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Inside

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CIGS Manufacturing: Promises and Reality

With this edition of Applied Cost Modeling, we are publishing the first installment in a series examining the economic issues that are the driving forces behind photovoltaic (PV) adoption. Even technological advances are measured against their impacts on cost per watt, levelized cost of energy (LCOE), and total cost of ownership for energy (TCOe™). In this sixth paper covering business analysis for PV processes, we look at two approaches to manufacturing thin film Copper-Indium-Gallium-diSelenide (CIGS) PV, sputtering and coevaporation, and their potential areas for cost improvement.

The Promise of CIGS[1]
In contrast to the noncrystallinity of amorphous silicon (a-Si), thin film CIGS is a polycrystalline material consisting of small crystallites. CIGS has several characteristics that make it a valuable PV material. One is its absorption coefficient, which is among the highest for semiconductor materials. Ninety-nine percent of the light incident on CIGS is absorbed in the first micrometer of the device. Thus, cells with a thickness of that order of magnitude are possible. Another favorable characteristic is that CIGS has one of the highest current densities of any semiconductor material, with the potential to produce high current outputs. Third, these films retain their performance properties better than most semiconductors. And last, CIGS is amenable to large-area, automated production.

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[Continued on page 3]

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Calendar of Events

March 2014

18-20 SEMICON China
Shanghai New International Expo Centre
Shanghai, China

30 North American Standards Spring Meetings
SEMI Headquarters
San Jose, CA

April 2014

1-3 North American Standards Spring Meetings
SEMI Headquarters
San Jose, CA

May 2014

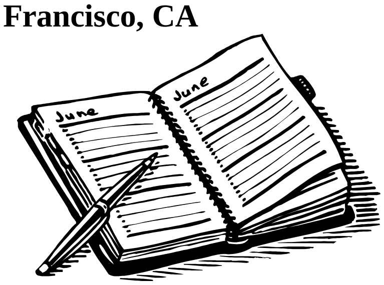
14-16 SNEC International PV Power Generation Conference & Exhibition
Shanghai New International Expo Centre
Shanghai, China

June 2014

10 Silicon Valley Strategic Advisers
SEMI Headquarters
San Jose, CA
(Open meeting held monthly on the second Tuesday - http://svstrategicadvisers.com/)

July 2014

8-10 Intersolar North America
Moscone Hall
San Francisco, CA



Efficiencies in excess of 20% have been reported for small-area, experimental cells made of thin film CIGS. A principal problem with the material is its low open-circuit voltage. However, this deficiency seems to be correctable by improving compositional uniformity by, for example, removing oxygen.

The CIGS portion is usually formed on a base electrode of molybdenum (Mo), chosen for its refractory nature and good electrical conductivity. Thin film CIGS is a p-type semiconductor and a junction is formed at the surface by deposition of a very thin layer of cadmium sulfide (CdS). This creates an n-p homojunction just inside the CIGS material, rather than a simple heterojunction. The device is completed by deposition of a transparent conducting oxide (TCO) such as zinc oxide (ZnO) on top of the junction to help collect the light-generated current. Figure 1 shows a typical CIGS solar module cross-section. In a manner similar to the definition and monolithic integration of thin film a-Si cells, individual CIGS cells are defined and serially interconnected via three patterning steps. The first scribe (in Mo) is performed by a laser beam, while the second and third scribes (to remove CIGS and separate the ZnO) can be performed mechanically or by laser. Again, metal foils are bonded to the first and last cells, and the module is encapsulated using a top cover glass laminated with encapsulant.

Figure 1: CIGS Module Cross Section

The principle of operation of the device is similar to that of conventional crystalline silicon (c-Si) solar cells. Light is absorbed in the CIGS layer, creating free electrons and holes. The electrons diffuse in the CIGS grains until they find themselves in the electric field within the junction region, at which point they are driven into the CdS/ZnO, thereby building up a voltage between the ZnO electrode and the Mo base electrode.

<u>Why is CIGS appealing?</u>[2]

If you realize the initial success of First Solar, you realize that a thin film cell with a higher efficiency than cadmium telluride (CdTe) with the potential to eliminate the toxic element cadmium would be of great interest. This major drawback has resulted in purchase restrictions on CdTe panels. In the CIGS manufacturing process, CdS is deposited in a very thin layer (30 – 50 nm) compared to 2 µm in case of CdTe. So the CIGS module contains 40 times less Cd than a same size CdTe module. Currently, using CIGS instead of CdTe makes the issue of toxicity a smaller one and it is expected that in 3 – 4 years CIGS manufacturers will have established a Cd-free buffer.

The benefits of CIGS modules are:[3]

- CIGS solar cells are an optimal form factor for rigid and flexible substrates; CIGS can be manufactured on low-cost glass substrates that enables access to the largest PV markets, enables use of existing mounting systems, is compatible with existing PV system infrastructure, and has the ability to dominate the building integrated photovoltaics (BIPV) market in the future.
- CIGS has the highest efficiency among all thin film solar

technologies; it can absorb over 99 percent of the solar spectrum and it has the highest current density. CIGS ranks the highest in conversion efficiency for laboratory samples among all other thin film solar technologies.

- CIGS modules can be produced at competitive costs even in the 100 MW/year volume range with high local content avoiding dependence on Si-wafer or Si-cell manufacturers.
- CIGS modules have demonstrated reliable and stable field performance for nearly 20 years.

Today and Tomorrow

Listed below is the current state of CIGS manufacturing and some near term projections.

- 14% module efficiency in production (Manz)
- 15.7% record module efficiency (TSMC)
- Annual efficiency improvement rate in last 5 years averaged 0.4% per year—outpacing p-type c-Si in latest 3 years
- Energy harvest data from Manz test installations:
    - Middle East: 7% better than p-type c-Si
    - Southern Europe: 5% better than p-type c-Si
    - Southern China: 10% better than p-type c-Si
- Operating Expense (OPEX) has reached CdTe levels; further efficiency improvements will result in lower OPEX ($0.50/watt-peak in 2014, $0.45/watt-peak in 2015)
- Future OPEX potential with scaled module format (1 x 1.6 m^2) : < $0.30/watt-peak
- Best footprint (150 MW) factory building: < 1 m^2/MW output
- Best headcount (all in production): < 1.5/MW output
- Lowest market entrance barrier: competitive OPEX reached at factory output of 150 MW

CIGS Production Processes

There are two major approaches to CIGS manufacturing; multitarget sputtering followed by a selenization furnace and coevaporation. There are a number of companies that have used or are using these processes and while the data used in this paper is based on publicly available sources, it is representative of the corresponding companies in Table 1.

CIGS Companies	Absorber Formation Method	Substrate
Q-Cells, Solibro	Coevaporation	Monolithic on glass
Mantz-Wurth Solar	Coevaporation	Monolithic on glass
Heliovolt	Coevaporation	Monolithic on glass
Centrotherm	Coevaporation	Monolithic on glass
Johanna Solar	Coevaporation	Monolithic on glass
Miasole	Reactive sputtering	Cell-based roll-to-roll
SoloPower	Eletroplating	Cell-based roll-to-roll
NanoSolar	Printing	Cell-based roll-to-roll
Stion	2-step sputtering	Monolithic on glass
AVANCIS	2-step sputtering	Monolithic on glass
Solar Frontier	2-step sputtering	Monolithic on glass
Bosch Solar CISTech	2-step sputtering	Monolithic on glass
TSMC	2-step sputtering	Monolithic on glass

Table 1: CIGS Companies and Absorber Formation Method

Multitarget Sputtering/Selenization Furnace

The process flow used in this paper is based on Figure 2 with only the CIGS formation steps (see blue cells) being changed. The key parameters for each step (some cells in Figure 2 represent more than one step) are shown in Table 2.

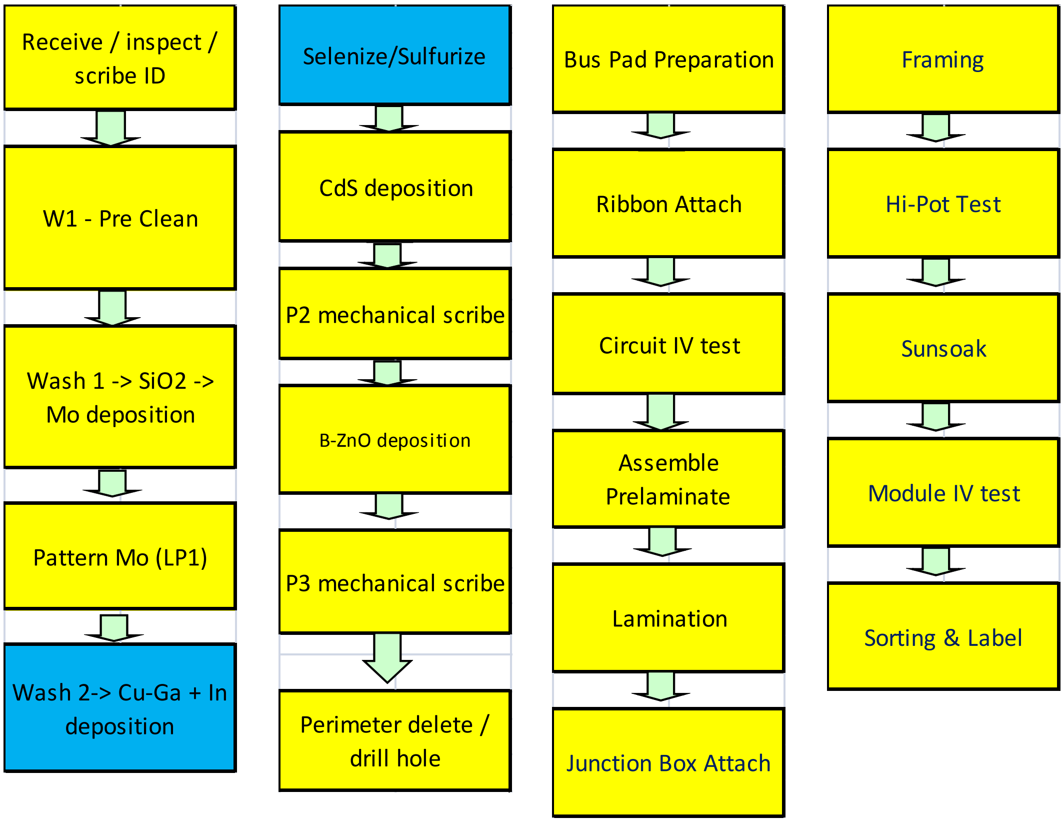


Figure 2: Sputtered CIGS Process Flow

Step Description	Tool Group	Process Throughput, Panels/Hour	Step Yield	Availability	Number of Tools	Purchase Capital (K$/tool)	Main Materials
Receive / inspect / scribe ID	Scriber	120	99.10%	90.0%	1	65.0	
W1 - Pre Clean	GlassWash	120	99.10%	90.0%	1	190.0	
Wash1	MoCleaner	120	100.00%	90.0%	1	190.0	
SiO2 -> Mo deposition	MoSputter	120	99.10%	90.0%	1	6,213.0	Moly Target, Silicon Target
Pattern Mo (LP1)	LaserScriberP1	120	99.10%	90.0%	1	1,786.0	
Wash2	CIGCleaner	120	100.00%	90.0%	1	190.0	
Cu-Ga + In deposition	CIGSputter	120	99.10%	90.0%	1	6,098.0	Cu-Ga Target 1, Cu-Ga Target 2, Indium Target
Selenize/Sulfurize	SASFurnace	5	99.10%	90.0%	28	1,056.0	Hydrogen Sulfide, Hydrogen Selenide
CdS deposition	Cji	60	99.10%	90.0%	2	1,462.0	Thiourea, Cadmium Sulfate, Ammonium Solution
P2 mechanical scribe	LaserScriberP2	120	99.10%	90.0%	1	1,065.0	
B-ZnO deposition	MOCVD-TCO	6	99.10%	90.0%	28	510.0	
P3 mechanical scribe	LaserScriberP3	120	99.10%	90.0%	1	1,012.0	MOCVD TCO 1, MOCVD TCO 2
Perimeter edge deletion	Laser4J	60	99.90%	90.0%	2	675.0	
Hole Drill	HoleDrill	60	100.00%	90.0%	2	675.0	
Bus pad prep and clean	Cutter	60	100.00%	90.0%	2	288.0	
Ribbon Attach	RibbonAttach	60	100.00%	90.0%	2	288.0	Copper Ribbon, Tin Solder, Indium Solder
Circuit IV test	CircuitTester	60	99.90%	90.0%	2	200.0	
Front glass clean	GlassWash2	60	100.00%	90.0%	2	190.0	
Assemble pre-laminate	PLATool	60	100.00%	90.0%	2	190.0	Ethyl Vinyl Acetate, Top Glass
Lamination	Laminator	60	99.90%	90.0%	2	623.0	
Junction Box attachment	JBATool	60	100.00%	90.0%	2	50.0	Pottant, Junction Box,
Framing	FrameTool	60	100.00%	90.0%	2	50.0	Frame
Hi-pot test	HiPot	60	100.00%	90.0%	2	100.0	
Sun Soak	SSTool	60	100.00%	90.0%	2	100.0	
Module IV test	ModuleTester	60	99.90%	90.0%	2	360.0	
Sorting & Label	SLTool	60	100.00%	90.0%	2	200.0	

Table 2: Sputtering/Selenization Input Parameters

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Step Description	Tool Group	Process Throughput, Panels/Hour	Step Yield	Availability	Number of Tools	Purchase Capital (K$/tool)	Main Materials
Receive / inspect / scribe ID	Scriber	120	99.10%	90.0%	1	65.0	
W1 - Pre Clean	GlassWash	120	99.10%	90.0%	1	190.0	
Wash1	MoCleaner	120	100.00%	90.0%	1	190.0	
SiO2 -> Mo deposition	MoSputter	120	99.10%	90.0%	1	6,213.0	Moly Target, Silicon Target
Pattern Mo (LP1)	LaserScriberP1	120	99.10%	90.0%	1	1,786.0	
Wash2	CIGCleaner	120	100.00%	90.0%	1	190.0	
Cu-Ga + In + Se deposition	CIGSEvaporation	25	99.10%	90.0%	5	9,000.0	Sources for Cu, In, Ga, Se
CdS deposition	Cji	60	99.10%	90.0%	2	1,462.0	Thiourea, Cadmium Sulfate, Ammonium Solution
P2 mechanical scribe	LaserScriberP2	120	99.10%	90.0%	1	1,065.0	
B-ZnO deposition	MOCVD-TCO	6	99.10%	90.0%	28	510.0	
P3 mechanical scribe	LaserScriberP3	120	99.10%	90.0%	1	1,012.0	MOCVD TCO 1, MOCVD TCO 2
Perimeter edge deletion	Laser4J	60	99.90%	90.0%	2	675.0	
Hole Drill	HoleDrill	60	100.00%	90.0%	2	675.0	
Bus pad prep and clean	Cutter	60	100.00%	90.0%	2	288.0	
Ribbon Attach	RibbonAttach	60	100.00%	90.0%	2	288.0	Copper Ribbon, Tin Solder, Indium Solder
Circuit IV test	CircuitTester	60	99.90%	90.0%	2	200.0	
Front glass clean	GlassWash2	60	100.00%	90.0%	2	190.0	
Assemble pre-laminate	PLATool	60	100.00%	90.0%	2	190.0	Ethyl Vinyl Acetate, Top Glass
Lamination	Laminator	60	99.90%	90.0%	2	623.0	
Junction Box attachment	JBATool	60	100.00%	90.0%	2	50.0	Pottant, Junction Box,
Framing	FrameTool	60	100.00%	90.0%	2	50.0	Frame
Hi-pot test	HiPot	60	100.00%	90.0%	2	100.0	
Sun Soak	SSTool	60	100.00%	90.0%	2	100.0	
Module IV test	ModuleTester	60	99.90%	90.0%	2	360.0	
Sorting & Label	SLTool	60	100.00%	90.0%	2	200.0	

Table 3: Coevaporation Input Parameters

As can be seen from Table 2, the line balance for a 100 MW factory is very good with almost all equipment having a 120 or 60 panel per hour throughput. It takes approximately 120 panels per hour in a 24x7 operation to approximate a 100 MW factory size given 150 watts per panel and utilization between 70 and 80%. Two exceptions are the selenization furnace and the transparent conductive oxide (TCO) deposition equipment.

Coevaporation

The second approach is based on CIGS formation using coevaporation equipment. Referring to the previously described Figure 2, the coevaporation process replaces the CIG sputtering step and the selenization furnace step with a single process step utilizing all four elements required to form the CIGS film.

As can be seen from Table 3 in comparison to Table 2, the coevaporation process has eliminated 1 step and reduced the equipment set by 24. However, the coevaporation equipment is more expensive than the equipment they are replacing.

References

1. Solarthinfilms.com, http://www.solarthinfilms.com/active/en/home/photovoltaics/cigs_technology.html
2. Sinovoltaics.com, http://sinovoltaics.com/solar-basics/solar-cell-guide-part-2-thin-film-cdte-cigs-solar-cells/
3. U.S. Photovoltaic Manufacturing Consortium, http://www.uspvmc.org/technology_PVMC.html

Note: The models used in this paper are available as part of licensing Factory Commander® software from WWK.

New Technical Publishing Platform Revolutionizes Mobile Media Distribution

In response to the disappearance of the vast bulk of science/business-to-business (B2B) trade media titles in recent years, a new platform is being built by InPress Media Group called; Apptheneum. The platform is a cross discipline discovery engine that allows scientists, engineers, technologists, and researchers to find and publish/distribute media across traditional disciplinary borders, enabling ideas to spread beyond their point of origin to accelerate understanding and innovation.

Introduction to Apptheneum: http://youtu.be/iT3oVot2vRY

To get a test account, email: beta@apptheneum.com or visit one of these social pages:

Youtube: http://www.youtube.com/channel/UCQCgIAvVx6iCzrmo4OpUy7g/videos

Facebook: https://www.facebook.com/apptheneum

G+: https://plus.google.com/105073868196192203762/posts

Twitter: https://twitter.com/apptheneum (@apptheneum)

LinkedIn: http://www.linkedin.com/groups/apptheneum-5106292/about

Tumblr: http://apptheneum.tumblr.com/

The first mobile application published on the new platform is the "Solar Channel" that can be downloaded at:

https://itunes.apple.com/gb/app/solar-channel/id715441844?mt=8

https://play.google.com/store/apps/details?id=com.imgzine.solarchannel&hl=en

For more information, contact Matt Grimshaw at matt@impressmediagroup.com.

Warning to Anyone Upgrading to Windows 8.1 from 8.0

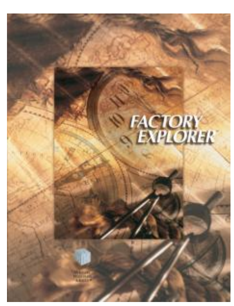
Microsoft has an issue with the Windows 8.1 upgrade that requires removal of Sentinel Runtime Drivers (HASP drivers). Simply uninstalling the drivers will NOT allow the upgrade to continue. This is a known issue with Microsoft and they have done nothing to fix it. The best solution we have found is located at:

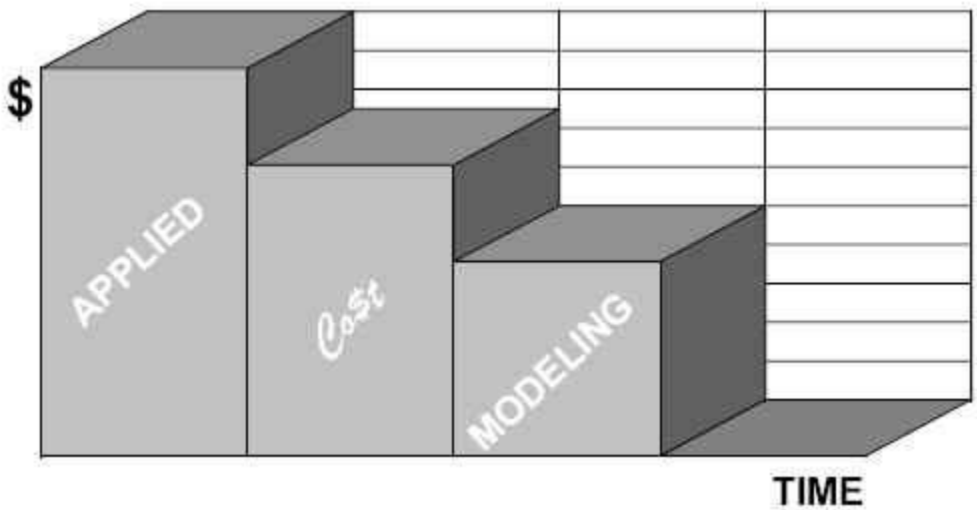
http://answers.microsoft.com/en-us/windows/forum/windows8_1-windows_install/windows-8-81-uninstallation-of-sentinel-runtime/8870b89c-3223-4848-a749-9ca02f45c312

WWK can confirm that on our Windows 8 test platforms we were able to successfully uninstall the Sentinel Runtime Drivers, upgrade to Windows 8.1, reinstall the drivers, and verify correct operation of WWK software tools. Simply uninstalling the HASP drivers from the Control Panel will not complete the process. The latest Sentinel Runtime Drivers must be installed, uninstalled, and the computer rebooted before the 8.1 upgrade will proceed. We did not need to use the command line version, (used GUI version) but others have indicated that was the only thing that worked for them.

Equipment Dedication Comes to Factory Explorer®

WWK has just released a beta version of FX 2.10.3 that includes equipment dedication capabilities. Equipment dedication can be selected by equipment group and turned on and off at the process step level. Customers on maintenance are eligible to request this beta and will be provided the final release as part of their contracts.





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