More Power at the Same Size

The new 1200V CAL diode provides 30% more power yet is still the same size as the previous chip generation, leaving more space in the power module. What's more, the new fourth generation of CAL freewheeling diodes is suitable for high application temperatures up to 175°C. These benefits mean that IGBT modules now take up less space and can be used with higher temperatures, making them suited for use in harsh ambient environments such as the engine compartment of hybrid electric vehicles.

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Power density is today's magic word in the world of high tech yet affordable electric drives, especially when it comes to the two workhorses in power electronics - the IGBT and its accompanying freewheeling diode. Together, these two components constitute the core of high tech power electronic solutions. Regardless of the application – motor control systems or power conversion units in solar power systems or wind power installations – trends continue to go in the direction of increased power density on the same-sized chips. In fact, high power density means smaller footprint, greater freedom in design and, even more importantly, lower cost. In terms of the power semiconductor itself, this trend means that the usable current per chip area can be increased due to higher current density.

However, regarding the technology used and the physics that apply, limits are often reached. The inevitable diode and IGBT power losses cause the components to heat up, resulting in high temperatures in the power electronics system. Such high temperatures during operation are, however, particularly unfavourable as they shorten the service life of power devices. As a result, costly cooling solutions are often used to contain the temperature in the power electronic components. Thus, financial gains made owing to the increase in current per chip area may be virtually cancelled out by the costs for additional cooling, meaning that for total systems there is no real cost advantage. As a manufacturer of freewheeling diodes, Semikron has concentrated its efforts on finding a solution to this problem for diodes.

Towards higher operating temperature

In the end, the maximum permissible operating temperature of the semiconductor limits the usable current. Just enough current is applied to the diode as required to cause the maximum permissible operating temperature to be reached. Any further increase in current density causes the temperature of the diode to increase – unfortunately to the detriment of the diode's service life.

How can this problem be solved? First of all, diode heating due to power losses could be reduced. On the one hand, losses occur when the diode is in conducting state (static losses). On the other hand, losses occur when the diode is commuted from conducting to blocking-state (dynamic losses). One possible way of increasing the current per chip area while keeping the temperature constant is to reduce the static and dynamic diode losses. But this is not an easy task. The first problem is that static and dynamic losses cannot be optimised independently. A reduction in static losses leads to an increase in dynamic losses, and vice versa. In the end, the losses would essentially be unchanged, which does not result in any real advantage as regards to chip temperature. Other further constraints to the current density are due to important diode requirements: the freewheeling diode must not generate overvoltage during AC operation, should display high robustness at high currents, and must not generate high-frequency interference noise (EMI). A good freewheeling diode boasts a well-balanced combination of all requirements, which leads to a situation where the increase in current density by reduction of power losses is associated with considerable development time/effort and cost.

Another possible solution to this problem would be to accept higher operating temperatures. Usually, freewheeling diodes have a continuous duty temperature of 125°C and a maximum temperature of 150°C. If the temperature was increased by 25°C to 150°C for continuous duty - or to a maximum temperature of 175°C - the current density of the freewheeling diode went up by 20 to 30%. This approach can, however, be detrimental to the long-term stability of the power semiconductors, especially in view of the

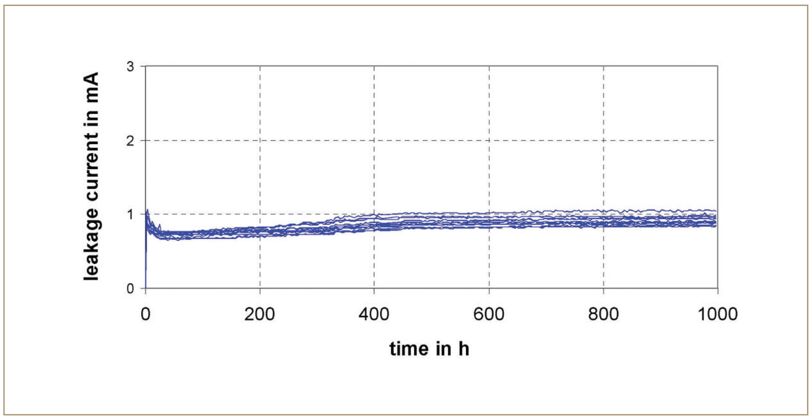

Figure 1: High temperature reverse bias test (HTRB) to show the stability of the freewheeling diodes at 175°C

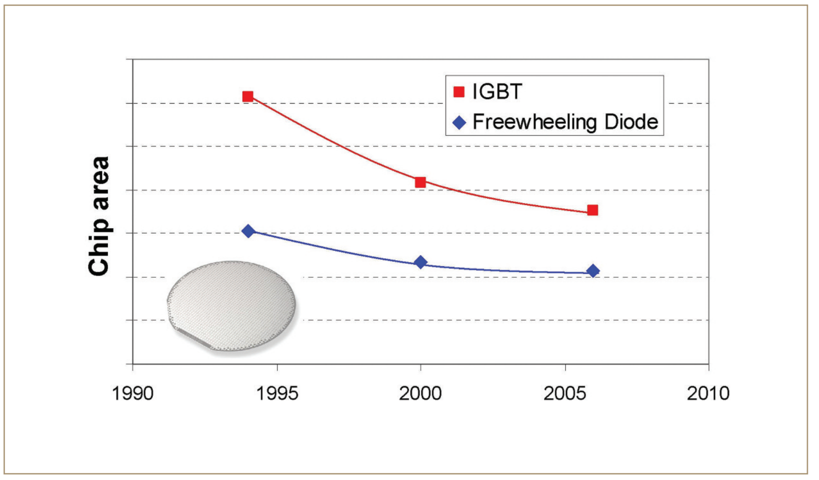

Figure 2: Development of chip size for IGBT and freewheeling diodes in the last decade. Improvements in the device technology lead to a significant decrease of chip area. This trend however, seems to slow down, due to the fact that it is more and more difficult to mange the heat generated in the power semiconductor devices

expected average service life of 8 years. But this approach has one major advantage: no compromises have to be made in terms of diode properties - increased current density and a well-balanced combination of diode properties.

High operating temperatures are particularly harmful to the diode passivation layer. The function of the passivation layer is to provide electric isolation of typically 600, 1200 and 1700V. In the previous CAL diode generations, this task was performed using a passivation layer made of composite glass. This glass passivation layer has proven reliable over the years; one shortcoming of this material, however, was that the maximum diode temperature was limited to 150°C. Higher temperatures alter the properties of the glass and adversely affect its insulating properties. This leads to leakage currents that may further increase the diode temperature, thus accelerating the glass degradation process. For this reason, Semikron has re-thought its passivation concept and has come up with a new passivation scheme for the CAL4 diode: a combination of an oxide layer and field ring concept. An additional polymer passivation layer protects the entire structure.

The new passivation concept has proven to be highly thermostable and reliable. To verify thermostability, accelerated reliability tests are performed usually. These tests involve exposing the diode to high temperatures and a constant blocking voltage for a period of 1000 hours. A change of the glass passivation often causes a continual increase of the leakage current. A reliable diode is deemed to show no significant increase of leakage current during the test. At 175°C the CAL4 diode displayed the ideal properties, thus verifying the excellent high-temperature properties of the new passivation concept: the diode blocking state currents were low and showed no signs of increasing despite the long test period. Figure 1 shows the leakage current of CAL-freewheeling diodes as a function of test time. Throughout the whole test period of 1000hr the leakage currents are low and stable, proving the thermostability of the diode even at such high temperatures.

High temperatures and low cost

Thus, all prerequisites are in place to raise the temperature by 25 to 150°C in continuous operation and to 175°C at maximum. The known reliability of the CAL diodes is preserved, as is the balance between electrical losses, robustness and noise immunity.

Exactly what effect does the higher operating temperature have on the increase in power of the diode? Simulations of typical operating conditions show that, depending on the application, the increase to 175°C results in 20 to 30% higher load currents for the same size diode. Or in other words, with the same load current, the size of the diode can be reduced by 20 to 30%. For the user, this means more space and thus, more leeway in the design of power modules. Along with the also improved new IGBT generations, the volume of power modules can consequently be further reduced. This trend becomes impressively apparent when we look at the development of chip sizes for IGBT and freewheeling diodes over the past few years (see Figure 2).

It was possible to significantly reduce the chip size of the IGBT in the last decade. With the new CAL4, this trend is also continuing with freewheeling diodes. However, it seems that both for diodes and IGBTs, it is becoming more and more difficult to further increase the current density for the next chip generation.

The new CAL 4 has the cost advantage of high current density, without further costs being entailed, for instance through cooling solutions. Cost and volume of the power electronics system are drastically reduced. This is an advantage, particularly for applications where space is limited: the power electronics no longer has to 'emigrate' because of lack of space, but can now often be installed in places that are technologically more practical. Coupled with higher reliable operating temperature, this gives them a strong competitive edge - power semiconductors can now also be installed in places where they could not be used previously due to ambient temperatures that were too high. It is the engine compartment of hybrid vehicles, where average ambient temperatures of 105°C require costly solutions by either using complex cooling solutions or going back to larger chip areas. The increased operating temperature of 150°C has eliminated this disadvantage - more power and easier to construct plus lower cost.

What will the next generation of freewheeling diodes look like? Is a further increase in the current density still possible with silicon, or will the silicon now be replaced by diodes made of silicone carbide (SiC)? It seems that silicon freewheeling diodes will still be in the race. On the one hand, newly promising designs pave the way of reducing the overall losses. On the other hand, the new passivation scheme also seems to be suitable for temperatures above 175°C. A maximum temperature of the diode in the range of around 200°C could be possible, providing another significant step towards higher current densities. Technology will continue to move along the path towards providing even more power at less space.