularly. The precursor coating is converted into a CIGS layer of the desired electronic properties by annealing it through a couple of steps of gas solid reactions. This process was developed for manufacturing terrestrial CIGS modules on rigid glass substrate and we have attempted to use it for the fabrication of CIGS solar cells on flexible Mo foil. The results of our preliminary efforts are very encouraging and this paper briefly describes the process of fabrication flexible solar cells and their performance results.

EXPERIMENTAL

Fabrication of CIGS Solar Cells on Flexible Mo Foil

Figure 1 shows the schematic of CIGS solar cell in substrate structure and figure 2 shows the process of fabricating CIGS solar cells on flexible Mo foil. We fabricated solar cells on Mo foils of thickness 25 μm and 50 μm . The Mo foil surface was cleansed with acetone, methanol and water successively and then dried by blowing dry nitrogen gas on its surface. No other special treatment was carried out to prepare the surface. A precursor coating of estimated thickness 18 μm was applied to the surface of a clean Mo foil using a 'knife edge' with a precise opening of 37.5 μm . Drying of the wet coating in air left a mixed oxide coating of thickness about 3.0 μm without any agglomeration, on the surface of the Mo foil.

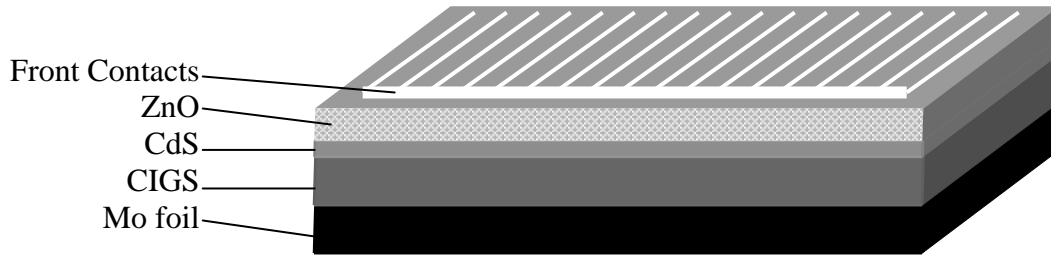


Figure 1. Schematic of the structure of CIGS solar cell

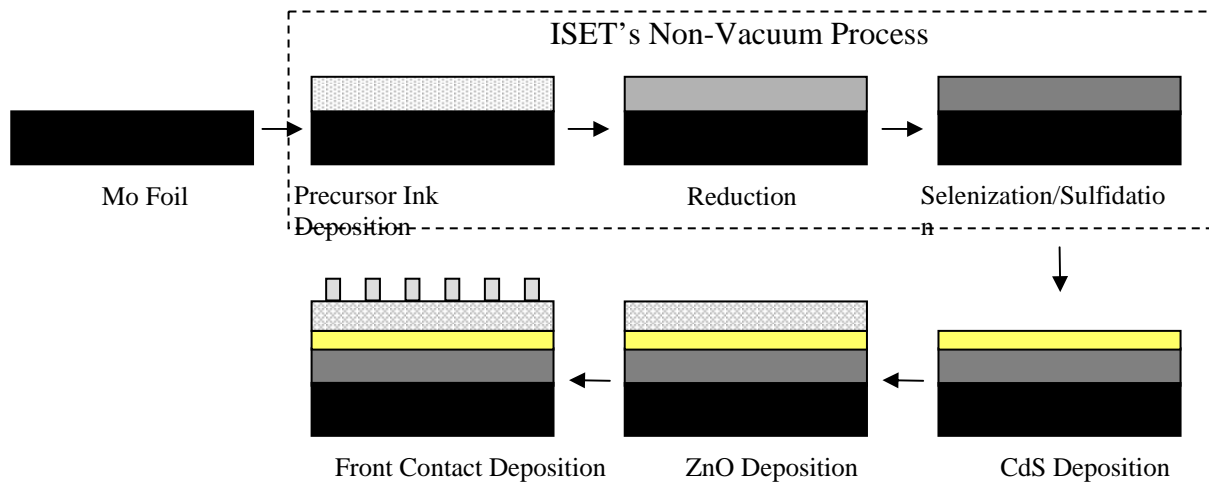


Figure 2. Schematic of ISET's non-vacuum process for making CIGS solar cell on Mo foil.

. This oxide coating was reduced under a mixture of H_2 and N_2 gases at temperatures in the range of $475\text{--}525^\circ\text{C}$ for a period of 30–50 minutes to obtain a compact coating of metal alloys consisting of Cu, In and Ga. This alloy coating was then selenized using H_2Se gas at temperatures in the range of $440\text{--}475^\circ\text{C}$ for a period of 20–30 minutes to form the CIGS absorber layer. The cell fabrication process was completed by depositing CdS and ZnO using chemical bath deposition (CBD) and low pressure chemical vapor deposition (LPCVD) processes respectively. Silver contacts were evaporated through a shadow mask on top of the ZnO layer of solar cells of area 5.0 cm^2 . These cells were measured in our laboratory for their output under global AM1.5 spectrum and they were also measured under AM0 at the Air Force Research Lab (AFRL) Kirtland, New Mexico.

RESULTS AND DISCUSSIONS

Figure 3 shows a dark and light I-V curves of the best cell made by the above process. Table 1 shows the cell parameters measured under AM0 for a number of cells of area 5.0 cm^2 fabricated on Mo foil of thickness $50\text{ }\mu\text{m}$. It is clear that a quick adaptation of our process, which was originally developed for fabricating solar cells on rigid glass substrate, to the flexible Mo foil gave us very encouraging results. A number of solar cells of area 5.0 cm^2 were measured with their AM0 conversion efficiency approaching 9.0%. For thin film solar cells these early results

are quite respectable. We would like to point out that these results were obtained without any process optimization on Mo foil.

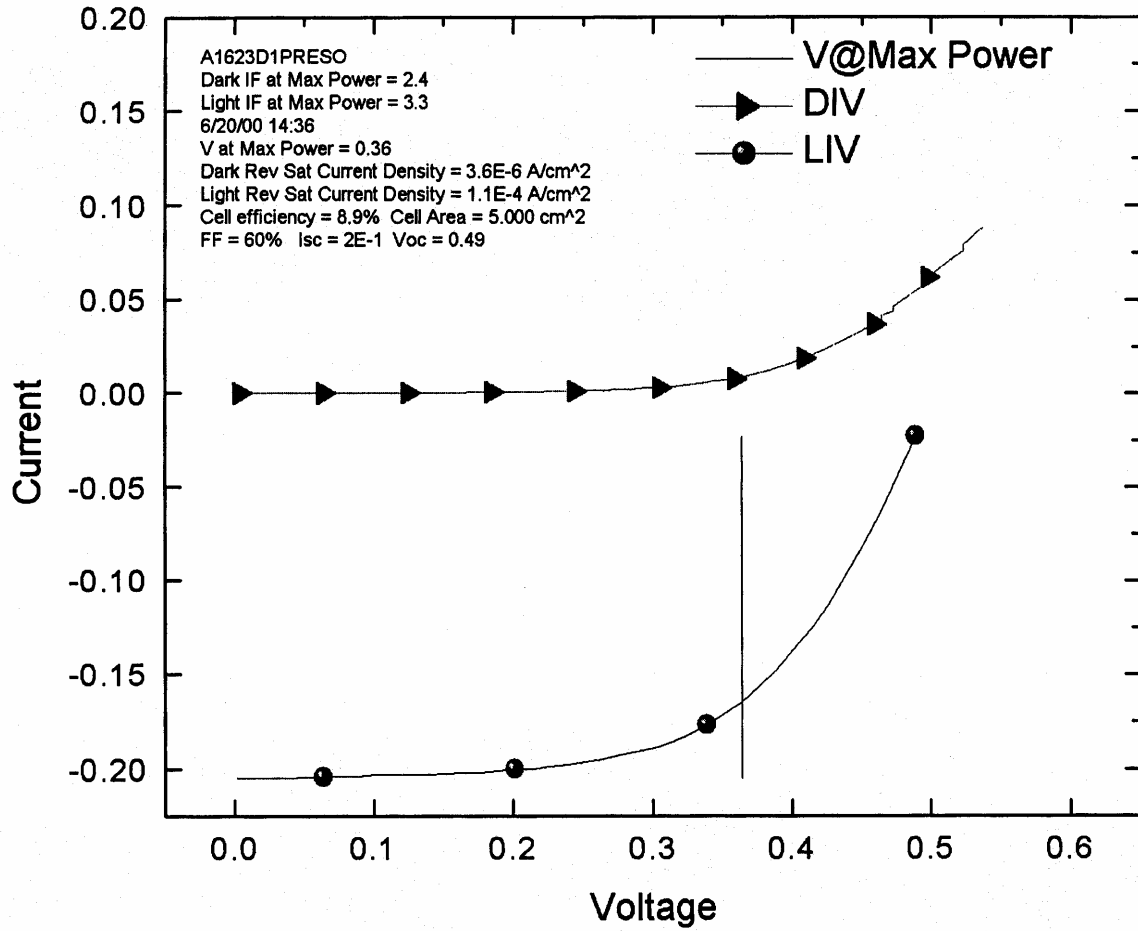


Figure 3. Dark and Light(AM0) I-V curves for the best CIGS cell made by the non-vacuum process

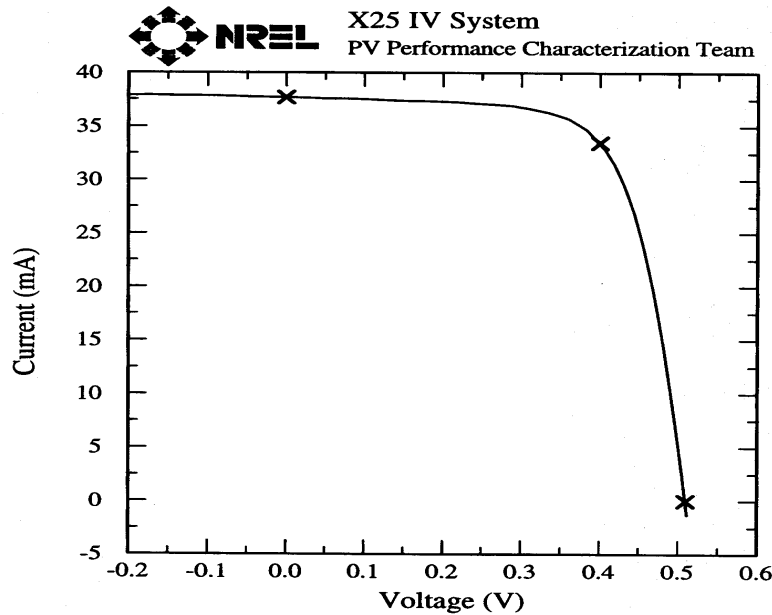
Table I. Results of I-V measurements on CIGS cells made at AFRL on 2 mil Mo foils measured under AM0 irradiation conditions

Sample ID	1622C1	1622C2	1622D1	1623D1	1623D2
Cell Area (cm ²)	5	5	5	5	5
V _{oc} (V)	0.451	0.451	0.459	0.501	0.486
I _{sc} (A)	0.219	0.218	0.199	0.205	0.203
V _{max} (V)	0.326	0.316	0.326	0.339	0.339
I _{max} (A)	0.181	0.180	0.165	0.177	0.165
P _{max} (W)	0.059	0.057	0.054	0.060	0.056
FF	0.60	0.58	0.59	0.58	0.57
Efficiency (%)	8.72	8.41	7.97	8.88	8.27

Figures 4 and 5 show the light I-V and the spectral response of a **terrestrial** solar cell fabricated on glass substrate using ISET's non-vacuum process. We observed that the ratio of AM0/AM1.5 ratio of our CIGS solar cells is between 0.90–0.95. This high ratio may be due to their very good spectral response in the short wavelength region of the spectrum (Figure 5). The AM1.5 efficiency of CIGS solar cell of area 1.0 cm² was measured to be about 12.3% and there is plenty of room for improvement of the performance of these solar cells. Our current efforts are focused on improving the Voc and the fill factor in these terrestrial solar cells and our near term target is to fabricate 15% efficient terrestrial solar cells.

International Solar Electric Technology CIGSS Cell

Device ID: CO 1580B (Best) Device Temperature: 25.0 ± 1 °C
 Mar 7, 2000 1:37 PM Device Area: 1.094 cm²
 Reporting Spectrum: Global AM1.5 Irradiance: 1000.0 W/m²



V _{oc} = 0.5097 V	I _{max} = 33.49 mA
I _{sc} = 0.03767 A	V _{max} = 0.4002 V
J _{sc} = 34.44 mA/cm ²	P _{max} = 13.40 mW
Fill Factor = 69.79 %	Efficiency = 12.3 %

After 10 minute soak at P_{max}, 2 minute cool.

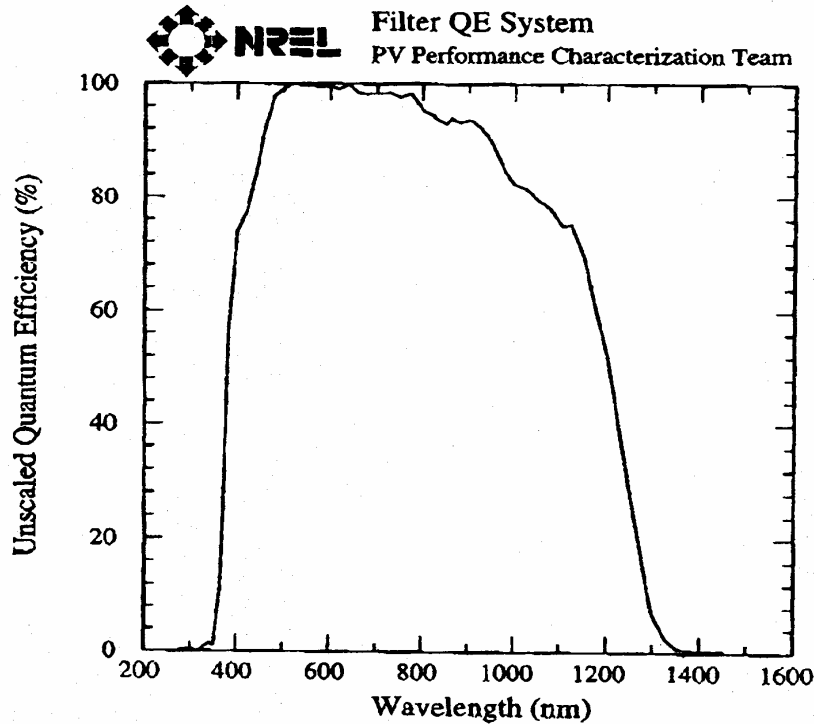
Contact to both Indium strips.

Figure 4. Light I-V curve of a CIGS solar cell made on glass for terrestrial application, using ISET's non-vacuum process.

International Solar Electric Technology CIGSS Cell

Device ID: CO1580B-Best
Mar 6, 2000 12:29 PM

Device Temperature: 25.0 ± 1 °C
Device Area: 1.094 cm²



Voltage Bias: 0.0 V
Light bias for 21.1 mA
Light Bias region area: 1.094 cm²
Light Bias Density: 19.32 mA/cm²

J_{sc} Estimate:
 J_{sc} (Global) = 42.6 mA/cm²

Figure 5. Spectral response curve of a CIGS solar cell made on glass for terrestrial application, using ISET's non-vacuum process.

With some efforts devoted to the optimization of our process for fabricating solar cells on foils, we expect to fabricate flexible CIGS solar cells with their AM1.5 conversion efficiencies in the 12-13% range and their corresponding AM0 efficiencies in the 11-12%. As we improve our overall device structure to obtain 15% efficient terrestrial solar cells we expect to fabricate flexible solar cells with AM0 efficiency over 13%. We estimate that the power density of CIGS solar cells on 50 μ m thick Mo foil is about 250 watts/kg. We fabricated CIGS solar cells on 25 μ m thick Mo also which posed a challenge in handling and the efficiencies of these solar cells were slightly lower than 9%. However, with proper tooling it is possible to fabricate equivalent solar cells on thinner foil, which would give the power density approaching 500 watts/kg.

In addition to improving the process and device performance, we plan to test the flexible solar cells for their performance and integrity after thermal cycling and radiation testing. In order to achieve 1.0 kW/kg power density we plan to fabricate solar cells on other foils much lighter than the Mo foil however, compatible with our process scheme.

CONCLUSION

We could in a very short time demonstrate that ISET's low cost process for manufacturing terrestrial solar cells could be used to fabricate flexible solar cells on foils. Adaptation of this process for manufacturing CIGS solar cells for space power applications could meet the requirements of low cost, high power density and radiation hardness in solar cells for future applications.

ACKNOWLEDGEMENTS

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