CIGS, CdTe thin-film PV equipment sector emerges, but standardization remains elusive

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ABSTRACT

Although the entire solar manufacturing industry, from raw materials to finished modules, has enjoyed strong double-digit growth rates over the past several years, few sectors have soared like the amorphous-silicon thin-film photovoltaic equipment space. Much of this prodigious multibillion-dollar booking activity can be attributed to the acceptance of the turnkey production packages offered by the likes of Applied Materials, Oerlikon and Ulvac. These suppliers' plug-and-play, standard toolset solutions are attractive to companies seeking to get into the TFPV module business on a fast track and then scale up their capacities in multimegawatt chunks to achieve grid-competitive cost-per-manufactured-watt metrics. One notable exception to this turnkey trend is United Solar Ovonic, which has spent years developing its proprietary roll-to-roll a-Si TFPV production equipment and factories. But what about the equipment sector for the two main non-silicon thin-film PV technologies, the direct-bandgap polycrystalline pair of cadmium telluride (CdTe) and copper indium gallium (di)selenide (CIS/CIGS)?

The vast majority of nonsilicon TFPV cell and module manufacturers have developed their own processes and designed their own custom toolsets, especially for the semiconducting absorber layers, often building the gear with the help of contract manufacturers and OEMs. CdTe pioneer First Solar regards manufacturing technology as one of its IP crown jewels and a crucial part of the company's successful 'copy smart' capacity-scaling strategy.

This nonstandardized situation is unlikely to change in the near term, since CIGS companies in particular are placing their bets on a wide variety of absorber-layer growth/deposition strategies and substrate types to differentiate themselves competitively as low-cost, volume-manufacturing TFPV contenders. The vacuum and atmospheric processes range from thermal coevaporation to sputtering, electroplating to nanoink printing, sometimes in combination with some sort of selenization or rapid thermal step. The integration approaches can be either discrete or monolithic, and the substrate materials receiving those critical films range from flat-plate or cylindrical glass to flexible steel foils and polymer sheets.

For both CdTe and CIGS, the U.S. National Renewable Energy Laboratory (NREL) has identified the standardization of equipment for the growth/deposition of the absorber layer as a critical issue for the development of lower-cost, reliable TFPV modules. Two early examples of de-facto standard processes (though by no means standardized handling systems, substrates, or tool designs) exist in the CIGS realm: molybdenum, deposited via

Figure 1. Zinc oxide TCO sputtering tools for CIGS thin-film PV being assembled at centrotherm's factory.

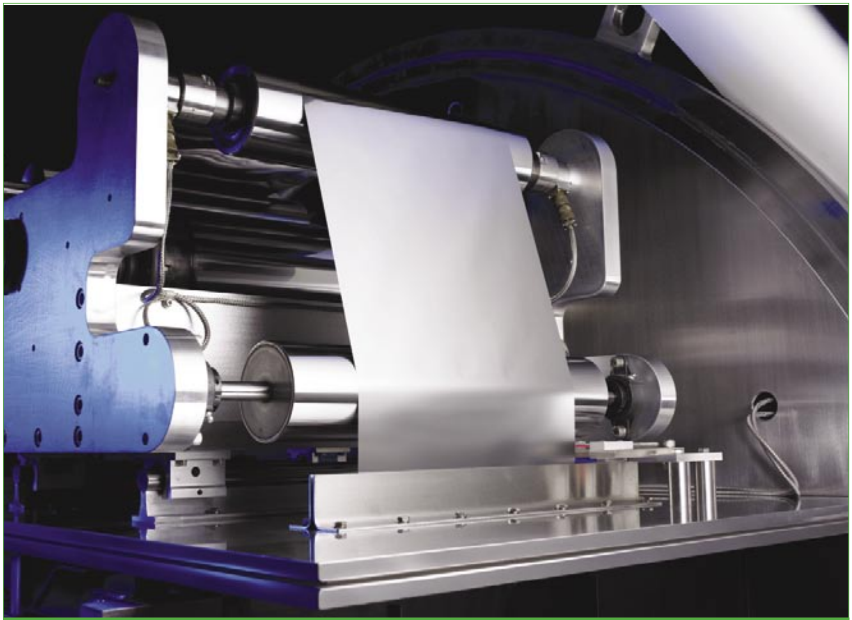

Figure 2. The web payout system of the molybdenum and TCO modules on Veeco's FastFlex CIGS processing platform.

sputtering, remains the back-contact film of choice; and most device-makers use zinc oxide, laid down via sputtering or chemical vapor deposition, as their front contact/transparent conducting oxide (TCO) layer (although a few use indium tin oxide). Laser scribing, curing, and testing tools also have a fair amount of commonality across some platforms.

Off-the-shelf integrated systems solutions, especially for CdTe/CIGS absorber tools, may be years from widespread acceptance. Yet a growing number of OEMs and custom tool developers are jumping into the fray, betting that the nonsilicon portion of the thin-film/organic PV equipment sector will be a substantial part of an overall market forecast by NanoMarkets to reach nearly US$1.44 billion by 2011.

While Applied Materials and Oerlikon stay focused on their a-Si TFPV equipment and turnkey factory efforts and have yet to confirm any CdTe or CIGS business, process-oriented companies like Veeco, centrotherm, BTU, Stangl, and Solarcoating have made inroads in the nonsilicon TF sectors. Custom equipment and automation systems outfits like Northfield and Owens Design are also working with a growing number of PV start-ups for their tool design, engineering, and manufacturing needs.

To turnkey or not to turnkey

One company taking a page from AMAT's playbook – and its own – is centrotherm, which launched what it calls the first turnkey CIGS module production line in early 2008. The German company hopes to leverage both its years of experience in the crystalline-silicon side of the solar business, where it has made a tidy sum selling turnkey manufacturing systems, and the thin-film sputtering expertise of its FHR unit.

Figure 3. BTU's thin-film PV furnaces offer tight thermal uniformities for CdTe and CIGS manufacturing.

"We want to offer to someone new to the industry or sector a low-risk, complete production solution," said Wolfgang Herbst, Senior Manager of market and technology research. Throughput, efficiency, and yield guarantees are part of the package, as well as project management, equipment installation and start-up, production ramp, and customer staff training components.

To target the "large-scale, high-volume markets," centrotherm has chosen to go with a CIGS-on-glass (1.5m^2) approach, using thermal coevaporation for the absorber-layer process and sputtering for the precursor and back-contact metal films, he explained. The company claims its 550°C self-adjusting process has a speedy 60-second cycle time, compositional uniformity of ±2% and thermal process uniformity of ±2.

Although the company has an R&D pilot line and well-equipped thin-film analysis lab in Blaubeuren, Herbst was quick to point out that, "we are not getting into the module business." Centrotherm has yet to receive any orders for its compact 5000m^2, 35 to 50MW CIGS turnkey lines, but the company is "in negotiations with potential customers."

Flexible process, flexible substrate

Although Veeco does not characterize its CIGS tools as being part of a turnkey solution, its FastFlex equipment platform, much of which came through the door with the purchase of Mill Lane Engineering in May 2008, integrates all of the core process steps except the cadmium-sulfide buffer/junction layer. The product name suggests the substrate and production method at work: spools of flexible steel foil or polyimide material, run on a roll-to-roll or web-process system.

John Patrin, Director of business development and product marketing, explains the rationale behind the acquisition. "Customers had asked, 'since you sell (deposition) sources), why don't you sell the whole system? It would be advantageous to have one vendor to work with.'" Mill Lane was already shipping molybdenum and TCO systems at the time of the buyout, then Veeco added its sources for the CIGS thermal evaporation steps. "One of the biggest challenges is integrating the thermal source technology into these (flexible) architectures, because of the demanding process temperatures."

Veeco's modular system architecture employs what Patrin calls "deposition zones," up to five each for the Mo and TCO films, and one to three for the CIGS, currently allowing the user to optimize its process and increase throughput for flexible webs up to 350mm wide, and scalable to a metre in width soon. He says total thickness variation for the sputtering and coevaporation sequences is better than ±5%, with TTV often seen down to ±3%. As for materials utilization of the 1.7μm- to

2µm-thick CIGS layers, he claims "results of better than 50%" using the thermal sources.

Patrin pointed out the possible pitfalls of processing flexible TFPV materials without proper metrology and control measures. "If you have a thousand-metre roll, you don't want to finish that roll and realize that your stoichiometry wasn't right, or there was some problem that you could have fixed right away if you had a thickness monitor or compositional measurement in situ. You can't run for a day and a half, and measure it and say, 'oh shoot!' That's a lot of material and a lot of cost that you could just throw in the garbage. There needs to be better in-situ metrology, so then they can maybe have longer rolls and higher uptime."

"It's an area that we'll be spending a lot of time on, since we think it's something really critical to bringing down the cost of solar, because it will help improve yields," he noted. In addition to the potential for using optical inspection tools to measure scribe widths and depths in a production setting, another process control application that Veeco is exploring is the "integration of XRF (x-ray fluorescence) capability into the system." He believes that this might be done "on a per-module basis, because then you can understand that the copper in a particular module needs to go higher or lower, that the rate wasn't sufficient or was too high."

The heat is on

Although BTU's Jack McCaffrey admits that several of his CIGS and CdTe customers are asking about in-line process controls, he believes it is "not a big concern yet." People are more likely to say, "get me capability and get me volume," with "get me quality" coming once the production lines are more mature, according to the VP of engineering and product development of the company's alternative energy group.

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BTU's bailiwick is providing high-quality belt furnaces, some notably customized, others more standard, for several process steps for the pair of II-VI compounds. Its cadmium chloride ($CdCl_2$) annealing tool for CdTe, which operates in the mid-400s°C, features tight uniformity and thermal controls specifications, with performance around ±2°C under steady-state conditions. The company's gas containment and atmospheric control also helps manage uniformity but more importantly features a barrier technology that keeps the nasty likes of cadmium contained.

"We're focusing in an area which isn't the crown jewels, it's really a middle step – CdTe's real crown jewels are laying down the cad telluride and cad sulfide," explained McCaffrey. "We're in an area where most people do it the same way, so it's about getting market share, and not that big a change from something we've already built. It's a real sweetspot for us."

As for CIGS, BTU does not work with any of the companies using thermal coevaporation but "plays best in the two-step/RTP process," where companies sputter, plate, or nanoprint the CIG absorbers in some fashion, and then need to "find a way to get selenium into the matrix to react" and activate those key layers, according to McCaffrey. "Some use hydrogen passivation just prior to the selenization step, some do not, but where they use it, we have a play and can deliver hydrogen either to a sheet of glass or a moving web, typically in the 400°C range."

"Selenization is probably the most crucial step in CIGS," he continues, "and the most common method used is solid-source selenium deposition, which we can

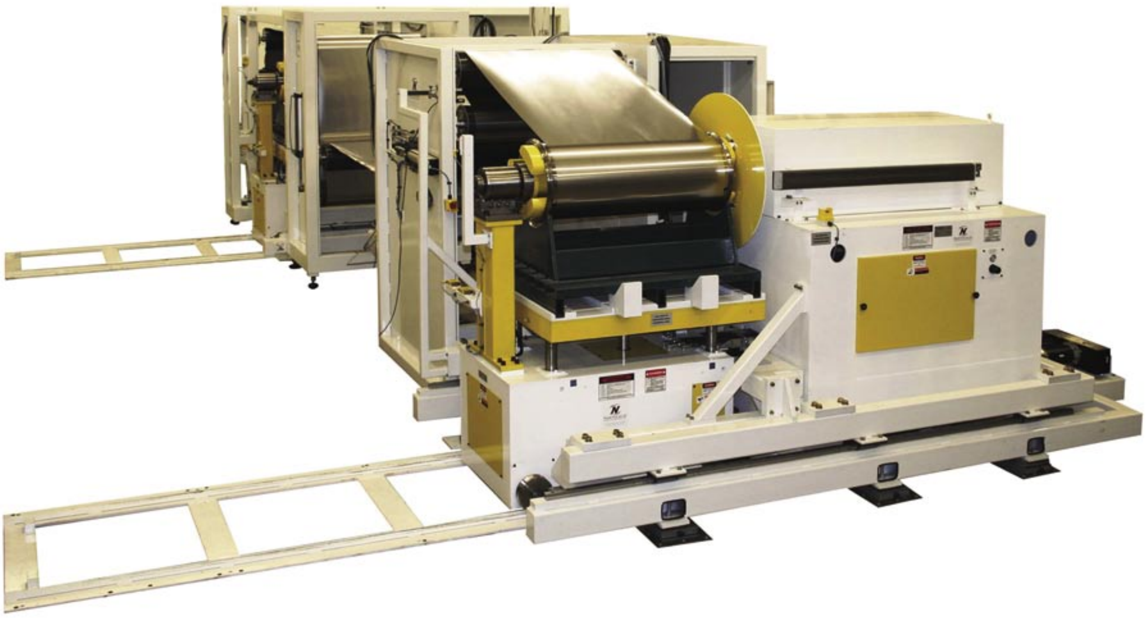

Figure 4. A 12,000lb (5455kg) heavy roll system developed for flexible thin-film PV applications by Northfield Automation.

deliver, with good temperature uniformity and control in the 500°-550°C range. For those who add sulphur in their zeal to get higher efficiencies, it's usually deployed in a similar way to how the selenium is, and we can provide a similar machine."

With some CIGS customers that boast "very fast front ends" asking first for 30-metre-long furnaces with 60MW capacities and now seeking something double that size or more, and flexible webs widening to a metre across and more than one web possibly running through the tool, BTU's vaunted thermal uniformity is being put to the test. To deal with this trend, McCaffrey said the company has a "configurator project" with an objective of "working on standard heater designs and the like so we can really work out a scheme where we'll be able to model that quickly and cut down on some of the engineering lead time that we need to do to (design and build) a longer, wider system."

Web automation situation

One company thoroughly versed in the vagaries and nuances of advanced thin-film roll-to-roll web processing is Northfield Automation, which works with customers in the flexible display, battery, and microdevice sectors as well as with photovoltaics players. The firm recently partnered with Solarcoating Machinery, a German company also expert in the realm of flexible TFPV process and equipment, especially coating and deposition.

Helping new customers understand that flex TFPV processing is not just "unrolling and rolling the web" is a "big battle," according to Mark Wegner, Executive VP of Northfield. "As an equipment manufacturer providing the automation, you're working with them and educating them" about issues such as "thermal cycling over a lifetime" and the challenges of transitioning "from a benchop sheet process to production-scale R2R manufacturing."

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"As you're working with each layer and building that stack up," he said, "it's about the tolerances of what you're trying to hold with each of those layers and matching them up. You're dealing with adhesives, coating and thickness, all those variables – the overall tolerance of that package as it's completed needs to be very tightly controlled.

"You're dealing with plastics expanding as you're curing on a particular web, and the thermal properties that you're getting from the plastic, but then you're doing an additive process in a state where it's not truly stabilized. How do you achieve that end window you're looking for, when you've already burned up three-quarters of that window of tolerance with the previous processes?"

Another nagging issue is the quality of the web material itself (with certain polymers said to vary ±10% across the width of the film) and the impact it has on processing quality and efficiency, Wegner believes. "The incoming material has to have certain characteristics and tolerances that are maintained. Otherwise, if you want a manufacturing tool that does this process, you need to have vision registration and capabilities because the stresses and changes to that material must be compensated for. If you have to localize registration and do that on a wider web, it creates more capital cost and slower throughputs."

The customer speaks

Although the equipment vendors pursuing CdTe and CIGS contracts are winning an increasing amount of business and seeing a few early signs of standardization, some basic customer wish-list items have nothing to do with a system's capabilities or reliability and reveal that tool suppliers still have some improvements to make in their own operations.

Bret Adams, Senior Director of sales and marketing of CIGS start-up DayStar Technologies, said his company takes a "commodity approach" toward equipment, except for the IP embedded in its critical absorber-layer processing system. When asked in what areas OEMs needed to improve, he didn't hesitate. "First and foremost, tool vendors have lead times that are too long. Sometimes their lead times take them out of consideration; in some cases, we can design things faster than the tool guys."