Development and Future of Photovoltaic HJT Cells

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Abstract: Heterojunction Technology (HJT) cells, also known as heterojunction cells, feature a unique PN junction structure. They are formed by covering a crystalline silicon substrate with a layer of amorphous silicon film, combining the properties of both amorphous and crystalline silicon. As a type of N-type cell, HJT cells hold significant importance in the photovoltaic field. They offer high conversion efficiency, a straightforward manufacturing process, applicability to thin silicon wafers, a low-temperature coefficient, and no light-induced degradation or potential-induced degradation, and they can generate electricity on both sides. Notably, HJT cells can be advantageously combined with other technologies. By integrating advanced technologies like IBC and perovskite, the theoretical conversion efficiency of HJT cells could potentially exceed 30%. This prospect makes HJT cells a highly competitive choice in the photovoltaic industry.

Keywords: Photovoltaic; HJT cells; Technology

1 Analysis of Different Cell Technologies

From the perspective of equipment investment, the choice of different cell technologies brings distinct capital expenditure considerations. The cost to establish a new TOPCon cell production line is approximately 220 million yuan per gigawatt (GW), which is higher than the 150-200 million yuan per GW investment cost for PERC cells. However, it is noteworthy that if a company opts to upgrade an existing PERC cell production line to TOPCon, the investment cost is significantly reduced, with the per GW cost expected to be around 50-80 million yuan. [1]

In comparison, the equipment investment cost for HJT cells is particularly high, which is one of the primary reasons HJT cells have not yet achieved large-scale mass production. For new market entrants, choosing HJT cell technology means bearing a substantial financial burden. For companies already operating in the market, converting existing PERC production lines to the more cost-effective TOPCon lines is clearly a more economical choice. [2]

Although HJT cells have numerous technical advantages, the high investment cost remains a significant barrier to their widespread adoption.

2 From Theory to Reality: The Marathon of Cost Reduction for HJT Cells

Compared to the highly popular TOPCon cell technology, HJT (Heterojunction Technology) must focus on cost reduction and efficiency improvement to compete effectively. [3] Lowering costs is crucial for increasing production capacity and market penetration. Chinese photovoltaic companies are continuously iterating their technology and have achieved excellent results in this regard.

In the short term, HJT cell manufacturers do not hold significant bargaining power over materials and equipment costs. Therefore, they focus on internal strategies to reduce costs. [4-5] A cost analysis of HJT cells from an earlier stage reveals that 65.3% of the costs are attributed to silicon wafers, making it the largest cost component. The second-largest cost is silver paste, accounting for 15.7%.

As a result, HJT manufacturers have set their cost reduction targets on silicon wafers and silver paste. The most direct way to reduce the cost of silicon wafers is to make them thinner. Due to HJT cells' double-sided symmetrical structure, mechanical stress during manufacturing is reduced, leading to lower breakage rates. Additionally, HJT cells use a low-temperature process, which adapts well to thinner silicon wafers in mass production. From 2018, the thickness of HJT silicon wafers decreased from 180μm, gradually reducing to 120μm by 2023 (in mass production). Estimates suggest that for every 20μm reduction in silicon wafer thickness, the module cost drops by approximately 0.05-0.06 yuan/W. From 2018 to

2023, the cumulative thickness reduction of 60μm led to a module cost reduction of 0.15-0.18 yuan/W.

In September 2023, during an investor survey, Risen Energy disclosed that the mainstream HJT products used silicon wafers between 120-130μm. The company had already introduced 110μm silicon wafers at the start of mass production and was validating 100-90μm wafers on pilot lines, aiming to introduce 100μm or thinner wafers into mass production by 2024. The integration of thinner wafers with the additional revenue from self-produced wafers presents considerable potential for cost reduction in HJT products. Successfully introducing 100μm or thinner wafers into mass production by 2024 would be a significant milestone, providing more substantial cost reductions and potentially opening new opportunities for the entire solar cell industry.

Having achieved staged success in wafer thinning, the next cost reduction focus for HJT cells is silver paste, the second major cost component. Due to the double-sided structure of HJT cells, the total silver consumption is higher. In 2020, the silver consumption for double-sided HJT cells was as high as 240mg per cell, significantly exceeding that of PERC and TOPCon cells, making it a major factor in HJT's high costs.

Through continuous technological iteration, silver consumption had decreased to 127mg per cell by 2022, nearly halving compared to 2020.

3 Domestic HJT Cell Companies Seeking Silver Reduction Solutions in Various Stages

Since it is not feasible to reduce costs from the silver powder and paste end in the short term, domestic HJT cell companies have turned their efforts inward, seeking cost reduction solutions at various stages to reduce silver consumption.

First, there is the grid line stage, from refining the main grid lines to ultimately having no main grid lines. With the development of cell technology, grid line patterns have evolved from 4BB and 5BB to MBB (Multiple-Busbar, 9-15 grid lines) and SMBB (Super-Multiple Busbar, 16 or more grid lines). Increasing the number of main grid lines can reduce the width of the main grid lines, thereby lowering the consumption of silver paste. Currently, the mainstream MBB technology uses 9-12 grid lines per cell.

SMBB technology further increases the number of main grid lines, shortens the length of fine grid lines between main grids, effectively reduces the resistance of fine grid lines, and optimizes current transmission paths. Additionally, finer grid lines become possible; increasing the number of main grid lines significantly shortens the photogenerated current transmission path and reduces power loss. The width of the grid lines becomes thinner, and combined with the use of a knot-free screen, further reduces silver consumption. For example, 12BB technology can reduce HJT cell silver paste consumption to around 130mg.

Estimates suggest that with 0BB technology, the silver paste cost for PERC cells can be reduced to 0.03 yuan/W, TOPCon cells to 0.01 yuan/W, and HJT cells to 0.04-0.06 yuan/W.

Having achieved a phased victory in grid line silver-saving technology, HJT cell companies are now focusing on silver-coated copper technology.

Silver-coated copper technology is a key technique used in HJT cell manufacturing. By adjusting the proportions of silver, copper, and additives in the paste, it maintains cell performance while significantly reducing silver consumption, achieving substantial cost reduction. The silver content in silver-coated copper paste is typically controlled between 55% and 75%, resulting in a main grid resistivity similar to pure silver, with good conductivity. The silver coating also provides oxidation protection, ensuring long-term performance. Compared to traditional pure silver paste, silver-coated copper paste can reduce costs by 20%-50%.

Currently, the use of paste with 50% silver content is well-established, and efforts are underway to break through to ultra-low proportion pastes below 40%. Enterprises began mass production in the second half of 2023.

In the fourth quarter of 2023, with the support of silver-coated copper technology, leading HJT cell companies achieved another reduction in silver consumption to 85mg for 210 silicon wafers.

Another approach in the HJT silver-to-copper transition path is electroplated copper technology. Photovoltaic electroplated copper is a process of depositing metal copper electrodes on a transparent conductive oxide (TCO) layer through electroplating. Replacing screen-printed silver grid lines with electroplated copper grid lines can significantly reduce silver paste usage. Electroplated copper also reduces shading losses on the cell front and minimizes grid line resistance losses, while improving the contact between electrodes and TCO.

Despite the superior conductivity and conversion efficiency of electroplated copper over screen-printed low-temperature silver paste, there are challenges to its use. The copper electroplating process requires at least five steps, and even if simplified to selective electroplating, it is more complex than traditional screen printing, leading to lower yields and difficulties in meeting mass production demands. Additional electroplating steps increase the investment in manufacturing equipment, potentially negating cost savings. Long-term stability and reliability of copper electrodes need further verification, as incomplete TCO coverage or defects introduced during electroplating could lead to copper diffusion into crystalline silicon, causing cell or module failure. Copper grid lines are prone to oxidation, affecting conductivity and adhesion, making it challenging to meet the 25-year lifespan requirement for solar modules. Furthermore, electroplating produces organic pollutants and wastewater, posing environmental assessment challenges for mass production. Therefore, to achieve widespread use, copper electroplating technology requires optimization in preparation processes, equipment capacity, lifespan, and environmental handling.

4 Conclusion and Outlook

In recent years, HJT cell cost reduction has achieved several phased successes, attracting more companies to join in. As a result, HJT cell and module production capacity is gradually increasing, signaling a hopeful future.

In the quest for HJT cost reduction, not only cell companies but also domestic silver paste manufacturers, equipment companies, and silver powder companies have joined the cost reduction battle.

Combining HJT with perovskite tandem technology will further enhance HJT cell conversion efficiency and lifespan, injecting new vitality into HJT development.

TOPCon dominates the present, but HJT is gearing up for future battles. The future is promising and just around the corner.

Reference

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