Alleviate The Power Struggle

MATERIALS. INNOVATIONS. FOR GENERATIONS.

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Summary

Demand for electric vehicles (EVs) is growing. But with growth comes struggle about the best way forward. Around 20% of global carbon dioxide (CO_2) emissions are generated by cars. Improving the carbon footprint for EVs is critical.

Key questions now define the EV industry's future trajectory:

- How can EV lifetimes be extended to improve their sustainability?
- How can emissions be cut from the EV production process?
- How can green electricity supplies for EVs be powered up?

There are struggles between the efficiency of manufacturing and the efficiency of EVs themselves, between performance versus cost, and between the best ways to balance power, heat, and reliability.

Power electronics signposts a route through these struggles. It has the significant potential to reduce CO_2 emissions in the journey towards a zero emissions world. For EVs, the decisions about power electronics that are made today will drive how quickly we reach that destination.

This whitepaper examines the struggles around power electronics, focusing specifically on automotive inverters. It explores the most popular options for module attachment - soldering and sintering - and discusses the advantages and considerations for both.

As a global leader in advanced materials for power electronics, Heraeus Electronics provides sintering and soldering solutions that help ease the power struggle. These solutions include mAgic® PE360 sinter paste and Microbond® Innolot® solder preforms, alleviate the sticky problems associated with EV inverter performance and manufacturability.

This paper has been carefully compiled by Heraeus Electronics. Although the content is considered accurate, we cannot guarantee that this paper is suitable for any application. The descriptions and engineering data shown here have been compiled by Heraeus Electronics using commonly accepted procedures, in conjunction with modern testing equipment, and have been compiled according to the latest factual knowledge in our possession.

From Saturation to Expansion: Mapping the Next Mobility Boom

Electrifying transportation is an important step towards reaching global climate goals. In 2024, more than 20% of all new cars sold worldwide were electric. In China, the figure was close to 50%, representing almost two-thirds of electric cars sold globally[1].

At the same time, overall vehicle ownership in China remains comparatively low. With about 353 million cars on the road among a population of roughly 1.41 billion people, only around 25% of Chinese citizens own a car today - meaning that **approximately 75% still do not.**[2] This sizeable gap highlights the vast long-term growth potential of the Chinese automotive market, especially as rising incomes and driving-license penetration continue to increase.

A look across global regions reinforces this perspective. **Europe already exceeds 50% car ownership** and the United States is close to 90%, making both highly saturated markets with limited headroom for expanding the total vehicle base. **Africa, by contrast, sits at roughly 4% ownership** — representing the largest long-term mobility opportunity, yet one constrained by infrastructure, financing, and economic development.

The broader Asia Pacific region outside China is rapidly emerging as a major engine of global EV growth. In 2025, the **APAC EV market is valued** at USD 419.66 billion, and it is projected to more than double to USD 927.96 billion by 2030, reflecting a robust 17.2% compound annual growth rate.

Global car-ownership comparison

China	~25%	75%	Very high upside, but dependent on infrastructure expansion and affordability.
Europe (EU)	~57%	43%	Limited volume growth; fleet electrification driven mostly by regulation. cost structure optimization is critical.
United States	~89%	11%	Low expansion potential; upgrades mainly through EV substitution.
Africa	~4%	96%	High long term potential, but constrained by infrastructure, affordability, and grid reliability.
South America	~20-25%	-75-80%	Strong upside, but economic volatility and infrastructure gaps slow adoption.
APAC (excluding China)	~30%	-70%	Significant long term potential, but uneven across countries; large markets like India and Southeast Asia remain under motorized.

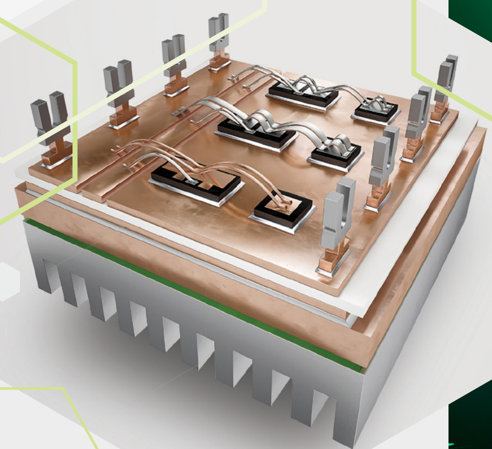
What this means for EV manufacturers is clear: the direction of travel is one way. The global EV share of light-vehicle sales is forecast to exceed 64% by 2035 and reach 83% by 2040.[2] Meanwhile, China's EV market alone is expected to grow at a compound annual rate of more than 27% between 2025 and 2030, driven by scale, and strong domestic demand.

EV Manufacturers: How Far Do You Want to Go?

For EVs to be sustainable, they must remain on the road long enough to offset the emissions generated during manufacturing. This shifts the conversation from *building more vehicles to building vehicles that last* — and doing so through smarter material and design choices.

As OEMs push for greater range, faster charging, and higher performance, the electrical and thermal demands placed on the powertrain are rising just as quickly. High voltage architectures — once exceptional — are now standard at 600V and 800V, with leading platforms moving toward 1,200V and beyond. These advances reduce power losses and enable longer driving distances but also intensify the stress on the inverter, the critical system responsible for converting DC battery power into AC motor output.

In this environment, the core question for EV manufacturers is no longer *whether* to pursue higher performance but *how far they intend to go* — and whether their material and joining technologies can sustain the journey.

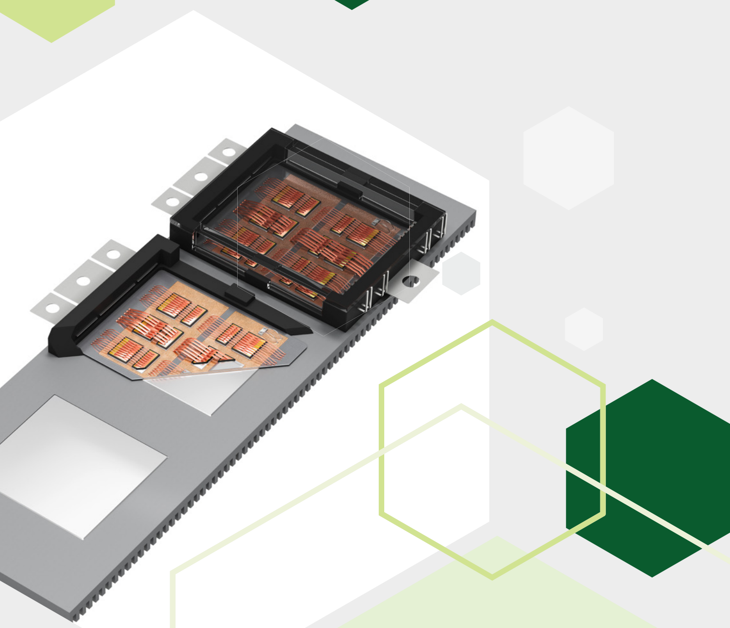


Manufacturers face a strategic trade off:

- Maximize performance to differentiate on longevity, acceleration, and range
- Optimize cost to achieve scale in price sensitive segments

The power struggle takes many forms across different areas of the EV industry. In this paper, we focus on the challenge of attaching the core components of inverters, power modules, to heatsinks. The two main options are sintering and soldering.

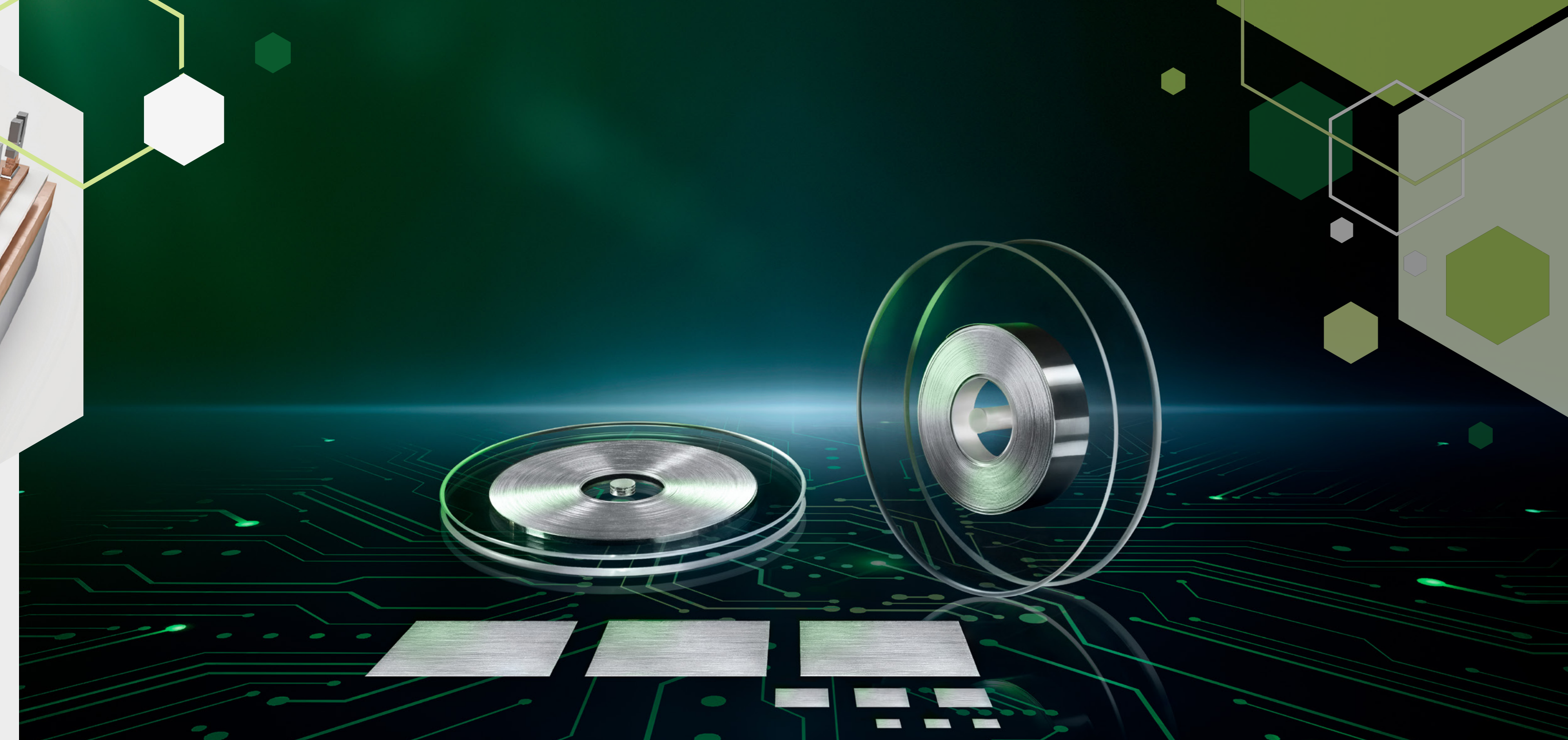
Sintering Vs Soldering: Choosing the Right Path



Moving from Silicon (Si) to Silicon carbide (SiC) dies has enabled smaller, more efficient modules that can handle higher voltages and switching frequencies. However, reducing module size has increased the thermal and mechanical stresses.

This places new demands on the materials that connect the semiconductor dies, substrates, and heatsinks. When it comes to attaching SiC dies in high power EV inverters, sintering became the established solution, replacing soldering. Even a small amount of sinter paste ensures that the expensive SiC chip is well protected. It is a small price to pay for much better module reliability.

Today, sintering is competing with soldering for module attach. Let's look at the sintering versus soldering struggle in more detail.



Solder Preforms: Cost-Effective Confidence

For mass-market EVs, soldering offers a great balance between cost and performance. It is more than 10 times cheaper than silver-paste sintering. The placing of preforms is more straightforward than printing. Highly reliable solder preforms, such as Heraeus Electronics' Microbond® with Innolot® alloys, give good strength and fatigue resistance at a low cost.

Microbond® solder preforms perform consistently in varying environments, including repeated heating and cooling, high-power conditions and wide temperature ranges. They provide strong joints at low temperatures, ensuring the protection of thermally sensitive components and minimizing stress.

Innolot® is one of the most recognized solder compositions in automotive and industrial power electronics. Its alloying elements (primarily tin, silver, copper, nickel, antimony, and bismuth) provide a low-melt, highly reliable material that maintains mechanical strength at temperatures up to 218 °C. Innolot® solder joints have exceptional resistance to fatigue and minimal voiding, even after 1,000 thermal cycles between –40 °C and +125 °C. This ensures reliable long-term performance.

Our recently introduced Innolot® 2.0 alloy offers comparable reliability and stability with a lower silver content and significantly lower material costs. Its melting temperature is only slightly higher than standard Innolot®, making it well-suited for power modules interconnections in molded modules or frame modules with multiple substrates.

Thermal cycling results prove that these solder alloys perform significantly better than standard tin-silver-copper (SAC) alloys and maintain structural stability over thousands of cycles under real automotive conditions.

Solder preforms have a lower thermal conductivity than sinter (less than 65 W/mk compared to over 200 W/mk). But they're a reliable solution for lower-cost, mass-produced EVs with shorter driving requirements where price is the priority.

However, the driving temperature of 175℃ for SiC chips represents a struggle for soldering, because it is close to melting temperatures (melting temperatures for SAC are 217℃ - 220℃ and for Innolot® 206℃-218℃). Increasing power demands may lead to larger modules in the future, which may impact vehicle space, weight, and design.

SnSb5 may seem like a tempting alternative, but when considering performance in the module-attach process, the primary differentiation between the two alloys is their respective reflow temperature profile. Innolot® exhibits a lower processing temperature, which can be crucial for modules containing temperature-sensitive components or substrates. For applications where thermal exposure must be minimized, Innolot® preforms provide a safe and robust joining option. This is especially true for molded modules where the mold compound exerts significant stress on the interface at high temperatures.

To address mass markets and make EVs accessible to a wider audience, affordable pricing is required.

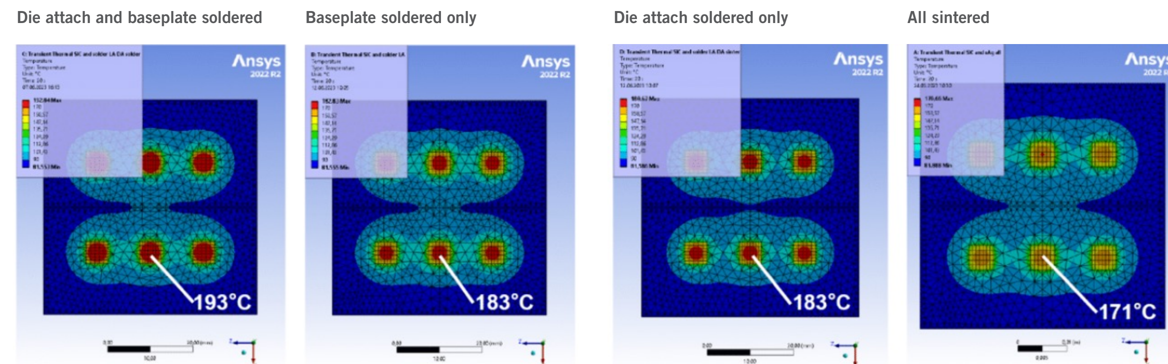
Sintering: Premium Performance Baked In

Sintering is already used to attach modules in high-end vehicles like Tesla that use the TPAK power module.

For the high thermal loads from SiC chips operating above 175°C, large area sintering (LAS) has emerged as an effective solution, creating joints with superior thermal conductivity and mechanical strength. As demonstrated by Heraeus Electronics and AMX4, replacing a soldered base plate or soldered die attach, by sintered interconnects can reduce maximum die temperature by more than 10° C[5], doubling the lifetime. Consequently, a fully sintered module is expected to last four times longer than a fully soldered one.

The importance of paste and device factors when using sintered baseplate attachments is discussed in our whitepaper 'Thermal Shock Temperature Lifetime Modelling of Large Area Sinter Silver Baseplate Modules'[6]

Benefit of LAS: heat dissipation with SiC die



22 K difference completely soldered vs sintered device
10 K difference completely soldered vs baseplate soldered only
12 K difference completely soldered vs die attach soldered only

Large-area silver sintering involves bonding the module to the cooler using a pressure-sintered silver layer. Unlike solder, sintered silver doesn't melt during the sintering process, because it is a solid-state diffusion. That means modules can withstand significantly higher junction temperatures without degradation. Thermal cycling tests show that sintered modules can remain intact for over 2000 cycles from -50°C to +150°C, with minimal delamination or voiding.

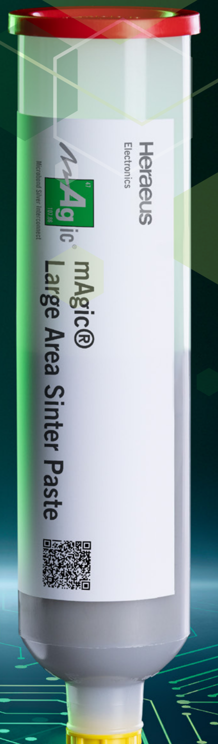
For a detailed exploration of large area sintering (LAS), see our application note 'Large Area Sintering for High Performance Power Module Packaging' by Heraeus Electronics and AMX Automatrix[7].

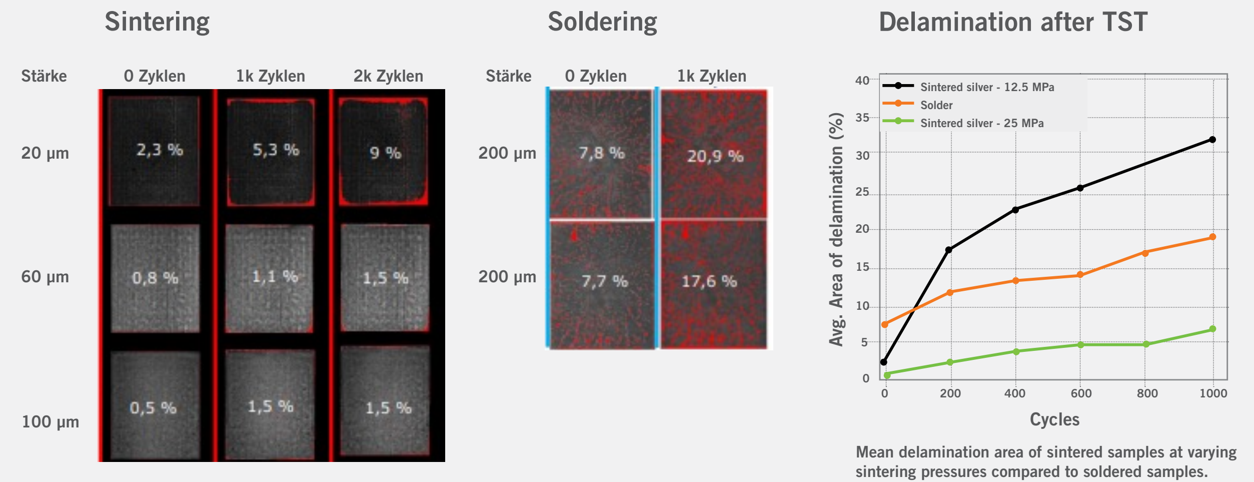
Material And Process Innovation: mAgic® PE360

To advance module attach sintering, Heraeus Electronics developed the mAgic® PE360 sinter paste as PE360P for printing and PE361D for dispensing.

The paste, which has been successfully qualified in automotive projects, won the 2025 Global Technology Award in the Thermal Interface Materials category. It enables high bond strength with relatively low process parameters (typically five minutes at around 200°C under moderate pressure).

Unlike conventional sintering materials that require high pressure and complex handling, PE360 sinters at low pressure and temperature. The low sintering parameters also enable the fastening of pre-assembled components and encapsulated modules with optimal, void-free attachment.





Mean delamination area of sintered samples at varying sintering pressures compared to soldered samples.

In thermal cycling tests (-50°C to +150°C, >1000 cycles), PE360 has shown excellent reliability. With sintering parameters of ~210ºC and ~10MPa on silver surfaces, it meets or exceeds the performance of traditional sintering materials and outperforms solder-based interconnects in harsh conditions. Optimized for large area sintering or module attachment, PE360 provides increased shear strength at lower temperatures and pressures to protect the module.

Our studies show that sintered silver baseplate attachments can outperform traditional SnAg3.5 solder joints by a factor of up to 30, depending on processes and materials8. However, silver sintering works best on silver-coated baseplates, and both come at a cost. Copper sinter paste is emerging as a lower-cost alternative to silver paste and works perfectly on bare copper baseplates.

Both solutions enhance the thermal and mechanical performance and the lifetime of the module interface. While silver and copper sintering offer thermal conductivity beyond 200 W/mK, copper sintering features a higher melting temperature and has a lower expansion coefficient than silver.

Sintering offers superior thermal and mechanical performance

SOLDERING	AG SINTERING	CU SINTERING	CTE
Thermal conductivity <65 W/mK	Thermal conductivity <65 W/mK	Thermal conductivity >200 W/mK	Chip material: Si: 2,6 ppm/K; SiC: 3,6 pmm/K
Melting temperature SnAg3.5 221°C	Melting temperature Sinter Ag 962°C	Melting temperature Sinter Cu 1,085°C	Ceramic material: Al203: 7-8 ppm/K; Si3N4: 3,2 pmm/K
Coefficient of Expansion (CTE) 27.9 pmm/K	Coefficient of Expansion (CTE) 18.5 pmm/K	Coefficient of Expansion (CTE) 16.5 pmm/K	Heat sink material: Cu: 17 ppm/K; Al: 24 pmm/K

As we continue to advance copper solutions for material matching and smoother processing, the performance gap between silver and copper is expected to narrow.

Soldering Vs Sintering: At-a-glance Comparison

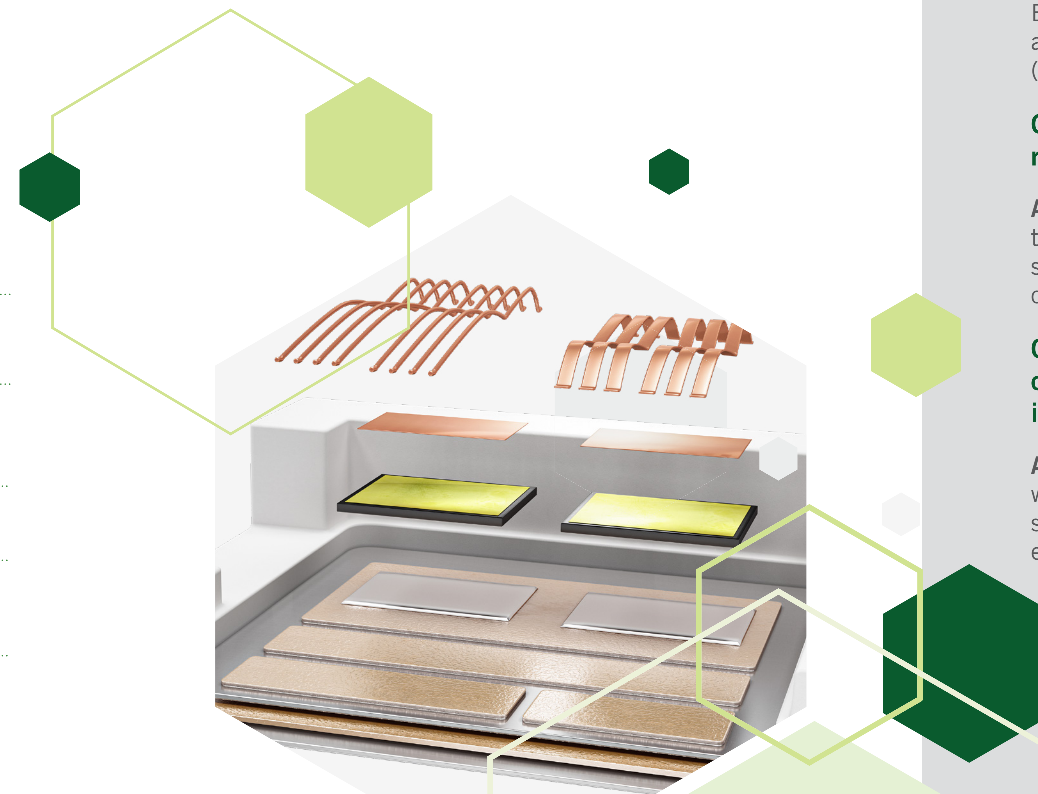
Comparison Aspect	Soldering	Sintering (Silver / Copper)
Thermal Conductivity	~65 W/mK	>200 W/mK
Reliability (Thermal Cycling)	Lower ΔT tolerance (-40-125 C°)	Higher ΔT (-50-150 C°) potential; superior fatigue resistance
Cost Hierarchy	Lower cost	Silver sintering = premium (silver cost 7-9 times higher than solder alloy); copper sintering = cost efficient alternative
Simulation and Testing Results	Junction temperature reduction limited; notable degradation after 500 cycles	Lower junction temperature supports chip and interface lifetime extension; near-zero delamination after 500 cycles
Consumer Implications	Ideal for urban commuter EVs and plug-in hybrids	Enables better performance for long-distance driving

Advancing The Automotive Industry with Heraeus Electronics

Heraeus Electronics' mAgic® PE360 pressure sinter paste has been developed for module attach applications. It comes in two different versions. PE360P is suitable for stencil printing and dry module placement and PE360D works for dispensing and the wet-/dry-placement process. Both offer excellent thermal performance, fast process times, and optimized workability for manufacturers operating across varied assembly processes.

Microbond® Solder Preforms are engineered to meet the mechanical, thermal, and reliability requirements of modern power modules. Designed for secure attachment of power packages to baseplates or coolers, they use advanced Innolot® alloys to ensure consistent performance, including improved creep resistance - even under harsh thermal cycling and high-power conditions.

The Heraeus Electronics Engineering Services team works with tier 1 suppliers and OEMs to ensure our products are engineered, tested, and designed to advance customer performance.



Automotive Component Manufacturers: What You Need to Know

Heraeus Electronic's leading position in the development of material solutions for the automotive industry means we're regularly asked to provide advice on the best ways to improve reliability, performance, and efficiency. We've included some of the most frequently asked questions below:

Q: How do I decide whether to use sintering or soldering for module attachment?

A: Power, lifetime, thermal resistance, efficiency, pricing, and performance are all key considerations in deciding which option to choose.

Q: Is module attach or large area sintering already being used in power electronics?

A: Yes, Tesla uses large area sintering (LAS) for its TPAK custom module package and others are copying this approach. We know of another automotive manufacturer that's manufacturing a much larger sintered module approximately 40x40 mm², while others are evaluating large area sinter pastes for 800-1200 V applications.

Q: What's the best way to test LAS or module attach?

A: We recommend arranging a test with our Engineering Services team. Testing should include a shear test, scanning acoustic microscopy (SAM), and temperature cycle testing.

Q: What's the improvement in thermal resistance between soldering and sintering?

A: Very high, as silver has significantly higher thermal conductivity than solder alloys and the sintered layer is usually thinner than a soldered one.

Q: Will sintering with copper be much cheaper than sintering with silver when implementation costs are included?

A: Yes. The powder will become cheaper with wider adoption. No formic acid is required for sintering with copper paste, and dinitrogen is not expensive.

Accelerating The Chinese Automotive Industry

The highly competitive Chinese EV market - particularly plug-in hybrids and extended-range vehicles - leads the way in scale. In 2024, China took more than 60% of the market share for the light EVs.

China's abundance of critical raw materials, expertise in large scale production, and the rapid and early adoption of new technologies, have supercharged the country's EV growth. Government support has traditionally been crucial, but subsidies are now beginning to decline, and the EV sector can expect this trend to continue. An interesting characteristic of the Chinese market is a broader and deeper involvement by OEMs in supply chains than in elsewhere, particularly in the power electronics segment[9]. Other important developments include the rise in battery EV popularity compared to plug-ins - particularly for smaller cars - and growing interest in Advanced Driver Assistance Systems (ADAS).

As inverter power densities and operating voltages rise, the performance of thermal interfaces becomes a key differentiator. This is creating more opportunities for SiC chips in a rapidly growing and highly competitive market as more OEMs release premium models and high-end sports EVs with SiC in the main inverter.

For SiC semiconductors, the most popular solution is sinter paste, while for IGBT (insulated gate bipolar transistor) silicone chips, soldering dominates. The uptake in large area silver sintering remains limited so far, as cost competitiveness increases. However, large area copper sintering signposts a way forward for future module attach.

Copper sintering, which offers the reliability and thermal benefits of sinter technology at significantly lower material costs, may provide China with a bridging solution between high-end and mass-market EVs, accelerating both domestic adoption and global competitiveness.

Ease The Power Struggle

The decision about whether to choose sintering or soldering isn't about which is better; it's about which is right for your application. Sintering gives you unmatched thermal and mechanical reliability, but soldering provides manufacturing scalability and cost efficiency. Recent research conducted by AMX Automatrix and Heraeus Electronics, corroborated by system-level modelling, shows that the lower junction temperatures you get using sintering do significantly increase module lifetime, whereas optimized soldering ensures lower cost reliability.

Making the right decision can be challenging, we know. But Heraeus Electronics can help you find the best solution to alleviate your power struggle.

We are a leading manufacturer of materials for the assembly and packaging of devices in the electronics industry, providing material solutions for the automotive, power electronics, and advanced semiconductor packaging markets.

Our integrated power electronics portfolio spans sintering, soldering, metal ceramic substrates, bonding wires and die top systems. Beyond supplying industry-leading materials, we provide engineering services to test your ideas, have a fully equipped application center to support your ramp up and offer a wide range of analytics to help understand and solve any issues along the way. At Heraeus Electronics, we empower you to reach your destination.

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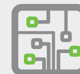
ABOUT
HERAEUS ELECTRONICS

Heraeus Electronics is a materials innovation partner for the electronics industry with global reach and local presence. The company develops material solutions for the automotive, power electronics and advanced semiconductor packaging market and offers its customers a broad product portfolio – from materials and material systems to services.

Headquartered in **Hanau, Germany**

1300+ employees worldwide

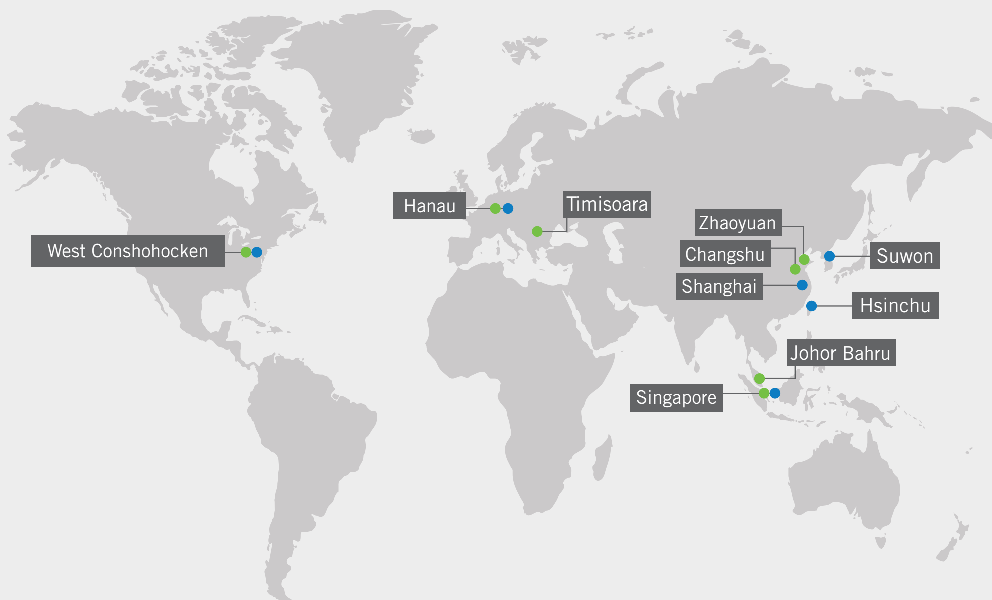


More than **60 years** of experience in providing materials for the electronics industry

6 research and development centers and **8 production sites** in **6** countries

Product distribution to **over 50 countries**

Production sites and application centers
Strategic locations to support our customers worldwide



PRODUCTION SITES

Hanau, Germany
Timisoara, Romania
West Conshohocken, United States
Johor Bahru, Malaysia
Changshu, China
Zhaoyuan, China
Singapore (2x)

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