Aluminium packaging for power semiconductors: Efficient and reliable battery switch for 48 V Li-ion batteries

Author: Dr. Louis Costa, AB Mikroelektronik GmbH, Salzburg, Austria

In the case of a traffic accident, it must be possible to disconnect lithium-ion batteries independently and safely from electrical consumers. At present, mechanical relay switches are used, but these cause noise. For electric cars in particular, the requirements for noise emission of components are becoming more stringent. A semiconductor-based isolating switch can be used as an alternative for this application. The solution presented in this article offers advantages in terms of high current capability, excellent thermal properties (continuous and transient) and long service life, while at the same time being cost-effective, since the power electronics are largely made of a pure aluminium alloy.

Requirements

The noise requirements for components in electric cars have become much stricter than those for conventional combustion engines. Lithium ion (Li-ion) batteries, as high-density energy sources, must also be monitored by sensors and, in the event of a fault, safely disconnected from the vehicle's consumer system. If necessary, this should also be performed autonomously and completely. In addition, a targeted and metered control of power from the battery to numerous parts of the vehicle system can significantly improve energy efficiency and so increase the operating range.

State of the art: Relay

Electromechanical switches, or ‘relays’, meet the requirements only to a limited extent. Mechanical switching with its contact surfaces generates noise, and switching operations take a few milliseconds. In addition, relays generally have a finite number of switching cycles, since each switching operation removes a small amount of material from the contact surfaces.

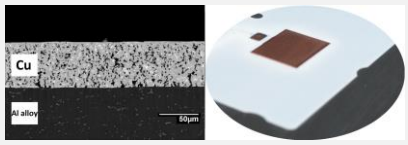
Semiconductor-based, bidirectional switch for 48 V lithium-ion batteries. © AB Mikroelektronik

Semiconductor based solutions

Semiconductor-based switches react much faster in such applications and can selectively control the current flow between batteries and loads. AB Mikroelektronik GmbH has developed an efficient semiconductor-based bidirectional switch for 48 V Li-ion batteries, see figure 1. Compared with conventional lead acid batteries, Li-ion batteries generate up to ten times higher short circuit currents at the same capacity due to the lower internal resistance, with ten times shorter temporal pulse length (some 100 µs). Through decades of

experience in the field of thick film technology and screen printing processes, AB Mikroelektronik has applied a specially developed printed circuit board, consisting mainly of a solid aluminium alloy, as a new approach for packaging technologies of semiconductors in power electronics. Suitable material selection ensures a long service life. Particularly for high short-term current loads, aluminium alloys offer a decisive advantage due to their relatively high specific heat capacity of 890 J/(g K) for absorbing a lot of thermal energy for a short time. In addition, the present technology allows the cost optimized and efficient use of the semiconductor area for comparable high performance applications, since aluminium can quickly absorb the resulting dissipation power due to its high thermal conductivity. In addition to the extensive technical advantages, this technology enables a reduced use of cost-critical conventional semiconductors in power modules of high performance classes.

Innovative aluminium printed circuit board technology: small, light, efficient



In aluminium metal thick-film hybrids, the copper is interspersed with pores. This compensates thermal stresses highly efficiently. © AB Mikroelektronik

Aluminium is the most common metal in the earth's crust. Compared with copper, which is widely used in power electronics due to its high electrical conductivity, aluminium offers some additional application-specific advantages. Metallic aluminium has a very low density of 2.70 g/cm3 (Cu: 8.92 g/cm3 at 20 °C), good physical properties and a higher bending capacity (Young's modulus Al: approx. 70 GPa, Cu: approx. 120 GPa), which makes the material very attractive, especially in metal processing. It is almost impossible to imagine an industry without it, although it has only been known since 1825 and was initially more expensive than gold. In today's industrial applications, aluminium is valued more highly than copper, but its price is only about a quarter as high. In addition, aluminium offers good recycling properties, so that in the overall production energy balance there is potential for savings via secondary production routes.

To use aluminium as an efficient current carrier in power electronics, the inert natural oxidation layer must be broken up. AB Mikroelektronik has developed a proven process for the production of circuit carriers based on an aluminium alloy. On the same circuit carrier, both insulated conductor tracks and direct contact pads for the connection of line semiconductors can be produced. Thus, a simultaneous integration of passive components, sensors, ICs and power semiconductors in SMD is possible. Complex mixing processes of soldering and bonding can be avoided, and production is significantly simplified.

Process for producing thick film hybrids by screen printing

The substrates are produced by a screen printing process. The materials required for the circuit design are applied as a paste to the solid substrate and printed with a steel screen. Repeated printing, drying and firing processes are used to build up several layers of isolating, conducting and masking materials. The additive process allows materials to be used efficiently and cost effectively. For the production of an aluminium circuit carrier, a copper paste in combination with a dielectric paste is burned in just below the melting temperature of aluminium at about 650 °C.

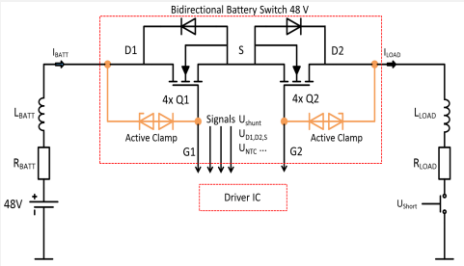
In contrast to Direct Metal Brazed Copper (DCB) substrates, in the present aluminium metal thick-film hybrids the generated copper is interspersed with pores, see Figure 2. It has been shown that it is precisely through these defect locations that thermal-mechanical stresses, which are always present in power electronics, can be better compensated. In the case of a thin and stiff copper foil (bulk) with about 300 - 400 µm in a DCB substrate, this situation pertains only to a limited degree. Typically, silver sintering processes are increasingly used for DCB substrates to connect semiconductors in order to achieve similarly long lifetimes. However, very good lifetime properties can also be achieved with standard soldering processes using the aluminium circuit substrate with copper metallization.

Using copper metallization, various types of power semiconductors can be soldered over the entire surface. Due to the high thermal conductivity of aluminium, a power density within the semiconductor material of up to 7 W/mm2 for 0.5 seconds without damage to components and within the SOA (Safe Operating Area) can be achieved for a short time with existing electrical insulation of the line electronics. In the application of a semiconductor-based battery switch for 48 V systems, this offers decisive advantages.

Battery Switch 48 V for high switching currents

Due to increased E/E requirements and increased integration of additional safety relevant features in the electrical supply architecture of a vehicle, a semiconductor-based solution can offer significant advantages over a mechanical relay, especially since a higher switching speed is possible. In the event of a short circuit, every second counts to ensure that the battery is disconnected safely. The main switch protects the supply circuit of a 48 V battery bidirectionally during charging and discharging in the event of overcharging or a short circuit. It is exactly for these two faults that a "thermal runaway" of the battery must be prevented under all circumstances.

In the bidirectional switch presented here, a total of eight low-ohmic 100 V power MOSFETs are integrated, which form a total resistance of the switch of typically 0.65 mW at 25 °C, see Figure 1. In the bidirectional version of the switch, the source contact of two serially connected MOSFETs is short-circuited and the current flow between the two drain contacts of the MOSFETs can thus be controlled in both directions. These are in fact each made up of four discrete MOSFETs connected in parallel to increase power performance. Together with an excellent thermal resistance of the switch of only about 0.1 K/W, with one-sided cooling at 80°C coolant temperature, and with rear insulation with a TIM foil, this results in a power dissipation of 98 W, and a temperature increase of the module by only 11 K at a continuous current load of 300 A.



Separation of a 48 V Li-ion battery using a semiconductor-based switch. Two MOSFETs Q1 and Q2 are short-circuited at the source (S) contact and the current flow between battery and load can be controlled between the drain contacts D1 and D2. Due to the inductances in the battery and load circuit, the drain-source voltage can rise sharply during a short circuit. A voltage limitation is achieved by active clamping.

In the transient case, currents of up to 1300 A can be supported for half a second per switch. The module measures 101.6 mm x 60.3 mm x 7.3 mm, but can also be made more compact depending on the current pulse requirements. For direct contact via screw connection or via direct welding with busbars in the circuit, 20 mm x 20 mm aluminium connection surfaces are provided on each drain side. To ensure higher mechanical stability, good moisture protection and improved durability, the entire module is overmoulded with an epoxy resin.

Optionally, double-sided cooling and increased integration of electrical functions such as temperature and current sensors and gate drivers can be implemented. In addition, the integration of protective circuits in the case of a short circuit or a specific assembly for different performance classes is possible in order to provide customer specific, cost efficient solutions.

Battery Switch 48 V for the functional safety of the supply circuit

For future autonomous vehicles, redundant supply circuits will have to provide electrical power in an emergency. Main circuit breakers are located between the emergency supply circuit, the main supply circuit and possibly other on-board networks - for infotainment for example. These control the electrical power distribution and, if necessary, completely disconnect faulty vehicle electrical systems.

A second possibility is to adapt on-board voltages via DC-DC converters in the supply circuit according to the requirements of the consumer. Various approaches for the electrical supply architecture must meet the functional safety requirements of ISO 26262. The switching behaviour of semiconductors is influenced by existing inductances in the overall circuit, see Figure 3, which is mainly caused by interconnection elements and long cables. The solution presented offers advantages due to the aluminium technology used, since unnecessary high current connecting elements can be dispensed with, and the module also has a very low parasitic stray inductance of less than 10 nH. Especially in the case of a short circuit, very high voltages can occur due to inductances, and these can even be above the breakdown voltage of the semiconductors. When currents flow, they induce an amplification of electron avalanches, the so-called avalanche effect, which can damage the active structure of semiconductors. The device is originally in a blocked state, but due to the exceeding of a critical electric field in the p-n structure of the semiconductor, free electron-hole pairs can be formed. This effect is well known and semiconductor manufacturers specify here maximum values for possible avalanche energies for their components. In the special case of the present application of a safe electrical supply in the vehicle, however, it is advisable to avoid this effect by taking appropriate protective measures with additional active components. A number of countermeasures are conceivable, the use of which depends on the specific application. In general, a wiring with TVS diodes is possible in the first step. It limits the drain-source voltage and absorbs electrical energy from the semiconductors in case of a short circuit. The remaining electrical energy must be thermally dissipated within a few hundred microseconds in the semiconductor. Particularly during temporary load peaks, this property can be ensured by using the efficient thermal heat spreader with aluminium, and the lifetime of the semiconductors, and thus the entire module, can be increased.

Conclusion

Increasing electrification requires smart solutions in the field of on-board power supply architecture. The electrical energy requirements of consumers can optimally and quickly be provided by semiconductor-based switches depending on the situation. The Battery Switch for 48 V Li-ion batteries presented here is a very cost efficient solution for high current levels. In addition, the robust power module is designed in such a way that customer specific adaptations can easily be implemented in many respects. The Battery Switch 48 V is small, approx. 28 cm3, and light, < 60 grams, and can easily be installed in a battery housing due to its very flat design and the existing aluminium high current busbars.

About AB Elektronik

For more than 40 years, the competence centres of AB Elektronik in Germany and Austria have been partners of leading automobile manufacturers, and since 2017, part of the AVX Group with headquarters in the USA.

Under the core brand AB Elektronik, the companies form AVX's Sensing and Control business and, with their development, production and sales capacities in Eastern Europe, Asia, Mexico and the USA, are regarded as specialists for future-oriented electronic solutions in customer-specific automotive applications. The optimization of the driving experience is as important as the broad technology base for the development of comfort, safety and emission reduction applications.

The product portfolio includes pressure, position, speed and temperature sensors, engine controls, power modules, LED technologies and pedals. A global network of development centres and manufacturing facilities supports leading automotive manufacturers and system suppliers for passenger cars, commercial vehicles, hybrid and electric vehicles as well as off-highway machinery, agricultural vehicles and motorcycle manufacturers.

Further information: www.abelektronik.com

Press contact:

Sandra Groß

Head of Marketing Communications

Sensing and Control

T: +49 2389 788-175 M: sandra.gross@abelektronik.de

Office: AB Elektronik GmbH | Feldmark 50 | 59368 Werne