PV's 20/20 Vision Demands Cost-Efficiency Duality

It is only by applying both efficiency enhancement and cost reduction simultaneously that some of the solar targets for 2020 are likely to be reached. And the heavy lifting will ultimately fall on the production equipment supply chain.

By Finlay Colville, Coherent Inc., Santa Clara, Calif. -- PV Society, December 10, 2009

Technology roadmaps for solar by the year 2020 have received a great deal of attention recently: revised forecasts for projected market sizes, expected breakdowns for the different technologies satisfying demand, and estimates of required capital/operating expenditures and levelized cost of energies. Contrasting this are the wish lists of our regional solar advocates — both policy-driven and industry-targeted — for cumulative installed capacity per country.

"Twenty" is a recurring theme everywhere by the time 2020 comes around: 20% efficiencies becoming mainstream for 120 µm thick crystalline silicon (c-Si) cells,[1] 20 GW installed capacities within single countries (take the example of India)[2] and, of course, renewed vigor toward the 20-20-20 targets from Europe's Climate Change Package (20% cut in emissions of greenhouse gases relative to 1990, 20% increase in the share of renewables in the energy mix, 20% cut in energy consumption).[3]

Ten years from today may not seem like a long time in the overall context of PV. After all, it did take 66 years between the photoelectric effect first being reported (Becquerel, 1839)[4] and finally explained (Einstein, 1905)[5] — enough time for a second industrial revolution to occur. Even then, it took another 15 years before the theory behind the photoelectric effect was generally accepted within the scientific community[6] — eventually overcoming the fixation by stubborn experimentalists[7] such as Millikan,[8] who held on to classical theory grounded in assumptions that light waves travelled within a mysterious ether.

Quantum theory reigned supreme by the mid-1920s, the photoelectric effect underpinned the emergence of photovoltaics, and the newly named photon (Einstein's light-quantum, the first particle predicted theoretically)[9] adopted a wave-particle "duality" as quantum mechanics swept modern physics firmly into the 20th century. Physicists got used to the duality concept — that the photon could exhibit the behavior of both waves and particles.

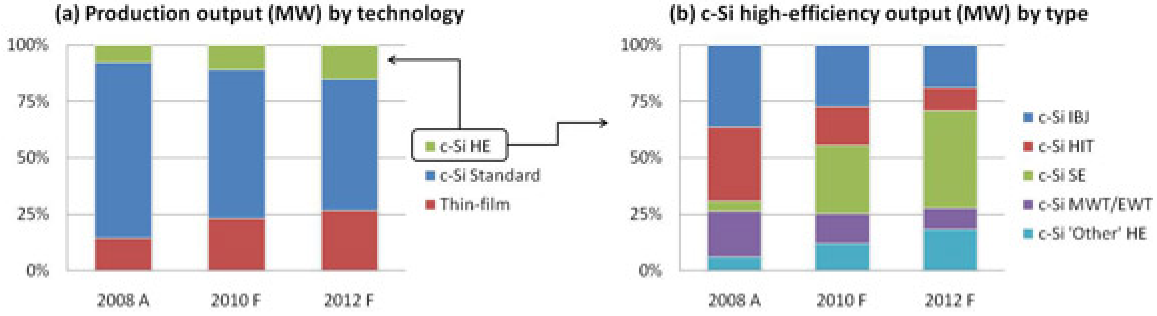
Long-term projections today within the solar industry deal typically with forecasted market size (or cumulative installations), with top-level technology splits (c-Si, thin film, etc.) representative of manufacturing output, with levelized cost of energies for the different approaches, and of course with supply-demand dynamics. And working backwards, it doesn't require using any quantum mechanics to come up with a to-do list in terms of raw material requirements, solar cell efficiencies, and capex/opex costs that are needed to reach these end goals.

However, a final category — often overlooked — is the availability (indeed capability) of the equipment supply chain to meet these targeted objectives. Although broad categories are often spelled out, allocating tool suppliers to either c-Si or thin-film equipment supply (or turnkey vs. customized), the current landscape and trends highlight an increased fragmentation in production tool choice.

Increased range of cell concepts

Looking at the range of technology types used within cell manufacturing, the standard segmentation is based on c-Si, thin-film, and a generalized group including almost anything "Gen 3" (concentrator cells, or CPV, kick in further downstream than cell manufacturing). The normal approach has been to break out thin-film technologies into a-Si/tandem/µc-Si, CIS/CIGS and CdTe, but short-term technology evolution within c-Si cell types demands a similar kind of approach. To guide the rationale that follows, the criteria for discrete cell/panel concepts is based on fundamental differences in the raw materials and/or equipment supply chain. Ultimately, the lack of viable production tooling may provide a greater barrier to new cell concepts being adopted than their theoretical cost/efficiency potential or raw material availability.

To clarify the increased range of technologies entering the mix, let's divide up production output (not capacity) properly by technology, both actual and forecasted. The graphs within Figure 1 highlight the key changes over the next few years that call out for different manufacturing processes, with high-efficiency c-Si cells having the greatest impact here. No attempt to extend this to 2020 — 10 years is actually a very long time by any standards. But, rather, one can assume (hope) by this point, panels are categorized only as (i) very high-efficiency, (ii) very low-cost, or (iii) high-efficiency and low-cost — not by their material/cell-concept nomenclature.



1. The changing landscape of solar production includes the decreasing fraction of production from standard c-Si cell types (a), caused by the success of thin-film and high-efficiency (HE) c-Si cells offering lower cost and higher conversion efficiencies, respectively. It also includes the strong growth of high-efficiency selective-emitter (SE) cells (b). The "other" category combines a range of technologies: laser-fired contacts, improved surface texturing, new passivation layers/stacks, and advanced metallization approaches.

New tooling for new cell concepts

The big game changers right now within the c-Si segment come under the heading of "selective emitter" — a somewhat generalized term that actually encompasses varying approaches (and process flows / production tooling) toward the same end goal.[10] Selective emitters provide an immediate efficiency boost to the standard c-Si cell type, anywhere from 0.3% to >2% depending on other efficiency-enhancement steps implemented alongside (improved passivation, metallization, etc.). Bear in mind that selective emitters are not new (BP Solar's trailblazing LGBC Saturn cells epitomize the rationale for selective emitter technologies being promoted today);[11] it is simply that the solar industry needs them now, and didn't in the past.

The other efficiency-enhancement steps for c-Si cells — much discussed within the research community — relate to improvements at the back surface: rear passivation stacks, laser-fired contacts (LFCs), rear localized contacts, etc. Possibly, a standalone category for rear-passivated LFC c-Si cells may emerge within the next 12 months, but the prevailing thought remains that rear-surface changes will form incremental improvements to the advanced c-Si cell types shown in Figure 1 (i.e., more additive in nature) with timelines dictated by industry-wide trends governing the introduction of wafers with thicknesses below ~160 µm. Put simply, front-surface selective emitter cells will eventually be complemented with rear-surface efficiency-enhancement options, when this emerges as a necessity.

This diversity across these c-Si cell concepts raises pertinent equipment supply chain and standardization questions — topics discussed for some time by the SEMI PV Group.[12] Will greater choice for cell manufacturers today end up diluting efforts to improve time-to-market for new cell concepts? And what impact does this have on industry standardization?

An indication of trends pursued by c-Si cell producers can often be found by reviewing the new cell processes being promoted down through the equipment supply chain, starting by default with the turnkey c-Si manufacturers. Similar to thin-film line suppliers diversifying equipment offerings to a-Si or CIGS manufacturers, c-Si end users may soon have turnkey c-Si line choices based on different approaches to selective emitter c-Si cells alone (etch-back, diffusion-masking, laser-doped), or even combined cell/module lines for complete back-contact/wafer-to-module wrap-through concepts.

New process steps for generic roadmap deliverables

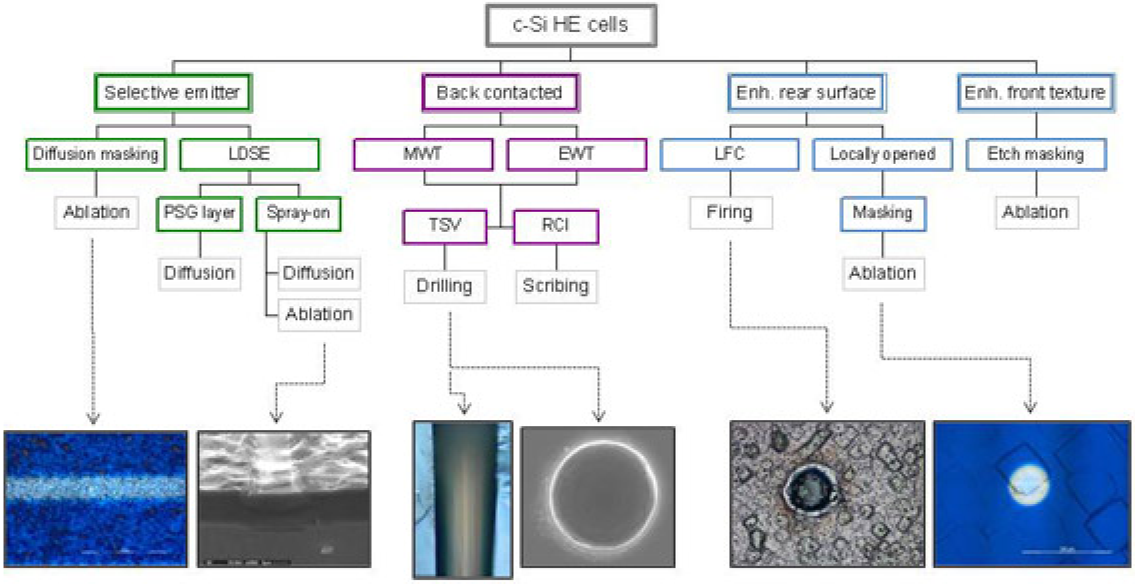
Too much attention, however, to the different c-Si cell concepts — or complete lines offered to each — somewhat masks the big challenges facing the whole equipment supply chain for roadmap alignment out to 2020. In fact, it turns out that any incremental (or standalone) efficiency enhancement steps that work across a range of cell types take on higher priority than the cell concepts themselves. So, although it is highly unlikely that every advanced cell concept will succeed in high-volume production, a common demand across the board will be for generic new equipment types that are:

- Applicable to analogous process stages across multiple advanced c-Si cell concepts.
- Suitable for use with c-Si wafer thicknesses at the 100 µm level, ideally based on non-contact technology.
- Fab-viable; some of the processes being proposed today are certainly highly speculative in nature, with limited data at the R&D level, far less in support of 24/7 operation.

Let's now take one technology type to illustrate these points — one with a somewhat fortuitous link with our historic, photonic theme of earlier. Having diverted his brainpower after 1905 (with the photoelectric effect) to the small task of unifying Newton's laws of gravity with special relativity ("general" relativity), in 1917 Einstein revealed a statistical probability-based analysis for light-quanta interacting with electrons moving between energy levels within the atom.[13] Noting that "a splendid light has dawned... about the absorption and emission of radiation," Einstein predicted an altogether new type of transition called "stimulated emission" — the SE within the acronym LASER.

Some 90+ years on, laser-based process tools now form one of these new equipment types that feature within the production lines for all high-efficiency cell concepts, and that satisfy the three bulleted requirements above. It is therefore no great surprise that laser-based process tools are currently the subject of some of the most extensive R&D and process development throughout the c-Si supply-chain.

Upgrading from a standard c-Si cell production line to an advanced high-efficiency c-Si cell concept often requires the addition of several new process steps (efficiency enhancements with single additive steps are always welcome). Within Figure 2, the laser-specific process is isolated for various schemes currently under investigation. Although there are naturally differences in the optimized tool layouts for each of these (different laser sources, output parameters, beam manipulation to the wafer surface), the underlying principle of adopting laser-based equipment remains a key deliverable to satisfy industry roadmaps being proposed out to 2020. Therefore, it almost becomes of strategic importance that laser-based process tools succeed within c-Si lines as a whole, and this calls for the immediate availability of new turnkey laser-based process tools optimized specifically for the high-efficiency cell concepts.



2. Illustrating how key technologies play a driving role through the equipment supply chain, applicable to a range of different cell concepts. Here, laser-based processes (identified by the terms "ablation," "diffusion," etc.) have common pull across various high-efficiency (HE) cell types.

Conclusions

The underlying theme today appears to be efficiency enhancement with the "same" cost structure presently in place for standard c-Si cell types. Somewhat conservative — but absolutely necessary — there is really no need for any quantum leap in the short term. Improving the efficiency of standard c-Si cells initially has a finite cost entry point until volume production and process optimization are complete. For now, increasing cell/panel efficiencies has its own set of challenges being felt down through the supply chain. To simply move into volume production for high-efficiency cells, while maintaining the same cost structure, is a considerable achievement.

Conversely, less newsworthy but equally valid are those quietly reducing capex/opex costs while retaining cell efficiencies at their current level. But ultimately, it is only by applying both efficiency enhancement and cost reduction simultaneously that some of the targets for 2020 are likely to be reached. And the heavy lifting will ultimately fall on the production equipment supply chain; whether turnkey or custom built becomes almost a secondary issue. Consequently, new tooling that can provide cost-efficiency duality will be required, with a timeline for introduction still a few years away. At this point also, standardization will be essential.

Much can be achieved, though, in just 10 years. The period between 1895 and 1905 witnessed the experimental discoveries of X-rays, the Zeeman effect, radioactivity, the electron, and the extension of infrared spectroscopy into the 3-60 µm region. And just 10 years later, the remarks of Robert Millikan provide further enthusiasm: "I was compelled in 1915 to assert [the photoelectric effect's] unambiguous verification in spite of its unreasonableness, since it seemed to violate everything we know about the interference of light."[14] Within the solar industry, there is no need for earth-shattering breakthroughs worthy of Nobel prizes, but of course they might just help in getting all those 20s in place ahead of time.

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