In-depth research report

Status and Trends of the N-Type Photovoltaic Battery Industry: Segment Types and Industry Chain

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INDUSTRY OVERVIEW

1.1 P-type and N-type

The cells used in this industry are categorized into P-type and N-type based on the substrate wafer type.

P-type cells are made from boron-doped P-type silicon wafers and include BSF and PERC cells. The raw material for N-type cells consists of N-type silicon wafers doped with phosphorus. Current technologies used for N-type cells include TOPCon (tunneled oxide passivated contact), HJT (intrinsic thin-film heterojunction), and IBC (intersecting back-contact cell). N-type cells conduct electricity through electrons, and the boron and oxygen pairs cause less photoluminescence attenuation, resulting in higher photovoltaic conversion efficiency.
N-type cells have clear advantages.

1.2 N-type advantages are obvious

The German Institute for Solar Energy Research in Hamelin (ISFH) states that the theoretical conversion efficiency limit of P-type monocrystalline silicon PERC cells is 24.5%, which is close to the maximum efficiency limit. It is unlikely to have a substantial increase. N-type cells have several advantages over P-type cells.

N-type cells have a higher cell conversion efficiency compared to P-type cells due to the holes for electrons that are not easily captured by impurities in the silicon wafer. This results in a lower surface compounding rate and a longer oligon lifetime, which can greatly improve the open-circuit voltage of the battery and increase its conversion efficiency. It is important to note that any metal impurity pollution should be kept the same for accurate comparison.

As a result, the near-zero photoluminescence attenuation effect is achieved. The N-type cell is doped with phosphorus, and the boron content in crystalline silicon is extremely low, which weakens the influence of boron and oxygen. This is due to the high infrared transmittance and the presence of many current channels.

Additionally, the N-type cell operates at a lower temperature, resulting in less impact on power. The operating temperature of an N-type cell is lower than that of a conventional single-glass module by 3-9℃. This reduces the power drop caused by temperature increases.

Additionally, N-type cells have a good response to low light conditions. They can still generate electricity on rainy and cloudy days, as well as in the morning and evening when the irradiation intensity is lower than 400W/m2.

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INDUSTRY STATUS AND TRENDS

2.1 N-type market share has significantly increased

Trends show that the N-type market share has significantly increased, while the P-type capacity will gradually be cleared out.

In terms of NP cell spread, the spread between TOPCon cells and PERC cells was more than $1/w in May 2023. As TOPCon capacity is gradually released, the price difference between the two has narrowed to around $0.5/w since August. However, with the market demand shifting rapidly towards N-type products in December, it is expected that M10P-type cell production in 2024 will face long-term cash losses, and P-type production capacity will gradually be cleared.

2.2 TOPCon has become the mainstream technology route in the marketplace.

Currently, TOPCon is the dominant technology in the market, while other routes continue to advance. It should be noted that in the N-type era, there is still no unified battery cell technology route. Although TOPCon is widely recognized as the next-generation mainstream technology with a production capacity expected to exceed 400GW by the end of 2023, new technologies such as HJT cells and BC cells are still generating interest. Additionally, chalcogenide and chalcogenide stacked batteries are also being explored as potential development directions. TOPCon is expected to replace PERC as the mainstream technology route in the market by 2024. However, TBC, calcitonite, and other technology routes will continue to progress.

2.3 TOPCon Battery: Making Rapid Progress in Industrialization

TOPCon cells are aligned with PERC production lines and are making the fastest progress in industrialization.

TOPCon is a tunneling oxide layer passivation contact solar cell with high ultimate efficiency. It uses an n-type substrate and an ultra-thin oxide layer on the back side, which is doped with thin film silicon to passivate the cells. The backside oxide layer, which was grown using wet chemistry, had a thickness of 1.4 nm. On top of the oxide layer, a 20 nm phosphorus-doped amorphous silicon layer was deposited, followed by annealing to recrystallize and enhance the passivation. The structure provides effective surface passivation on the backside of the wafer. The ultra-thin oxide layer enables polytronic electrons to tunnel into the polysilicon layer while blocking the oligon hole complex. The electrons are then transported laterally in the polysilicon layer to be collected by the metal. This greatly reduces the metal-contact composite current and enhances the open-circuit voltage and short-circuit current of the cell. It has a higher efficiency limit (28.2% to 28.7%), which is close to the theoretical limit efficiency of crystalline silicon solar cells (29.43%).

However, it is important to note that yield improvement is a long-term goal that requires further development.

Currently, there are three main technical routes for preparing TOPCon backside passivation: PVD physical vapor deposition sputtering coating process, LPCVD preparation of polysilicon film combined with boron expansion and ion implantation of phosphorus process, and PECVD preparation of polysilicon film and in-situ doping process. Before 2022, the market's TOPCon production capacity was mainly based on LPCVD technology. Although the LPCVD route technology is mature and has an excellent passivation effect, its low production capacity and the high cost of quartz parts have led some manufacturers to turn to PECVD. LPCVD technology is mature and has excellent passivation effects. However, due to the low capacity and high cost of quartz parts, some manufacturers have turned to the PECVD route. Although the PECVD route has its pain points, such as mold detachment, Tongwei and Trina have made significant improvements in PECVD technology efficiency and yield. As a result, more and more manufacturers are choosing this route to expand their production.

The market share of the TOPCon battery industry chain is expected to increase significantly, leading to increased demand in each segment.

The price of 3, P/N is about to be announced as cost reduction and efficiency improvements continue to progress.

The complex technical process still has room for improvement, although the yield is currently higher than PERC at 0.03-0.05 yuan / W. The TOPCon process involves more complex steps, including boron expansion, amorphous silicon deposition, and plating of oxide layer film, among 2-3 other processes. There are also technical challenges such as boron diffusion, de-winding degree cleaning, and passivation layer of tunneling film coating that have yet to be resolved. The industry's overall yield for TOPCon is between 93-97%, while the PERC cell yield is above 98%. Currently, the TOPCon industry yield ranges from 93-97%, while the PERC cell yield exceeds 98%. With the support of cleaning and automation technology maturity, as well as wafer technology advancement, the yield difference can be significantly optimized. TOPCon's cost reduction path is diverse, including wafer-side thinning and reduced consumption of silver paste in non-silicon parts. In the overall cost composition, the cost of silicon wafer accounts for a large proportion, at 58% of the battery cost, due to the silicon material tax-inclusive price of 80.5 yuan/kg. A decline in the cost of silicon material will help reduce the cost of silicon wafer. Assuming the price of N-type silicon material is 80.5 yuan/kg and every 10μm thinning of silicon wafer corresponds to a decline of about 2% in cost, the leading has been attempting to thin the wafer to 130μm or below. The cost of non-silicon materials is primarily attributed to silver paste, which accounts for 16% of the total cost. Currently, the TOPCon silver paste dosage is 12-13mg/W. Localization of silver paste is expected to reduce its cost. In the future, cost reductions can be achieved by optimizing the grid line and substituting the back of the silver and aluminum paste. SMBB + high-precision string welding is expected to reduce silver paste consumption to 90mg/piece.

2.4 HJT Batteries: Higher Costs, More Room for Efficiency in the Mid to Long Term

Compared to PERC and TOPCon, HJT cells have a higher cost but offer more room for efficiency gains in the medium to long term.

HJT batteries have multiple advantages.

- **Higher theoretical efficiency:** According to ISFH and LONGi Green Energy, HJT cells have a significant lead over PERC in terms of efficiency, and lag slightly behind double-sided TOPCon. HJT+Calcium-Titanium Ore stacked cells can reach more than 30% theoretical conversion efficiency. Additionally, HJT, TOPCon, and PERC cells have theoretical conversion efficiencies of 28.5%, 28.7%, and 24.5%, respectively.

- **The production process is also shorter.** The HJT core process consists of only four steps: cleaning and fluffing, amorphous silicon thin film deposition, TCO film deposition, and metal electropolishing. This process is greatly simplified compared to PERC and TOPCon cells, which helps to improve production yield rates and reduce labor, operation, and maintenance costs.
- **The low-temperature process further enhances cost-effectiveness.** HJT is produced at temperatures below 200°C, while PERC phosphorus expansion requires temperatures above 850°C and TOPCon boron expansion requires temperatures above 1100°C. This minimizes thermal damage during wafer preparation and reduces heating costs.
- **HJT has a high double-sided rate.** HJT cells have a symmetrical double-sided structure, allowing for a maximum double-sided rate of 90%. In comparison, PERC and TOPCon cells can only reach a maximum double-sided rate of 75% and 85%, respectively. This indicates that HJT has a higher capacity for power generation on the back-side.
- **HJT has a low temperature** coefficient of -0.24%/°C, which is lower than the temperature coefficients of -0.35%/°C and -0.30%/°C for PERC and TOPCon, respectively. The lower temperature coefficient of HJT cells results in higher power generation in high temperature environments due to less energy loss. Additionally, HJT cells have a low attenuation rate, with a first attenuation of 1% and linear attenuation of 0.25%, which is lower than PERC and TOPCon. This allows HJT cells to generate more power over a long life cycle.
- **HJT cells have a high degree of thin-filming.** The HJT structure is double-sided and symmetric, which reduces mechanical stress on silicon wafers and improves the rate of whole wafer preparation. Additionally, the low-temperature process reduces the possibility of warping due to heat, making it more conducive to thin-filming and cost-saving.

Although the HJT cell economy needs improvement, there is plenty of room for cost reduction.

The cost of HJT cells is primarily composed of silicon wafers, paste, equipment depreciation, and target materials. As of 2022, the cost of PERC cells ranges from 1.01 to 1.05 Yuan/W, while the cost of TOPCon cells ranges from 1.05 to 1.09 Yuan/W. The cost of HJT cells is higher, ranging from 1.12 to 1.16 Yuan/W, which is about 0.07 Yuan/W more expensive than TOPCon cells. The majority of the cost comes from the silver paste and target. There is significant potential for cost reduction.

2.5 IBC Batteries: More Diversification

The IBC cell is a solar cell structure with a back-junction back-contact, where positive and negative metal electrodes are arranged on the backlit surface of the cell in a fork-and-finger fashion.

This unique back-contact structure provides IBC cells with several advantages: The front side of the cell effectively reduces optical loss by eliminating electrode grids, resulting in a 5% to 8% increase in short-circuit current density compared to traditional solar cells. Additionally, the positive and negative electrodes are located on the back side of the cell, allowing for optimal optimization of electrode grids. This reduces series resistance and improves cell efficiency. 3) The front side without metal grid line design considerations can optimize the surface passivation and anti-reflection structure, thus improving battery performance. 4) The front side without grid lines can be combined with module packaging technology to prepare good-looking and suitable building-integrated PV (BIPV) module products, expanding their potential applications.

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