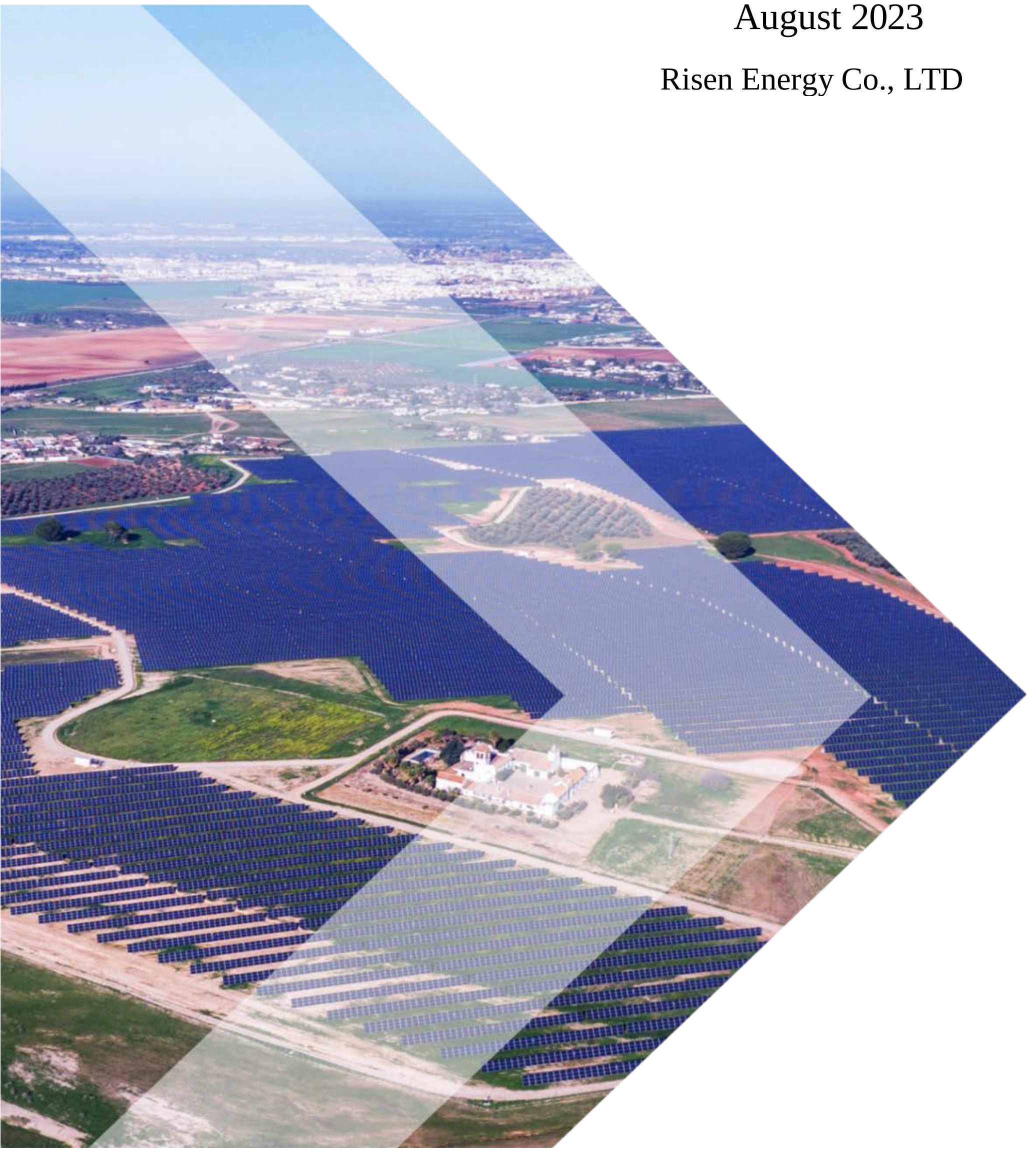
White paper of HJT Hyper-ion products of Risen Energy

Development and application of Low-silver metallization paste

August 2023

Risen Energy Co., LTD



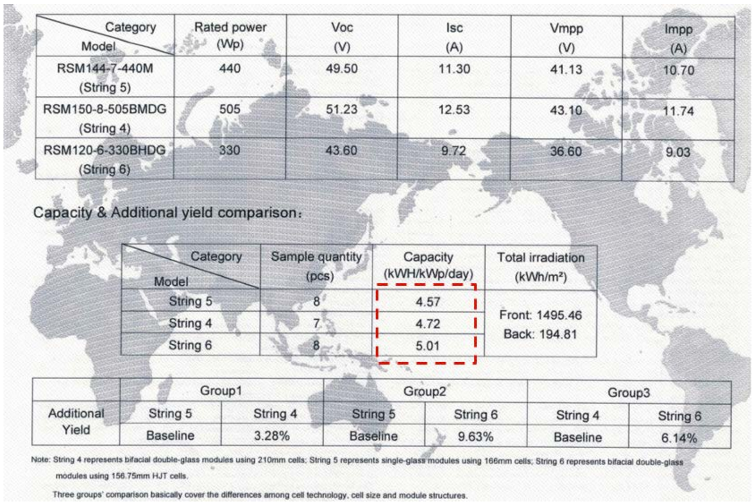
Catalogue

1. Preface

If *p*-type polysilicon (*p*-Poly) cell is referred to as the 1st generation cell, *p*-type passivated emitter and rear contact (*p*-PERC) as the 2nd generation cell, and *n*-type tunnel oxide passivated contact (*n*-TOPCon) cell as the 2.5th generation cell, then the *n*-type heterojunction (*n*-HJT) cell deserves to be called the 3rd generation cell.

The HJT cell represents the next generation of cell technology for its inherent advantages. For example, the efficiency of HJT cell is the world record holder in crystalline silicon cells and is expected to exceed 27%, closest to the theoretical limit of crystalline silicon cells. The HJT cell is not only of high efficiency, but also naturally immune to many types of degradation common to the previous generation cells, such as PID/LID, with simple manufacturing and energy-efficient procedure (only four major steps) and a yield rate over 99%. Additionally, the entire manufacturing process of HJT products employs a low-temperature below 200°C and is compatible with ultra-thin wafers of a thickness less than 90µm. Together with Risen Energy's zero-busbar cell and Hyper-link interconnection technology, HJT technology can significantly contribute to an ultra-low carbon footprint.

HJT modules offer numerous performance advantages, including a stable power temperature coefficient, ultra-high bifacial factor and excellent antidegradation property, which makes HJT the leading products with the highest power generation. According to the simulation of power generation per watt, the power generation of HJT modules is about 6% higher than that of PERC modules and about 3% higher than that of TOPCon modules. Risen Energy also conducted a year-long field test in Yinchuan, China. The data revealed that the power generation of bifacial HJT modules exceeded that of mono-facial PERC modules by approximately 9.6% and was higher than that of bifacial PERC modules by about 6.1%, as depicted in Figure 1.1. Higher power generation will significantly reduce the balance of system (BOS) cost and levelized cost of energy (LCOE) of photovoltaic systems, leading to higher power generation revenue to customers, as well as more carbon emission reduction, and even a higher carbon value to customers in the case of carbon trading.



Category / Model	Rated power (Wp)	Voc (V)	Isc (A)	Vmpp (V)	Impp (A)
RSM144-7-440M (String 5)	440	49.50	11.30	41.13	10.70
RSM150-8-505BMDG (String 4)	505	51.23	12.53	43.10	11.74
RSM120-6-330BHDG (String 6)	330	43.60	9.72	36.60	9.03

Capacity & Additional yield comparison:

Category / Model	Sample quantity (pcs)	Capacity (kWH/kWp/day)	Total irradiation (kWh/m²)
String 5	8	4.57	Front: 1495.46 Back: 194.81
String 4	7	4.72	
String 6	8	5.01	

	Group1		Group2		Group3	
Additional Yield	String 5	String 4	String 5	String 6	String 4	String 6
	Baseline	3.28%	Baseline	9.63%	Baseline	6.14%

Note: String 4 represents bifacial double-glass modules using 210mm cells; String 5 represents single-glass modules using 166mm cells; String 6 represents bifacial double-glass modules using 156.75mm HJT cells.

Three groups' comparison basically cover the differences among cell technology, cell size and module structures.

Figure 1.1 SGS & CPVT Report Empirical test in Yinchuan, China

At present, the main challenge that needs to be urgently addressed is cost reduction. As a result of Risen's years of efforts as well as the development and progress in the industry, the cost of HJT modules is expected to be on a par with that of TOPCon or even PERC modules by the end of 2023 or the beginning of 2024.

1.1 Brief analysis of the cost composition of HJT cell

In the cost composition of HJT cell, the costs of wafer, paste, and equipment depreciation account for 90% (as shown in Figure 1.2), so in the whole cost reduction strategy of HJT cell, these three aspects should be first focused on. Among them, the cost of wafer accounts for the largest proportion of 55%, more than the half. In addition, with the decline in silicon price, the cost of wafer is also declining (as shown in Figure 1.3), but the cost of wafer still occupies the largest part of the whole cost of HJT cell.

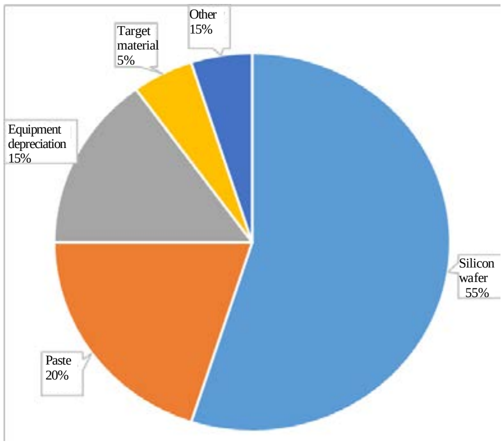


Figure 1.2 Cost composition diagram of HJT cell

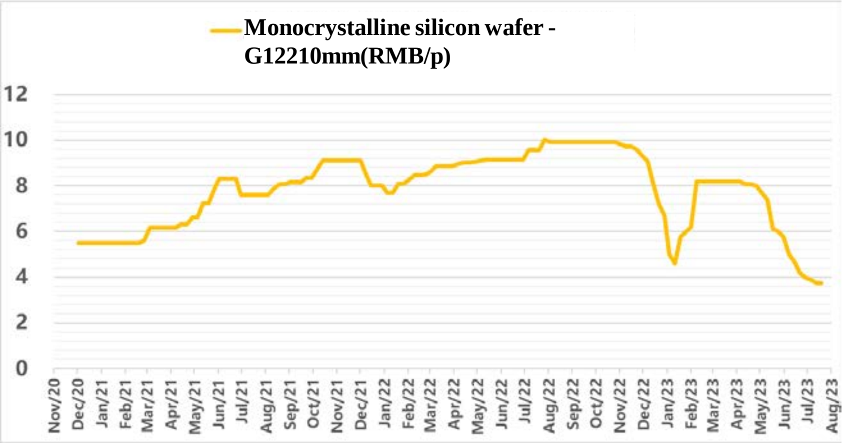


Figure 1.3 Price chart of 210 monocrystalline silicon wafer [1] *(Data source: Financial Power new)*

At present, Risen Energy has begun to mass produce ultra-thin wafers with thickness less than 100 μm and also has introduced self-produced wafers and explored the reuse of ingot trimmings for cost reduction which has already achieved good results. About the ultra-thin wafers in the mass production of HJT technology and product reliability will be shared in the next article.

1.2 Cost reduction scheme-application of low-silver-content paste

Metallization paste accounts for the second largest share of the cost, about 20%. At present, the metallization paste used in the photovoltaic industry is basically called silver paste, of which the silver contents of the paste used by PERC and TOPCon is usually more than 90%. From the silver price trend chart as shown in Figure 1.4 [2], the silver price is still continuing to rise. Due to the large amount of low-temperature silver paste used in HJT, the cost proportion of paste will further increase. Currently, practitioners in the heterojunction industry are looking for alternative materials that can have good conductive performance and low price.

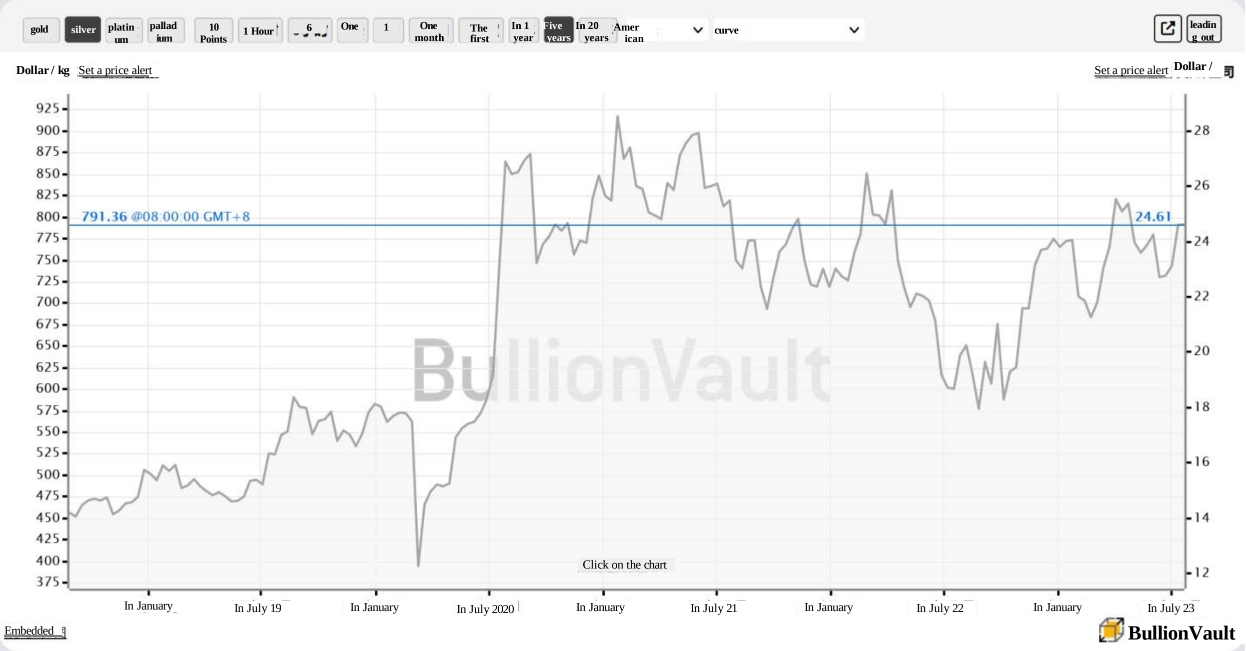


Figure 1.4 Silver price trend chart [2]

Through extensive R&D and rigorous validation, Risen Energy has fully introduced and utilized low-silver-content paste with low cost metal in its HJT hyper-ion products, and moreover has developed a detailed technology roadmap to continuously reduce the cost of cells and module while ensuring cell efficiency and module reliability. This white paper will provide an in-depth exploration of the underlying rationale behind the utilization of low-silver-content paste and will present the empirical results from performance tests conducted on Risen Energy's HJT Hyper-ion products.

2. The development logic of low-silver-content paste

As mentioned above, the main component of the current solar cell paste is silver, which is a precious metal with a high price. According to the “China Mineral Resources Report” wrote by the Ministry of Natural Resources of the People's Republic of China, silver reserve is 71783.66 tons, which is comparatively lower than reserves of copper, aluminum, zinc, and nickel. This vulnerability to future market prices significantly influences cell costs. For the development path of transistor integrated circuit, the gold material originally used as a connection is replaced with the copper or even aluminum, which has greatly reduced the cost of integrated circuit, and has also brought about large-scale applications of integrated circuit. Similarly, in the photovoltaic industry, replacing the precious metal in the metallization paste of the cell is also a must to reduce the cost. To choose the appropriate low-cost metal, three aspects need to be considered: conductivity, reserve and price of the material.

2.1 Electrical conductivity

Table 2.1[3] shows the electrical conductivity of some main metals. Among them, the silver, as the material with the best electrical conductivity, is currently widely used in the metallization paste of photovoltaic cell.

Table 2.1 Electrical conductivity of the different metals [3]

Sequence	Material	Electrical conductivity σ, at 20℃(S/m)
1	Silver	6.30×10^7
2	Copper	5.96×10^7
3	Annealed copper	5.80×10^7
4	Gold	4.11×10^7
5	Aluminum	3.77×10^7
6	Brass (5% Zn)	3.34×10^7
7	Calcium	2.98×10^7
8	Rhodium	2.31×10^7
9	Tungsten	1.79×10^7
10	Zinc	1.69×10^7
11	Brass (30% Zn)	1.67×10^7
12	Cobalt	1.60×10^7
13	Nickel	1.43×10^7

2.2 Reserves of Cu, Al, Zn, Ni

As shown in Table 2.2, China's reserves of copper ore, bauxite, zinc ore, and nickel ore are documented as 34.9479 million tons, 711.1374 million tons, 44.229 million tons and 4.2204 million tons. China's zinc ore reserve ranks second in the world, accounting for 21% of the world, while copper, aluminum and nickel reserves account for 3.1%, 3.3% and 3.3% of the world respectively. Although the overall proportions of copper, aluminum and nickel are not high, they are still more prospective than silver reserve (about 120,000 tons), as shown in Figure 2.1.

Table 2.2 Data on copper, aluminum, zinc and nickel reserves
(Excerpted from "China Mineral Resources Report" in 2022)

Order number	Mineral products	Unit	Reserve
1	Copper ore	Metal, Million tons	34.9479
2	Bauxite	Ore, Million tons	711.1374
3	Zinc ore	Metal, Million tons	44.2290
4	Nickel ore	Metal, Million tons	4.2204

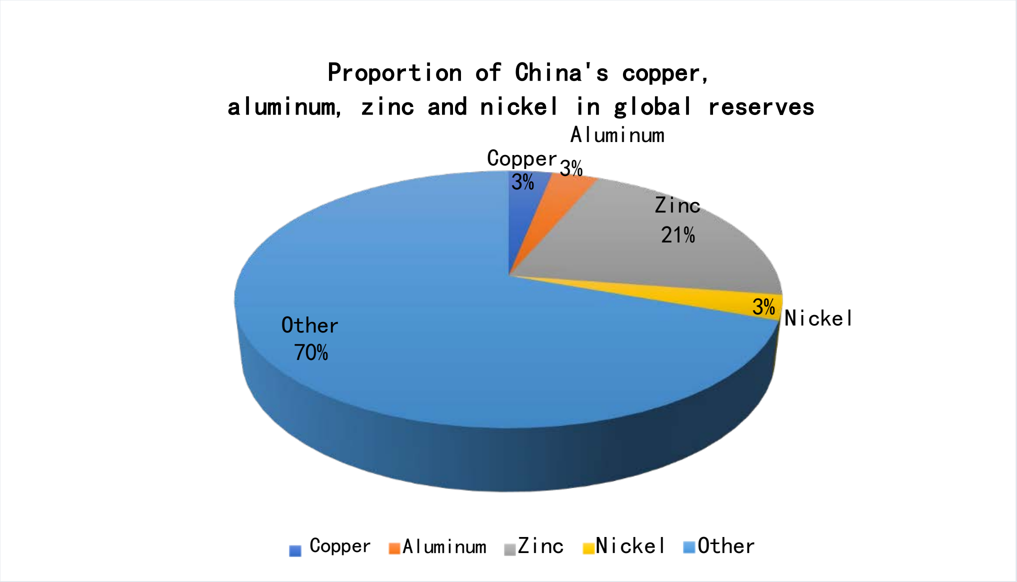


Figure 2.1 Global reserves proportion of copper, aluminum, zinc and nickel

Data source: Orient Securities

2.3 Prices of Cu, Al, Zn, Ni

Graph 2.2[4] shows the five-year historical price trend of the four metals, which peaked in 2022, with all units of USD/ton. At the time of this writing, the price of copper was $8,422/ton, aluminum $2,198/ton, zinc $2,347/ton, and nickel $20,809/ton, which is very cheap compared to silver at $791,360/ton, so the industry is now focusing on how to replace silver with low-cost metals.

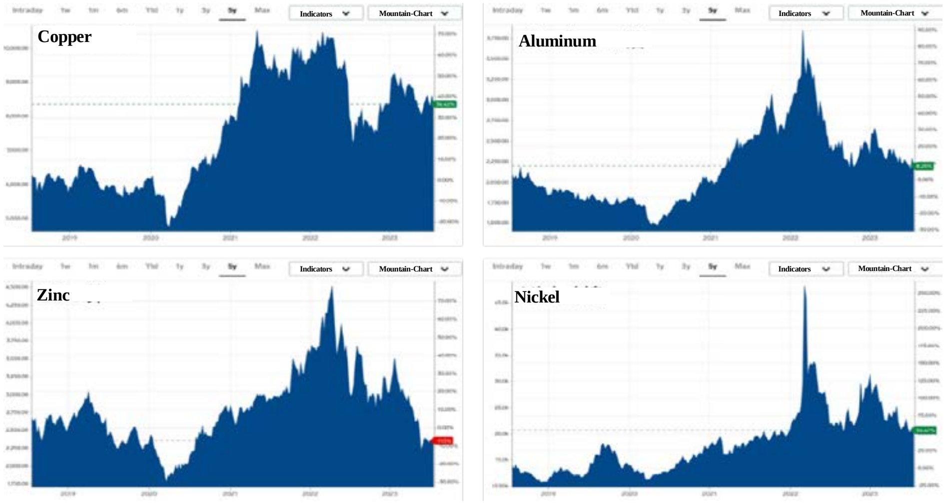


Figure 2.2 Historical prices of copper, aluminum, zinc and nickel

Considering various factors such as electrical conductivity, reserve, price etc., it is found that the more suitable alternative materials are copper, aluminum, zinc, nickel.

But how to replace and which material to replace, there are two main technical routes in the industry: one is the adoption of electroplating to achieve a silver-free metallization. But for the time being it is not mature, with expensive equipment and consumables, wastewater treatment and other shortcomings, which will cause that the cost of metallization does not fall rapidly with no silver, so people often use the method to improve the effectiveness rather than reduce cost; the another one is to replace pure silver paste by using low-temperature paste of low-price metal materials encapsulated in silver shell. This low-silver-content paste is very similar to the pure silver paste, with the same morphology and close performance, and it is compatible with the existing production lines without the need to invest new equipment, greatly reducing the metallization cost.

During years of research and development for HJT product, Risen Energy has laid out a number of cost reduction routes and has completely introduced and mass produced the low-silver-content paste in the current metallization industrialization technology route. In addition, Risen Energy is also working with material suppliers, equipment manufacturers to continuously develop and optimize metallization materials, processes and equipment with better performance and lower cost.

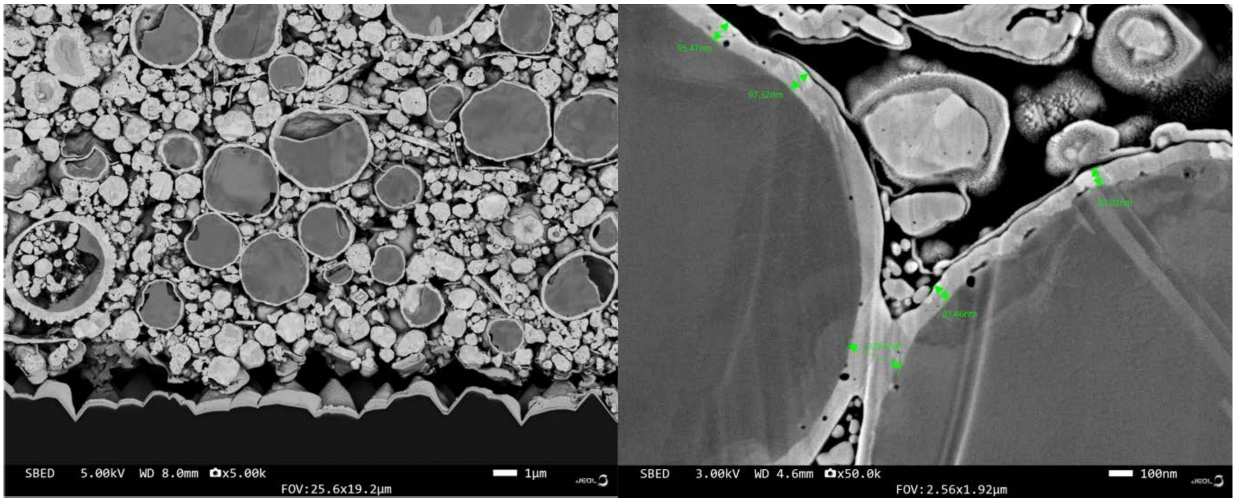
3. The development and applications of low-silver-content paste

Low-silver-content paste is the paste of low-cost metal encapsulated with silver shell. If the silver shell is damaged, there is a risk of exposing the low-cost metals, which are often highly reactive. If the low-cost metals diffuse into the cell, it will form a recombination center and thus reduce the efficiency of the cell. In the development process of low-silver-content paste, Risen Energy together with suppliers, has developed low-silver paste with good performance in material preparation, process control, and optimization of cell and module technology.

3.1 Coating uniformity of the low-silver-content paste

Figure 3.1 shows the photo of FIB-SEM (Focused Ion Beam Scanning Electron Microscopes), in which the outer wrapped white shell is silver, and the inner wrapped ball is the low-cost metal. It’s clearly seen that the coating uniformity is excellent and there is no risk of exposure.

It can also be clearly seen from the enlarged photos that the thickness of the silver shell is between 80 and 100nm, which can effectively ensure that the silver shell is not easy to be damaged and can prevent the exposure of the low-cost metals, as shown in Figure 3.1 (b).



(a) (b)

Figure 3.1 (a) (b) Photo of FIB-SEM of paste with low-silver content

3.2 Effects of light exposure, electrification and heat on the low-silver-content paste

If the cells with the low-silver-content paste are exposed to light, electricity and heat for a long time, the accelerated aging treatment can simulate the cell state in the module after a long period of operation. It is worth exploring whether there will be the weakening of silver shell and the precipitation of low-cost metal ions after the cell aging. Therefore, Risen's R&D team has validated this uncertainty through the following two experiments:

One is to illuminate the cell for a long time with the positive and negative electrodes of the cell not conducted. The main purpose of this is to verify that if there is a precipitation of low-cost metal. If yes, the low-cost metal should diffuse on the cell surface, and XPS (X-ray photoelectron spectroscopy) can be used to detect the horizontal migration of low-cost metal ions on the cell surface.

Another is to short-circuit the front and back of the cell and then illuminate the cell for a long time after heating it a long period in furnace, the EDS (Energy Dispersive Spectrum) is used to test the longitudinal diffusion of low-cost metal ions inside the cell.

3.2.1 Testing of transverse migration of low-cost metal ion

Samples were taken from qualified cells using open circuit and long-term light exposure. The detection area is shown in Figure 3.3 as a circular circle of 400 μm in diameter at the midpoint of the two fingers, with an information depth of about 5nm.

Figure 3.3 XPS (Transverse transportation of low-cost metal ion)

The actual test results of the energy spectrum distribution of XPS are shown in Figure 3.4, in which the indium signal is very strong, and no signals of low-cost metal elements are detected on the cell surface and the 5nm down to the cell surface.

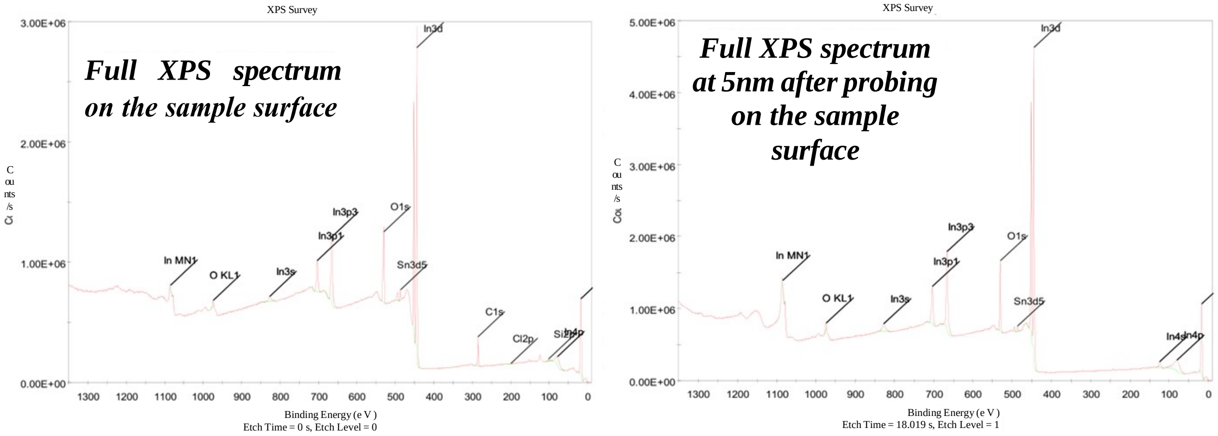


Figure 3.4 XPS (Energy spectrum distribution)

The above test results are summarized in Table 3.1. The ITO on the cell surface is indium tin oxide alloy, so it is a normal that the indium, tin and oxygen appear in results. At the same time, some impurities are found on the surface of the cell, of which the silicon is caused by the silicon powder falling after cell cutting when the sample was made, while the carbon and chlorine are from air. The results show that after the cell aging test, there is no weakening of silver shell and the precipitation of low-cost metal ions, which indicates that the light exposure, electrification and heat will not cause degradation to the low-silver-content paste.

Sample depth	**Test results Unit: At%**					
	In	O	C	Sn	Si	Cl
Surface 0nm	19.6	39.29	35.22	1.08	3.83	0.98
Sputtering 5nm	40.22	58.56	/	1.22	/	/

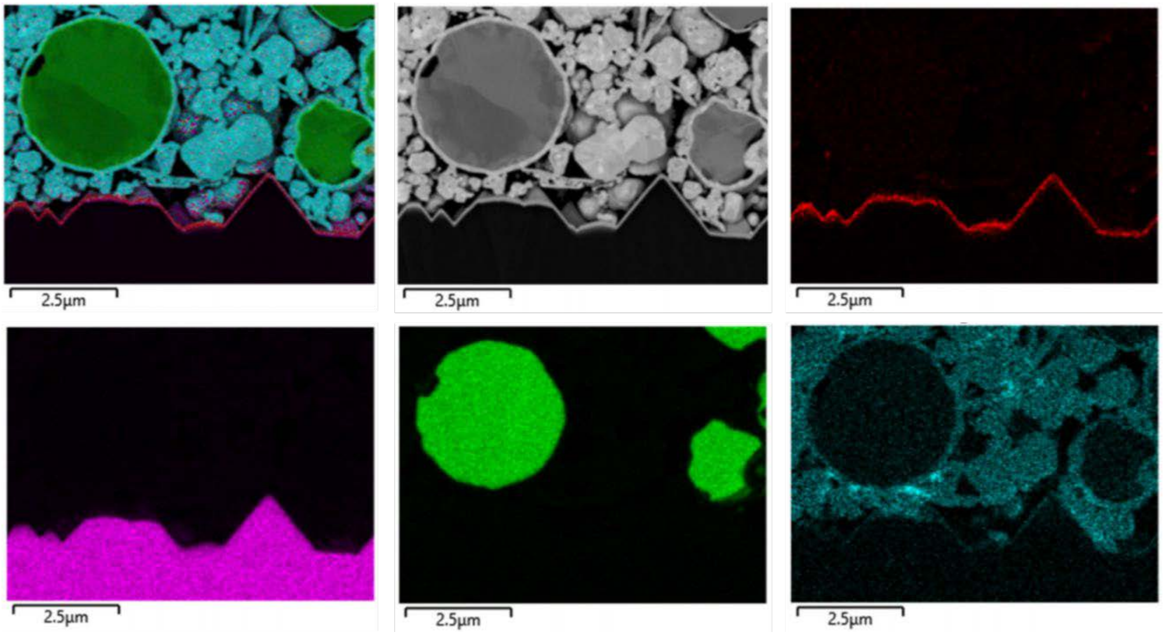
Table 3.1 Summary of the measured results of the energy spectrum distribution of XPS

3.2.2 Testing of deep diffusion of low-cost metal ion after heating and light exposure

Considering that high temperature and electrification will accelerate the penetration of low-cost metal ions, the cell is heated for a long time, then the positive and negative terminals are connected and subjected to a long period of light exposure, so that the cell is in a normal working state, and then observe the diffusion of low-cost metal ions.

After carry out FIB-SEM cutting to the sample cell, launch layered scanning with EDS, as shown in Figure 3.5, different colors represent different elements, red for oxygen, pink for silicon, green for low-cost metal, indigo for silver. As showed from the Figure, the low-cost metal exists only within the wrapped silver shell.

Figure 3.5 FIB-SEM & EDS Layered Fig



In order to further check whether the low-cost metal elements have entered the depths of the cell, 4 points below the finger of low-sliver-content paste and at different depth are selected for precision detection, as shown in Figure 3.6.

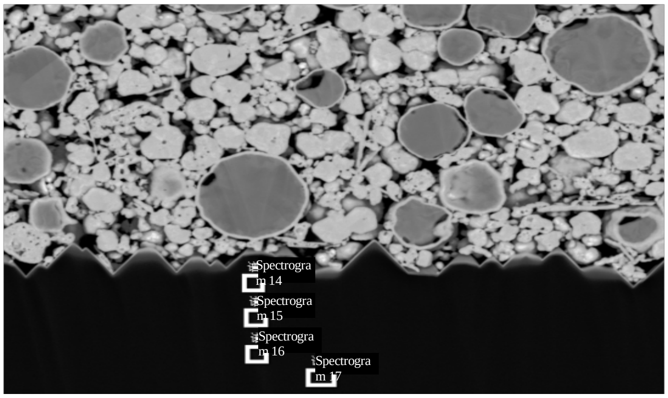


Figure 3.6 FIB-SEM

Figure 3.7 shows the element detection at each position in Figure 3.6. In the silicon substrate below the finger, there are only silicon signals at the four positions, and no signals of low-cost metal elements are found.

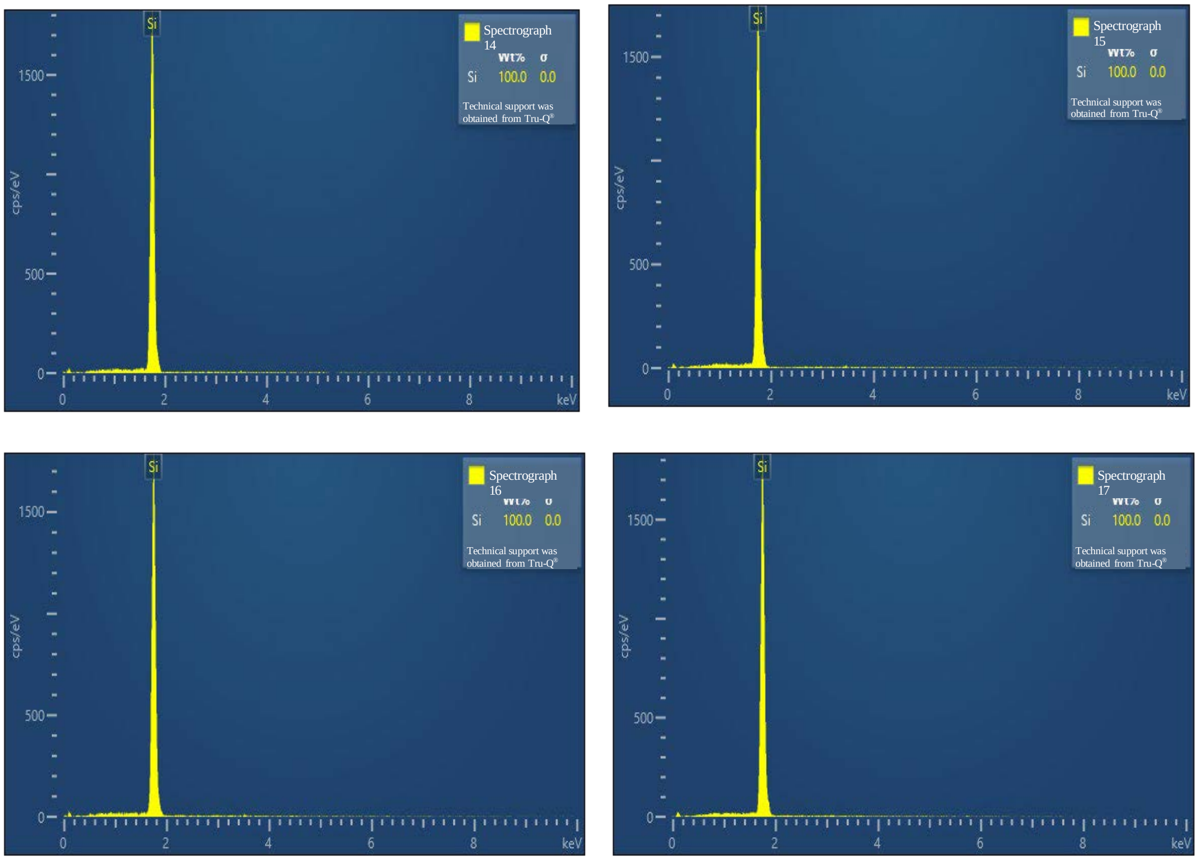


Figure 3.7 EDS (Detection of low-cost metal deep inside the cell)

In conclusion, the above tests conducted on the interior of the cell reveal that neither sustained high temperatures nor prolonged exposure to light with short-circuit conditions lead to the precipitation of low-cost metal ions following damage to the silver shell. Additionally, the low-cost metals within the low-silver content paste will not permeate into the cell after long period of normal operation.

3.2.3 Testing of copper electroplating

Copper, aluminum, zinc and nickel all can be used as low-cost metals for the low-silver-content paste, among which copper is often the most worried to spread and diffuse into the cell and cause the degradation of cell performance. Therefore, where copper is used, a limit test has been applied to see if this problem occurs when the copper is directly in contact with the HJT cell.

Therefore, we use the method of copper plating for circumstantial evidence [5]. As shown in Figure 3.8, an ITO of 10nm thickness is deposited on the sample cell and electroplated copper was directly overlaid on it.

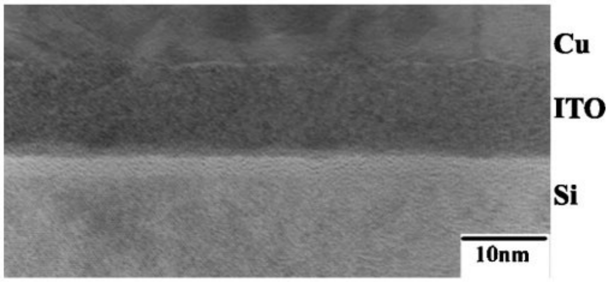


Figure 3.8 Schematic diagram of copper plating

After the sample cell experienced different annealing temperatures, a sheet resistance test is performed to the sample cell, as shown in Figure 3.9 [5], when the annealing temperature is less than 650 ℃, the sheet resistance does not change, but when the annealing temperature is more than 700℃, the sheet resistance changes sharply.

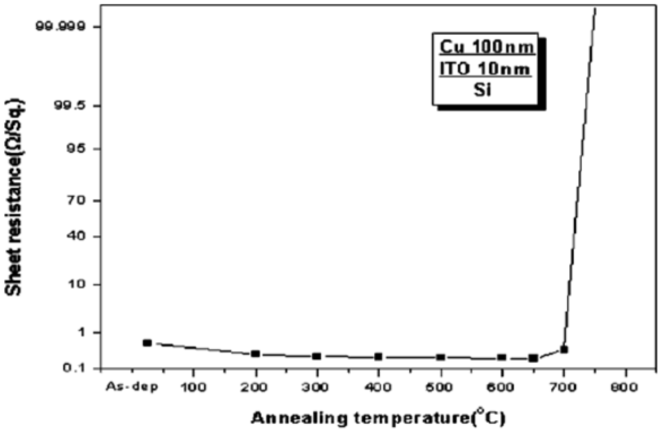


Figure 1. Sheet resistance variations of the Cu/ITO/Si stacked films with the RTA treatment.

Figure 3.9 Sheet resistance variations

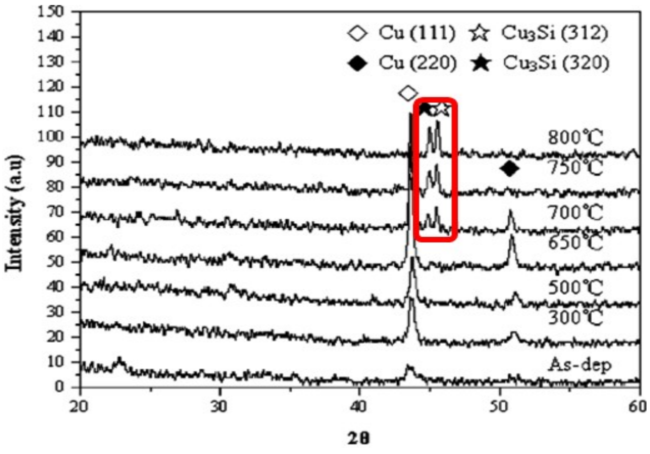


Figure 5. XRD patterns of Cu/ITO/Si sample before and after annealing.

Figure 3.10 XRD patterns before and after annealing

Through the XRD (X-ray diffraction) test, as shown in Figure 3.10[5], Cu_3Si alloy is found when the annealing temperature exceeded 700℃. The diffusion of copper element forms the deep-level trap, which destroys the passivation effect and cause drastic change in performance.

According to the study above, an ITO layer of 10nm thickness on the wafer surface can effectively prevent the diffusion of copper ions when the temperature is less than 650℃, while the ITO thickness of the front and back of the HJT cell reaches 80nm, which is far more than that in this example. Furthermore, the whole HJT process is under the low temperature, including annealing, not exceeding 200℃. Therefore, the copper electroplating is a counter argument that the HJT cell will be safer with the low-silver-content paste containing various low-cost metals.

4. Reliability tests and results

HJT high efficiency cell possesses superior passivation effect, which puts higher demand on module encapsulation. With the improvement of the novel encapsulation technology, the high efficient HJT modules achieve better resistance against oxygen and water, which ensures the reliability of the low-silver-content modules.

The IEC-61215 standard specifies diverse weather resistance and aging tests, including Damp Heat tests (85℃ + 85% relative humidity, 85℃ + 85%RH) for 1000 hours (DH1000) and Thermal Cycling tests(-40℃ and 85℃) with 200 cycles (TC200). In order to maximize the verification of the limit of the low-silver-content paste, limit test based on 6 times the IEC standard were conducted.

Four samples are selected for the low-silver-content paste, among which, the low-silver-content of 1.0/2.0 with V1/V2 represent four different samples.

The DH test results are shown in Figure 4.1. According to the DH2000 test results, the degradation of pure silver paste is 1.92%. Notably, low-silver-content samples of 1.0-V1, 1.0-V2 and 2.0-V2 outperform pure silver paste. Moreover, the degradation after DH6000 test are lower than 3%, which is very excellent. The results for low-silver content paste 2.0-V1 is bit worse, but the degradation can still be controlled within the 5% after DH6000, which meets IEC standards.

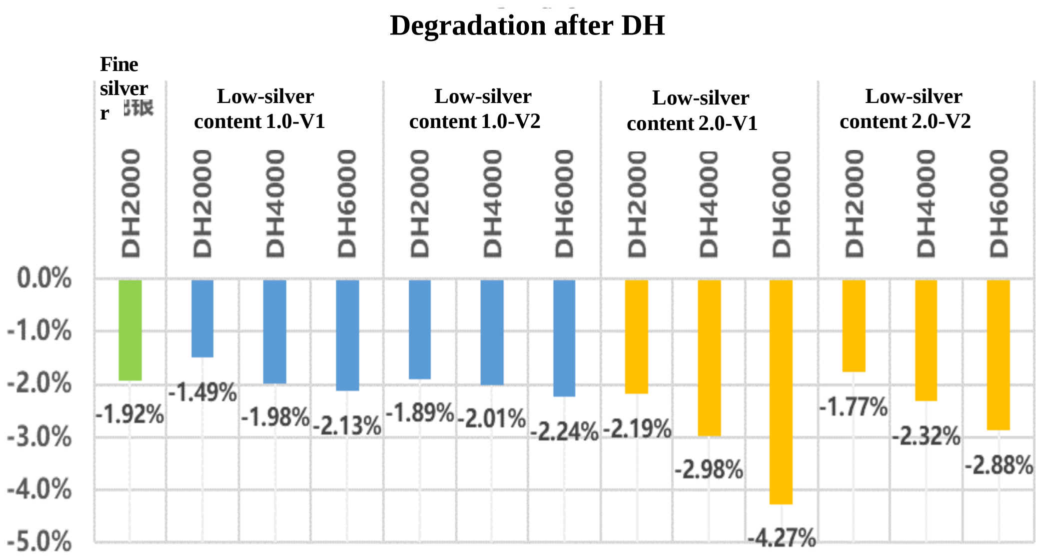


Figure 4.1 Degradation after DH tests

Figure 4.2 presents the results of the TC tests. The degradation of module with pure silver after TC400 is 0.67%, while these four low-silver-content pastes are all better. Following TC1200 test, low-silver content paste 1.0-V1 even exhibits a gain of 0.57%, while low-silver content 2.0-V1 and 2.0-V2 show negligible degradation. Only low-silver content paste 1.0-V2 experiences a minor degradation, but overall results remain commendable.

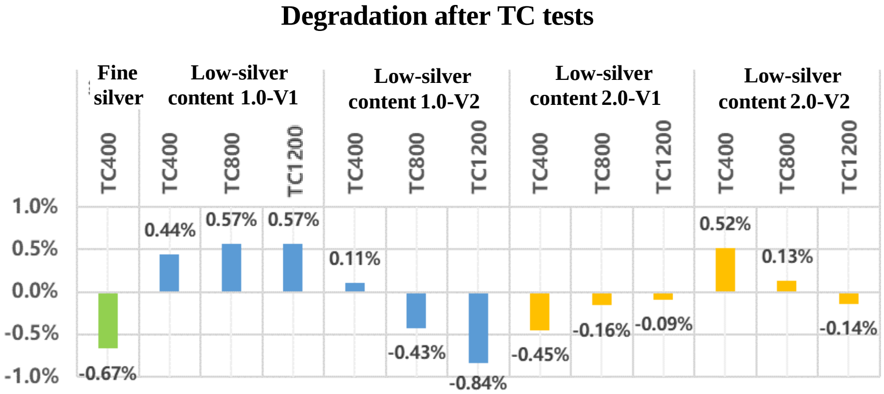


Figure 4.2 Degradation after TC tests

To sum up, compared with the pure silver paste products, the DH and TC tests of the products with low-silver-content paste can meet the requirements, or even better, especially after tests of multiple times the IEC standard, most of the degradation can still be controlled within 3%. This shows that the modules using the cell with the low-silver-content paste can fully meet or even exceed the performance of the modules with pure silver paste cells.

5. Comparison of power generation

The weather resistance and aging test results have demonstrated the reliability of the HJT modules with the low-silver-content paste, so will the use of the low-silver-content paste affect the power generation of the modules? To this end, the actual power generations of the modules using the pure silver paste and the modules using the low-silver-content paste are monitored and compared by the Risen Energy’s field power station at Changzhou Jintan base.

The field test started from February 8, 2023. From the collected data for several months, it can be seen that the equivalent power generation time of the two are almost completely overlapped as shown in Figure 5.1, which proves that the modules using low-silver-content paste cells have the same power generation capability as those using pure silver paste cells. It also shows that the use of low-silver-content paste has no impact on the power generation of HJT products.

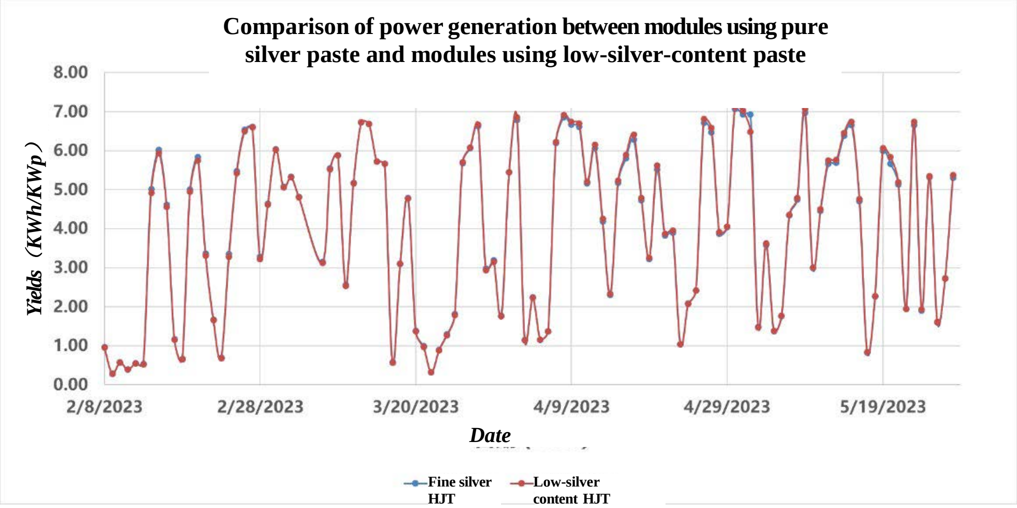


Figure 5.1 Comparison of power generation between modules using pure silver paste and modules using low-silver-content paste

6. Review

Starting with the content of "development and application of low-silver-content metallization paste", this white paper expounds some exploration and achievements of Risen Energy on the road of cost reduction of HJT technology. Through the material selection of the low-silver-content paste, the optimization of coating uniformity of the paste, the impact on the low-silver-content paste by light exposure, electrification and heat, and the reliability test and power generation comparison of the modules, it is fully proved that the low-silver-content metallization paste of Risen Energy has high reliability and can be mass-produced. At present, with the industrial application of HJT Hyper-ion technology, the pure silver consumption of Risen Energy HJT cell has been reduced to 10mg/W, which is the leading in the industry and is expected to drop 1mg/W per quarter in the future to realize the application of metallization paste with lower silver content.

"Cost reduction and efficiency improvement" is the eternal theme of photovoltaic industry, Risen Energy will continue to reduce the cost of HJT cells and modules from the application of the low-silver-content paste, equipment localization, the application of ultra-thin wafer, and further improve the cell efficiency and module reliability, accelerating the industrialization of HJT technology.

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[4] Historical trend chart of metal price, the “metal-price” at the end of the link needs to be replaced by “copper-price”, “aluminum-price”, “zinc-price” and “nickel-price” (https://markets.businessinsider.com/commodities/metal-price)

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