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Smart Design of Electric Vehicle Batteries and Power Electronics Using Thermal Interface Materials

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Summary

Heat dissipation and thermal management is a growing issue in the design of electric vehicles and their components. Within the battery pack, heat is generated during charging and discharging. Power circuits that transform and control the electric current are also subject to strong generation of heat that has to be dissipated by cooling. Heat transfer between components and cooling devices can often be accomplished by using thermal interface materials. Especially thermal adhesives enable force-fitted and thermally conductive joints found in traditional soldering and welding, but avoiding high thermal loads during processing and subsequent distortions or discolorations. Moreover, joining of difficult material combinations is possible without restrictions. Compared to mechanical fixing, there is no need for additional parts like screws or clamps, and the heat transfer takes place over the whole area. Adhesive joints are gap-filling and resistant to most processing fluids. In case that thermally bonded parts must later be separated or replaced without being damaged, paste-like thermal interface materials may be applied in order to bridge any non-conducting air gap, given that additional mechanical fixing is provided. Some examples of thermal interface materials applied to module and battery assembly and to die-attach of power chips are presented.

Keywords: *battery management, control system, cooling, materials, thermal management*

1 Thermal Management in Electric Vehicle Drivetrains

1.1 Thermally Conductive Assembly of Batteries

The design of a battery system from Li ion cells puts special requirements to thermal management [1]. As the performance and durability of the cells depend strongly on the temperature of their environment, the thermal management system has to care for an efficient dissipation of the heat losses, as well as for the heat supply in case the batteries are cold. In operation, heat is generated when the system is being discharged due to accelerating, but also when charged during braking or at the charging station. To avoid hot spots and to slow thermal response within the battery pack, a big thermal mass and good inter-cell thermal conductivity is advantageous.

Heat delivery and dissipation can be provided in various ways [2]. Within the battery packs, the heat transfer can be accomplished either directly from the cells into a cooled baseplate, or via active or passive cooling sheets located in between the cells. Both mechanical and thermal connection is usually done by mechanical joining (bolts, clamps) or various welding procedures. Alternatively, thermally conductive adhesives and thermal interface materials provide a novel but already proven solution [3].

1.2 Thermal Issues in Power Devices

Thermal management of power devices like converters, inverters, or control units, is a critical factor in design. Power electronic devices may transform tens or hundreds of watts into waste heat, so they require specialized heat sinks or active cooling systems. Bonding of power chips to heat sinks is often accomplished by soldering or sintering but adhesive bonding is a promising alternative.

2 Applications of Thermal Interface Materials

2.1 Thermally Conductive Mounting of Li-Ion Cells

Mounting of Li-ion cells onto the cooling baseplate using thermally conductive adhesives is a technology already proven in HEV mass production (Fig. 1). Suitable adhesives must feature good thermal conductivity, mechanical stability as well as vibration and environmental resistance. Further, it is inevitable that they are fast curing at room temperature or slightly elevated temperature, because the batteries cannot stand high temperatures in the process. Newly developed epoxy-based products feature high thermal conductivities of 1 - 2 W/mK, thus making adhesive bonding increasingly attractive instead of welding or mechanical joining.

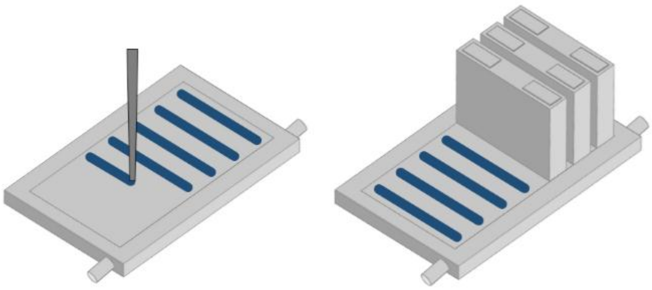

Figure 1: Mounting of prismatic cells onto baseplate.

The challenge in formulating adhesives for cell mounting is to achieve both good thermal and mechanical properties. Generally, epoxies, like other polymers, have a poor intrinsic thermal conductivity of 0.2 - 0.3 W/mK. When these epoxies are filled with ceramic or metallic powders, heat transfer increases substantially. The bulk thermal conductivity of these particles ranges between 30 and >300 W/mK. In the respective composites, thermal conductivity depends on the relative ratio of the filler to the epoxy, but not linearly. A well-acknowledged model is the equation found by Lewis and Nielsen [4],

$$\lambda_C = \lambda_M \cdot \frac{1 + (A-1)B\phi}{1 - \psi B\phi}$$

where λ_C is the thermal conductivity of the composite, λ_M is the thermal conductivity of the matrix, and the right part of the equation consists of various parameters where Φ is the volume fraction of the filler. The parameters A, B, and Ψ take account of the particle form, the thermal conductivity, and the maximum possible packing density of the filler.

Data generated using this equation (Fig. 2) shows that the volume fraction of the filler should be 50% or more just to achieve a thermal conductivity of above 1 W/mK.

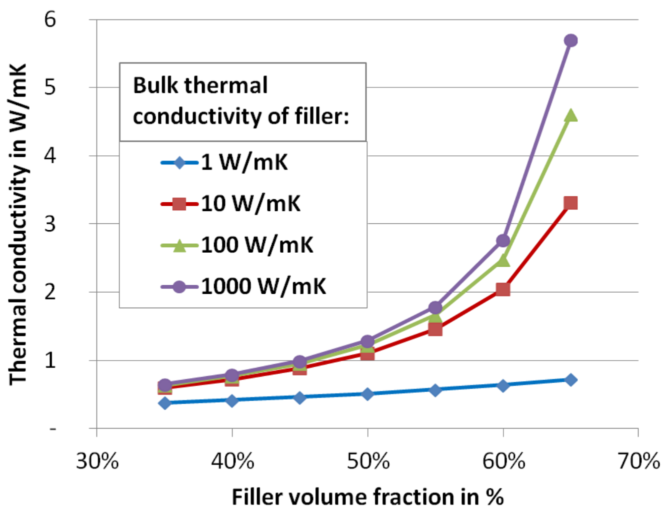

Fig. 2: Modelling of composite thermal conductivity.

Considering these properties, the goal to maximize thermal conductivity therefore requires a high ratio of filler content. However, a high ratio of abrasive particles reduces reasonable flow properties that will be needed to mix and apply the adhesive. Further, mechanical strength may suffer as filler displaces epoxy. As a consequence, any product development team will have to find a compromise between thermal conductivity and processing parameters. Basic properties of two of the newly developed products (Polytec TC 452 and VP 2027-28) are displayed in table 1.

2.2 Reworkable Thermal Connections

In case that thermally bonded parts must later be separated or replaced without being damaged, paste-like thermal interface materials (Fig. 3) may be applied in order to bridge any non-conducting air gap, given that additional mechanical fixing is provided. For example, modules assembled in EV battery packs should be removable in case of maintenance or repair.

Figure 3: Dispensable thermally conductive paste.

Thermally conductive pastes are well-known from computer technology. They are easy to apply and to remove, and they feature a permanent thermal contact to the substrate surface due to good intrinsic wetting properties. However, in order to serve as a thermal gap filler for batteries, such materials will have to accomplish a couple of additional requirements.

First, thermal pastes for semiconductors are often customized to achieve high thermal conductivity by using high-price components like silver or boron nitride. However, in order to be compatible with mass application, gap fillers will have to be based on low-cost components that are well available on the market.

Further, thermal pastes for computers are usually flowable and are customized to fill very narrow gaps in the 50 … 100 µm range while the respective voids in battery modules can reach several millimetres gap width. This in turn requires thixotropic materials that will be mechanically stable and non-sag, especially when considering dynamic loads like operational vibrations, shock impacts due to road holes while driving, and varying vehicle inclination when parked.

In conclusion, a thermal paste for battery applications has been developed from scratch thus addressing all of the mentioned specific requirements. Fig. 4 shows the product applied into a module base. In case of repair, the thermal paste can be easily removed and replaced (Fig. 5).

Figure 4: Thermally conductive paste in a battery module.

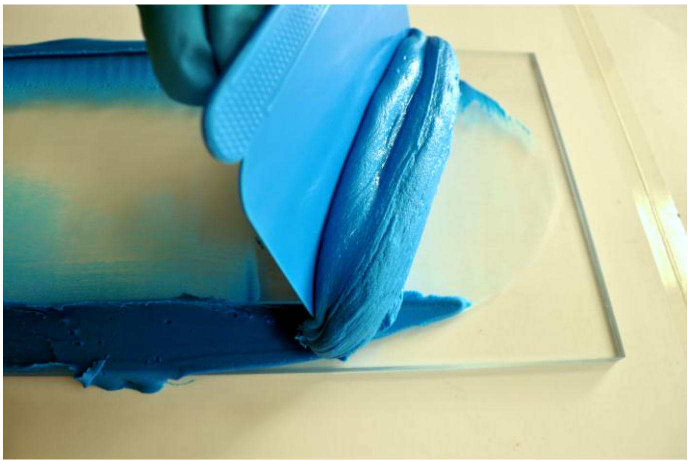

Figure 5: Removal of thermal paste from the surface.

2.3 Low Stress Assembly of Power Circuits

Adhesive bonding of power modules can often be an alternative to usual joining techniques. This has been revealed by a research project [5] performed by the IMTEK Department of Microsystems Engineering and the IESY Institute of Electric Power Systems at the University of Freiburg and Magdeburg, resp., together with Polytec PT and other manufacturers of conductive adhesives. Fig. 6 shows a power module assembly using an IGBT and a diode attached onto a DCB substrate by using Polytec EC 242 silver-filled adhesive, a new product with a low specific resistance at approximately $5*10^{-5}$ Ohm cm and a high thermal conductivity of 4.2 W/mK (see Table 1).

According to the project outcome, Polytec PT's conductive silver adhesive has shown good mechanical and electrical performance [6], including high die shear strength between 25 and 30 MPa, stable over 2500 temperature cycles (see Fig. 7), as well as superior thermal and electrical conductivity. All of these features are critical for the thermal management of power chips.

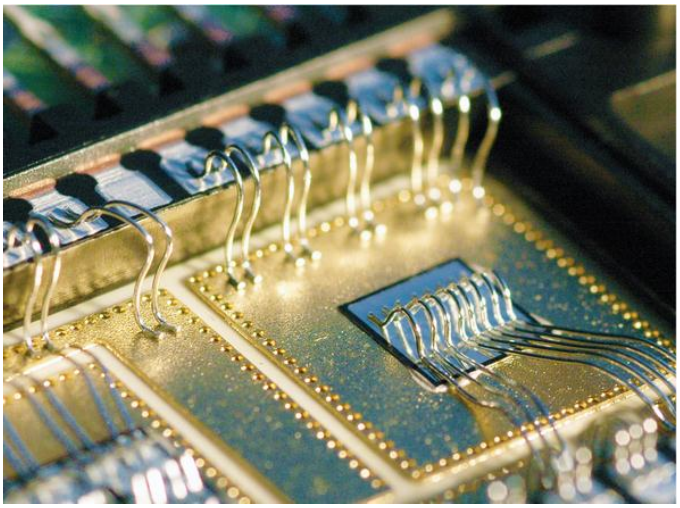

Figure 6: Power module bonded with electrically conductive adhesive.
Photo courtesy of IMTEK

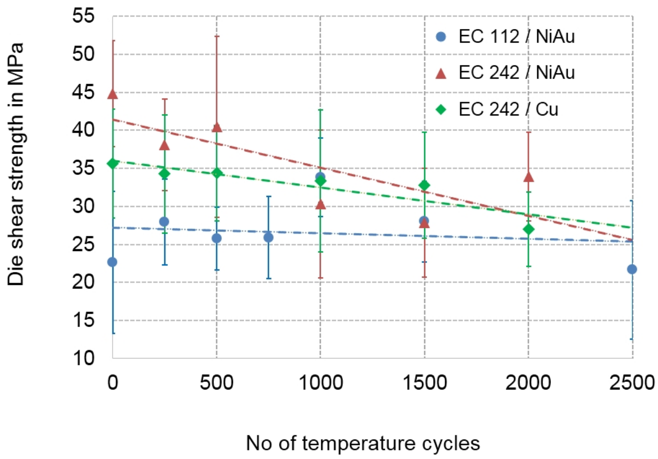

Figure 7: Die-shear strength of specimens bonded with conductive adhesives vs. number of temperature shock cycles.

Table1: Typical properties of thermally conductive adhesives

Product (Polytec PT)	TC 452	VP 2027-28	EC 242 frozen
Mix ratio	100 : 20	100 : 13.5	pre-mixed
Mix viscosity	22,000 mPa s	55,000 mPa s	35,000 mPa s
Max. cont. operating temp.	+180 °C	+120 °C	+220 °C
Thermal conductivity	1.0 W/mK	1.5 W/mK	4.2 W/mK
Young’s modulus	2,800 MPa	490 MPa	9,000 MPa

3 Conclusion and Outlook

According to a recent market study [7], the global demand for thermal interface materials will increase roughly threefold and reach 3,5 billion $ until 2026. When considering future application requirements in EV battery and power electronics assembly, thermally conductive adhesives and pastes are fairly flexible. There is a growing demand for customized materials that are easy to apply and that feature high conductivity and durability. In coordination with our customers’ requirements, a couple of new development products have evolved which are currently under test.

References

[1] N.N., *Thermal Challenges in Automotive High Density Lithium-Ion Battery Packs*, QPedia December 2009, 18-20.

[2] Zeyen, M.G., Wiebelt, A., *Thermisches Management der Batterie. In: R. Korthauer (Ed.): Handbuch Lithium-Ionen-Batterien.* Springer Vieweg, Berlin/Heidelberg, 2013, 165 – 175.

[3] Maurer, A., *Rewards for good conduct(ivity) - Thermally conductive bonding aids electrical and electronics assembly.* European Coatings Journal, 2 (2016), 42 – 47.

[4] Nielsen, L., *Thermal conductivity of particulate-filled polymers.* Appl. Polym. Sci., 17 (1973), 3819.

[5] Möller, E., Middelstädt, L., Grieger, F., Lindemann, A., Wilde, J., *Investigation on the Suitability of Electrically Conductive Adhesives for Die-Attachment of Power Devices*. 2015 European Microelectronics Packaging Conference (EMPC), Sept 14 – 16, 2015, Friedrichshafen, Germany.

[6] Maurer, A., *Adhesive Bonding to Replace Soldering of Power Modules*. Adhesion Adhesives and Sealants 14(2), 2017, 24 – 27.

[7] Gordon, R., *Thermal Interface Materials 2016-2026: Status, Opportunities, Market Forecasts*. http://www.idtechex.com/research/reports/thermal-interface-materials-2016-2026-status-opportunities-market-forecasts-000474.asp?viewopt=showall.

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Polytec PT GmbH develops, manufactures and distributes special adhesives for applications in electronics, electrical engineering and automotive electronics as well as the solar industry and the manufacture of smart cards. A particular strength is the manufacturing and delivery of custom formulated adhesives and thermal interface materials.