Silicon Carbide MPS Diodes Boost Efficiency and Reliability

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Navitas' Merged PiN Schottky (MPS™) diodes combine low forward voltage with high surge-current capability and low reverse leakage. With the superior breakdown voltage and reverse recovery performance of silicon carbide, the latest SiC MPS diodes deliver greater reliability with high efficiency across all load conditions.

The Best of Both

The wide-bandgap revolution in power conversion is well under way as energy-conscious applications must adapt to reach efficiency and power density targets that ordinary silicon devices cannot achieve. Silicon carbide (SiC) is the most commercially mature of the technologies available today, as vendors have now released several generations of diodes and power MOSFETs, each offering successively improved performance. Valued at close to $3 billion in 2023, the SiC market is growing as quickly as 40% and is expected to accelerate as more and more applications make the change.

SiC devices outperform silicon counterparts in both conduction and switching characteristics. Among them, SiC Schottky barrier diodes (SBD) combine a lower forward voltage (V_F), with superior reverse recovery compared to silicon fast-recovery diodes (FRDs), greatly reducing overall energy losses. Moreover, the reverse-recovery time (t_{rr}) is stable over the full operating temperature range whereas silicon FRDs display increasing recovery time at higher temperatures.

On the other hand, any Schottky diode is inherently vulnerable to current surges, which are a known hazard in applications like power-factor correction (PFC) in power supplies for converters and inverter systems. Ordinary PiN diodes can offer greater reliability in such situations, although this comes at the expense of reduced efficiency due to their higher V_F compared to the Schottky devices. Of course, lower energy efficiency is undesirable and, in equipment such as server power supplies, translates into higher electricity costs, increased cooling management, and a slower return on investment.

The merged PiN-Schottky (MPS) diode presents a solution. These devices bring together the best features of Schottky and PiN diodes as a single device by combining the surge-current robustness and low reverse leakage of the PiN diode with low V_F owing to the Schottky structure. With the superior breakdown voltage, reverse-recovery characteristic, stability over temperature, and high-temperature operating capability associated with SiC devices, MPS diodes introduced in a PFC or boost circuit enhance reliability and significantly increase the overall efficiency of the power-conversion system.

MPS Design and Optimisation

Compared with a conventional Schottky structure, the MPS diode contains additional P-doped wells implanted in the drift zone. These form a P-Ohmic contact with the metal at the Schottky anode while also forming a P-N junction with the SiC drift layer, effectively combining a Schottky diode and a PiN diode connected in parallel (figure 1). In normal operation, the Schottky carries almost the entire current. On the other hand, during high-current surges, the voltage across the MPS device rises causing the PiN diode at the drift layer to conduct. This intrinsic diode has lower resistance than the Schottky and so diverts current thereby reducing dissipation and relieving thermal stress on the device.

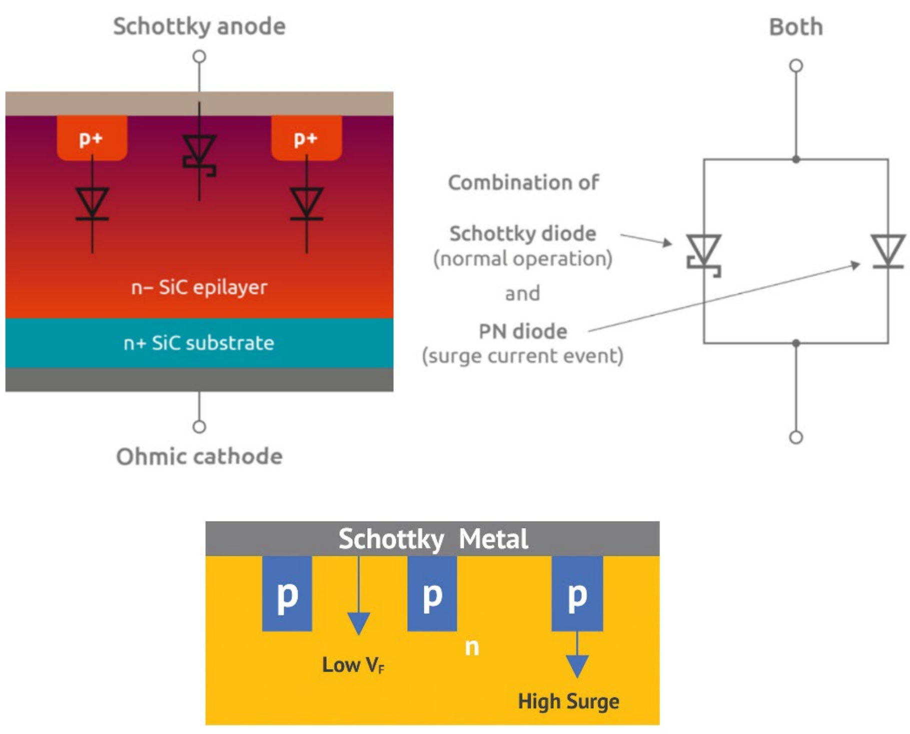

Figure 1: MPS combines PiN and Schottky diode attributes.

Under reverse bias, the maximum field strength occurs in the drift region of the MPS diode. This contrasts with the situation in a standard Schottky architecture, where the greatest field strength occurs at the metal barrier. Imperfections in this barrier allow relatively large leakage current to flow. By moving the region of maximum field strength away from the metal barrier, the MPS diode benefits from lower leakage current than a standard SiC Schottky diode.

By optimising the dimensions and doping of the P-type wells, device designers can engineer the MPS forward voltage drop, surge-current capability, and leakage current to meet specific requirements. In addition, thinning the substrate below the drift region reduces both the MPS forward voltage and the thermal resistance between the Schottky area and back-side metallisation, permitting reduced energy losses, enhanced thermal efficiency, and greater reliability.

Design for Optimal Performance

Navitas has created their Gen-5 650V SiC MPS™ diodes that feature high surge-current capability and low V_F to minimise losses in the forward-biased mode. The devices also have extremely low reverse-leakage current, and high avalanche robustness. This combination of attributes is achieved through optimising the device architecture and engineering the barrier metallurgy for ultra-low Schottky barrier height (SBH) of 0.88 eV (at 25°C).

In typical Schottky and MPS diodes, the barrier metal is titanium, and the devices exhibit a trade-off between SBH and reverse leakage current. With their novel, proprietary barrier metal, Navitas' MPS SiC diodes have SBH more than 26% lower than alternative titanium-barrier devices while the leakage current, at 100 nA, is at least six times lower. Moreover, enhanced shielding of the Schottky metal interface minimises any increase in reverse leakage current at higher voltages.

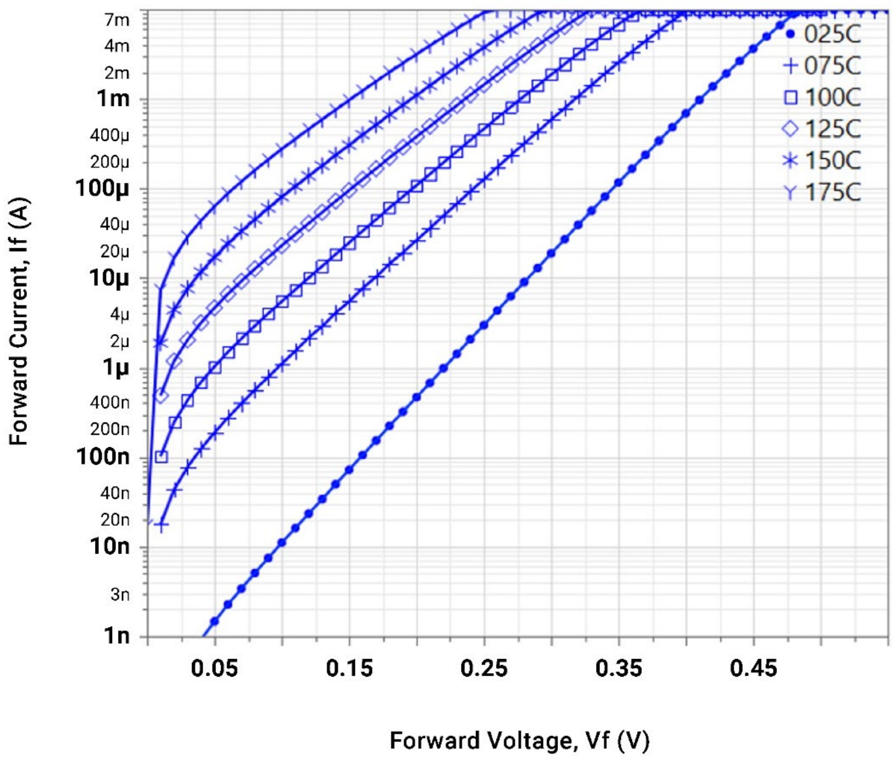

Figure 2: Low current forward I-V characteristics for 10 A SiC MPS diode.

Figure 2 shows the low-current forward I-V characteristics of these diodes at temperatures from 25°C to 175°C. The results display consistent linearity across the temperature range, indicating a stable SBH that confirms good spatial homogeneity of the Schottky metal interface.

The SBH displays a small increase with temperature. This tendency is common among MPS diodes from various vendors. 'Ideality' quantifies how closely the diode's behaviour conforms to the ideal diode equation under different conditions and typically decreases with temperature. Well-behaved diodes have ideality close to 1 under normal conditions and may deviate due to unwanted effects such as recombination currents and parasitic series resistances. Real-world diodes can depart from ideal behaviour and often display ideality greater than 1.

As far as the high-current I-V characteristics are concerned, figure 3 shows the trend at various temperatures. The cross-over from unipolar (SiC Schottky) to bipolar (PiN) operating mode can be seen at about 90 A at 25°C. This decreases to 50 A at 150°C. The diagram also shows a lowering of the knee-voltage at higher temperatures, which helps maintain a low temperature co-efficient of the on-state voltage drop at the rated current of 10 A.

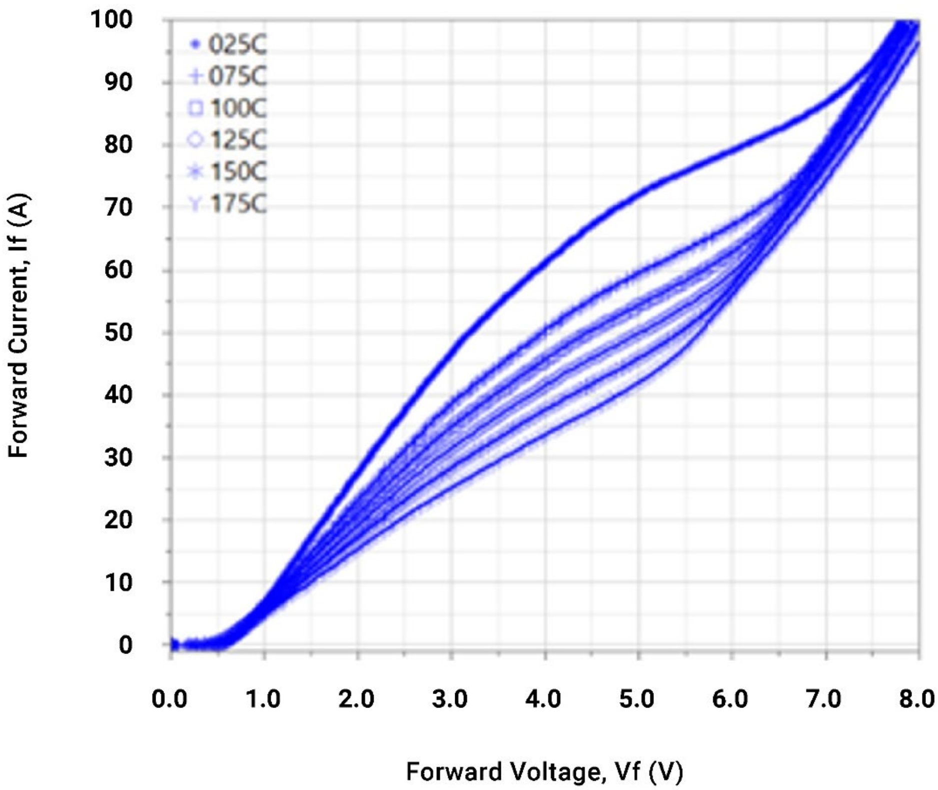

Figure 3: High-current forward-IV characteristics from 25°C to 175°C.

Figure 4 compares the measured C-V curves with diodes from various vendors, showing that the Navitas MPS has one of the lowest values of capacitance charge, Q_C, which ensures low reverse-recovery losses. The product of the capacitance charge and forward voltage (Q_C x V_F) gives the figure of merit for MPS diodes. While improving one of these parameters typically impairs the other, a good FOM balances a low forward voltage drop for reduced power losses with low capacitance charge for superior switching performance. Ensuring the lowest possible value for each helps enhance overall diode performance in power electronics applications.

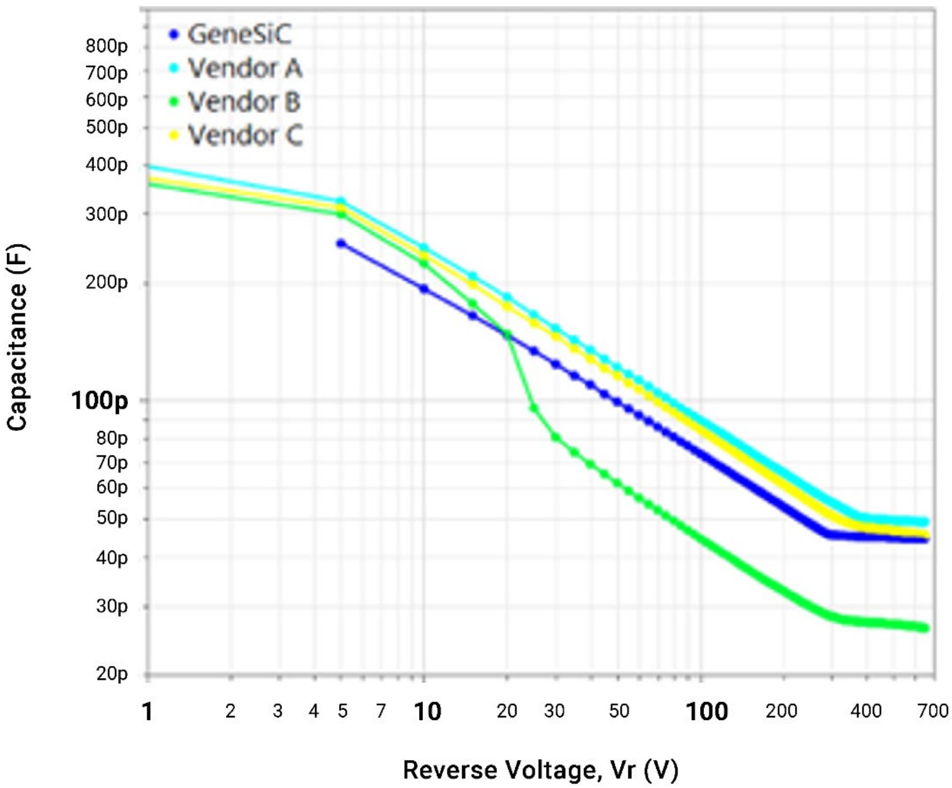

Figure 4: C-V curves for Navitas and competitor SiC MPS diodes.

The avalanche robustness of SiC MPS diodes is assessed by applying unclamped inductive switching (UIS/UIL) tests. Figure 5 shows the current waveform under UIS and current-surge conditions respectively, indicating a high value of non-repetitive surge current that confirms the diode's robustness.

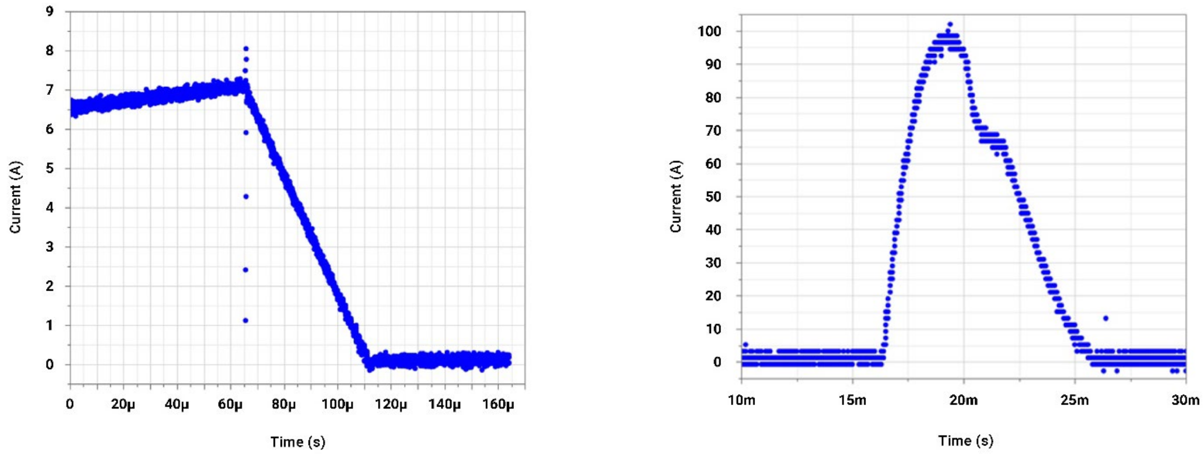

Figure 5: (a) Avalanche testing and (b) surge current characteristic

MPS Diode Applications

MPS diodes can offer superior performance in applications such as the boost circuit that raises the solar-panel output voltage to the 450-600 V required for the inverter. MPS diodes are also used in PFC circuits, which are mandatory in line-powered applications above 75 W according to IEC/EN 61000-3-2. These include power supplies for telecom equipment and data centre servers, including interleaved PFC circuits, as well as power supplies for lighting systems.

Consumer devices such as televisions can also benefit from MPS diodes. With the advent of 4K UHD, the latest models demand significantly more power than their predecessors and hence place emphasis on efficiency to achieve a suitable energy rating and maintain proper performance. The power supply is often positioned directly behind the display and can impair colour rendition if excessive heat accumulates due to poor efficiency.

Various package options are available and can offer several advantages in different applications. For high-voltage sensing circuits like desaturation detectors for overcurrent protection, as well as in the gate-drive bootstrap circuits of high-side switches (figure 6), the DO-214 and TO-252-2 packages are ideal solutions.

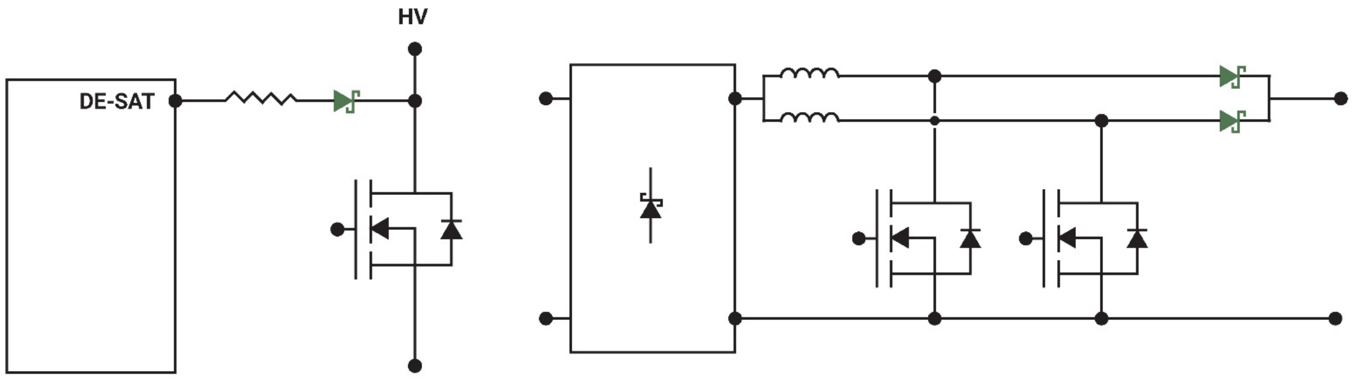

Figure 6: MPS diodes in desaturation detection circuit and interleaved PFC circuit

On the other hand, the TO-247-3 package provides extra flexibility where high power density is required and can help reduce the bill of materials in applications like interleaved PFC circuits that share a common cathode between two diodes.

Conclusion

SiC MPS diodes can directly replace Schottky diodes in circuits that need to combine high energy efficiency with robustness and reliability when exposed to surge currents. These can occur when powering highly-capacitive or inductive loads, or if the power quality of the main AC line is poor. As a straightforward drop-in replacement, these devices are easy to design-in for a significant boost in power-conversion efficiency.