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GaAs Schottky Diodes Allow Higher Power Density

GaAs and SiC devices will find more and more use

The IGBT3 technology which combines the trench cell and the field stop concept is successfully GaAs power devices were mainly used up to 300V, while 600V applications like PFC were regarded to be perfectly served by SiC devices. A new generation of 600V GaAs power Schottky devices turns out to be a cost effective and rugged alternative.

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When high power density and high frequency applications like Switch Mode Power Supplies (SMPS) or Power Factor Correction (PFC) are discussed, Silicon bipolar diodes are known to limit the efficiency of these systems due to their reverse recovery behaviour and the resulting switching losses. Therefore, higher bandgap materials like Silicon Carbide (SiC) or Gallium Arsenide (GaAs) are preferable. So far, GaAs power devices were mainly used up to 300V, e.g. in 36V or 48V SMPS systems, while 600V applications like PFC were regarded to be perfectly served by SiC devices. But now a new generation of 600V GaAs power Schottky devices turns out to be a cost effective and rugged alternative.

Increase of power density is one of the main tasks for power electronics today: system sizes shall be minimized while in general the power output of the user applications increases. There are two ways to meet this challenge: 1. reduction of losses by more efficient power electronic devices; 2. reduction of active and passive components' number, weight and size, generally by increasing switching frequencies.

An important example is the optimisation of Power Factor Correction systems (PFC). Boost converters with PFC can typically be operating in Continuous Current Mode (CCM) or Discontinuous Current Mode (DCM). In DCM, however, most of the circuit components have to be oversized due to high current peaks, which in turn mandates complex EMI filtering. Moreover, the system tends to be unstable at light load [4].

CCM operation does not have these drawbacks, so the system can be realised with fewer and smaller components. Though, because of the hard switching, it requires boost diodes with extremely low switching losses. Even more important than the losses in the diode itself are the additional losses induced in the MOSFET that has to conduct the diode's reverse recovery current. Without diode reverse recovery, the MOSFET size can be reduced and costs can be saved.

Unfortunately, Silicon (Si) bipolar diodes always show significant switching losses due to their reverse recovery behaviour, especially at elevated temperatures as occurs in operation. Unipolar ("pure Schottky") diodes on Si can only be made for voltages up to about 100V. To overcome this silicon limit, high band gap semiconductors have come into focus during the last few years. Gallium Arsenide (GaAs) and Silicon Carbide (SiC) Schottky diodes have been made with breakdown voltages up to 600V and even several thousands of Volts respectively without (or more precisely with extremely small) reverse recovery. These devices are available for several years now, and their advantages have been shown in numerous applications and papers [1-5].

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Considering the general physical parameters of Si, SiC and GaAs, SiC seems to be the material of choice for high frequency power devices. It can withstand the highest electric field leading to diodes with very high breakdown voltages and low forward voltage drop. Moreover, it has the lowest thermal resistance allowing a higher on-state current density.

Nevertheless GaAs has some advantages, which have to be taken into account:

The non repetitive peak current in SiC is limited due to the significant positive temperature coefficient of the forward voltage drop [5]. Therefore the device size has to be chosen large enough to avoid over-current destruction. The 2nd gen. GaAs devices from IXYS offer more than two times higher surge currents for the same average current rating.

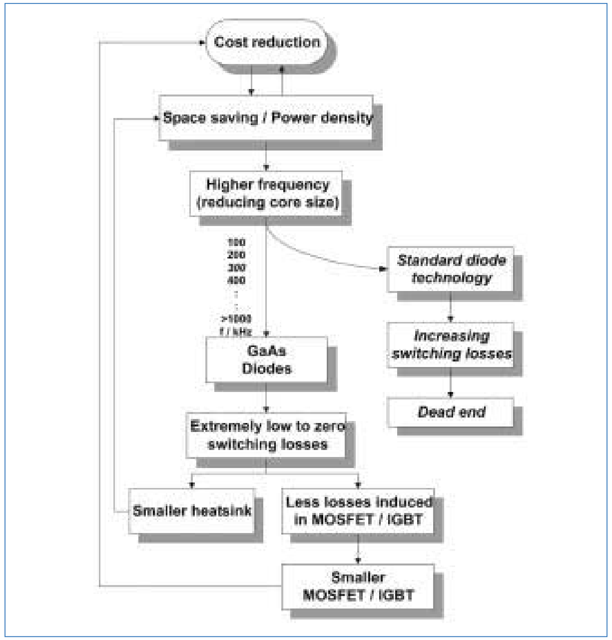
The junction capacitance of GaAs devices is much smaller compared to SiC (more than 5 times), even though SiC diodes can operate at higher current densities.

Avalanche capability is higher in GaAs. In SiC bipolar current flow can lead to defect growth and finally to the destruction of the device.

SiC technology still suffers from material problems, so costs are significantly higher than for GaAs, which offers larger wafer size, higher yield, no need for high temperature processing and higher growth rates.

So far, GaAs power Schottky devices only had been available with breakdown voltages up to 300V. For 600V applications, especially in the PFC market, SiC had been the only technology beyond the Silicon limits.

IXYS has now used its 2nd Generation GaAs technology to introduce a 600V alternative [1, 2]. These devices, so called “Injection Mode Schottky Diodes”, use the phenomenon of minority carrier injection. When the Schottky barrier is chosen to be higher than half the semiconductor’s band gap, the region close to the metal becomes p-type because electrons from the semiconductor enter the metal until the Fermi level is flat. Under forward bias, the holes from this p-type layer are injected into the neutral n- region and so carry a part of the current. Furthermore at high current densities, additional electrons are entering the n- region to maintain charge neutrality. This leads to a conductivity modulation of the n- layer [8].



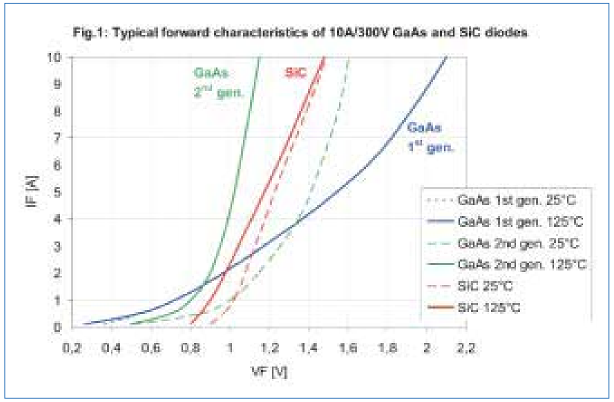


Figure 1. Typical forward characteristics of Gen.1 and Gen.2 GaAs and SiC Schottky diodes, 300V/10A types.

As a consequence the diodes show decreasing differential resistance with increasing current flow and temperature (Figure 2), leading to lower VF, higher surge current capability and higher current rating. Due to the very short minority carrier lifetime in GaAs, the resulting reverse recovery still is extremely low compared to Silicon devices.

Gen.1 GaAs (pure Schottky diode) shows almost no temperature dependency but has the highest VF at high currents. Gen.2 GaAs (injection mode Schottky diode) shows decreasing differential resistivity with increasing current and temperature due to minority carrier injection and resulting conductivity modulation. They even outperform typical SiC devices.

In the new DGSS10-06CC, two of these 2nd Generation 300V Schottky diodes are series connected in a backside isolated ISOPLUS220 package. By this, the resulting capacitance is reduced not only by the series connection of the two junction capacitances, but also the ISOPLUS package offers a much lower parasitic capacitance than a comparable standard TO220 package (15pF compared to 124pF [3]).

To give an application example, different diodes (600V, 10A) were tested in a typical 200W PFC circuit. This boost converter was running in continuous current mode (CCM). Input voltage varied from 90V to 260V, switching frequency from 110kHz to 250kHz. Measurements were done at 20°C and 70°C environment temperature. The PFC transistor was an 11N60S5 MOSFET by Infineon. The temperatures of the diode and transistor were measured to characterise the losses. The schematic of such a PFC board is shown in Fig 2.

Figure 3 shows a typical measurement result of system efficiency vs. input voltage. It can be seen, that the usage of GaAs and SiC Schottky diodes leads to significantly higher efficiencies compared to the ultrafast Si diodes as expected from their superior properties.

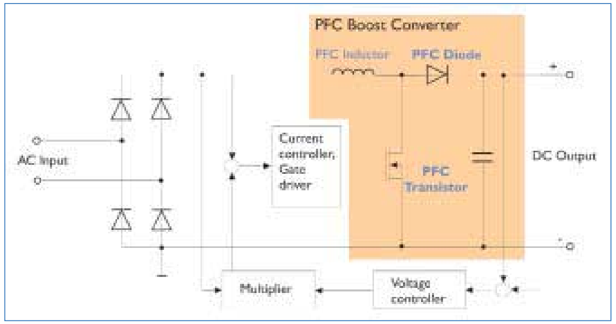


Figure 2. Simplified Power Factor Correction Circuit.

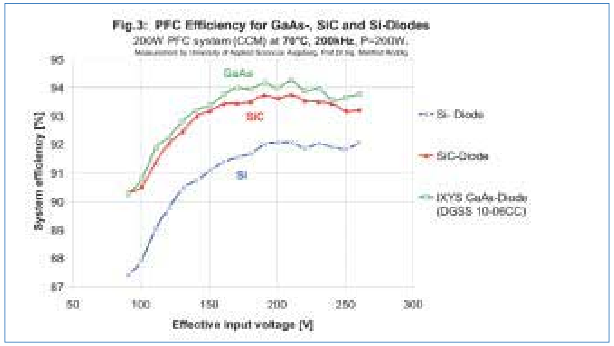


Figure 3. Typical measurement results of PFC efficiency for different diode types at 200kHz at 70°C.

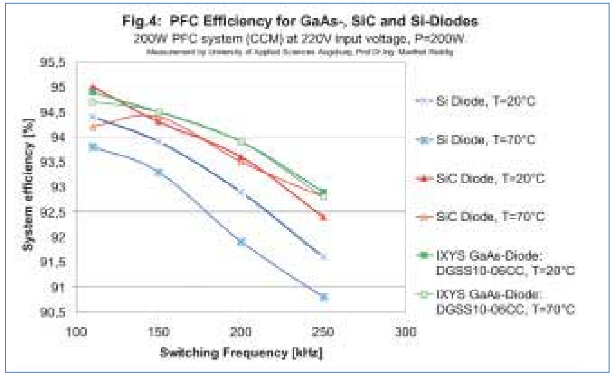


Figure 4. PFC efficiency for different diode types and temperatures vs. switching frequency at 220V input voltage.

Figure 4 summarizes the results for an input voltage of 220V for all tested frequencies. Obviously, the system losses with the GaAs device are almost temperature independent, while the Si diode leads to increased losses at higher temperature, especially at higher frequencies.

In Figure 5, the corresponding losses are shown relatively to the losses of the Si diode. At 110kHz the GaAs diode already leads to about 15% less total losses compared to Si. This increases with switching frequency up to 25%.

The SiC diode shows similar results, but in this experiment under no condition did they lead to higher efficiencies than the GaAs devices (see fig.4). This can be explained by analyzing the losses in the diode and transistor as indicated by their temperature. In operation, the GaAs diode itself gets warmer than the SiC diode due to the higher on-state losses. But the transistor gets warmer with the SiC diode due to its higher capacitance that has to be discharged when the MOSFET turns on. Consequently the losses in the diodes and transistors add up to the same amount and so lead to the same total efficiency.

Furthermore, with increasing temperature, the GaAs on-state diode losses decrease while the SiC diode losses increase. With increasing frequency, the losses due to capacitance discharge increase less for the GaAs diode than for the SiC. Therefore, the evaluated cases (low temperature, moderate frequency) are the worst cases for GaAs.

Of course, the whole PFC circuit would have to be optimised in a real application. A PFC board design has to find an optimal trade off between shrinking of passive components (by increasing frequency), increasing system efficiency, and the right choice of MOSFET and diode type and size to get the maximum value of the system within the requirements of the application. Nevertheless, the new GaAs device DGSS10-06CC is a viable alternative, which might be the best choice for many applications.

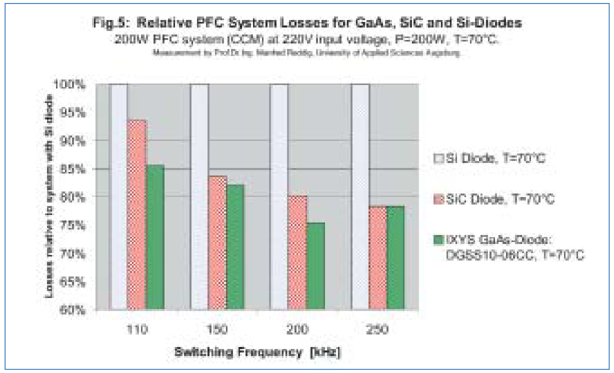


Figure 5. This graph compares the PFC system losses when using Si bipolar, GaAs and SiC diodes for different switching frequencies at 220V input voltage at 70°C. It can be seen that losses can be reduces by 15-25% when GaAs or SiC diodes are used.

We think that in future power applications both, GaAs and SiC devices will find more and more use. The increase of power density—and therefore system value—easily pays for the higher costs for the GaAs or SiC devices compared to Si diodes.

It depends on the specific design of the application which technology is optimal. Generally up to 600V, GaAs is preferable, while for voltages much higher than 600V, SiC will be the semiconductor material of choice. In a transition region at about 600V, the circuit conditions have to be analysed carefully. In the example of a PFC system that has been shown here, the GaAs devices turned out to result in at least as good system efficiencies as the SiC diodes, and GaAs will be the more cost effective solution.

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