Discussion on Metallization Schemes with Less Silver and No Silver

苏 州 晶 银 新 材 料 科 技 有 限 公 司

Suzhou iSilver Materials Co., Ltd.

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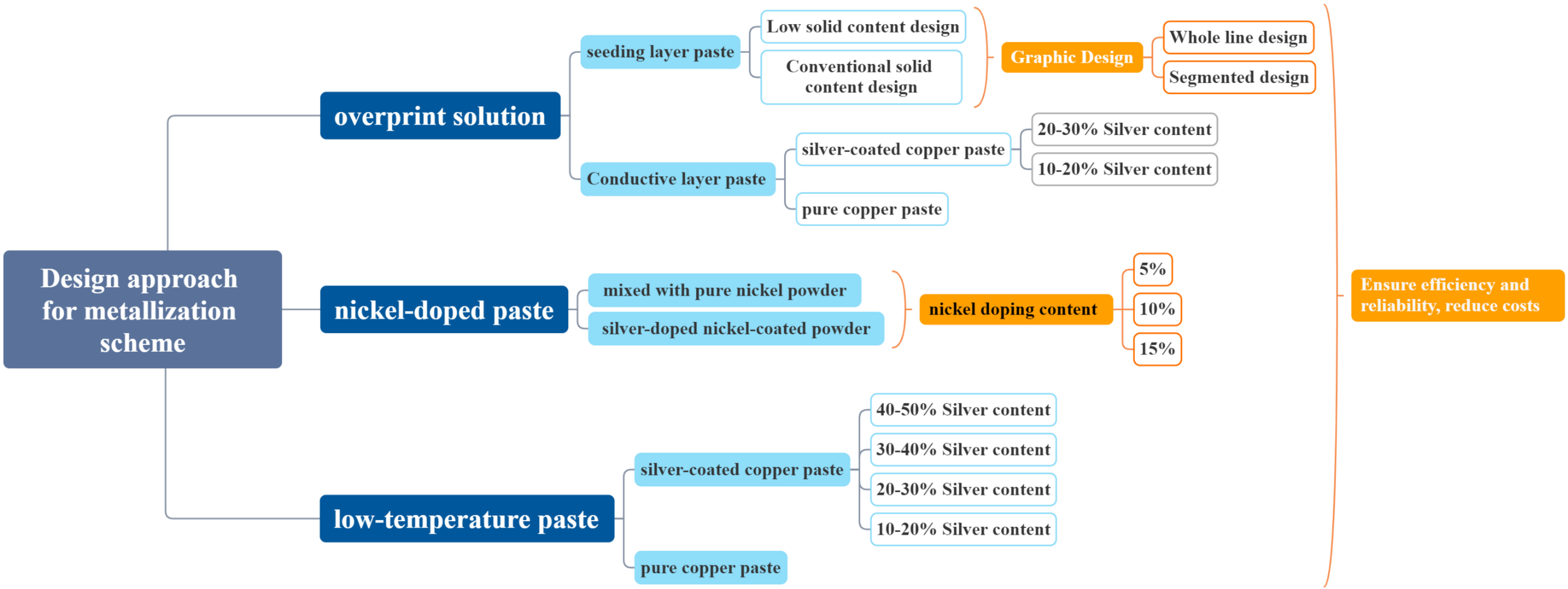
Part 1

Design ideas for metallization schemes

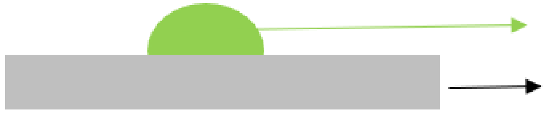
Design idea of metallization scheme



Part 2

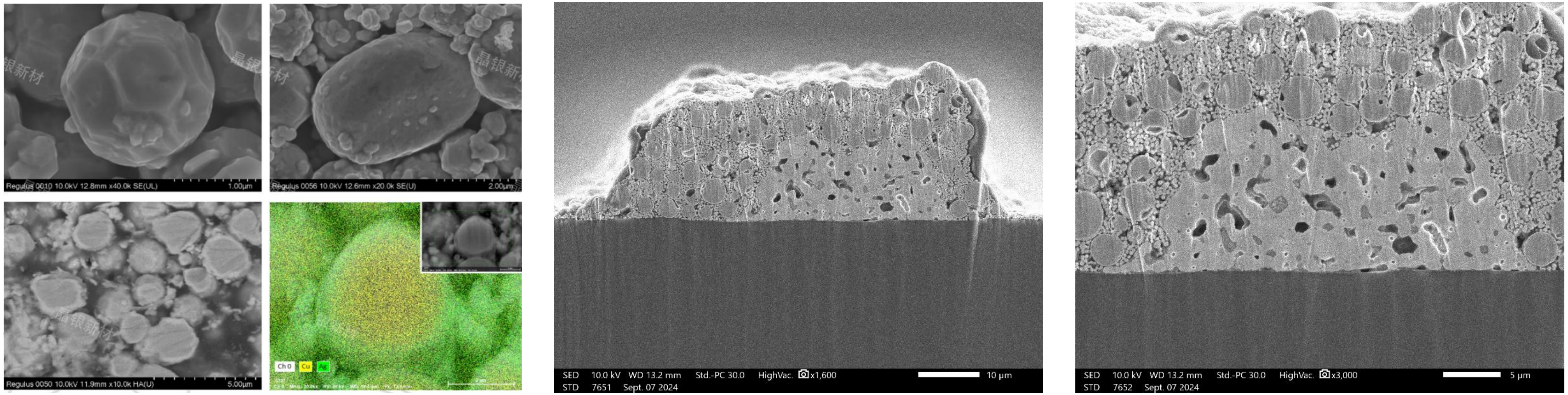
The design ideas of overprint cost reduction

Cost reduction design scheme for Ag-Cu paste



✓ Reduce costs

✓ Improve efficiency



Ag-Cu paste overprinting technology is used to reduce silver consumption

* The data is sourced from the laboratory.

Seed layer — Conductive layer

- **Thin silver at the bottom Seed layer**

Straight line

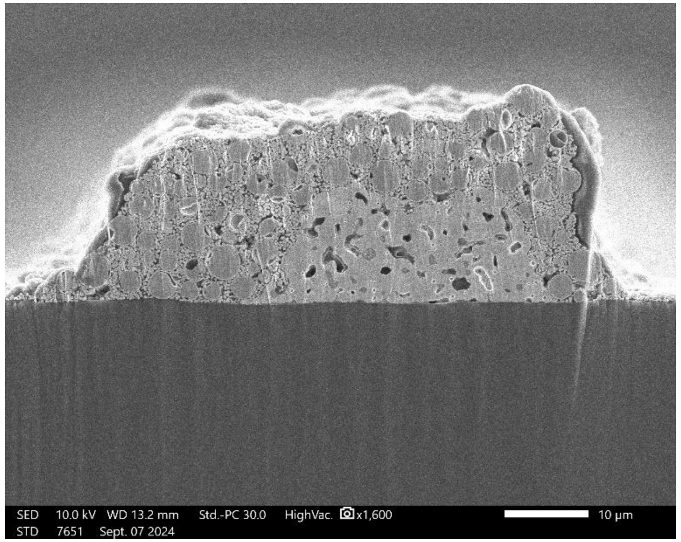
line segment

◆ The bottom silver can use conventional low solid content Topcon back fine paste. On this basis, the fluidity and ink penetration ability of the paste can be adjusted according to the requirements of the screen and solid content.

- **AgCu - Conductive layer**

◆ The conductive layer uses 10-30% AgCu paste.

◆ The silver layer thickness is approximately 40-80nm.



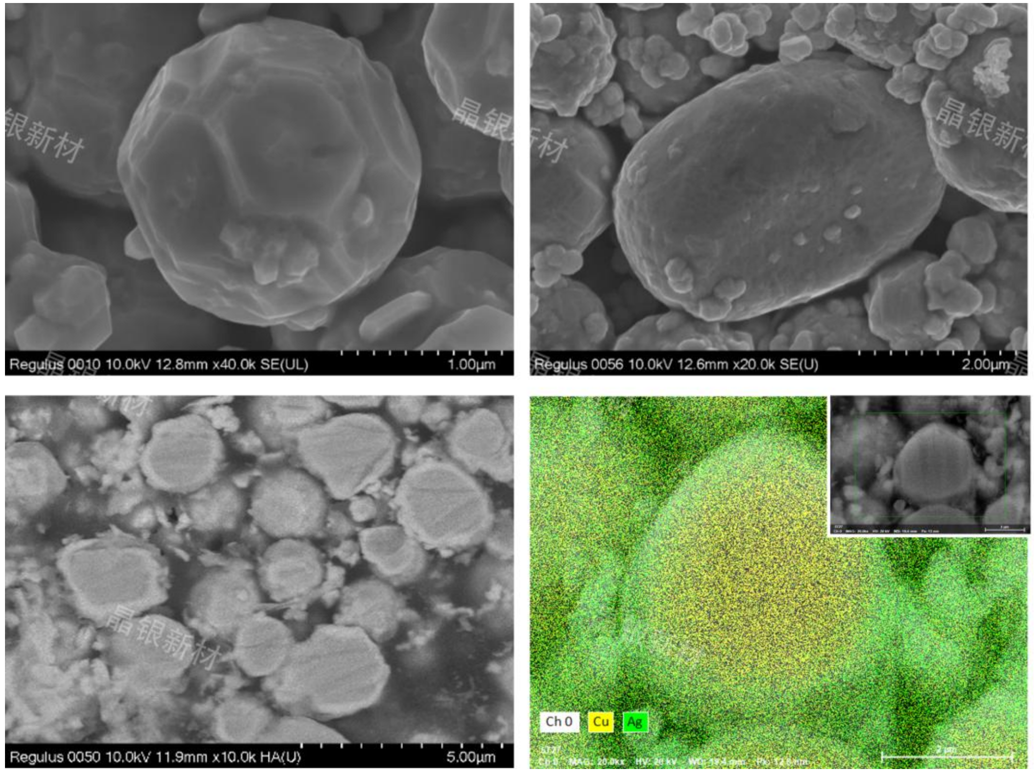
Research Status of silver-coated Copper powder

Current research status of preparation processes

- The main component of the plating solution is silver nitrate solution. The electronegativity of copper is higher than that of silver, and it can undergo displacement reactions. Free silver ions undergo displacement reduction reactions on the surface of copper powder, forming a silver coating.
- Modern processes often employ complexing agents to complex free silver ions, increase the complexation constant of silver ions, and ensure the stability of the plating solution during the metal coating process.

Silver-coated copper powder process

- The current electroless plating process can already ensure the uniformity, stability and integrity of the coating.



施玉雷. 银包铜粉的制备、表征及性能研究[D].东南大学

Key technology of low silver copper paste

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Surface modification of silver coated copper powder

Modification purpose

- Increase the bond strength of paste
- Improve paste compatibility
- Improve the stability of powder and paste
- Inhibition of ion migration
- Improve powder dispersion
- Improve interface contact
- Improving paste resistivity

Stability
Reliability
Printability
Conductivity
improvement

Modification method

- **mechanical treatment**

Ball milling, sand blasting, etc

- **Surface Modification Treatment**

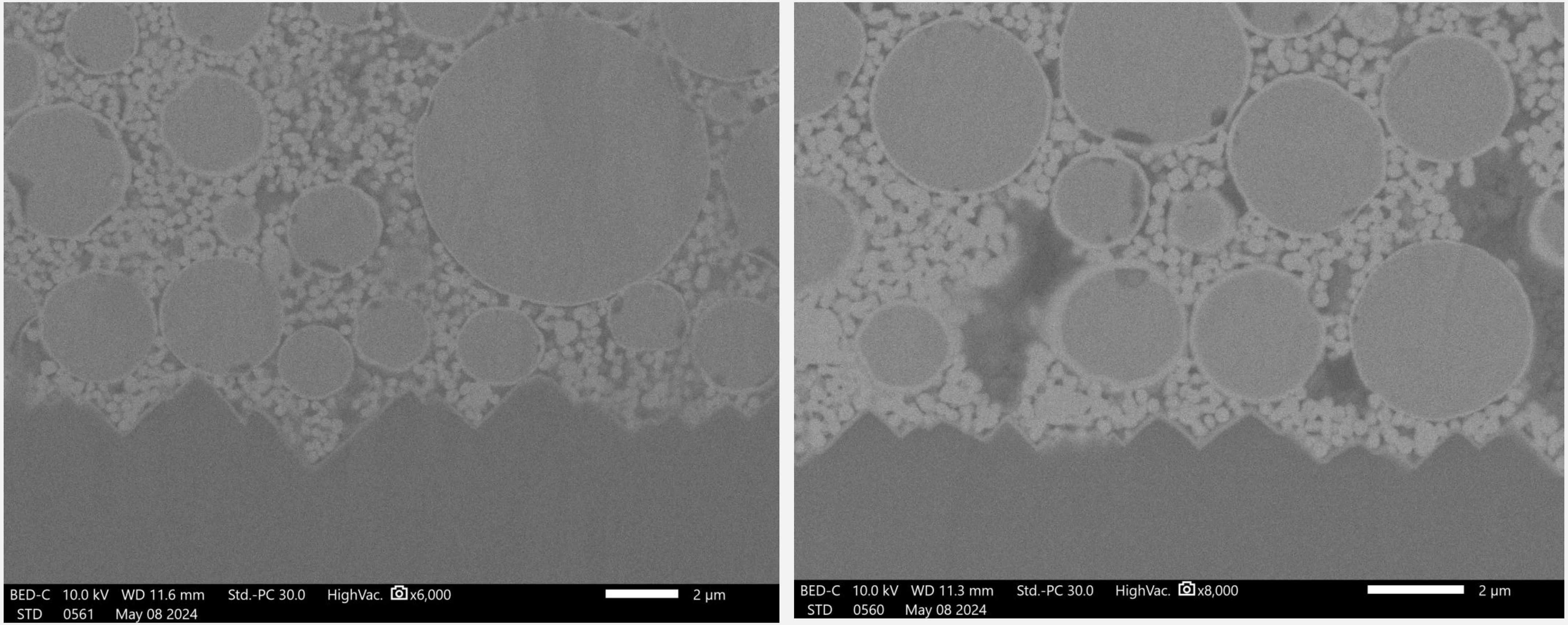
Surfactant

Antioxidant

Coupling agent

……

The characteristics of silver-coated copper powder



- **The overall silver coating of the silver-coated copper powder is uniform, with a silver layer thickness of approximately 60-80nm, and there are no issues of uneven coating or exposure.**
- **All 20% Ag-Cu low-temperature pastes have passed the standard IEC reliability tests.**

Ag-Cu fine finger paste

	TAC609-T	TAC809-T	TAC899-T	TAC909-T (R&D product)
Silver content (%)	30-32	22-26	15-20	10-15
Bulk resistivity (μΩ.cm)	5.0-7.0	6.0-7.0	7.0-9.0	8.0-10.0
Printing speed (mm/s)	≥450	≥450	≥450	≥450

- Low-silver silver-containing copper-coated paste, maintaining low bulk resistance and high printing speed;
- The high-temperature seed layer on the back and the silver-coated copper finger with 20% silver content or less significantly reduce the metallization cost.
- The 30% and 20% silver-containing copper pastes have both passed the standard IEC reliability tests.

*晶银实验室数据

Customer Experiment Result NO.1

	Wet weight (mg)	Eff (%)	Uoc (mV)	Isc (A)	FF (%)	Rs (Ω)
BL	28	—	—	—	—	—
BN-08 (Single-print seed layer)	15	-0.18	1.1	-0.003	-0.68	-3
BN08+TAC589 (Seed layer + silver-coated copper)	15+35	-0.06	1.9	-0.007	-0.33	/

- The initial test shows that the efficiency of the overprint scheme is 0.06% lower.
- At the current wet weight, the silver-coated copper paste with 20% or less silver content has a cost advantage of about 1 fen /w in metallization cost.
- The contact performance of the seed layer and the wet weight of the silver coated copper paste can be further optimized.

*客户数据

Customer Experiment Result NO.2

	Wet weight (mg)	Eff (%)	Uoc (mV)	Isc (A)	FF (%)	Rs（Ω）
BL	39.5	—	—	—	—	—
BN07 (Single-print seed layer)	20.4	-0.044	-0.2	0.0006	-0.171	0.00011
TAC809（25%）	59.6	0.018	0.8	0.0046	-0.058	0.00002

- The overprint scheme is 0.018% more efficient.
- The silver content of the silver-coated copper paste with 25% silver content and the seed layer is 2-3 mg lower than that of pure silver.
- The contact performance of the seed layer and the wet weight of the silver coated copper paste can be further optimized.

*客户数据

Customer Experiment Result NO.3

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	Wet weight (mg)	Eff (%)	Uoc (mV)	Isc (A)	FF (%)	Rs（Ω）
BL	44.4	—	—	—	—	—
BN07 (stencil printing: Opening 11.5μm, total thickness 24μm Single-print seed layer)	21.5					
TAC809（25%）	48	-0.001	0.9	0.0052	-0.139	0.00006

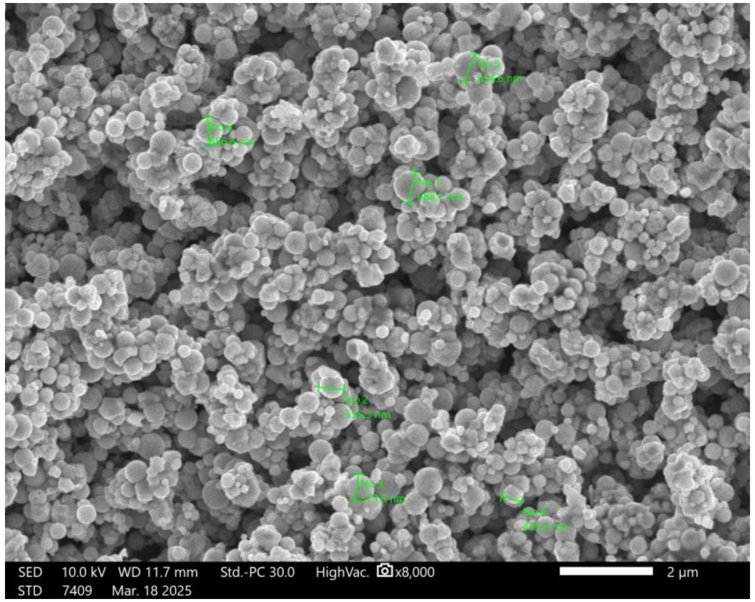
- The efficiency of the overprint scheme is 0.001% low.
- The silver content of the silver-coated copper paste with 25% silver content and the seed layer is 7-8 mg lower than that of pure silver.

*客户数据

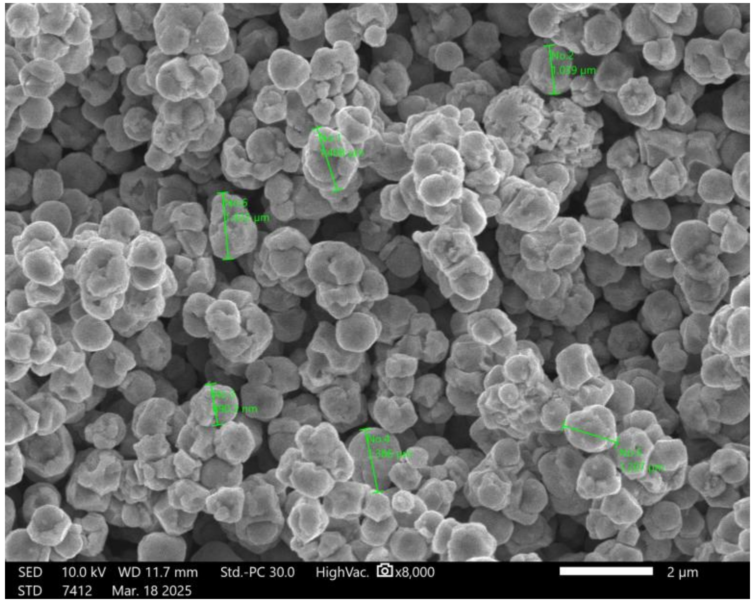
Part 2

Nickel-doped (silver-coated nickel) cost reduction design scheme

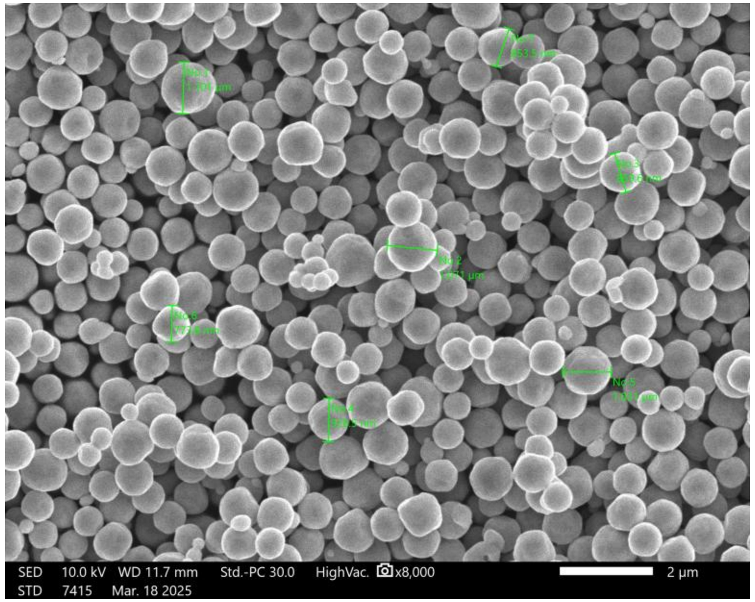
The SEM of silver-coated nickel and nickel powder



Silver-coated nickel powder A

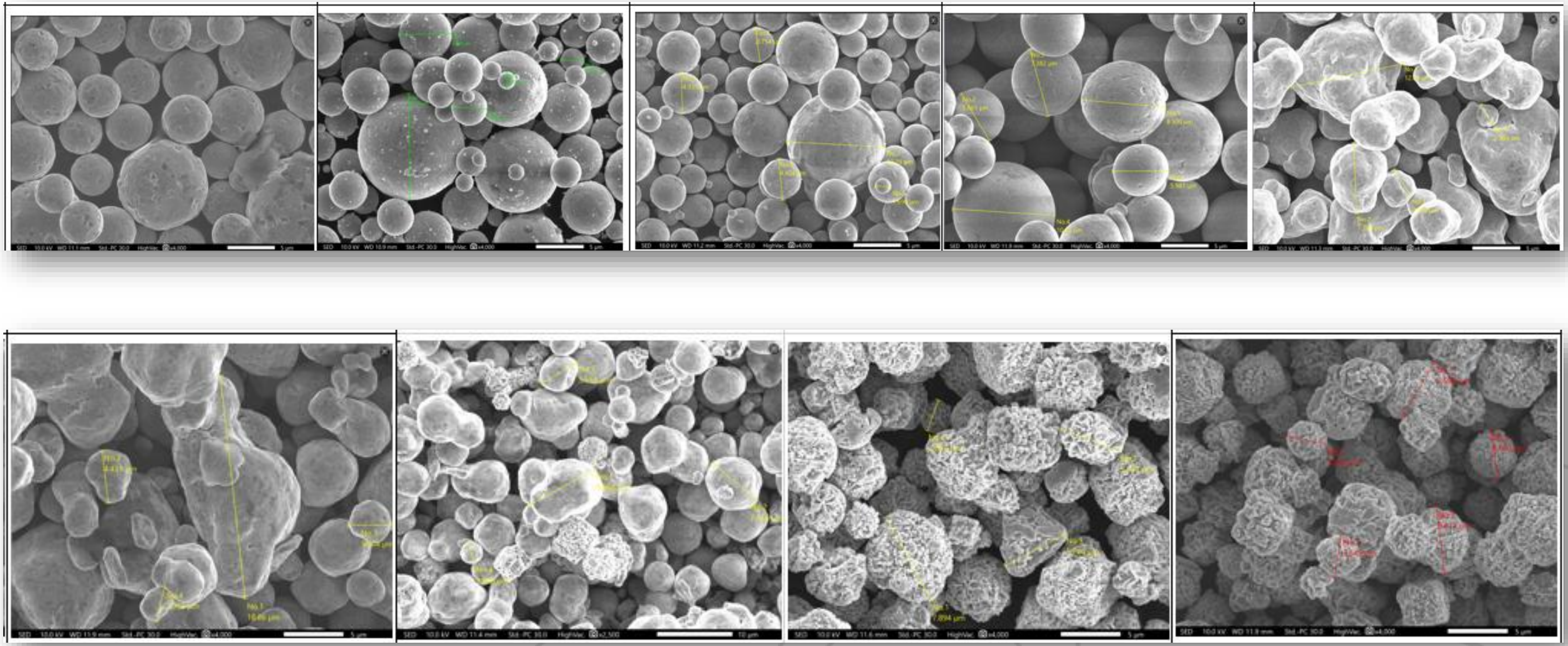


Silver-coated nickel powder B



Nickel powder

The SEM of silver-coated nickel and nickel powder



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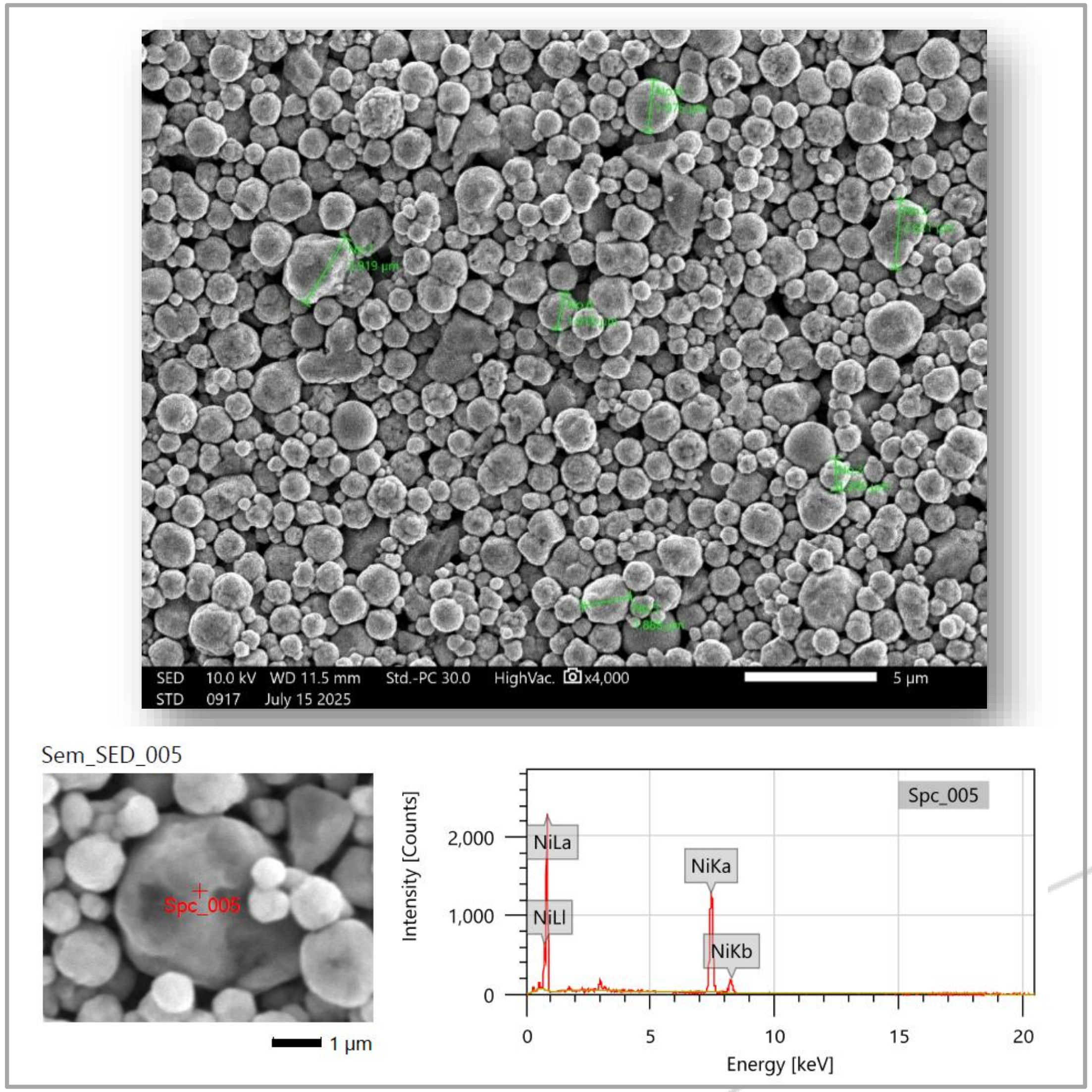
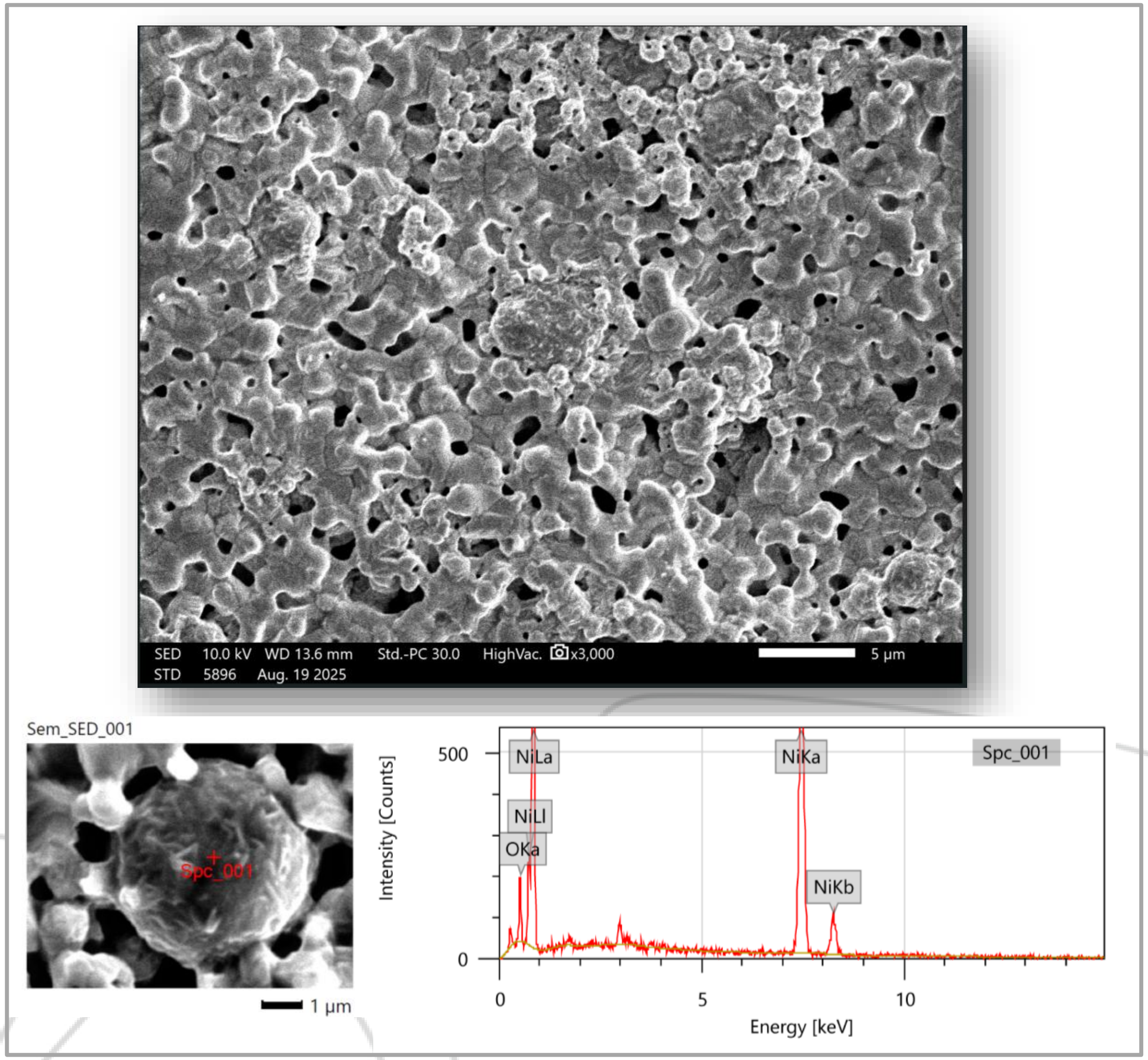
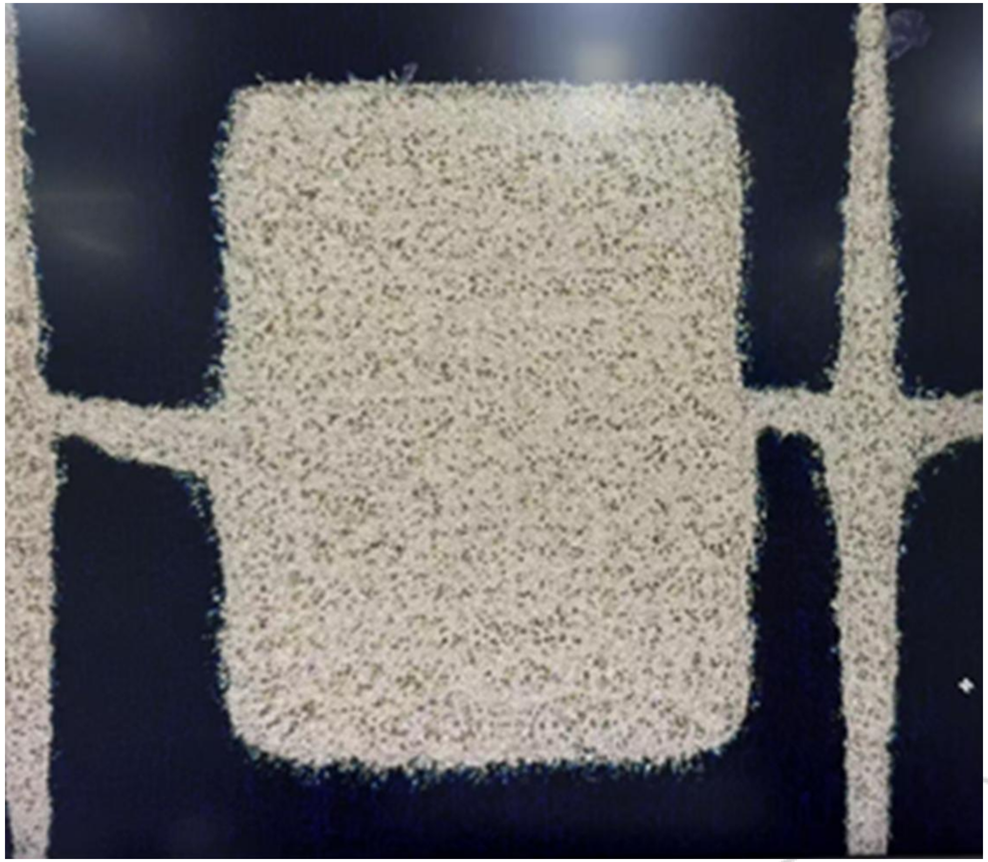
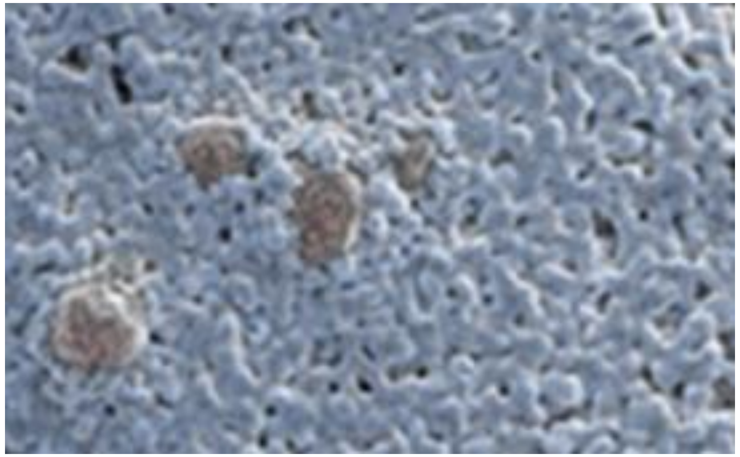
The SEM of silver-coated nickel and nickel powder

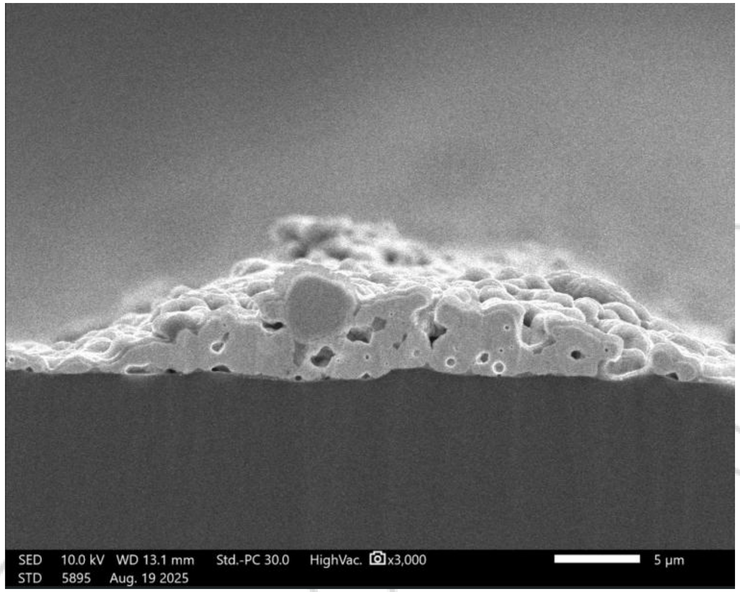




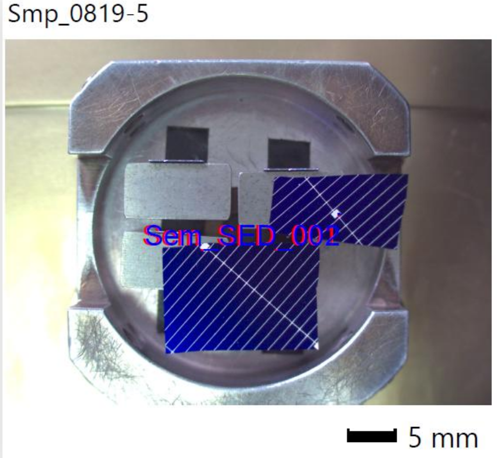
The SEM of silver-coated nickel and nickel powder

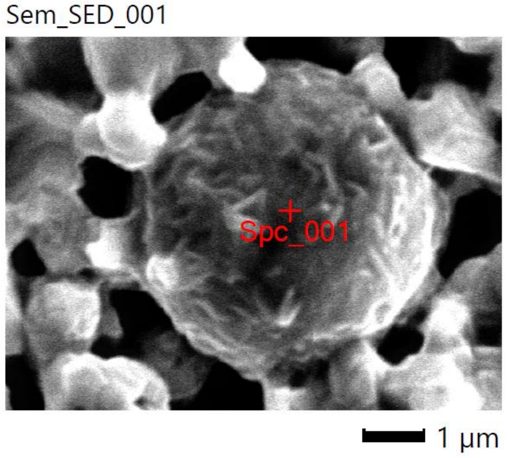






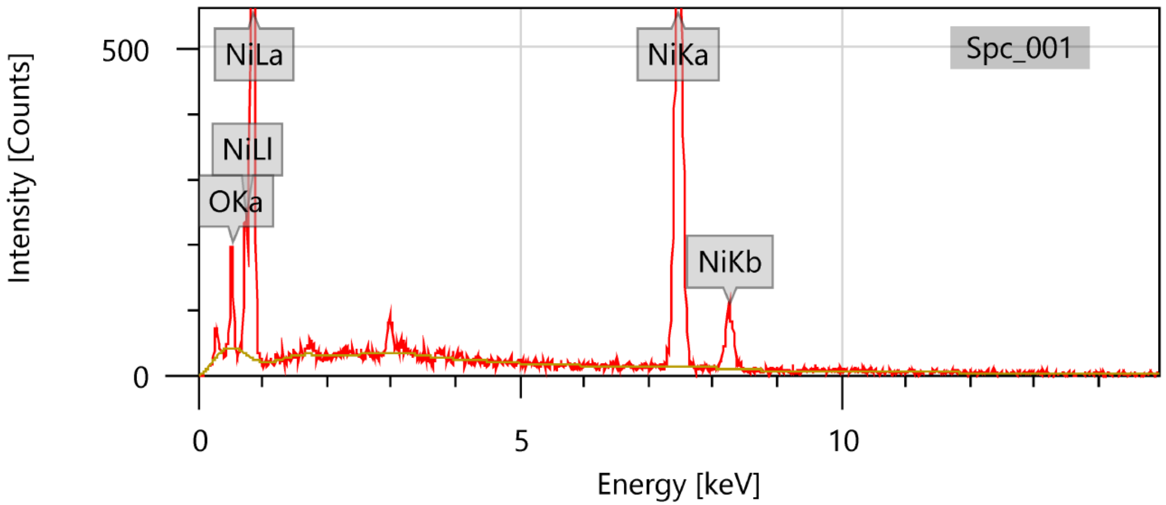
The SEM of silver-coated nickel and nickel powder





Signal SED
Landing Voltage 20.0 kV
WD 13.7 mm
Magnification x16,000
Vacuum Mode HighVacuum

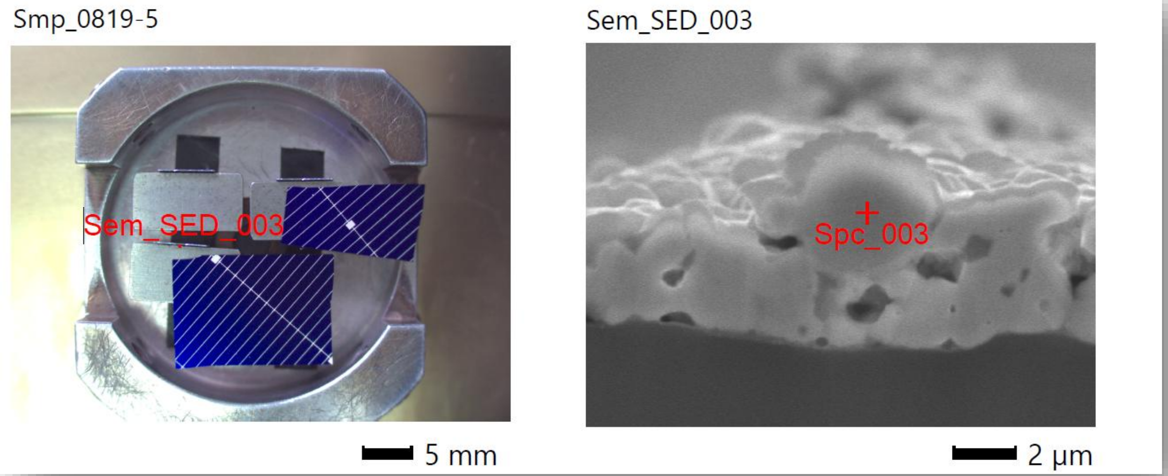
Items	Value
measurement conditions	
Acceleration voltage	20.00 kV
Probe current	-
Magnification	x 16000
Process time	T4
Measurement detector	First
Live time	10.00 seconds
Real time	10.91 seconds
Dead time	8.00 %
Count rate	4161.00 CPS



Display name	Standard data	Quantification method	Result Type
Spc_001	Standardless	ZAF	Metal

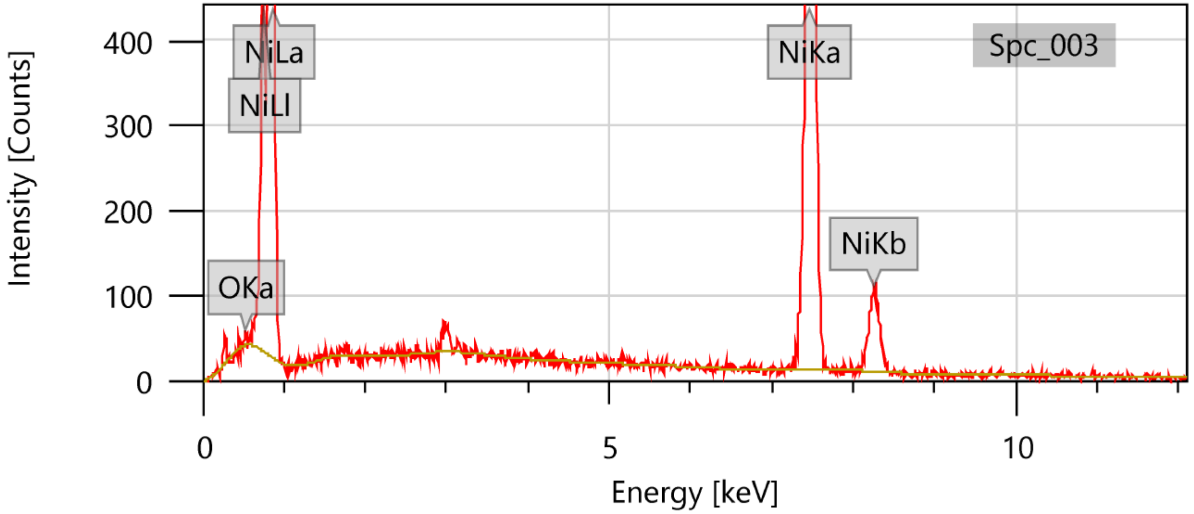
Element	Line	Mass%	Atom%
O	K	5.29±0.18	17.00±0.58
Ni	K	94.71±1.19	83.00±1.04
Total		100.00	100.00
Spc_001			Fitting ratio 0.0531

The SEM of silver-coated nickel and nickel powder



Signal SED
Landing Voltage 20.0 kV
WD 13.2 mm
Magnification x8,000
Vacuum Mode HighVacuum

Items	Value
measurement conditions	
Acceleration voltage	20.00 kV
Probe current	-
Magnification	x 8000
Process time	T4
Measurement detector	First
Live time	10.00 seconds
Real time	10.98 seconds
Dead time	9.00 %
Count rate	4787.00 CPS



Display name	Standard data	Quantification method	Result Type
Spc_003	Standardless	ZAF	Metal

Element	Line	Mass%	Atom%
O	K	0.42±0.07	1.52±0.25
Ni	K	99.58±1.18	98.48±1.17
Total		100.00	100.00
Spc_003			Fitting ratio 0.0386

Test data from Customer

	Wet weight (mg)	Eff (%)	Uoc (mV)	Isc (A)	FF (%)	Rs (mΩ)	Rsh (Ω)	Irev2
BL	—	—	—	—	—	—	—	—
10%Ni	1.2	-0.004	0.1	0.006	-0.05	/	-22	-0.02

	Wet weight (mg)	Eff (%)	Uoc (mV)	Isc (A)	FF (%)	Rs (mΩ)	Rsh (Ω)	Irev2
BL	—	—	—	—	—	—	—	—
12%Ni	4.0	-0.02	-0.3	-0.024	0.10	0	-88	-0.001

Test data from Customer

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	Wet weight (mg)	Eff (%)	Uoc (mV)	Isc (A)	FF (%)	Rs (mΩ)	Rsh (Ω)	Irev2
BL	—	—	—	—	—	—	—	—
15%Ni	4.0	-0.011	0. 5	0.005	-0.12	0.0001	67	0.001

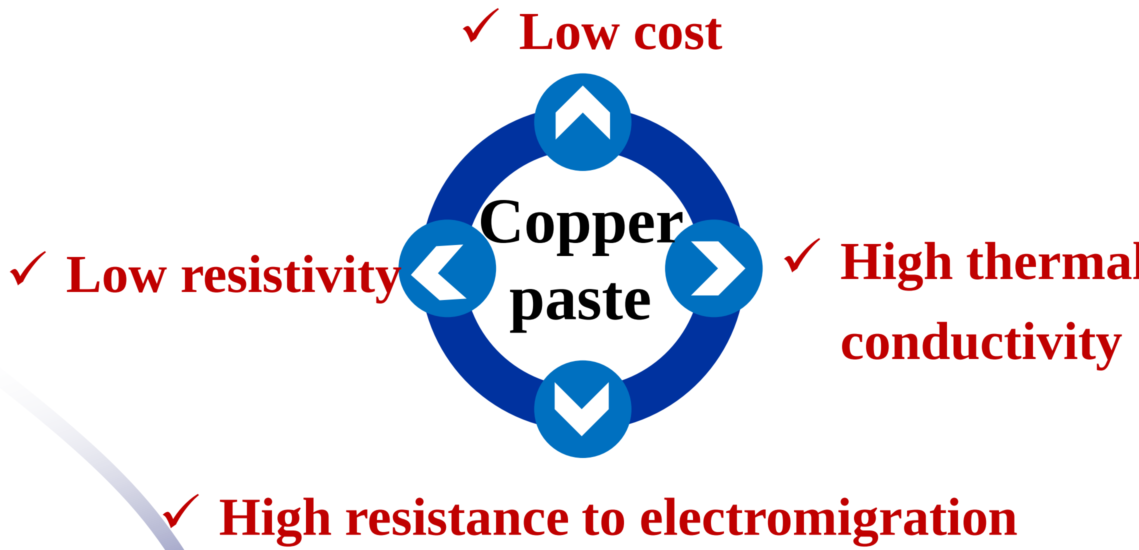
	Wet weight (mg)	Eff (%)	Uoc (mV)	Isc (A)	FF (%)	Rs (mΩ)	Rsh (Ω)	Irev2
BL	—	—	—	—	—	—	—	—
15%Ni A	-0.4	-0.012	-0.1	0.014	-0.10	0.0001	122	-0.005
15%Ni B	-1.8	-0.004	0.2	0.007	-0.08	0.00000	164	0.016

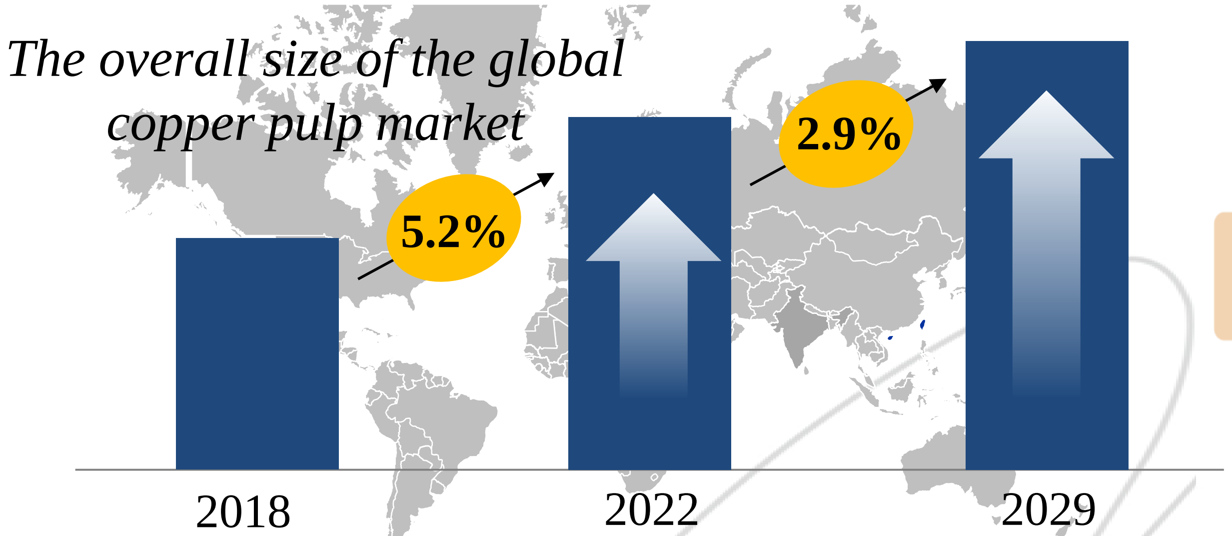
Part 3

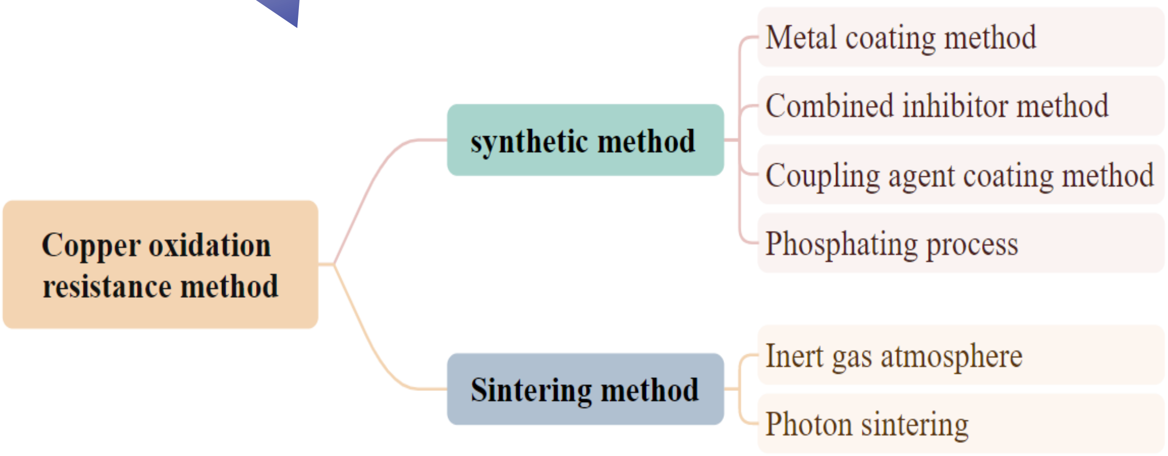
Pure copper paste solution

Pure copper paste

	silver	copper
World reserves	530000 tons	880 million tons
Price	8000yuan/Kg	80yuan/Kg
Chemical property	stabilize	Easily oxidized
Conductivity	63.01×10^{6} S/cm	59.6×10^{6} S/cm
Volume resistivity	**1.59 μΩ.cm**	**1.75 μΩ.cm**







Challenges in the development of pure copper metallization

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Antioxidant issue

- The sintering performance of copper oxide is poor, which affects the sintering compactness.
- Poor conductivity, seriously affecting battery efficiency and reliability.
- Prone to brittle fracture, leading to functional failure

Low temperature sintering problem

- High specific surface area and abundant uncoordinated atoms make it extremely prone to oxidation reactions.
- The smaller the particle size, the easier it is for copper powder to agglomerate
- The bonding force between copper and silicon interface is weak, and the contact resistance is high.

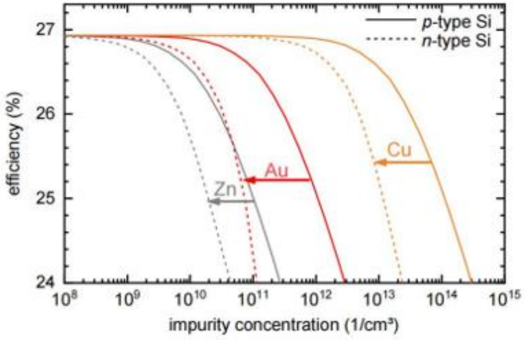
Development challenges

1
2
3
4

silicon substrate etching

The diffusion of copper into silicon materials can form composite active precipitates, reducing the lifetime of minority carriers in solar cells and decreasing the open-circuit voltage.

Long-term stability issues



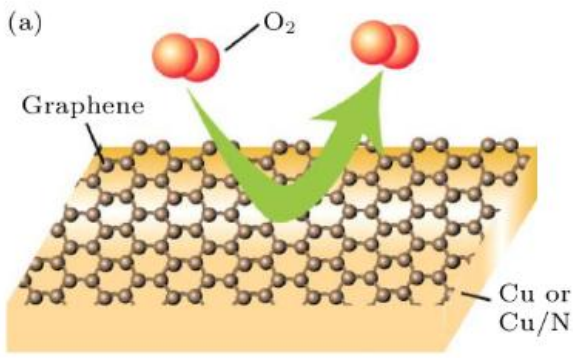
模拟电池效率取决于对n型硅更具破坏性的杂质[14]

Antioxidant method for copper powder

Surface coating treatment

Metal/non-metal inorganic coating

- Silver/Nickel/Tin-coated Copper
- Carbon/Graphene-coated Copper



organic polymer coating

- Corrosion inhibitor
- coupling agent
- reducing agent

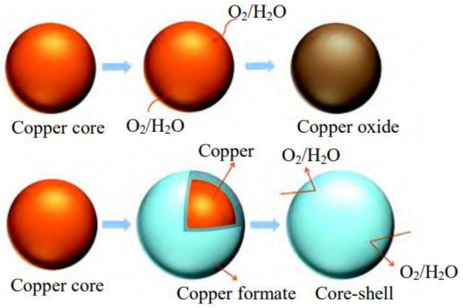


图 8 铜-甲酸铜核-壳颗粒示意图

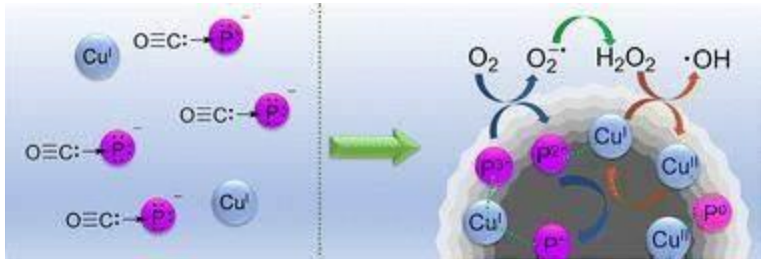
Principle: A stable, high-density, and low-porosity film is formed on the surface of micro-nano copper powder through coating treatment, preventing direct contact between surface copper atoms and air. This slows down the movement of oxygen atoms, preventing the effective formation of surface oxides

Surface conversion treatment

Surface phosphating treatment

A chemical treatment method for metal surfaces, where the metal surface comes into contact with an acidic solution containing phosphate, undergoing a chemical reaction to form a stable, insoluble inorganic compound film layer on the metal surface.

$$3Cu^{2+} + 2PO_4^{3-} \rightarrow Cu_3(PO_4)_2.$$



Surface passivation treatment

Using passivating agents or antioxidants to render the surface inactive, thereby providing protection and preventing oxidation.

Antioxidant method for copper powder

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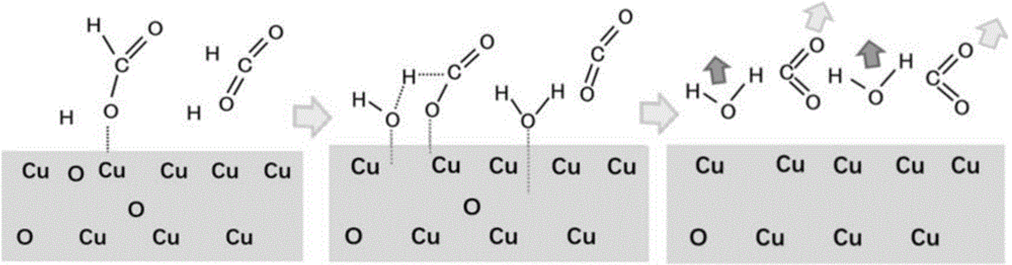
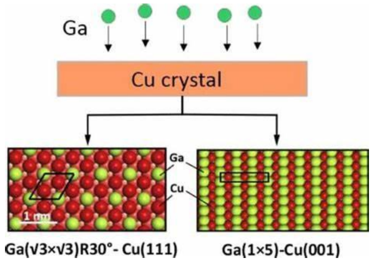
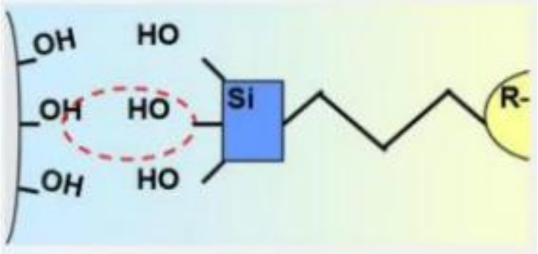
surface functional group modification

- Long-chain functional groups increase oxygen diffusion pathways.
- Form coordination bonds or chemical bonds with copper surface to reduce the electronic activity of copper
- Hydrophobic polymers reduce surface hydrophilicity and reduce water molecule adsorption

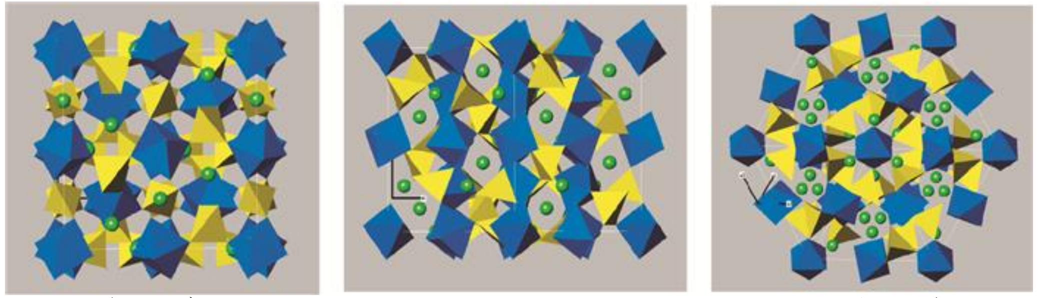






surface crystal reconstruction

Crystal plane	Atomic coordination number	Oxygen dissociation energy	Compactness of oxide layer	Antioxidant activity
(111)	9	High	Close-packed atoms	Excellent
(100)	8	Medium	Medium loose	Average
(110)	7	Low	Open and loose	Poor



（100） （110） （111）

Principle： By utilizing the energy and crystallinity differences of different crystal faces formed by copper atoms, the higher crystallinity results in a highly ordered and tightly packed arrangement of copper atoms with low defects, making it difficult for oxygen atoms to erode, thereby significantly reducing the rate of oxidation.

Copper metallization antioxidant idea

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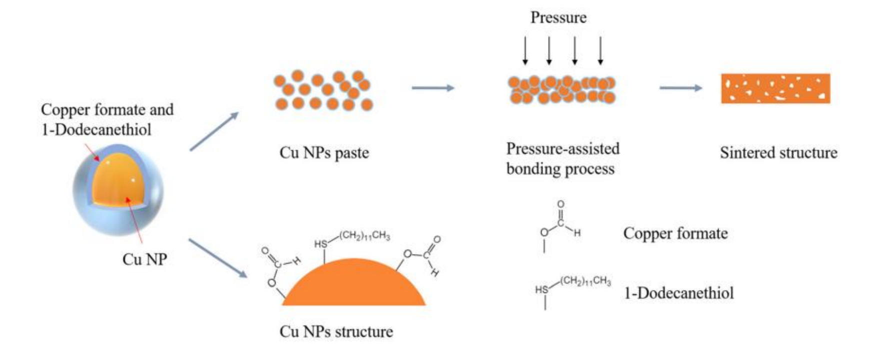
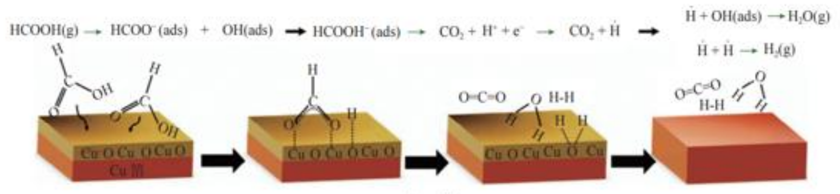
Restore and remove oxides

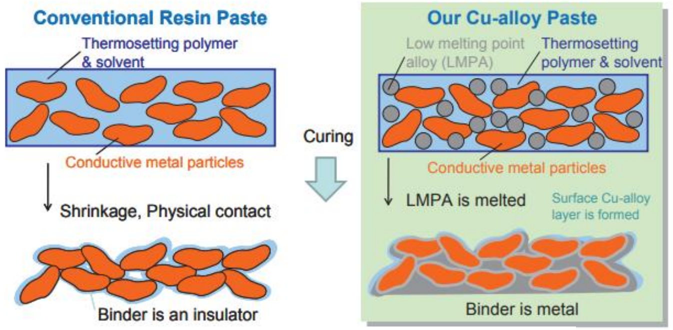
- Removal of oxide from copper particle surface by short-chain carboxylic acid.
- In-situ treatment of copper powder using reducing conditions (powder surface, slurry components, sintering environment, etc.) can effectively remove the surface oxide layer

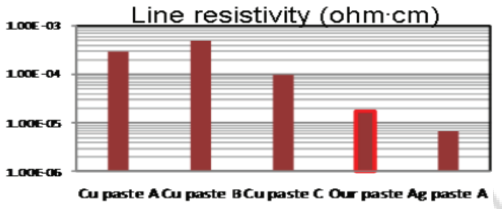




Low melting point alloy oxidation resistance

- After melting, the low-melting alloy forms metal contact with copper particles enhancing conductivity, and infiltrates the
- surface of copper particles to prevent oxidation.





low temperature short time sintering

- Isolating from air to prevent oxidation.
- Organic system and low melting point alloy help rapid solidification at low temperature.
- Copper particles melt when heated, forming a conductive path.

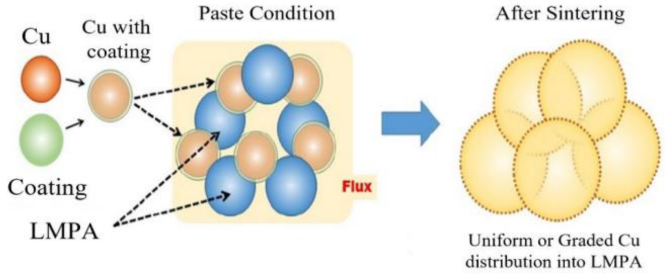


图 1-11 铜纳米浆料的烧结过程[56]

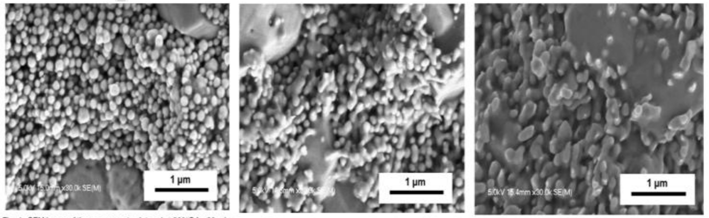


Fig. 4. SEM image of the copper paste sintered at 200°C for 30 min. Fig. 5. SEM image of the copper paste sintered at 230°C for 30 min. Fig. 6. SEM image of the copper paste sintered at 260°C for 30 min.

Research and development direction of pure copper metallization - organic system

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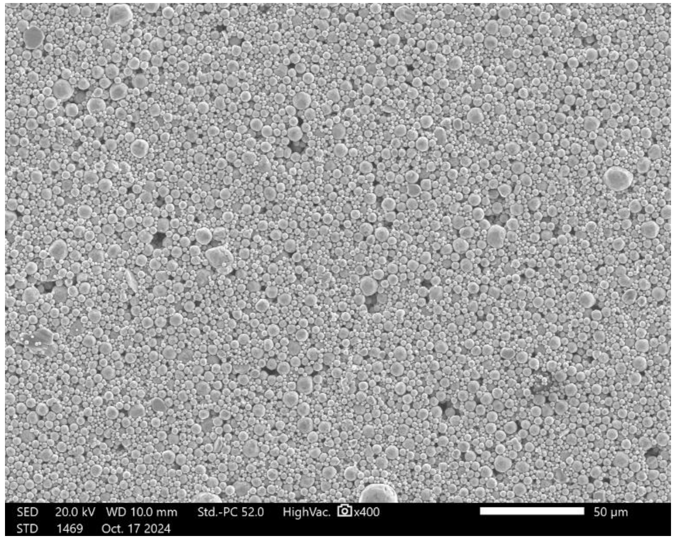
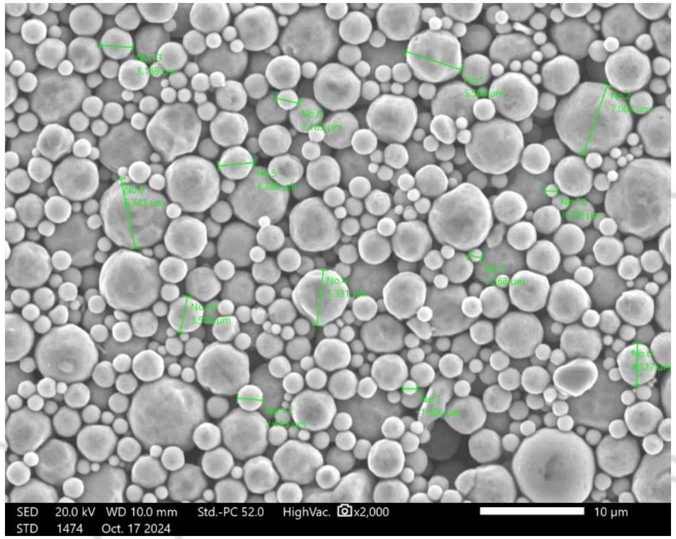
- Organic system
  - principal system
    - resin
      - Bonding effect: maintain close contact of copper particles
      - Low temperature curing characteristics: lower Tg, low temperature crosslinking
      - Dispersibility: Help copper powder disperse evenly
      - Interface compatibility: Forming coordination bonds with hydroxyl groups or oxide layers on the copper surface to enhance interfacial bonding
      - Chemical reduction: It has reducibility and can reduce the oxide layer on the copper surface
    - **Curing agent:** low temperature curing, reducing property, and reaction with resin groups to promote cross-linking structure
    - **Solvent:** low boiling point, reactive, reducing solvent
  - additive agent
    - **Reducing agent:** Reacts with the surface oxide layer of copper powder to reduce copper to its elemental form
    - **Antioxidant:** A dense protective film is coated on the surface of copper powder to slow down the oxidation rate
    - **Coupling agent:** Promotes the close combination of organic materials and inorganic materials
    - **Dispersant:** Prevents copper particles from aggregating
    - Leveling agent, defoaming agent, thickening agent .....

Pure copper paste product

	HCT145 series (Pure copper paste)
Copper content（%）	86-90
Volume resistivity (Ω·cm)	$8\text{-}12\times10^{-6}$
Match screen printing (μm)	≥16
Printing speed (mm/s)	≥400
Curing temperature (℃)	≥240
Curing time (s)	10-30





Part 4

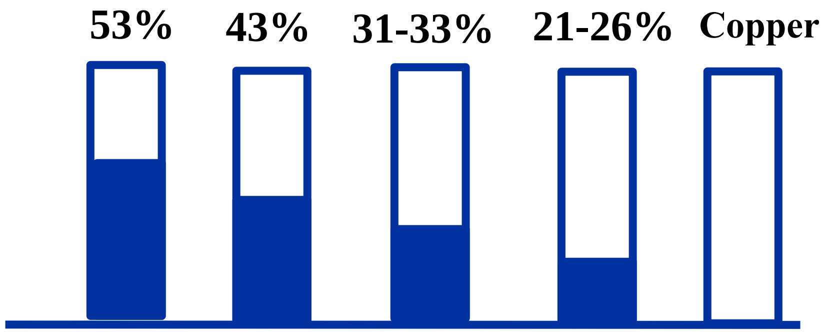
Cost Reduction Scheme for Low-Temperature Paste

The roadmap for HJT paste

Finger paste

	2025.Q1	2025.Q2	2025.Q3	2025.Q4
PI screen	18-22μm	16-18μm	13-15μm	11-13μm
Stencil screen	15-16μm	12-14μm	10-12μm	8-10μm

Silver Content



Busbar paste

Base Metal Replacement

Silver-coated copper → Tin alloy → Other Base Metal Replacements

Silver Content

50% | 40% | 30%

Single tile paste consumption

16-18mg/w ↓	14-16mg/w ↓	12-14mg/w ↓	10-12mg/w ↓

Printing speed matching

400mm/s ↑	450mm/s ↑	500mm/s ↑	550mm/s ↑

Low-silver content silver-coated copper finger paste

	HAC589-T	HAC609-T	HAC809-T	HAC899-T	HAC909-T	HAC939-T (R&D product)
Silver content（%）	40-45	30-35	25-27	21-23	15-20	10-15
Volume resistivity（μΩ.cm)	5.0-7.0	5.0-7.0	6.0-7.0	7.0-9.0	7.0-9.0	8.0-10.0
Printing speed（mm/s)	≥450	≥450	≥450	≥450	≥450	≥450

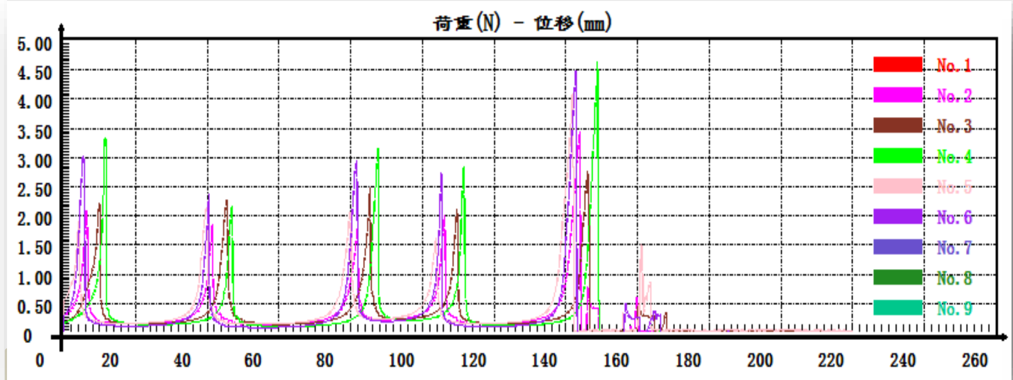
- The silver-coated copper paste with low silver content still maintains low volume resistance and high printing speed, and its efficiency is basically equal with pure silver paste；
- **The combination of 10 - 20% silver - containing low wet-weight fine finger on the back and 20 - 30% silver - containing fine finger on the front** significantly reduces metallization costs；
- **HAC809-T、HAC899-T、HAC909-T 、HAC939-T** have all passed the standard IEC reliability test.

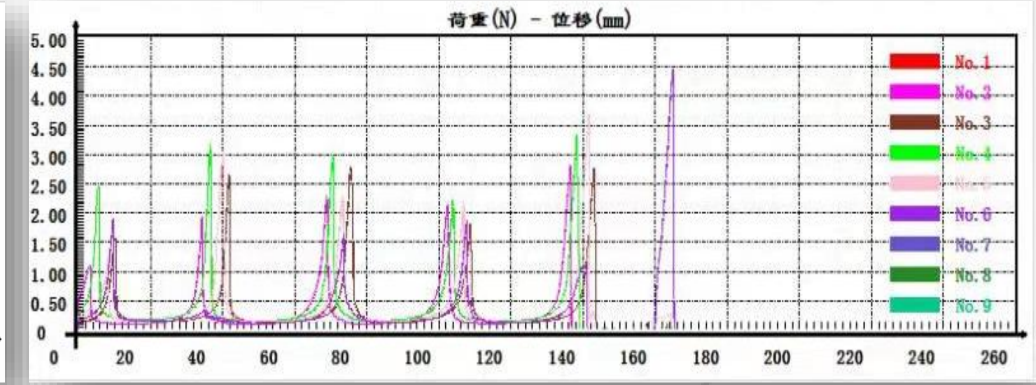
* Data from Jingyin Laboratory

Low-silver content silver-coated copper busbar paste

晶银新材 ISILVER MATERIALS

	HC539-ZX	HAC539-ZT	HAC589-ZT	HAC609-ZT Series (0BB Ag-Cu busbar paste)
Silver content（%）	92-93	50-60	41-43	30-35
Volume resistivity（μΩ.cm)	5.5-6.5	6.5-7.5	7.0-9.0	8.0-9.0
Busbar tensile force(N/mm)	≥2.2	≥2.2	≥2.2	≥1.0





2.09	1.85	1.78	2	3.44	2.23	2.655	合格	正面
2.23	2.27	2.47	2.1	2.76	2.37			
3.33	2.15	3.15	2.83	4.64	3.22			
1.89	2.14	2.05	1.61	4.08	2.35			
3.02	2.36	2.94	2.73	4.47	3.10			
1.09	1.92	2.29	2.14	2.81	2.05	2.213	合格	背面
1.55	2.65	2.8	1.82	2.76	2.32			
2.45	3.17	2.96	2.23	3.34	2.83			
1.26	3.03	2.27	2.21	3.7	2.49			
1.9	0.34	1.65	1.87	1.12	1.38			

- The peel force of the front and back sides of the silver coated copper barsbar **is not much different from that of pure silver.**
- H**as passed the reliability test.**

*数据来源客户端

Part 5

Summary of Schemes and Tests

晶银新材 ISILVER MATERIALS

Summary

Product	Base Metal Type	Silver Content	Testing Situation
Topcon	Silver-plated copper finger	30%	Adopting backside overprinting technology, the efficiency can basically be equalized, and the comprehensive wet weight is reduced by about 5mg;
		25%	Adopting backside overprinting technology, the efficiency is about 0.05 lower, and the comprehensive silver consumption is reduced by about 8mg;
		20% and below	Adopting backside overprinting technology, currently in client matching testing;
	Nickel-containing paste	80%	Backside paste testing: efficiency is basically equal, wet weight is equal, re-testing is planned subsequently；
		75%	Backside paste testing: efficiency is basically equal, wet weight is equal re-testing is planned subsequently；
HJT&HBC	Silver coated copper finger	30%	Compared with high-silver-containing paste, efficiency and power are equal, and large quantities are supplied to clients；
		20-25%	Compared with 30% paste, efficiency and power are equal, reliability has been verified, and mass supply is available；
		10-15%	Efficiency is slightly lower by about 0.05%, reliability has been verified, and small-batch supply is available；
	Silver coated copper busbars	43-58%	Efficiency and module power on SMBB is basically equal, with pure silver , mass production is available；
		31-35%	Testing is underway on 0BB；
	Alloy main busbar	60-70%	Module power has advantages, but silver content is high；

Thanks!

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Suzhou iSilver Materials Co., Ltd.