Why are monocrystalline wafers increasing in size?

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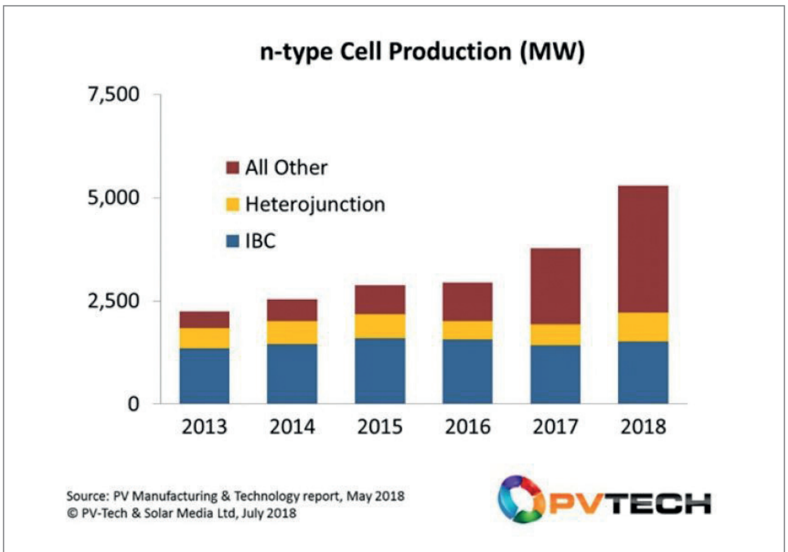
Abstract

The PV industry is undergoing rapid technology changes that have been driven by the well-documented swift adoption of monocrystalline wafers. Less well understood, however, is that within this wafer technology transition comes a shift to larger wafer sizes, and this includes p-type and n-type mono-Si wafers.

The solar industry has been undergoing major technology changes, notably the shift to passivated emitter rear cell (PERC) and more recently the migration away from multicrystalline wafers to monocrystalline. These developments have led to the mass production of high-efficiency p-type mono-PERC bifacial cells, and half-cut and shingled technologies for modules, which are available in double-glass, multi-busbar and half-cell configurations. All of this is pushing high-efficiency products into the mainstream high-volume markets.

Various n-type cell options (for example, nPERT and selective emitter), as well as heterojunction (HJT) technologies, have secured a gradual but increasing foothold in the market, not least because of a shift in wafer size, which reduces overall production costs. The net result of the new capital investments has seen the number of (meaningful) n-type cell producers grow to approximately 20, with many others engaged at the R&D level too, or working with research institutes on collaborative projects. Consequently, global cell production of n-type has grown from the 2GW level in 2013 to just over 5GW in 2018, and is projected to be more than 5GW in 2019 (Fig. 1).

Figure 1. New entrants to n-type manufacturing drive annual production levels to more than 5GW in 2018.



"Wafer size change is occurring faster than many people realize."

Indeed, a big part of SunPower's latest next-generation technology (NGT) interdigitated back contact (IBC) cells, which will power its S-series modules, is the shift to larger n-type wafers (Fig. 2). This is also the path taken by LG Electronics.

Traditionally, monocrystalline silicon wafers before 2010 were classified as *small size* with dimensions 125mm × 125mm (164mm-diameter silicon ingot), and only a small number with dimensions 156mm × 156mm (200mm-diameter silicon ingot). These had been the dominant ingot size in the semiconductor industry until leading companies adopted 300mm-diameter ingots.

Monsoon Wang, Director of Product Marketing at LONGi Solar, told PV Tech that the wafer size change is occurring faster than many people realize.

"Yes, this trend is happening," noted Wang. "Only ten years ago, almost all the mono wafers were 125mm. A few years later, some producers were starting to supply 156mm wafers, and we have seen that these almost complete transitions can take two to three years. So, by 2014, the transition to 156mm wafers had happened. The reason for this change is that the wafers were much smaller and production costs much higher, as the overall capacity was much lower than for multi. This was the driver for all cell producers to switch to the then larger wafer size."

After 2010, 156mm × 156mm wafers increasingly became the popular choice (lower cost per watt) for p-type mono and multi wafer sizes. As a result of the lower production costs, 125mm × 125mm p-type wafers were almost eliminated from the market by 2014, with only a few IBC and HJT cells using the 125mm × 125mm n-type wafers, as the larger-size technology lagged p-type investments because of the niche nature of the applications.

By the end of 2013, a number of China-based wafer producers (LONGi, Zhonghuan, Jinglong, Solargiga and Comtec) jointly issued the standards for (M2) 156.75 × 156.75 p-type mono wafers (205mm-diameter silicon ingot) and (M2) 156.75 × 156.75 p-type mono wafers (210mm-diameter silicon ingot).

Without increasing the overall dimensions of a 60-cell module, M2 wafers could increase module power by more than 5Wp, a significant boost for a competitive cost per watt, thus rapidly becoming the mainstream and maintaining that status for several years. During that period, there were also a few (M4) 161.7mm × 161.6mm (211mm-diameter silicon ingot) wafers on the market; the area of the M4 was 5.7%

larger than that of an M2, and these wafers were mainly used for n-type bifacial modules.

The move from 156mm × 156mm to the larger format of 156.75mm × 156.75mm in mass production started in 2016. The old 6” format (156mm × 156mm), recognized by all, is expected to disappear completely from the market by the end of 2019, according to the 2019 edition of the ITRPV survey (Fig. 3).

The transition to a new larger ‘standard’ wafer size, however, is going to prove difficult, as will comparing cell/module conversion efficiencies on a like-for-like basis going forward. Nevertheless, the industry is transitioning faster than expected and key PV module manufacturers, such as LONGi and JinkoSolar, are ramping up mono-Si wafer capacity, which is compatible with the production of larger silicon wafers.

Multicrystalline wafer sizes are also expected to follow suit. The dominant format is 156.75mm × 156.75mm in mass production but, according to the ITRPV 2019 edition, other sizes are also emerging in mass production, such as 157mm × 157mm; an even larger format, of dimensions 158.75mm × 158.75mm, could be the standard for the next few years. Driving the 158.75mm × 158.75mm format has been GCL-Poly as it transitions the largest installed base of multicrystalline DSS furnaces to its mono-cast technology.

Mono-cast move

On March 8, 2019, GCL-Poly gathered its major customers to highlight its new era of mono-cast production. Emphasis was placed on how comparable in performance to monocrystalline technology its mono-cast technology was. Highlights included presentations noting that PV modules using its cast mono wafers had no notable surface defects, and that the latest G3 wafer surface quality problem had been resolved completely. Low minority-carrier lifetime was said to have been greatly reduced, with a lower dislocation density.

The difference between the cell conversion efficiencies of cells produced on the same production line were therefore less than 0.3%. The power difference between a 72-cell GCL mono-PERC module and a 72-cell Cz module was said to be less than 5Wp. The power output of a 72-cell module was said to able to reach 405Wp. By the end of 2018, several customers were reported to have started mass production of products using the GCL-Poly Mono G3 wafer.

GCL-Poly also noted, however, that in their opinion there were too many different wafers sizes, just ranging between 156.75mm and 158.75mm, on the market. Standardizing silicon wafer sizes is therefore conducive to the sustainable development of the entire industry.

GCL-Poly believed that its own market forecasts meant that the 158.75mm wafer size would become the dominant product on the market in 2019. The company said that by the end of 2019, the total production capacity of the Mono G3 wafer would range from 8GW to 10GW.

Image: SunPower Corp

Figure 2. SunPower is transitioning to larger n-type wafers.

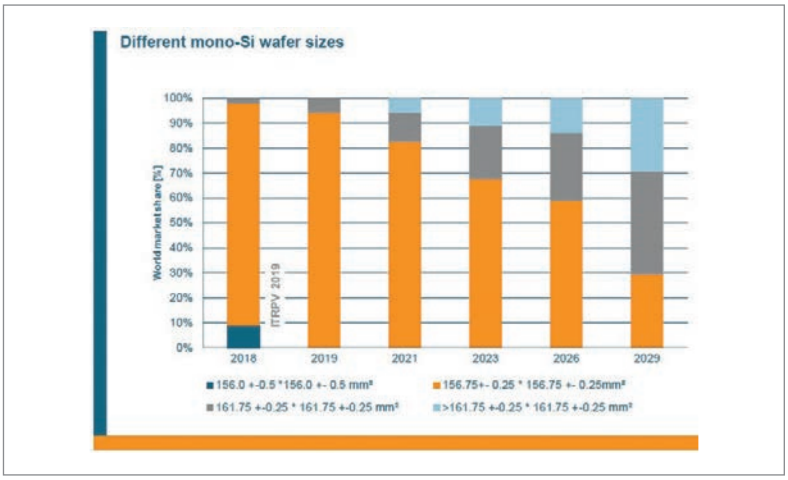


Figure 3. The ITRPV survey shows various wafer sizes gaining volume market penetration, but supersized wafers are already entering the market.

The roadmap for GCL cast mono cells in 2019 was said to focus on further quality improvements of the wafers and enhancing cell production techniques, notably for the introduction of selective emitter cells, which are not yet ready for mono-cast wafers. The company aims to achieve an average efficiency of 22.2–22.3% for mass-produced cells.

Established mono ingot/wafer producers, however, are already entering production with even larger wafer sizes, such as 166mm × 166mm. LONGi Solar rolled out its Hi-MO4 module in May 2019 (Fig. 4); this is a new generation of advanced monocrystalline PERC cell technology and encapsulation technology of half-cell and bifacial construction, using 166mm × 166mm p-type mono wafers. Reported module outputs are 420W, peaking at 430W.

The pace of launching larger sized wafers is more than likely due to intensified market competition seen in the second half of 2018, when China cut

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Figure 4. LONGi Solar's official launch of its Hi-MO4 module gained a large audience at Intersolar Europe.

support mechanisms for utility-scale and distributed generation markets under the '531 New Deal'.

"During the second half of last year [2018], due to market requirements customers were asking for higher module outputs in the 400Wp range," noted LONGi Solar's Monsoon Wang. "This is very difficult to achieve at the cell level in such a short time. Changing the wafer size and moving to half-cut cells was seen as the best option to get to 400Wp.

"However, several manufacturers had their own ideas on what the larger wafer size should be, such as 157.4mm, 158.75mm and 161.7mm, which Korean firms such as LG and Q CELLS selected for n-type wafer cells. So, in the second half of last year there was some uncertainty in the market, which led to discussions with a lot of customers. What we found was the key concern centred around the impact on the LCOE of PV projects.

"The [downstream] market will need time to be informed and educated about the next wafer transition, especially in module dimensions and weight comparisons with say glass/glass bifacial modules. A key point to consider when moving to slightly larger module dimensions is that the modules will still only need two people to install, so the LCOE will still be lower, as will the BOS (balance of system)."

"This also applies to cell manufacturing, with cost per watt also reduced, along with paste. Although it could be a little difficult for existing cell and module production capacity to adopt the larger wafer sizes, as capex would need to be spent on certain upgrades, new production lines would not have that difficulty," added Wang.

The thought process at play was the hope that a further increase in module power outputs by expanding the size of silicon wafers would be the cheapest route to securing product competitiveness.

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According to LONGi, one route that PV manufacturers had evaluated was to adopt M2 wafers and continue to increase the width across the wafer, to 157mm, 157.25mm or 157.4mm, without increasing the overall dimensions of the module. However, modelling indicated that the increase in power output would be limited. Other factors, such as requirements on production accuracy, would also be increased. Furthermore, the certification compatibility could be affected (e.g. failing to meet the creepage distance requirement of UL certification).

LONGi also noted that another methodology was to follow the route of increasing the width across the wafer from 125mm to 156mm (increasing the size of the module), such as a 158.75mm pseudo-square wafer or square wafer (223mm-diameter silicon ingot). LONGi stated that the latter increases the wafer area by about 3%, which in turn increases the power output of a 60-cell module by nearly 10Wp. What also seems to be happening is that n-type module manufacturers could be choosing 161.7mm M4 wafers, while some are planning to launch 166mm-size wafers in the future, according to LONGi.

Perhaps not surprising is that the largest mono wafer producer has chosen the 166mm wafer size, as this is apparently the maximum size compatible with all standard horizontal diffusion furnace production tools. On the one hand, the depreciation and manual labour per watt will be significantly reduced because of the increase in the production capacity for cells and modules. On the other hand, modules with larger wafers have higher power and can reduce BOS cost, which in turn will reduce the total cost of the system.

With larger wafers, the need for half-cut or multi-cut cells also increases, because of the increase in negative resistive losses for p-type mono-based cells. Less resistance between the cells clearly increases the power output of a module.

So, going forward, in the case of p-type mono-based cells, bigger is going to be better, as long as cut cells and other cell-to-module loss-reduction technologies, such as shingling, are adopted.

"There is a growing consensus amongst manufacturers that the next standard will be the 166mm size M6 wafer, after we publicly launched it at SNEC. There will be work undertaken to inform the market about this next standard wafer as, being the number one mono wafer producer, we have that responsibility," added Wang.

Maximum size wafer breakthrough

In mid-August 2019, Tianjin Zhonghuan Semiconductor (TZS) held a product launch for its mono silicon 'Kwafu' M12 series wafers in 205mm × 205mm and 210mm × 210mm sizes (Fig. 5), which were produced from a 300mm-diameter ingot.

Shen Haoping, chairman of Zhonghuan said, "The release of 'Kwafu' will significantly reduce the BOS (initial investment cost) and LCOE of photovoltaic power plants, helping manufacturers to obtain higher returns while also making parity in more regions. And the successful implementation of the bidding project will effectively promote the further development of the global PV market."

The 300mm-diameter wafer has been used in the semiconductor industry for just over 20 years and is the standard wafer size for CMOS IC fabrication. Efforts by industry consortiums to push the size to 450mm were abandoned on cost and lack of industry support.

Zhonghuan also announced that the new product involved more than 100 declared patents (partially accepted) and its own intellectual property technology, through new technological breakthroughs, to achieve new product iterations. According to Zhonghuan, using the same 144 half-piece (72 cut-and-halved) components, with cell efficiencies of 22.25%, the M12 p-type PERC 60-piece half-cut module produced 200W more than the equivalent M2 wafer-based module with a peak power in the 610W range (Fig. 6).

Lack of standards

In August 2019, LONGi Group reinforced to PV Tech that the solar industry must work together to agree on standardized larger wafer sizes, according to the monocrystalline solar manufacturer. The company revealed that it had now sold 2GW of its Hi-MO4 module. The firm is now increasing its backing of that wafer size with a series of upgrades across its own facilities.

"By end 2020, LONGi will upgrade its existing cell and module lines and transform them for production with the 166mm wafer," said Wang Yingge, executive assistant to the chairman of LONGi Solar. "New lines such as the 5GW monocrystalline cell line in Yinchuan will be designed for the 166mm size from the start," said Yingge, adding that large-scale production of Hi-MO4 will commence in the third quarter of 2019.

"The 166mm wafer has reached the allowable limit of production equipment which is difficult to overcome. This would be the upper limit of the standard for a considerable period," said Professor Shen Wenzhong, Director of the Solar Energy Research Institute of Shanghai Jiaotong University.

"If manufacturers cannot reach an agreement on a size standard, it will restrict the development of the whole industry," said Li Zhenguo, President of the LONGi Group.

Shen Wenzhong added, "Existing crystal drawing and slicing equipment are compatible with 166mm size silicon wafers. Production equipment for cells and modules needs to be modified, though the costs are lower and easier to achieve. Calculated by 'flux', cell and module production lines using 166mm wafers will increase capacity by 13% as compared with the 156mm size."

"From LONGi's perspective it will take around half a year to make its transition to the M6 wafer in a module, and perhaps a year for the industry to transition to the M6 wafer. There is a good incentive to transition as quickly as possible," noted Wang.

Figure 5. Zhonghuan Semiconductor's 'Kwafu' M12 series brick, launched in August 2019.

Figure 6. With larger and larger wafer sizes, the module dimensions increase significantly. On the far right of the picture is Zhonghuan Semiconductor's M12 wafer-based 60-cell formatted PV module.

Conclusion

In just the last 18 months, a major shift to mono has been in full swing, including the shift by GCL-Poly to mono-cast production, sending multicrystalline to a place in the history books faster than expected.

Almost at the same time, the wafer size changes have been numerous and continue to expand in number, highlighting concerns of a lack of standard sizes in the future.

However, it would seem that the pace of the wafer size transition and increasingly larger formats being introduced to the market and ramped-up volume production is setting the industry on course to larger and larger module dimensions, with outputs exceeding 600W, perhaps as early as 2020. The ramifications of this in the upstream and downstream markets have yet to be fully understood.

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