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editorial

# Balancing optimization and innovation

Disruption is often a bad word in established industries, and electricity generation is no exception. But with silicon solar cells getting ever closer to efficiency limits, innovative solutions are needed.

The costs of the leading photovoltaic (PV) technology, based on crystalline silicon, have reduced tremendously in the past eight years due to demand growth and economies of scale. There is now less and less room to make savings in PV electricity by reducing the cost of the solar modules. Most cost reductions for the end-user will likely come from reductions in balance-of-system costs, which include land use, installation and so on[1]. One way to decrease these costs is to produce more electricity in the same area — in other words, to increase the module conversion efficiency. Therefore, for mass-production of PV electricity, the silicon PV community now prioritizes increased module efficiency over reduced module costs.

To improve the efficiency of silicon solar cells and modules, their optical and electronic properties need to be further optimized. One trend is to switch from p-type to n-type silicon wafers (wherein the majority carriers are holes and electrons, respectively), which are less sensitive to defects and degrade less over time. Strategies to passivate electronic defects at metal/silicon interfaces are being transferred from labs to industrial production lines. Cell designs are being optimized to reduce optical losses. For example, contacts at the front of the cell hide the absorber from the sun and can be replaced by contacts at the back of the cell, avoiding shadow losses.

Such continuous progress in materials quality, surface passivation and solar cell design is exemplified in a recent article by the Kaneka Corporation R&D team from Japan, published in this issue (article no. 17032). Kunta Yoshikawa and colleagues used passivated monocrystalline n-type silicon with contacts at the back of the cell, to reach a record efficiency of 26.3%. These efficiency gains bring silicon solar cells closer to their 29.4% theoretical efficiency limit. As explained by Pierre-Jean Ribeyron (article no. 17067), this is a small revolution for the community, for whom 26% represented a practical limit for monocrystalline silicon solar cells. At the Silicon PV conference held in Freiburg last month, Yoshikawa showed how Kaneka has subsequently achieved 26.6% efficiency based on the same design and described further plans for improvements.

In parallel, multicrystalline silicon solar cells with record 21.9% efficiency were recently prepared at the Fraunhofer Institute in Germany, using n-type silicon and an efficient back surface passivation[2]. Although multicrystalline cells are less efficient than their monocrystalline counterparts, they hold 65% of the silicon PV market thanks to their lower cost.

The PV industry is also exploiting these strategies to mass-produce high-efficiency monocrystalline solar cells. SunPower has announced a production average cell efficiency of 25% using n-type monocrystalline silicon with back contacts[3] and some of Tesla's solar tiles will use the Panasonic n-type passivated cells[4]. Research is also underway to simplify production processes. For example, Andrea Tomasi and colleagues (article no. 17062), report an innovative process to fabricate back contact solar cells, necessitating only a single alignment step instead of two.

Legitimate excitement surrounds all of these results, but as Yoshikawa noted at the Silicon PV conference: "As we are getting closer to the theoretical efficiency, I feel that we are also getting further." Additional improvements towards the fateful 29.4% limit for silicon single junction cells will require ever harder work for ever smaller gains. More innovative solutions are needed to further reduce the cost of PV electricity and increase its availability on a massive scale.

In this regard, researchers are solution-focused and pragmatic. Now that single junctions are near ideal, multi-junctions are coming to life. In multi-junction designs, several solar cells are placed on top of each other. Each sub-cell is optimized to harvest a different portion of the solar spectrum so that the ensemble harvests more light and with lower losses than a single junction. Extremely efficient multi-junction solar cells (38.8% under one sun illumination), using more expensive semiconductors than silicon, already exist but their high cost limits their market access. The silicon community believes that their solar cells offer a cheap alternative sub-cell and that silicon-based multi-junctions might be able to piggy-back on existing silicon production lines and markets. Currently there is no ideal partner to complement the silicon absorption spectrum. Halide perovskite cells hold some promise, particularly regarding ease of fabrication and costs, but perovskite/silicon multi-junction efficiencies are still below those of the best silicon single junctions[5,6]. In comparison, III-V/silicon multi-junctions already surpass the theoretical limit for silicon single junctions[7,8], but their design and/or cost structure is far from ready for industrial deployment. Finally, balance-of-system costs could vary with the specific multi-junction design, and a global vision will be important to drive the development and adoption of silicon-based multi-junctions.

In the meantime, module manufacturers and plant operators are adopting an elegant solution to increase the power production of single junction modules: bifaciality. Traditionally, light impinges solar cells from the front only. In bifacial solar cells, light from both sides reaches the absorber, so they also collect diffuse light at the back of the cell. Significant gains compared with monofacial modules (15–20%) have been evaluated in field tests and at bifacial plants[9]. Bifacial modules are forecast to make up about 20% of the market in 2021[10]. Finally, the time profile of their output power changes depending on their orientation, allowing shifting of electricity production peaks throughout the day.

Crystalline silicon PV develop in a delicate balance between technological optimization and innovation at both lab and industrial scales. Careful scale-up and skill transfers between these sectors are the keys to ensure the rise of silicon PV efficiencies. ❒

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