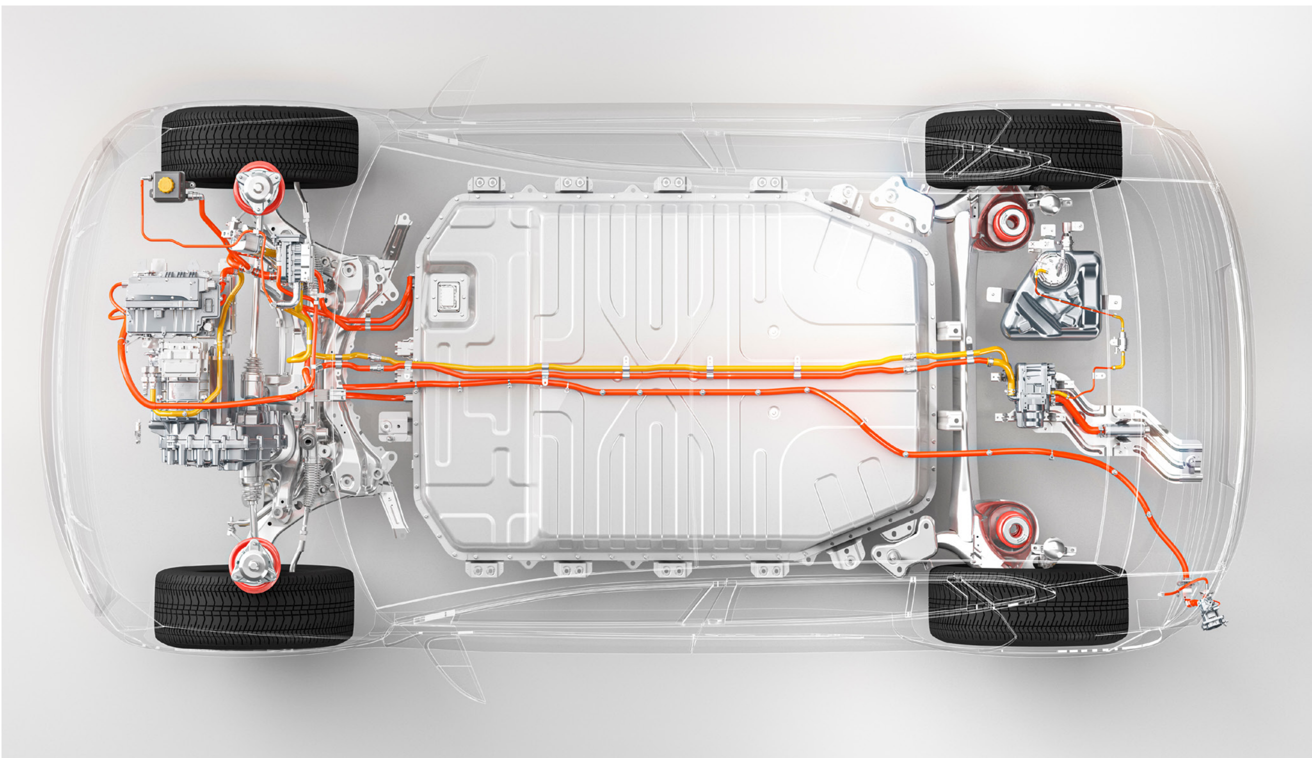
Nanostructured Metal Coatings for Electric Vehicles

Introducing LUNA® — The Next Step in Automotive Interconnect Technology



Xtalic's LUNA® nanostructured silver increases the maximum use temperature for silver to boost the performance of high-voltage electric vehicle (EV) components – enabling better power transmission and thermal stability at higher temperatures in high-power connectors and charger contacts, while also improving durability and corrosion resistance.

Xtalic: Unlocking the Next Level of Performance

Xtalic Corporation, headquartered in Marlborough, Massachusetts, was founded at the Massachusetts Institute of Technology (MIT) in 2005. Xtalic uses a powerful and proprietary toolkit to design, develop, and provide unique high-performance nanostructured metal alloys and coatings that solve our customers' mission-critical materials challenges. Our customers turn to us when existing material solutions limit their ability to unlock the next level of product performance and features.

Using our patented technology, we create stable nanostructures within our metal alloys, enabling us to engineer their properties. We use this approach to move beyond the limits of traditional materials to achieve the most demanding requirements for advanced wear and durability, corrosion resistance, strength, temperature tolerance, and other key performance measures – while maintaining safety, price, and environmental goals.

Xtalic technology and its fundamental benefits are proven in high-volume manufacturing. Over the past 16 years, more than 25 billion integral electrical contacts protected by Xtalic nanostructured alloys have been deployed worldwide. The applications range from improving the performance of more than 1 billion smartphone connectors to reducing the volume of gold used in electrical contacts and saving more than $100 million as a result. Today, Xtalic users include 5 of the top 10 smartphone original equipment manufacturers (OEMs) and 30 top electronic OEMs.

For electric vehicle manufacturers, Xtalic nanostructured metal coatings, specifically LUNA nanostructured silver coatings, are crucial to advance to the next step in high voltage automotive interconnect technology.

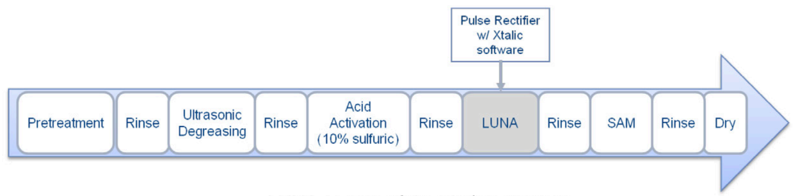
Introducing LUNA Nanostructured Silver Coating for Electric Vehicle Applications

LUNA is a patented alloy of silver and tungsten developed through our rapid alloy design platform, providing substantial performance improvement beyond silver and the silver alloys currently in use.

For EV manufacturers, LUNA represents a significant advancement towards achieving greater ampacity at higher temperatures. LUNA enables increased transient power transmission and extending thermal stability to 220 C – while ensuring reliability, safety, and performance.

Mechanically, LUNA provides a dramatic improvement in hardness. LUNA is twice as hard as silver across the temperature spectrum, has a lower coefficient of friction, and is thermodynamically stable to more than 220 C — a temperature at which other silvers will soften rapidly, while LUNA maintains its hardness. Its electrical conductivity is similar to hard gold.

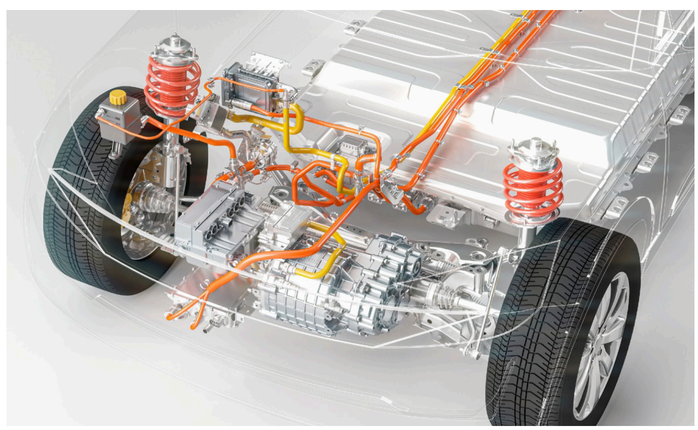
Manufactured by pulse reverse electrodeposition, LUNA chemistry and technology can "drop into" the manufacturing plating process of an OEM supply chain partner. LUNA chemistry and technology is cyanide-free.



LUNA as part of the plating process

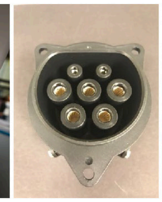
LUNA Optimized for EV: Performance Benefits

As EV manufacturers face a myriad of challenges related to increasingly higher maximum operating temperatures, LUNA delivers substantial performance benefits for high-voltage connectors and charger contacts. These include boosting high voltage connector drivetrain performance, extending safe temperature ranges in power electronics, and improving charging connector wear durability.



LUNA high-power interconnects enable a maximum operating temperature of 220 C — a dramatic increase over traditional silver (170 C). Furthermore, the hardness of LUNA coatings enables a low insertion force – yet allows for a fully crimp-capable contact plating.

LUNA delivers improved wear and improved corrosion resistance for EV charger contacts – at 25% thickness compared to traditional silver.



LUNA: Extending Thermal Stability Performance Beyond Today's Boundaries

One of the core elements of our technology is the ability to create thermodynamically stable nanostructured alloys. With traditional silver contact finishes, the maximum use temperature is defined to ensure that the contact plating does not soften, and subsequently gall or fuse during use. This operating temperature limit reduces overall performance by lowering the total current that can be carried through the power electronics.

Figure 1A details how LUNA's thermal stability provides low and stable LLCR (low-level contact resistance) after 210 C heat age for 4,000 hours. LUNA outperforms standard silver.

As detailed in *Figure 1B*, LUNA remains twice as hard as silver at 30 C, 180 C, and even at 210 C. Additionally, LUNA maintains hardness through temperature cycling, while traditional silver hardness degrades significantly and irreversibly.

Figure 1A

LUNA provides low and stable contact resistance after 210 C heat age for 4000 hours

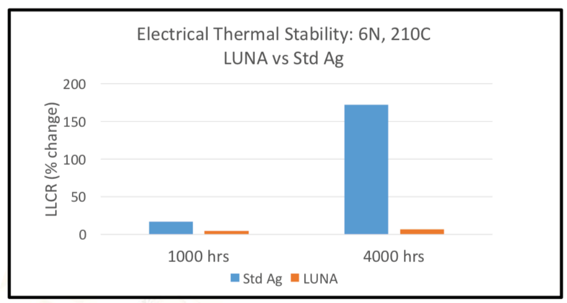
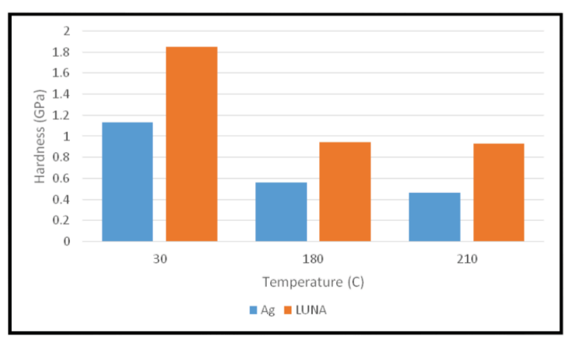


Figure 1B

LUNA is about 2 times harder across the temperature spectrum

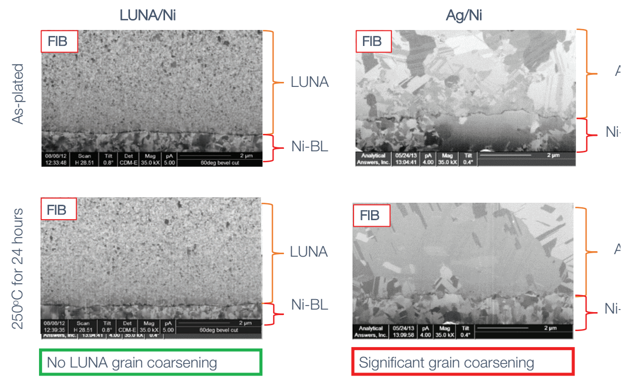


Nanoindentation hardness study at temperature using thick silver plating

Ensuring Stable Nanostructure with LUNA for Proven Thermal Performance

The stable nanostructure engineered into LUNA silver alloy ensures its consistent thermal performance – delivering additional reliability, safety, and performance to high-reliability applications.

Figure 2A



LUNA is thermally stable through 250 C while traditional silver shows significant grain coarsening and softening

Figure 2A shows the characteristic nanometer-scale grain size of LUNA after plating, compared to the much larger micrometer scale grain size of silver. Upon heating to 250 C for 24 hours, LUNA demonstrates thermal stability with no apparent grain growth, as seen in these FIB (focused ion beam) micrographs. By comparison, traditional silver shows significant grain coarsening and softening, an irreversible change to the structure, leading to a loss in performance.

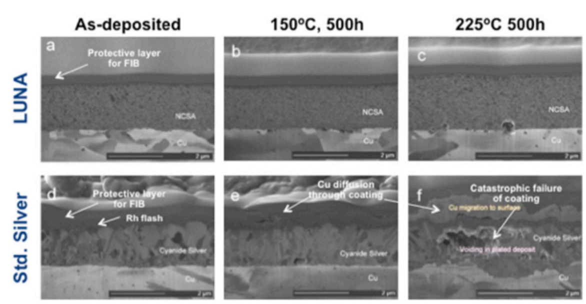
The same effect holds true for diffusion performance.

The diffusion of copper is another potential root cause of failure in high-temperature applications. The copper base metal can migrate through the silver layers and lead to oxidation, voiding, and increased electrical resistance.

LUNA is engineered to place alloying elements in the grain boundaries of the metal, which block diffusion. Following 500 hour exposure at temperatures at 150 C and 225 C, LUNA remains stable and virtually eliminates fast grain boundary diffusion, preventing copper migration and loss of performance. In sharp contrast, standard silver shows significant interdiffusion and Kirkendall voiding at 225 C. See *Figure 2B*.

Figure 2B

Diffusion Performance



LUNA microstructure virtually eliminates fast grain boundary diffusion, preventing copper migration at temperature. Standard silver shows significant interdiffusion and Kirkendall voiding at 225 C.

The impact: at temperature in demanding applications – such as high voltage power distribution connectors – LUNA provides significantly increased long-term reliability over standard silver.

Enhancing Wear Performance with LUNA

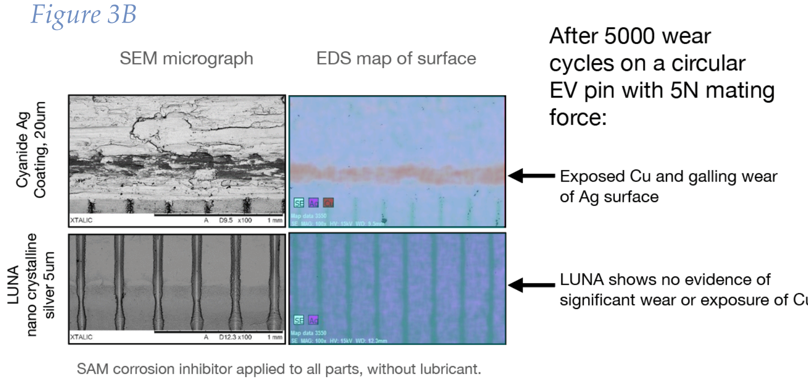
EV charging connectors must be designed for rugged durability, capable of withstanding thousands of mating cycles. While silver provides very low electrical resistance, the mechanical wear performance is poor and can lead to reliability issues. Charger contacts (*Figure 3A*) were plated with traditional silver plating that is 20 microns thick.

Figure 3A

Similar contacts were coated with LUNA nanostructured silver alloy and are only 5 microns thick — 1/4th the thickness of the standard silver.

Figure 3B details the impact of 5000 mate/unmate wear cycles on the charge plug connectors with a 5-newton mating force. For the standard silver, the 5000 cycles result in galling wear of the silver surface, which tears the silver away and exposes the copper underneath. As a result, the copper oxidizes, increasing the resistance of the contact interface, causing higher heat generation and problematic performance.

Figure 3B



The LUNA interface proves very durable, showing no evidence of wear or exposure of the underlying copper material, delivering consistent, reliable charging performance. The wear performance of LUNA is substantially better than silver even when LUNA is at 1/4th the thickness.

(*Figure 3B* Note: The groove marks, visible from the original machining of the contact, are retained throughout the life of the part.)

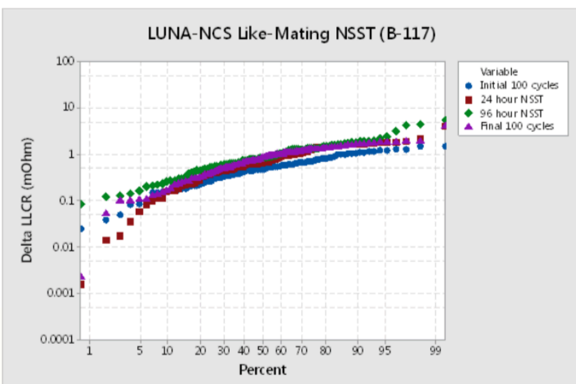
Increasing Corrosion Protection with LUNA

In industry-standard connector reliability tests, LUNA continues to outperform traditional silver materials.

Figure 4A depicts the performance of LUNA connectors in the neutral spray test (ASTM B-117) at various performance times and exposures up to 96 hours of salt spray. The result: no observed issues while providing both very low and stable contact resistance throughout the exposure.

Figure 4A

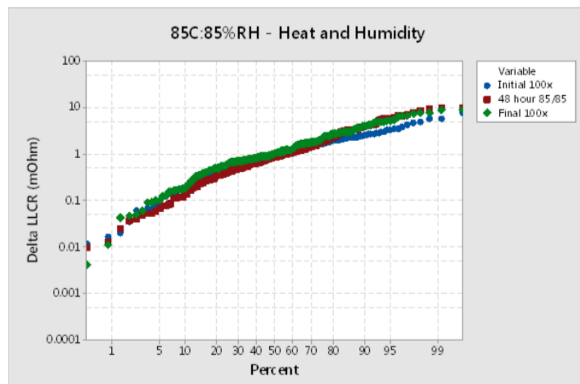
Neutral salt spray test (ASTM B-117)
No observed issues up to 96 hours of exposure with 100x initial and final durability cycles



	Initial 100x	24 hour	96 hour	Final 100x
Maximum	1.52	4.14	7.37	6.03
Minimum	0.02	0.00	0.69	1.27
Mean	0.55	0.83	3.01	2.82
Median	0.48	0.65	2.85	2.87
Std.Dev.	0.35	0.67	0.93	0.70
>5 mOhm	0%	0%	4%	1%

Figure 4B

85 C/85% - Heat and Humidity
No observed issues up to 48 hours of exposure with 100x initial and final durability cycles



	Initial 100x	48 hour 85/85	Final 100x
Maximum	7.77	9.92	8.99
Minimum	0.01	0.01	0.00
Mean	1.23	1.55	1.68
Median	0.94	0.87	1.05
St.Dev.	1.14	1.90	1.74
> 5 mOhm	2%	7%	6%

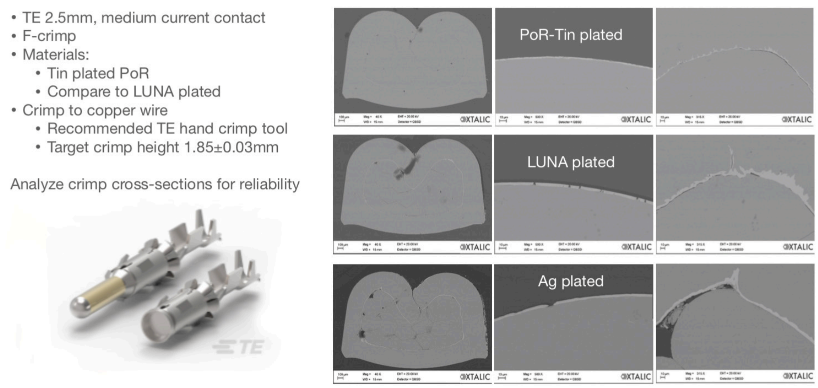
Figure 4B shows LUNA's similarly strong performance in an industry-standard 48-hour test for exposure to heat (85 C) and humidity (85%).

LUNA Crimp Performance

LUNA performs similarly to traditional materials when comparing crimp reliability.

Figure 5 shows the cross-section micrographs of tin-plated, LUNA-plated, and silver-plated materials in a typical industry crimp test.

Figure 5



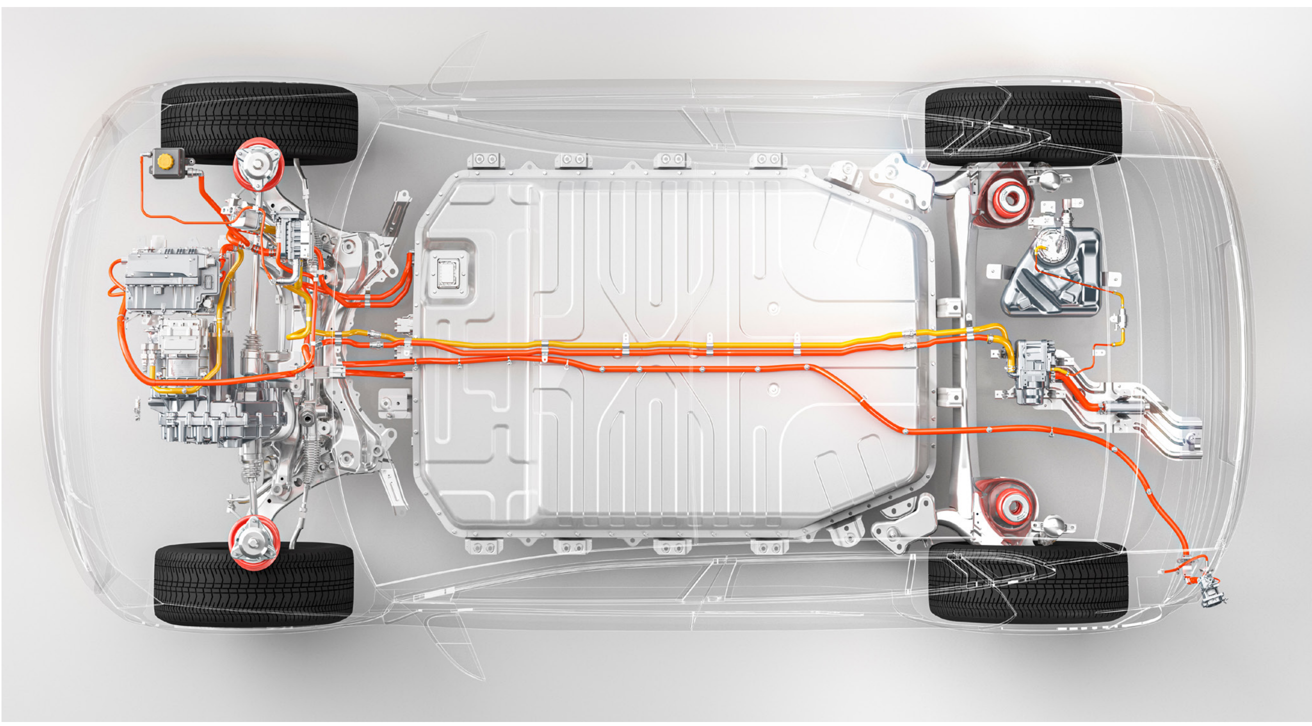
All of the connectors crimped well, showing good conformance and contact between the crimped connector and the copper wire to create a low resistance and stable connection.

LUNA In Production

The performance benefits derived from LUNA are enabling manufacturers to unlock the next level of performance in automotive interconnect technology.

The process of implementing LUNA in manufacture is simple.

LUNA is manufactured through a traditional electrodeposition process for connectors. Xtalic provides the chemistry, process, and IP access, enabling the use of existing electroplating facilities. Xtalic performs material design, early-stage samples, and production support with a global team of application engineers deployed across existing high-volume lines and new supply chain installations.



For more information:

For more information, visit the Xtalic website at https://www.xtalic.com/applications/ev/
Or, contact Robert Legg, Director of Product Management and Marketing, by telephone at +1-508-485-9730 or by email at Rlegg@xtalic.com.