Risen's HJT Hyper-ion: A White Paper

on Development and Industrial Application of Ultra-Thin Silicon Wafers

December, 2023

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1. Preface

In the previous Risen Heterojunction (HJT) Hyper-ion Products White Paper titled "Development and Industrial Application of Low-Silver Content Metallization Pastes"①, it is emphasized that cost reduction is the key for the industrialization of HJT and products. The costs of silicon wafers, metallization pastes, and equipment collectively constitute over 90% of the total cost, which is the primary focus for cost reduction in HJT products. Among these, silicon wafer cost accounts for the largest share at 55%, as illustrated in Figure 1.1. Despite notable declines in silicon material prices recently, wafer cost still dominates the cost structure of HJT solar cells.

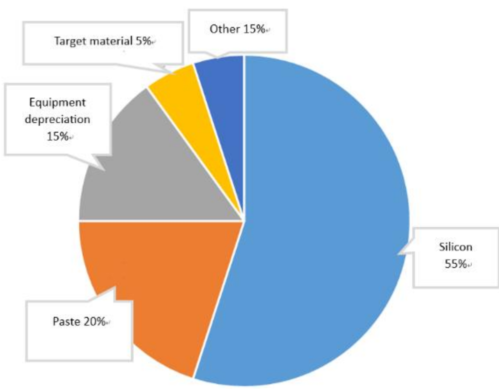


Figure 1.1: Cost Composition of HJT Solar Cells

Figure 1.2: Risen's flexible Ultra-Thin HJT Solar Cells

Various measures can be taken to reduce silicon wafer costs, and the most direct and effective approach is the wafer thinning. The low-temperature double-sided surface passivation process and a fully symmetrical cell structure of HJT dictate the feasibility of its mass production using thinner silicon wafer without compromising cell efficiency and yield rates. Moreover, the thinning of silicon wafer enhances the flexibility, creating more possibilities for cell and module design. Therefore, the thinning process represents a distinctive cost reduction measure for HJT, as depicted in Figure 1.2, HJT solar cell with ultra-thin silicon wafers produced by Risen exhibits excellent flexibility and bending capabilities.

After years of research and investment, Risen has made significant progress in the technical development and industrial application of ultra-thin silicon wafers. Currently, we have achieved mass production of solar cells and modules using 110μm thin silicon wafers and has the capability to produce cells with even thinner wafers, less than 100μm.

① Risen's official account: https://en.risenenergy.com/uploads/20230828/77456af7682eb30d9b8f409bc2da4c59.pdf

2. Development and Mass Production of HJT Solar Cells With Ultra-Thin Silicon Wafers

As mentioned above, the cost of silicon wafers constitutes the largest proportion in the overall cost of solar cells, and wafer thinning is the most direct and effective means for cost reduction. The low-temperature double-sided surface passivation process and fully symmetrical cell structure of HJT, as well as operating temperature below 200 ℃ throughout the entire manufacturing process, make it highly adaptable to ultra-thin silicon wafers. It also helps avoid issues such as silicon wafer warping and damage, which are often encountered in asymmetrical structures and high-temperature processes seen in PERC and TOPCon solar cell technologies. The use of ultra-thin silicon wafers is therefore a unique cost reduction feature of HJT and a significant indicator of third-generation HJT solar cell technology. However, practical challenges must be addressed during the production of cells and modules using ultra-thin silicon wafers. These challenges include:

1. Does the use of ultra-thin silicon wafers affect cell efficiency?
2. Does the use of ultra-thin silicon wafers affect the yield rate of the cell production line?
3. Does the use of ultra-thin silicon wafers affect the reliability of module products?

2.1 Effect of Ultra-Thin Silicon Wafers on the Efficiency of HJT Solar Cells

In general, the thickness of silicon wafers primarily impacts the cell performance concerning light absorption [1]. According to the calculation of ideal model, a silicon wafer of 280μm thickness is required to absorb all incident light. Additionally, there is a linear relationship between silicon wafer thickness and light absorption, the thinner silicon wafer, the greater the light transmission, as depicted in Figure 2.1.

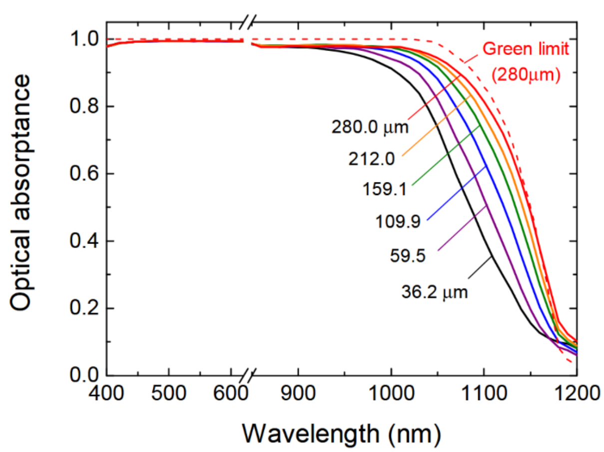


Figure 2.1: Relationship between Silicon Wafer Thickness and Light Absorption

[1] Hitoshi Sai et al 2018 Jpn. J. Appl. Phys. 57 08RB10 (https://doi.org/10.7567/JJAP.57.08RB10)

The amount of light absorption directly affects the short-circuit current density. As the silicon wafer thickness decreases, the short-circuit current density exhibits a nearly linear decline, as shown in Figure 2.2 (a).

However, the open-circuit voltage shows an opposite trend to the short-circuit current density. As the silicon wafer thickness decreases, the open-circuit voltage demonstrates an approximate linear increase, as illustrated in Figure 2.2 (b).

Another important parameter, the fill factor, does not change significantly with wafer thickness, showing a very slight downward trend and can basically be considered to remain constant, as shown in Figure 2.2 (c).

Hence, changes in silicon wafer thickness result in a seesaw-like relationship between the short-circuit current density and open-circuit voltage with the fill factor as the axis.

Starting from the original definition of conversion efficiency, a formulation that includes the three main electrical performance parameters Jsc, Voc, and FF is derived, as shown in Formula 1:

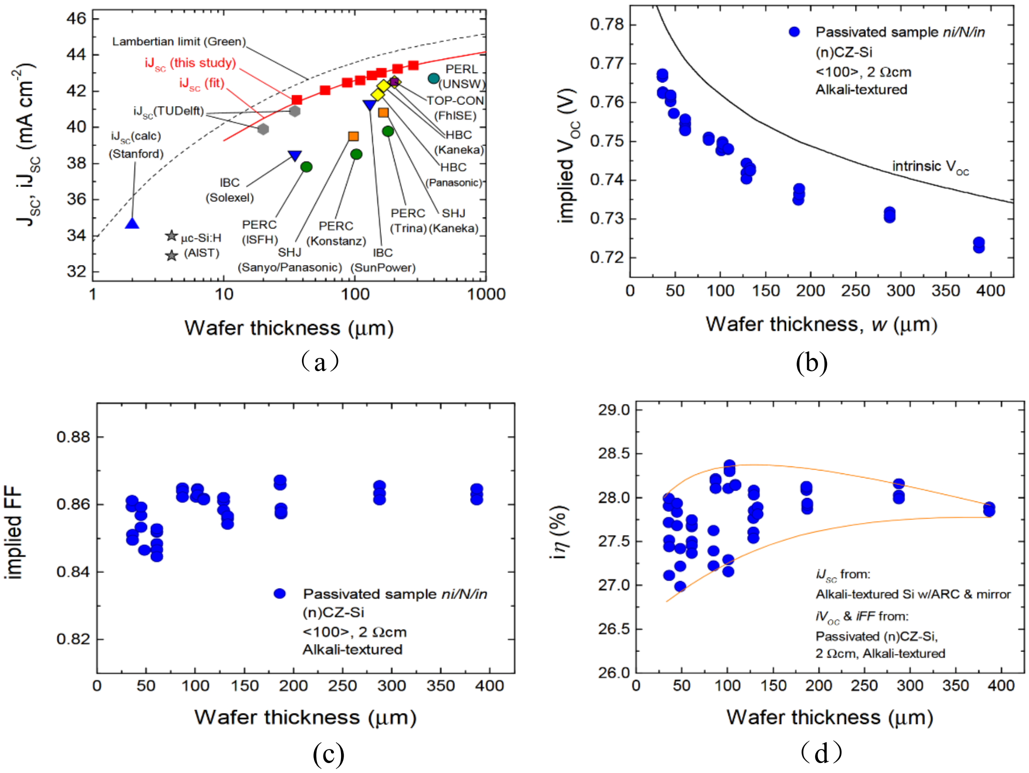
$$\begin{aligned} Eff(\%) &= P_{mpp}(W)/P_{in}(W) \cdot 100\% \\ &= [I_{sc}(A) \cdot V_{oc}(V) \cdot FF(\%)]/[CellArea(cm^2) \cdot 1000(W/m^2)] \\ &= J_{sc}(mA/cm^2) \cdot V_{oc}(mV) \cdot FF(\%) \cdot 10(cm^2/W) \end{aligned} \quad < \text{Formula 1} >$$

Under the assumption of Jsc in mA and Voc in mV, Formula 2 can be simplified by neglecting dimensions as follows:

$$Eff = J_{sc} \cdot V_{oc} \cdot FF \cdot 10^{-5} \quad < \text{Formula 2} >$$

From the above formulas, it can be observed that efficiency (Eff) is the product of short-circuit current density (Jsc), open-circuit voltage (Voc), and fill factor (FF). Due to the "see-saw" relationship, the change in silicon wafer thickness does not exhibit a linear impact on cell efficiency.

Instead, there is a “plateau” phase, within which the efficiency experiences a gradual decline and remains acceptable, as shown in Figure 2.2 (d).

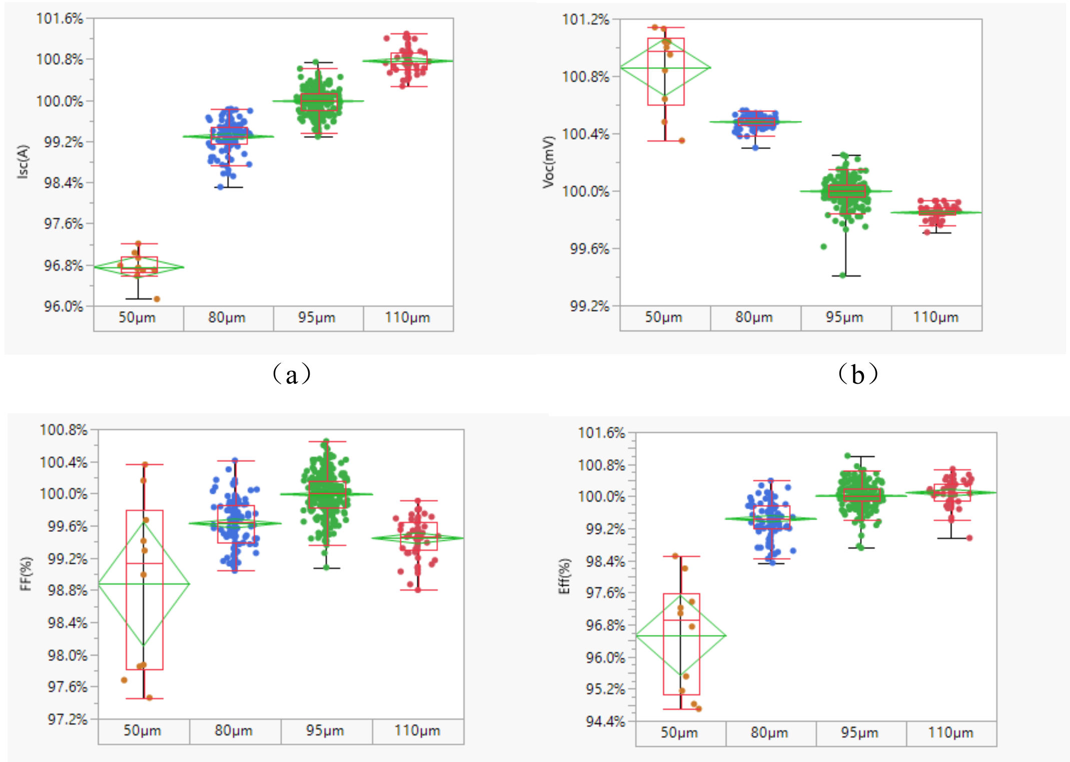


Figures 2.2 (a)(b)(c)(d): Relationship between Silicon Thickness and Short-Circuit Current Density, Open-Circuit Voltage, Fill Factor, and Cell Efficiency [1]

The above law has been validated in our experiments, and the experimental data in Figure 2.3 closely resemble the literature data presented in Figure 2.2.

As seen in Figure 2.3, the reduction in short-circuit current density is most pronounced after thinning the silicon wafer, while open-circuit voltage gradually approaches the theoretical limit. Due to external factors such as automation not matched to the optimal state in the experiment, the fill factor is slightly lower than expected, and there remains potential for an efficiency improvement after optimization.

[1] Hitoshi Sai et al 2018 Jpn. J. Appl. Phys. 57 08RB10 (https://doi.org/10.7567/JJAP.57.08RB10)



（a） （b）

（c） （d）

Figures 2.3 (a)(b)(c)(d): Relationship between Silicon Thickness and Short-Circuit Current, Open-Circuit Voltage, Fill Factor, and Cell Efficiency

Risen's HJT Hyper-ion cells, utilizing 110μm silicon wafers, achieved a significant progress from rolling off the production on April 27, 2023, to full-scale production on June 27, 2023. As shown in Figure 2.4, the average efficiency of the optimal batch reached 25.8% with a peak at 26.1%, aligning well with our expectations.

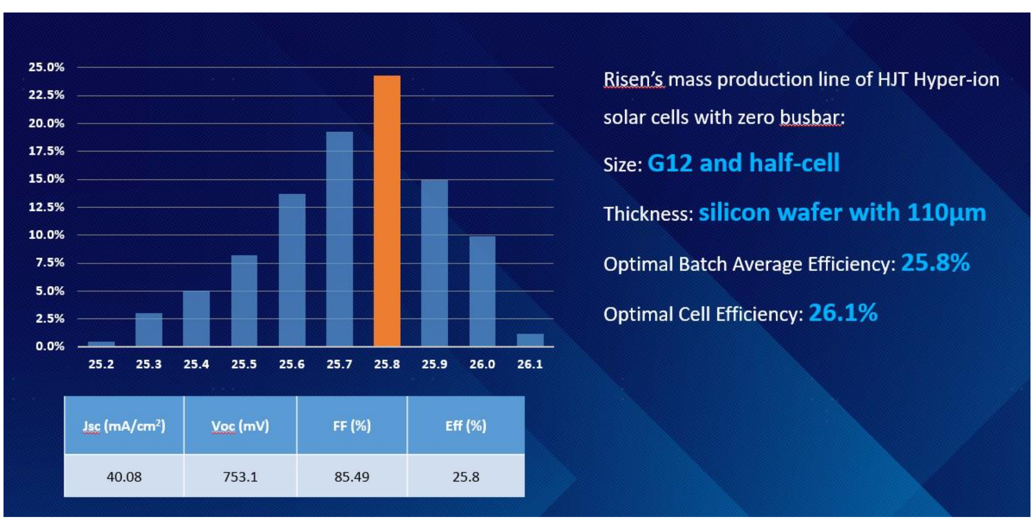


Figure 2.4: Conversion Efficiency of Risen's Ultra-Thin Silicon HJT Cells

2.2 Effect of Ultra-Thin Silicon Wafers on the Yield Rate of HJT Solar Cell Production

In the production process of solar cells, production yield rate directly affects product costs and is one of the most critical production indicators. With the increase in silicon wafer size and the decrease in thickness, ultra-thin silicon wafers perform differently in various production steps and transportation compared to thicker wafer. Consequently, new designs and adjustments are required in production processes, jig and fixtures, as well as automation equipment.

For instance, in early phase of the polit line, the cassette in production line was designed in a horizontal insertion mode due to equipment limitations. As silicon wafers become thinner, they naturally sag due to gravity, as shown in Figure 2.5. In this case, when the robotic arm handles the wafer, it may cause scratches. Therefore, a wafer carrier with vertical insertion mode is chosen as the basis for the design of the mass production line, and the automation design of each process are adjusted accordingly. Additionally, other equipment, jig and fixtures, including conveyors between equipment and vacuum devices, are designed and adjusted to match the characteristics of thin wafers, so as to ensure that all production targets are met after mass production.

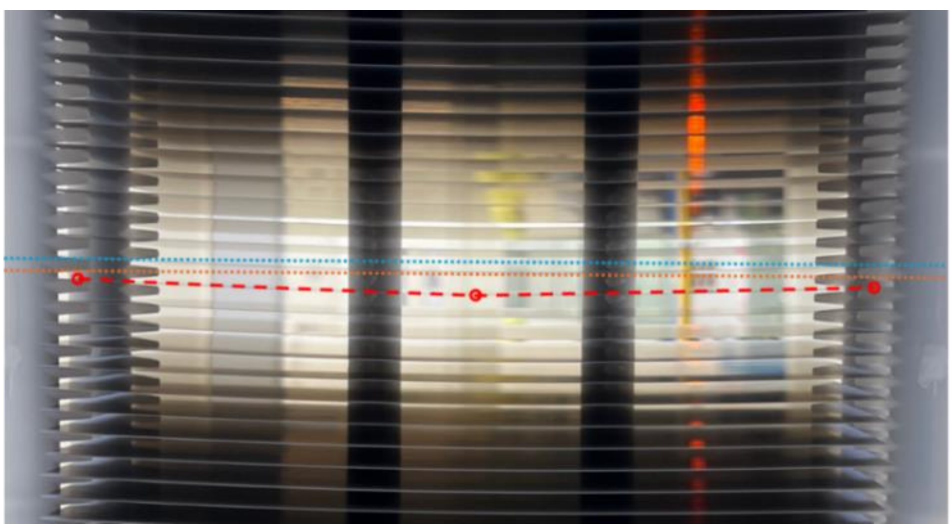


Figure 2.5: Silicon Wafer sagging When Placed Horizontally in a cassette

With continuous improvement and adjustments in processes, tooling fixtures and equipment, the production of Risen's HJT Hyper-ion solar cells undergo a rapid ramp-up. The stabilized yield rate for solar cells has consistently remained above 99%, while the fragment rate stays below 0.5%, meeting the specified yield and breakage requirements, as illustrated in Figure 2.6(a)(b).

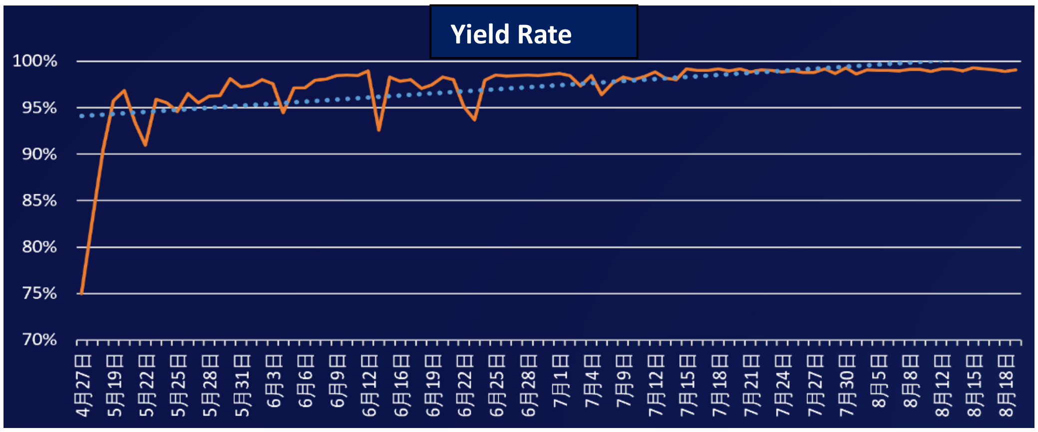


Figure 2.6(a): Yield Rate of Available Ultra-Thin Silicon Wafers

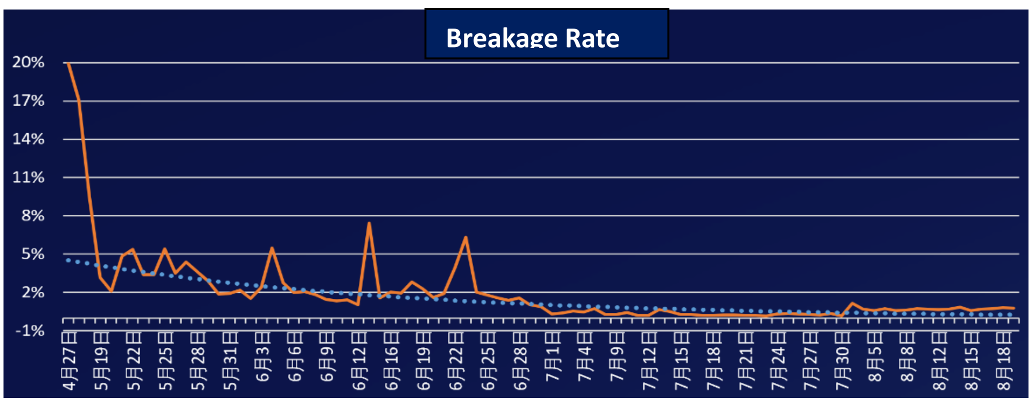


Figure 2.6(b): Breakage of Ultra-Thin Silicon Wafers

In general, thinner cells are perceived to have weaker mechanical strength. So, for HJT solar cells with ultra-thin silicon wafers, what is their mechanical strength? To address this, we conducted comparative tests on the mechanical strength of solar cells with different thickness and types.

As shown in Figure 2.8, (a) represents the 150μm PERC solar cell, (b) is the 130μm TOPCon solar cell, and (c) is the 90μm HJT solar cell.

(a) (b) (c)

Figures 2.8 (a) (b) (c): Mechanical load Test on Solar Cells with Different Thickness and Types

During the tests, both the 150μm PERC solar cell and the 130μm TOPCon solar cell experience breakage upon reaching a certain level of bending. In contrast, the 90μm HJT solar cell remained intact even after reaching the maximum range of movement of the mechanical load testing machine, as indicated in Table 2.1. It is evident that the flexibility of HJT solar cells is significantly enhanced with ultra-thin silicon wafers, positively contributes to further improvement in relevant yield rate indicators in the cell and module production processes.

Table 2.1: Deformation Data for PERC, TOPCon, and HJT Solar Cells with Different Silicon Thicknesses

Cell Technology	PERC	TOPCon	HJT
thickness (μm)	150	130	90
Deformation quantity (mm)	46.74 （broken）	53.68 （broken）	98.56 （intact）

3. Development and Reliability Tests on Ultra-Thin Cell Encapsulation Technology

The efficiency and yield rate requirements for HJT solar cells employing ultra-thin silicon wafers have been met. However, the subsequent challenge for researchers is the effective encapsulation of these cells, especially concerning is cell interconnection.

The conventional interconnection of solar cells in module encapsulation involves heating to melt tin-plated copper strips or wires, connecting them to silver busbars on the solar cells. This welding process typically requires temperature exceeding 200°C. However, since the entire production process of HJT solar cells needs to be conducted under temperatures not exceeding 200°C due to its nature, the use of conventional welding technology for cell interconnection may pose significant reliability risks. Especially in the application of ultra-thin cells, high-temperature welding can lead to an increase in breakage and a decrease in yield rate. Therefore, it is crucial to find a better, more reliable, and cost-effective method of cell interconnection. Choosing suitable interconnection materials and establishing a patent strategy are essential considerations during the product development and mass production.

In the development of HJT Hyper-ion products, Risen has first created a stress-free cell interconnection technology, Hyper-link, which boasts over 50 exclusive patents and has been complemented by development in collaboration with equipment manufacturers. By applying this technology, Risen has achieved mass production of high-efficiency and high-reliability HJT Hyper-ion modules in June 2023.

In order to assess the performance of modules using ultra-thin cells and Hyper-link, a series of tests are designed for a thorough validation, evaluating mainly the mechanical load reliability (static & dynamic) and performance degradation of the modules.

3.1 Higher Load Test Conditions

Following IEC 61215 standard, we conducted tightened static and dynamic load tests on HJT Hyper-ion modules. The test conditions are showed in Table 3.1.

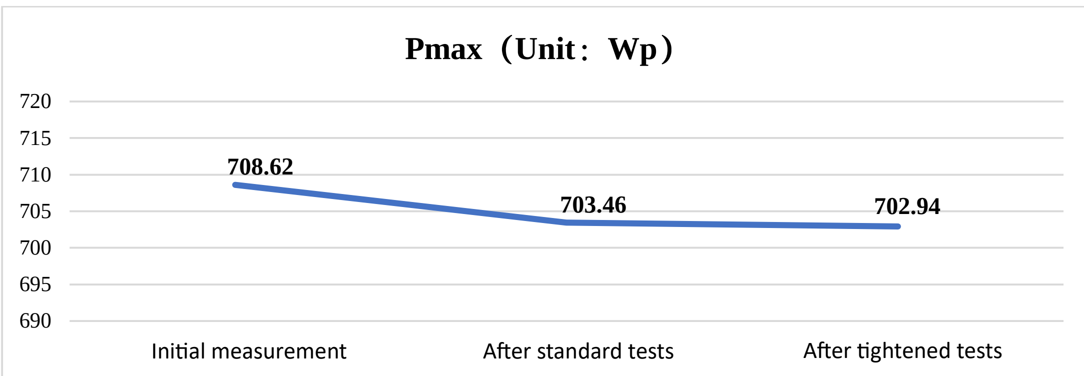
Table 3.1 Reliability Tests on HJT Hyper-ion Modules Using Ultra-thin cells

Tests	Test Condition
Static Mechanical Load	Clamp & no cross-beam installation / front 5400Pa, rear 2400Pa
Dynamic Mechanical Load	front/rear 1000Pa, 10000 cycles

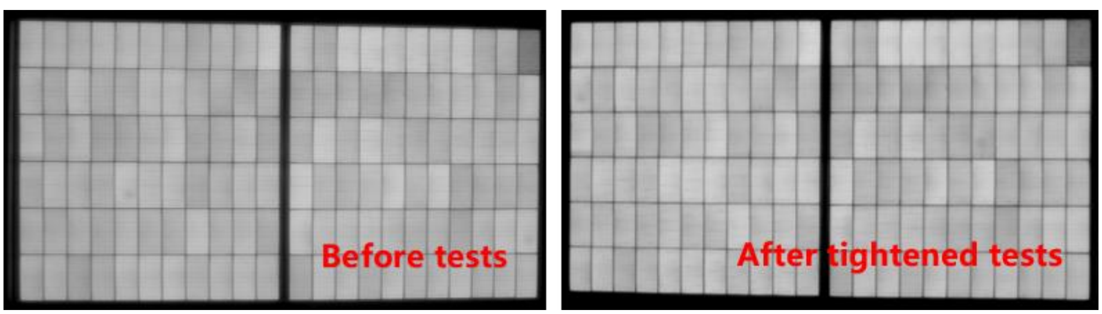
Test results shows that,

- With the beamless and clamp installation, no hidden cracks or broken cells were detected according to the EL test at 5400 Pa front load and 2400 Pa rear load, and the power degradation is less than 1% after test, as illustrated in Figure 2.9.

(a)



(b)

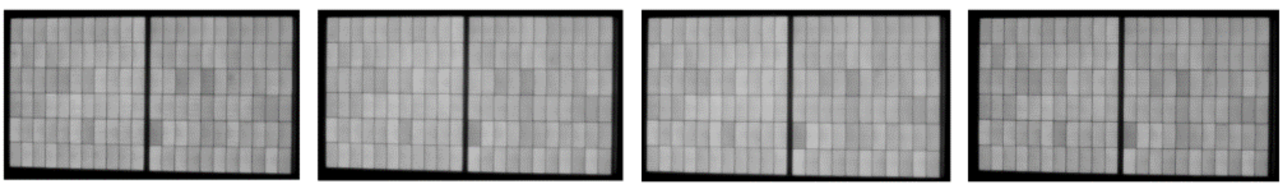


(c)

Figures 2.9 (a) (b) (c): Static Mechanical Load Test

- After 1000 cycles of standard dynamic load test, continuous testing 1000 cycles, continuous testing of 5000 and 10000 dynamic mechanical load cycles was performed. The test results showed no hidden cracks or broken cells according to EL detection, meeting standard requirements for module dynamic load performance, as depicted in Figure 2.10.

(a)



(b)

Figures 2.10 (a) (b): Dynamic Mechanical Load Test

3.2 Higher Aging Test Condition

To validate the reliability of HJT Hyper-ion modules using ultra-thin solar cells and Hyper-link technology, tests are designed to increase the standardized test cycles for different weatherability and aging tests of photovoltaic modules specified in IEC 61215:2021.

Two HJT Hyper-ion modules are randomly selected and subjected to the following reliability tests. Both modules passed the tests as per IEC requirements, and in multiple-cycles tests, such as for damp heat test (85°C+85%RH) for 2000 hours (DH2000), thermal cycling test(-40°C/85°C) for 400 cycles (TC400), humidity freeze test for 30 hours (HF30), potential-induced degradation test for 288 hours (PID288), the power degradation is less than 3% after tests, and for light and elevated temperature induced degradation test for 324 hours (LeTID324) showed a power degradation less than 1% after test. The test results are illustrated in Figure 3.1.

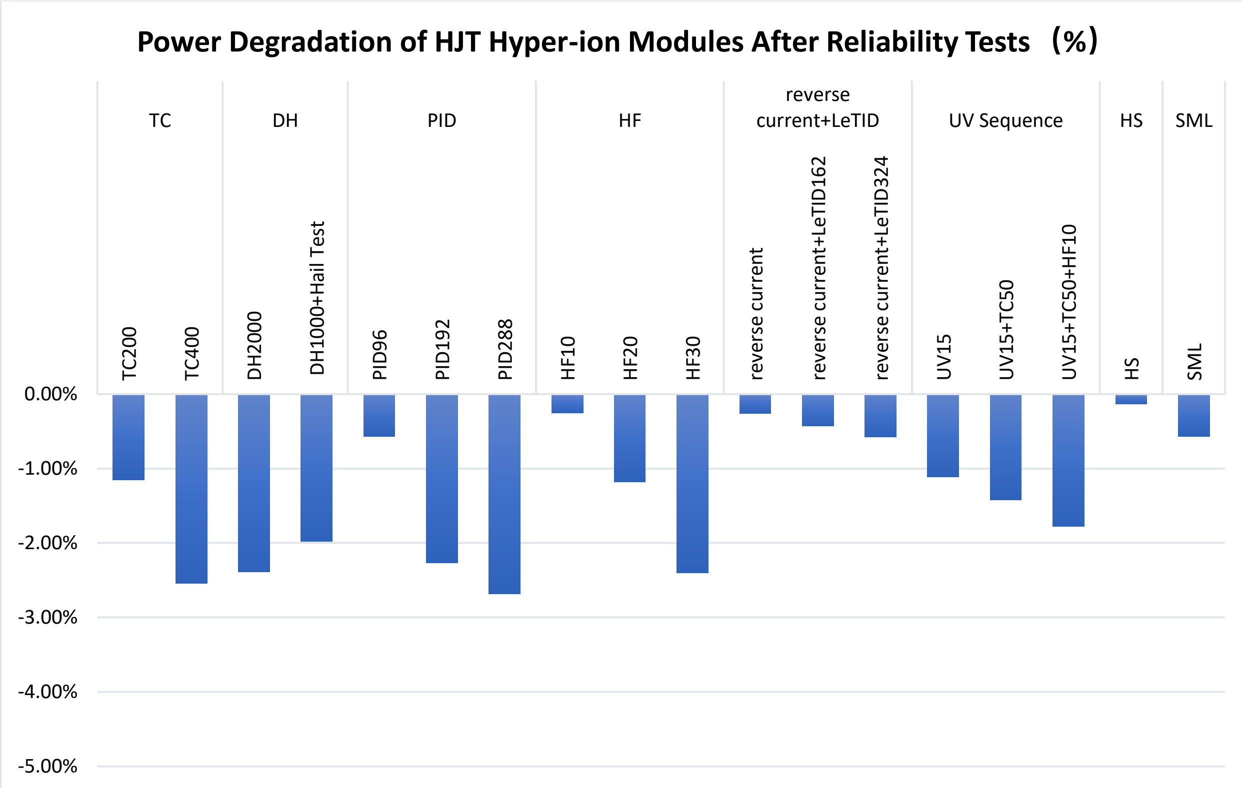


Figure 3.1: Reliability Tests on HJT Hyper-ion Modules

Based on the above test results, it is evident that when utilizing ultra-thin wafer and Hyper-link technology, the mechanical load and related reliability of the modules meet the requirements. With Hyper-link technology, ultra-thin wafers are perfectly suited for the production of HJT cells and modules to meet the demands of mass production, and the module performance fully complies with the IEC standards for long-term field application.

In conclusion, thinning HJT solar cells is a reasonable, feasible, and necessary path for cost reduction. Risen has led this revolution in the industry and is expected to have a profound influence on the future landscape of the industry.

4. Reflection and Outlook

As a pioneer and innovator in the development and industrialization of HJT, Risen Energy has accumulated extensive experience in this technology since 2018. First pilot line was established in 2019, and the shipment of HJT module began in 2020, which was ranked TOP1 worldwide for two consecutive years. By 2023, Risen's GW-scale Hyper-ion module production line was put into full operation, marking a significant achievement.

Throughout the entire process of developing and industrializing HJT and products, Risen faced numerous challenges in the mass production. Risen Energy deeply realized that the development and industrialization of HJT products require the vertical integration of the entire upstream and downstream industries, including the development of silicon wafer technology, solar cell technology and module encapsulation technology, which is interdependent as a whole. Imagine a scenario where there's excellent silicon wafer technology, yet it can't be utilized in mass production, or advanced solar cell technology that can't be effectively encapsulated into qualified module products. Each segment develops its technology independently without the organic integration of upstream and downstream technologies, which would fail to achieve the mass production of the final product. What a pity!

Risen is the first manufacturer in the industry to mass-produce using ultra-thin silicon wafers, low-silver paste, and zero-busbar solar cell technology. These three technologies play a crucial role in enhancing efficiency and reducing costs for HJT. However, the technology that truly integrates these technologies is Risen's Hyper-link stress-free cell interconnection technology, and it is this technology that unified upstream and downstream developments into a cohesive whole. With the support of these technologies and Hyper-link, Risen has successfully completed the mass application of ultra-thin silicon wafers. And Risen's 15GW HJT production base located in Nanbin has achieved mass production and delivery of 700Wp+ HJT modules in just one year.

In the future, Risen will continue to delve into the development and industrialization of HJT, continuously improving efficiency and reducing costs. Also, through the integration of HBC and perovskite tandem technology, Risen persistently iterate and upgrade Risen Hyper-ion products. As efficiency improves, we believe achieving 900Wp is not a dream, and 1000Wp should be within reach.