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Future Trends of Power Electronics in the EV Market

Revolutionizing High-Performance Power Electronics with Innovative Materials and Manufacturing Processes

Gustavo Greca, Global Director of Power Electronics and New Business Development at MacDermid Alpha Electronics Solutions, discusses the trends of power electronics in the electric vehicle (EV) market. This interview explores the revolutionary materials and manufacturing processes that are enabling higher-performance power electronics for EVs and other high-power applications.

Can you explain the role of semiconductor technology for EV powertrains?

Semiconductor technology is transforming electric vehicle (EV) powertrains, especially with the replacement of traditional Silicon semiconductors by high-performance materials like silicon carbide (SiC) and gallium nitride (GaN) in key components such as inverters and chargers. Many automakers are using SiC and GaN in place of traditional silicon, paired with advanced improved packages capable of handling higher temperatures and more power! These innovations improve power conversion efficiency, motor control, and charging speed, making EVs more powerful, energy-efficient, and competitive with traditional vehicles. Although SiC is more expensive, its benefits—like longer range, faster charging, and smaller, lighter components—make it a game-changer for the industry.

What are the key differences between high-performance semiconductor materials like silicon carbide (SiC) and traditional silicon (Si)?

SiC devices offer higher breakdown voltage and wider frequency bandwidth, resulting in significant performance improvements in applications such as radiofrequency, microwave, and power electronics. This enables SiC components to handle much higher power densities compared to their silicon-based counterparts.

A key advantage of SiC is their low switching losses, as it is approximately 10 times lower than silicon devices with comparable breakdown voltage. This is crucial for designing highly efficient

power electronics. Due to these benefits and the potential for future development, silicon carbide technology is attracting major semiconductor players, including power module suppliers, tier-one suppliers, and OEMs.

Reducing weight – increasing power

SiC technology allows for higher power levels with minimized power loss, improving average efficiency by up to 10%, reducing die size, and eliminating the need for freewheeling diodes (FWDs) used in silicon-based systems to block sudden voltage spikes when switching the power devices. SiC MOSFETs inherently include a P-N junction (body diode) that serves this function. The elimination of additional diodes, combined with higher current capacity, higher frequency operation ability, and lower losses, contributes to a reduction in size and total cost of ownership (TCO) in power electronics. This is particularly beneficial for inverters in cars, where weight, power density as well as volume are critical factors.

SiC-based devices can also operate reliably at much higher temperatures, providing significant performance benefits. However, this capability is only valuable if the interconnects and materials in the power devices can withstand the same extreme conditions. One of the main challenges of using SiC dies is adapting the environment—such as the EMC (epoxy mold compound) or insulation gel and epoxies, top and die attach interconnections, driver circuits, and filtering component's reliability—to the higher speed, temperature, and frequency capacities.

Over the past 12 years, we at MacDermid Alpha have been a pioneer operating in this environment and developing materials for SiC and the first to deliver assembly materials for SiC-based power modules in automotive traction for mass production. Our company has consistently presented key technologies to unlock the full potential of SiC. These include silver sintering, high-reliability soldering, plating chemistries, thermal interface materials, and protection coatings, all of which are critical for harnessing SiC's high performance and reliability in extreme conditions.

How is the adoption of SiC based semiconductor technology influencing the EV industry?

SiC-based MOSFET technology is revolutionizing EV traction inverters. These MOSFETs convert DC power from batteries into the AC power used by electric motors, offering superior energy conversion efficiency and extending battery range by reducing power losses during conversion. Additionally, SiC-based MOSFETs handle higher power densities, enabling smaller and lighter drive trains. We have demonstrated significant weight reductions in the systems we have been working with our customers. For example, a 30% weight decrease almost doubles the power density and increases in reliability by sixfold when compared to traditional systems without using our sintering technology.

Power losses in electronics are proportional to voltage and frequency levels. Increasing these factors allows for smaller, more cost-effective filtering elements as well as thinner charging cables during high-speed charging. These are trends facilitated by SiC technology. The automotive industry quickly adopted SiC for its superior power density and efficiency, accelerating adoption as semiconductors suppliers and tier 1 integrators have released new advanced, cost-effective SiC devices.

SiC adoption for improving the EV powertrain

Today, the global market shows a surge in demand for EVs. Nonetheless, the increasing availability at lower costs and improved performance of SiC technology make it a key time for its adoption in the EV industry.

With increased production and improved technology, SiC is becoming more affordable, driving further adoption in the full supply chain: OEMs, Tier-1s, and Power Module suppliers. SiC helps to enable longer range, superior performance, and enhanced reliability in EVs compared to silicon-based technology. However, to fully capitalize on SiC's high-performance benefits, advanced joining technologies like silver sintering and reliable plating chemistries are essential.

What is silver sintering, and why is it replacing conventional soldering for attachment of SiC-based power devices?

In silver sintering, tiny silver particles are sintered at temperatures well below silver's melting point. Under temperature and pressure, these small particles within a paste or film join, resulting in high densification. The outcome is a joint with very low porosity and a strong bond, offering superior mechanical, electrical, and thermal properties.

Revolutionizing power electronics

Silver sintering is revolutionizing power electronics by providing robust, reliable electrical connections in critical components like package, top, and die attach applications. This technology is especially important for high-performance materials like silicon carbide (SiC), which operate at high temperatures and mechanical stresses.

Unlike traditional solder, which melts at around 230-300°C and risks failure as operating temperatures approach 200°C, silver sintering offers a much higher melting point of 962°C. This significant gap ensures that sintered silver joints can resist extreme conditions without weakening or cracking, as often happens with solder under thermal cycling.

By maintaining strong connections in SiC-based devices, silver sintering ensures higher reliability and longer lifetimes, particularly in demanding power electronics applications, like inverters. Its superior performance in resisting heat and mechanical stresses makes it an essential technology for fully unlocking the potential of SiC components, enabling them to operate at peak efficiency and reliability. This has been proven in extensive thermal and power cycling tests, making silver sintering a key enabler of advanced power electronics.

Does silver sintering have other advantages or disadvantages compared to traditional solder joining?

Silver sintering has higher thermal and electrical conductivity than solder, which is inherent to the properties of silver. A key advantage related to its higher thermal conductivity is enhanced heat dissipation. The efficiency of heat dissipation, from the component to the heat sink to

coolant is notably improved with silver sintered attachments. This improvement often enables the simplification of the cooling system. Additionally, because sintering uses pressure to compress the paste in the z-axis, it produces a bond line that is thinner and more uniform than soldering. This characteristic enhances both thermal conductivity and reliability.

It is worth noting that bond line control is best achieved by using sintering films, when that is possible. This innovative laminate film technology was developed specifically for die and top attach applications. Sintering film offers a cleaner application compared to sinter paste, eliminating die tilt and top-side contamination issues. Film can be applied in a very clean, high volume, pick and place process before sending to a sintering press, resulting in a significant reduction in material waste. MacDermid Alpha has developed a portfolio of silver sintering films and related products, providing solutions at the wafer level and that attach onto bare copper surfaces.

Overcoming densification

The only possible drawback to sintering is the application of pressure that triggers densification. Pressure must be kept low to prevent damage to sensitive electronics. Fortunately, this challenge has been mitigated with the advent of innovative nanoparticle silver sintering formulations, such as MacDermid Alpha's patented Argomax® products. These formulations sinter at low temperature and low pressure. By using nano-sized particles instead of micron-sized particles, we can apply less pressure and achieve superior reliability.

Copper Sintering has been emerging as another alternative to conventional soldering, could you please comment on that?

Copper has been used in the electronics industry for decades and is well known for its superior electrical and thermal characteristics. Copper is more abundant than silver, is much cheaper, and has a higher melting point of 1084^{o}C. So, it is understandable that nanostructured copper sintering materials have been the focus of much study in the search for alternative technology that can meet the high-performance requirements of power electronics.

Copper sintering is emerging as the newest alternative to solder in various industries, including e-mobility. Like silver sintering, copper sintering enhances the reliability of power devices when operating at higher power, higher voltages, frequencies, and temperatures compared to traditional solder. However, copper sintering has faced two major challenges. Firstly, it is difficult to synthesize nano copper particles, and secondly, it is susceptible to oxidation in air before sintering, specially at higher temperatures. The industry has been actively working on new approaches to address these issues. Techniques such as utilizing a nitrogen atmosphere or a reducing agent like formic acid have proven helpful with oxidation. It has also been reported that the pressures and temperatures required for sintering copper are considerably higher than those for silver. However, the development of copper sintering technology is still in its early stages, and numerous advancements are expected for the coming years.

The future - ActiveCopper™

MacDermid Alpha recently acquired Kuprion, Inc., a company that has engineered and patented a family of ActiveCopper™ sintering pastes, adhesives and inks that overcome the challenges of

nano copper synthesis, oxidation and having the capability to be implemented in customer production lines with manufacturing parameters very close to what is used today for silver sintering! We have been working a lot on copper sintering technology! You can expect to hear more about our ActiveCopper™ products soon.

How can companies take advantage of these revolutionary trends in power electronics and become successful early adopters?

The implementation of new technology can be a formidable challenge. Car manufacturers, tier-one suppliers, and semiconductor customers in general are interested in emerging technologies but are lacking research or testing and are often in need of information and assistance. That's why MacDermid Alpha Electronics Solutions developed the MacDermid Alpha ecosystem, to help companies navigate the latest trends.
MacDermid Alpha ecosystem combines our partnerships, expertise, experience, and state-of-the-art application laboratories with our commitment to customer success. These elements enable us to provide total solutions, advising on new technologies, processes, and materials, and demonstrating and validating applications in our labs. With services, capabilities, and products spanning the entire supply chain, MacDermid Alpha can accurately predict interactions between different materials in power electronics applications.

While we emphasize the importance of silver sintering, we also offer unique solutions in plating chemistry, high-reliability solder alloys, resins, thermal interface materials (TIMs), and conformal coatings, which are all designed to achieve best-in-class performance in power electronics. For decades, we've focused on application-specific material development, staying close to customers from the initial concept to mass production.

The switch to SiC-based semiconductor technology is underway, with silver sintering playing a pivotal role in unlocking its full potential. Pioneering companies in the EV supply chain are leading this transformative shift. MacDermid Alpha Electronic Solutions, a global leader in fully integrated materials and process solutions, assists companies in exploring these groundbreaking trends. If you operate in the power electronics sector and have not yet transitioned from silicon to SiC technology, it is imperative to act promptly to stay competitive in this evolving landscape! Give us a call, it will be a great pleasure to help!

MacDermid Alpha Electronics Solutions at a Glance
MacDermid Alpha Electronics Solutions, a prominent business of Element Solutions Inc, holds a distinguished position as a global leader in the field of fully integrated materials; helping to deliver enhanced performance, reliability, and sustainability to electronic manufacturers worldwide.

Their expertise is segmented as follows:

- **Circuitry Solutions**: MacDermid Alpha Electronics Solutions pioneers advanced specialty chemical and material technologies tailored to meet the circuitry demands of the electronics industry.

- **Semiconductor & Assembly Solutions**: They specialize in delivering cutting-edge solutions for semiconductors and assembly processes, driving innovation and reliability in these critical sectors.
- **Film & Smart Surface Solutions**: With a focus on materials and technologies for films and smart surfaces, MacDermid Alpha Electronics Solutions is at the forefront of transforming the future of electronics.

With a legacy spanning over a century of innovation, MacDermid Alpha has garnered the trust of manufacturers around the globe and is actively shaping industries such as automotive, consumer electronics, mobile devices, telecom, data storage, and infrastructure. The business is uniquely positioned to deliver high-quality solutions and technical services to comprehensively cover the entire electronics supply chain.

For those seeking to power their path to success in the electronics industry, MacDermid Alpha Electronics Solutions offers exceptional business opportunities. Join them on their journey of innovation and excellence.