CONTACT
MacDermid Alpha Electronics Solutions
245 Freight Street
Waterbury, CT 06702
United States

Tel: +12035755700
Web: www.macdermidalpha.com

Q&A Piece

Meet an expert from the Electric Vehicle Industry

Q&A with MacDermid Alpha's Director of R&D Applications

Introduction

With rapid advancements in automotive technology, the pursuit of solutions that enhance performance, reliability, and efficiency for electric vehicles (EVs) is constant.

Innovative technology, introduced to the market by MacDermid Alpha Electronics Solutions, not only offers enhanced performance for EVs, but also contributes to the creation of more sustainable and environmentally safe automotive systems. An example of this is some of our lead-free products.

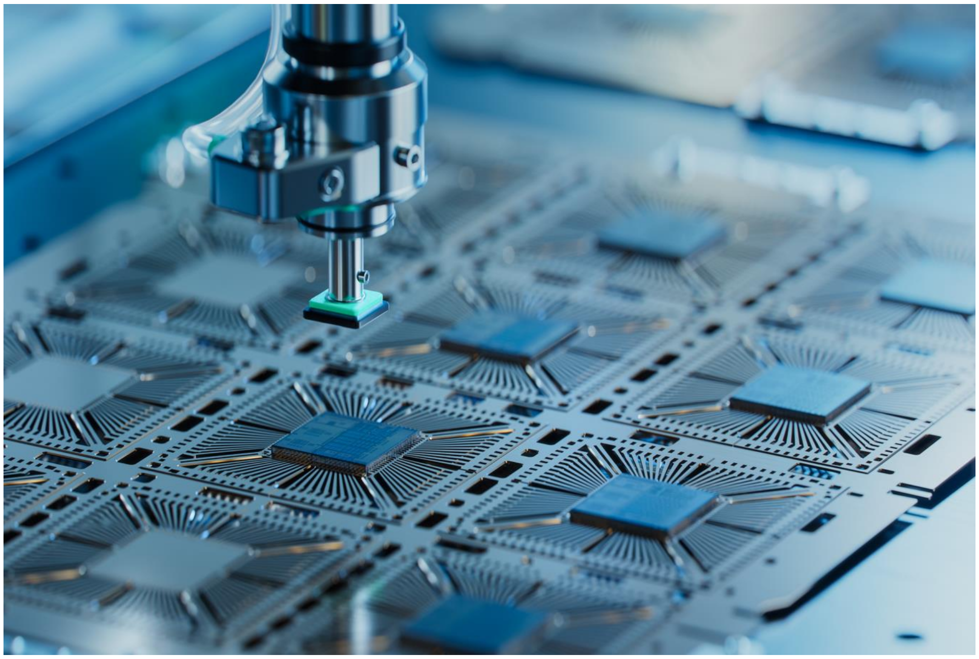
Maurizio Fenech, the Global Director of R&D Applications for Semiconductor Assembly, explores market technologies within the automotive sector, while highlighting the role our product portfolio plays in supporting the critical needs of the industry. He delves into the applications, benefits, and transformative impact of these products, propelling OEMs into a new era of technological excellence.

There are 3 main types of power module used in Chinese EVs today, Si-IGBT, Si-MOSFET and SiC-MOSFET (Silicon-Carbide MOSFET). Can you explain where each finds its main application and the primary differences between them?

The industry is directing itself towards even higher efficiency. An outcome of this is that we are seeing requirements of faster switching and higher voltages, to drive motors more efficiently.

This ultimately leads to greater vehicle milage and/or lower system weight.

MOSFETs can achieve higher switching frequency than the Si-IGBTs, so at first glance they are the technology to go to. However, we see a good long-term market for Si-IGBTs because of the lower operational thermal density, lower specific cost, lower assembly challenges and their general availability. This allows Si-IGBT´s to occupy a niche where high inrush capacity and system cost is more important than miniaturization and outright sustained performance.



Within the MOSFET space, we are seeing both more ground-up adaptation as well as a high transfer rate from silicon based MOSFETs to silicon carbide MOSFETs. This is mainly due to the fact that SiC-MOSFETs have a higher potential for high frequency switching without significant losses. Intrinsically, silicon carbide has better heat transfer properties than silicon allowing for larger current densities for a unit rise in temperature. SiC junction layers are also more stable at temperature. You can run SiC equipped cars harder with higher power densities, higher frequencies and higher operating junction temperatures with equivalent reliability expectations. This allows for a traction system that integrates a SiC equipped-power module to drive a motor more efficiently and with potentially less comprehensive cooling systems. However, integration of SiC produces significantly higher assembly challenges since a carbide die is thermo-mechanically mismatched with most, if not all, of the other components that need to be attached to it. Consequently, a SiC chip interface is stressed harder than any Si MOSFET and Si-IGBT chip will ever be, and the die attach concepts and materials that are used need to reliably operate in this harsh environment.

It has been highlighted in the media that research today says that 81% of the market is Si-IGBT. Do you see that changing over the next few years?

Cost optimization within the mission profile of a vehicle is reflected on the technologies used. We see that Si-IGBTs still have a position in the market. Of course, there are significant advantages that go with SiC-MOSFETs, such as higher overall efficiency and reduced footprints for the same handling capabilities. However, from a cost perspective, in particular conditions, a Si-IGBT can give you equivalent handling capabilities for a potentially better cost. Where there is no reason to use high frequency switching and/or junction temperatures beyond 150°C, Si-IGBT are often perfectly suitable.

We are deeply engaged within the automotive world and support the adoption of this balance in parallelized circuits both in coupled modules, as well as in integrated hybrid power modules. In such concepts silicon carbide-based circuits support long distance driving while the Si-IGBT circuits are mainly used for high acceleration where the motor is running at slow speed, but the torque requirements are high. As accelerating torque is ultimately provided by a high magnetic field generated by large currents passing through the power field at a relatively lower motor speed and for short durations, Si-IGBT can do this at a competitive KW/$.

Research also points out that in B/C/D class of vehicles SiC-MOSFET is already at 24%, double its adoption rate in all remainder vehicle classes. Can you explain why this might be the case?

This is because with higher classes, the price/performance balance tilts more towards performance. As the technology is maturing, foundries ramp up production, and more die manufacturers get into the market, we do expect that the adoption of SiC based technology will find its way in smaller vehicles.

Let's focus on joining technology. Are we correct in understanding that solder is the main joining material used today for Si-IGBT?

Soldering for IGBTs has been a mainstay in the industry. Si-IGBTs have been around for a long time and solder materials based on lead-containing alloys could reliably connect IGBTs to substrates before sintering was adopted as a mainstream joining system. Beyond building power modules that are RoHS[1] compliant and thus eliminating lead from their systems, power module developers understand that Si-IGBTs can technically benefit from sintering technology. Sintered Si-IGBTs are now in the market and can be found in class leading power modules that power industrial systems and commercial vehicles and that integrate sintering both under the die as well as on the top of the die, ultimately providing a fully sintered solution with silicon.

How do you feel that this particular market will develop in the next 5 years?

Within the power module market over the next five years there will be a requirement to be working at a high switching frequency with the lowest possible thermal resistance from the junction to the liquid coolant. Any power module that will be able to compete in next five years will need to consider this. Now, this requires a very high level of integration and a smart design that allows for shortest path from signal to current while not compromising manufacturability. These demands will provide an opportunity for the most talented power module designers to get creative and integrate smart joining technologies.

Will high reliability solder alloys such as Innolot have a higher adoption than traditional SAC 305 based on continued use of Si-IGBT?

The Innolot alloys have a good proven track record of higher reliability without sacrificing any of the solder ability. They are high-reliability SAC (tin-silver-copper) based alloys developed in conjunction with the automotive industry for use in environments exposed to high temperature and vibration. So, there is everything to gain and nothing to lose by transferring to Innolot alloys from traditional SAC systems. Innolot alloys finds their application when limitations of soldering temperatures are present, and comply with applicable environmental standards, including RoHS[1] for use in products requiring the use of lead-free material.

With the trend towards SiC-MOSFET, will the joining materials have to change?

This transition is happening, and any SiC-MOSFET that can maximize the potential of performance needs to be sintered on top of the substrate. Something that can help with this is Argomax from MacDermid Alpha. Argomax-based silver sintering technology provides a reliable die attach connection between the die and the substrate. The next reliability bottleneck that we are seeing is the long-term stability of the top connections. Metallization stacks on the source connection and the gate connection of a silicon carbide die are particularly susceptible to aging. With next generation low inductance assemblies, this requires a smart review of what can be used to connect the top side of silicon carbide MOSFETs. In turn, MacDermid Alpha is in the right position and has the right materials and technologies to cater to these trends with Argomax based engineered solutions.

Do you think silver sintering is an enabling technology which will further facilitate automotive engineers move to SiC materials?

Yes, it is indispensable. You cannot extract the potential of SiC-MOSFET-based semiconductors without having the speed of processing, the surface compliance, the heat transfer capability

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[1] RoHS – Restriction of Hazardous Substances in Electrical and Electronic Equipment (EU)

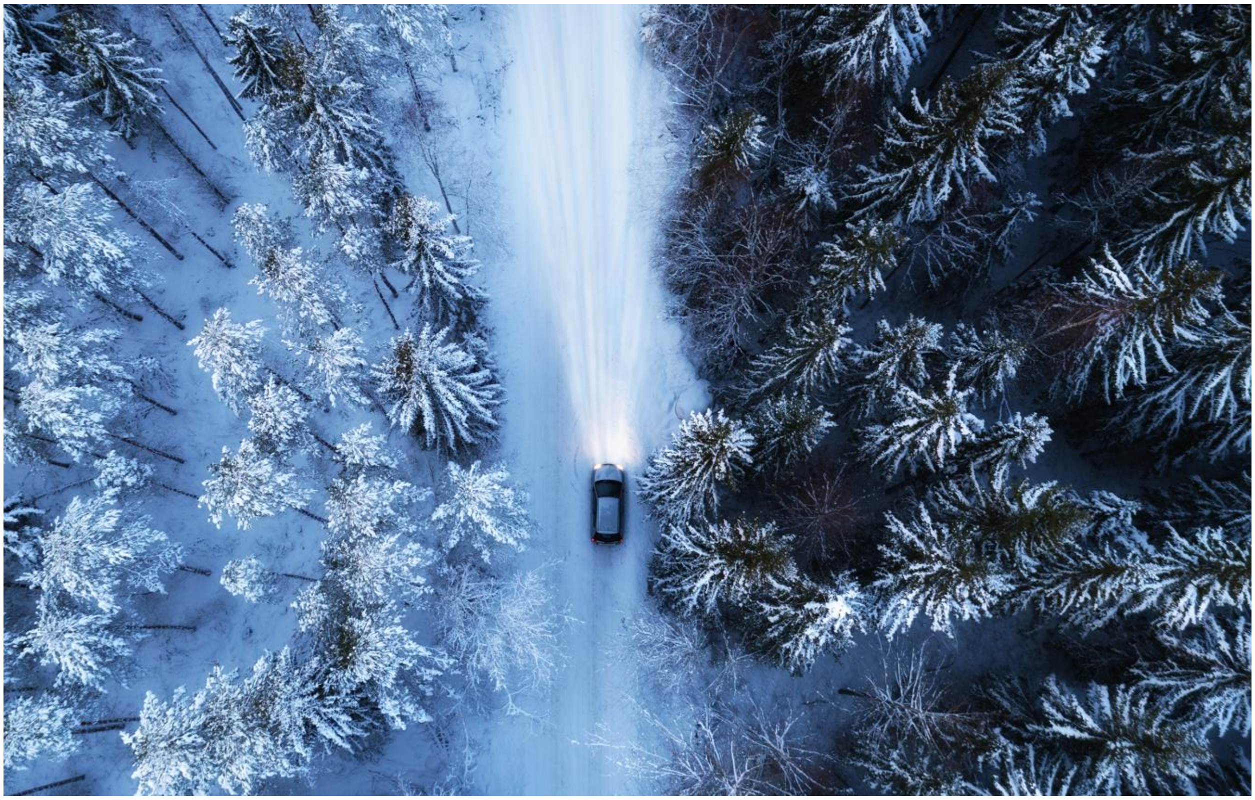
and power cycling reliability that nano engineered silver sintering provides.

Does this lead to performance improvements for the EV inverters and the vehicle in general?

SiC power modules can run reliably at higher temperatures because the components are connected by silver sintering. This has a beneficial cascading effect. On one hand, the fact that you are using SiC-MOSFETs enables you to drive motors with higher efficiency. The fact that you are driving a motor at higher efficiency means you will consume less kilowatts per hour for the distance and this means battery capacity can be reduced. The advantage of this reduced battery capacity is lower vehicle weight and production costs. Another interesting aspect is that SiC power modules, where silver sintering is used, can run at higher temperatures. Coolants that operate at a higher temperature have a greater delta with respect to ambient, thus requiring less heat exchanging area to achieve equivalent heat transfer and facilitate the integration of relatively simple cooling systems with the power module. This more efficient way of running creates a disproportionate net positive cyclic improvement on the whole vehicle.

Would you say that these improvements have helped to accelerate the pace of change in the EV market?

These improvements are surely helping the acceleration, but they are complimentary and not necessarily always the main drivers. When you have differentiated models where one model has a stronger performance, and others are trying to catch up, there are several factors that play a role, including battery-range.



What do you think is the general awareness of silver sintering capabilities for EV power electronics in the automotive engineering ecosystem?

Power module developers should be fully aware and have fully integrated silver sintering for die attach applications, especially in the paste format. We are seeing that the adoption of silver sintering is slower in non-automotive application, where requirements are not as stringent. This means that (in non-automotive applications) sintering has a high potential to grow.

Silver sintering for die attach is one thing but form factoring and the integration of engineering solutions that MacDermid Alpha can provide value in is another.

Are there any barriers to adoption? If so, what are they and how might they be overcome?

Adoption of silver sintering requires changes within the assembly where typically high-performance pick-and-place machines are required, as well as sinter presses. We are seeing a growing participation of highly established semiconductor equipment suppliers that are providing this kind of equipment.

We consistently conduct customer specific workshops, to make the whole supply chain aware of the value proposition of different assembly technologies. We also provide expertise on how to implement sintering over soldering, which in turn will allow them to have a stronger performing product.

Talk to us about large area sintering. What is considered a 'large area' in this application and what are the joining challenges?

Many times, when we are referring to the adoption of silver sintering for large areas, we are referring to the joining of overmolded power modules to water cooled heat exchangers. These power modules are complex and have different materials within their structure: ranging from temperature sensitive solder joints to sensors, ceramics and, of course, very sensitive semiconductors. Such power modules need to be attached to delicate, often hollow, heat exchangers through pressure, time and temperature. This is challenging, and you need to make sure you have the right material such as Argomax and the correct tooling to achieve a reliable joint while not damaging anything. Our organization is in a unique position to provide Argomax and expertise to achieve the lowest possible thermal and mechanical stress during the joining process while achieving the highest possible operational reliability.

Talking specifically about the ALPHA Argomax technology, I understand that is based on nano silver. Why is this important?

Correct, Argomax is based on nano technology that gives unparalleled advantages when sintered. The nano particle technology allows for the formation of highly homogeneous sinter joints at the lowest possible temperature and pressure sintering conditions. Argomax has proven to be the material of choice for sinter sensitive assemblies and for sintering silicon carbide dies.

With Argomax, we talk about the technology facilitating power, removing heat and joining and mitigating stress. Can you expand on these points and the importance for the power electronics.

Silver has the highest thermal conductivity of any pure metal, as such the fully metallic silver joint provided by sintered Argomax provides the highest thermal transfer possible, as allowed by physics. The fact that no intermetallics are produced during the sintering process means that the joint has no brittle interfaces that can initiate uncontrolled cracking. Homogeneously distributed micro-porosity in the sintered joint provides lowered

Young´s modulus[2] which can absorb the stresses of thermomechanically mismatched materials, resulting in predictable assembly lifetime.

I would like to talk about some products, specifically Bondpad, Accutak, Acculam and TrueHeight Sn95Sb5 alloy Preform. What is the significance of these in the inverter design?

In the quest of designing more power-dense, higher efficient products you need assembly materials that allows the designer to adopt sintering in all layers of the assembly with the smallest footprint possible. Bondpad, Accutak and Acculam are products that are based on our proprietary film technology, and they carry significant advantages when used instead of sinter paste.

For die to substrate sintering, Acculam is the leading solution. With Acculam, the engineer can design processes where die sintering can be achieved on a substrate using a film, that has exact dimensions as the die. No overprinting, no un-sintered material, no waste of sinter paste.

For die top sintering, our complementary offerings are Bondpads and Accutak. Bondpads allow the designer to consider using copper wires and/or ribbons instead of aluminium, to connect the top of the die. This facilitates a significant increase in reliability, for a given mission profile. Accutak is a paradigm shift in how sintering can be implemented in power modules. With Accutak technology the engineer can design processes where sintered material can be positioned in cavities, on top of dies, on lead frames and other difficult positions with absolute bond line

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[2] Young's modulus is defined as the ratio of the stress (force per unit area) applied to the object and the resulting axial strain (displacement or deformation) in the linear elastic region of the material

control. This can be done with ease using a capable Pick and Place machine.

Going back to solder materials, Sn95Sb5 alloy Preforms allow engineers to design power modules with highly reliable lead-free soldered joints. This facilitates highly reliable, environmentally compliant joints.

What is Wafer-Level Die Attach sintering?

Wafer-level die attach sintering is a game changer for how sintering is integrated in the production line. With this concept, MacDermid Alpha has proven that sinter material can be integrated onto the un-diced wafer, effectively providing ready to sinter dies at the back end of the factory. With this technology, the process of printing, drying and tacking of dies is eliminated, as the sinter material needs no extra handling at all. Unprecedented throughput can be achieved, and this finds perfect use in high volume manufacturing stations such as when building power discretes.

Further information about EV and silver sintering can be found on MacDermid Alpha’s website.

About MacDermid Alpha Electronics Solutions

MacDermid Alpha Electronics Solutions, a prominent division 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 electronics manufacturers worldwide.
Their expertise is segmented into three vital divisions:

- **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 spanning more than 50 countries.

What sets MacDermid Alpha Electronics Solutions apart is its unique ability to promptly deliver high-quality solutions and provide technical services that comprehensively cover the entire electronics supply chain. They are actively shaping industries such as automotive, consumer electronics, mobile devices, telecom, data storage, and infrastructure.

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