Silicon Carbide Diodes Make Solar Power Systems More Efficient

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Silicon carbide (SiC) diodes have already penetrated the quickly expanding solar inverter market, particularly in Europe. Cree's 1200-V SiC Schottky diodes are being used in place of their silicon (Si) PiN counterparts in the boost section of the DC link and will soon be seen in the inverter sections of commercially available systems.

Improvements in material quality, size and cost in the last few years have made SiC a truly viable replacement for silicon in power devices. With wafer size increasing (Cree is currently using 4-inch wafers), defect densities going down, and material costs dropping, larger power devices are now available with SiC. The technology has many unique properties that make it a near-ideal material for high-voltage or high-temperature operation. First, SiC's thermal conductivity is several times that of gallium arsenide and more than three times that of silicon. This enables the fabrication of higher-current density devices. Also, the breakdown field of SiC is almost ten times the breakdown field of silicon, so an equivalent design in SiC will have ten times the breakdown voltage rating of the silicon part. Because of this, it is possible to create very-high-voltage Schottky diodes. Finally, SiC is a wide-bandgap material and, because of this, has the ability to operate at much higher temperatures than any Si device. Figure 1 shows the difference in thermal conductivity, electric field breakdown and bandgap between SiC, GaAs and Si.

Cree uses SiC to manufacture high-voltage Schottky diodes. By virtue of the fact that Schottky diodes are unipolar devices, there is no minority carrier recombination, thus

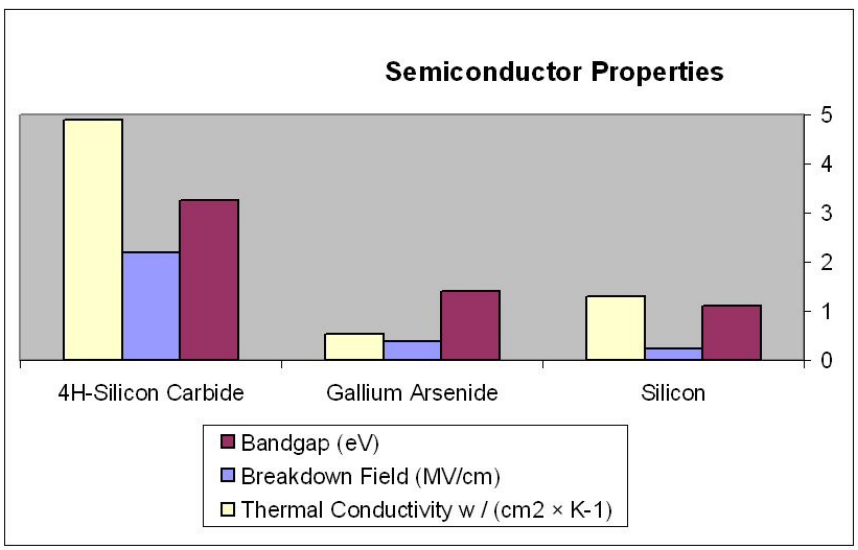

Figure 1. *Materials Comparison*

leading to zero reverse recovery currents (Figure 2). There is, however, a very small junction-capacitance charge. The magnitude of this charge is negligible in comparison to the equivalent reverse recovery charge in a Si PiN device, and it is also independent of temperature, forward current and switching di/dt. These Schottky diodes also have zero forward recovery voltage and turn on immediately. These switching characteristics have a sometimes-overlooked benefit of greatly energy demand is expected to increase by 19 percent over the next ten years, and in developing countries the demand will increase even faster. Europe has already embraced the benefits of solar power and some countries are providing incentives to both businesses and individuals to switch to solar energy. Because of the overall system efficiency improvement with SiC Schottky diodes, many manufacturers of solar equipment are turning to the technology. Solar panels collect the sun's energy and

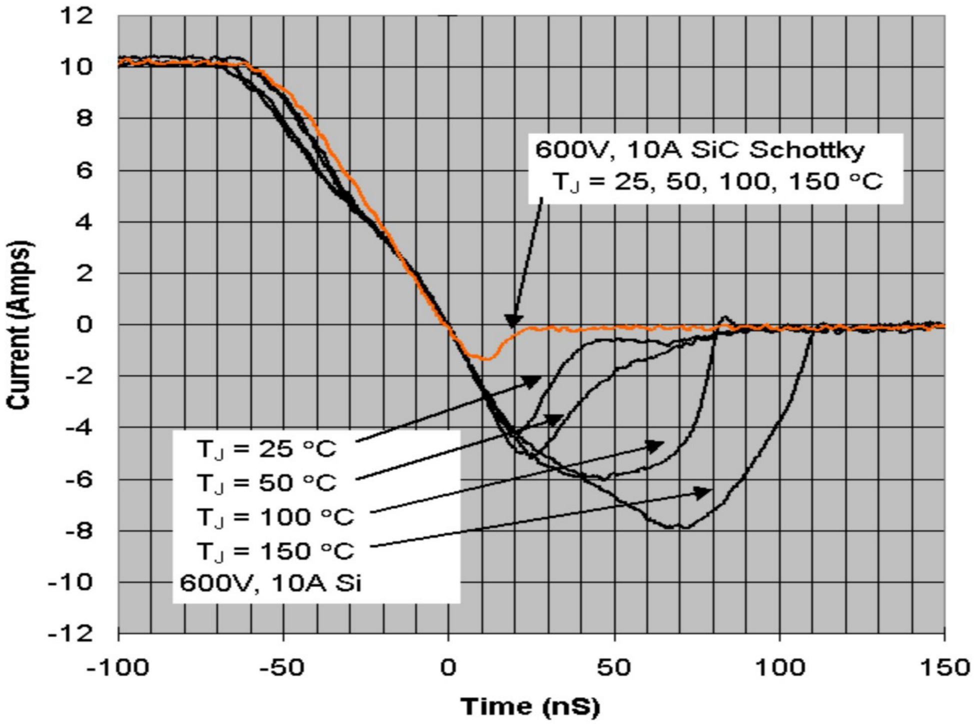

Figure 2. *Recovery of Schottky diode versus Silicon equivalent*

reducing EMI. These devices eliminate diode-switching losses in a power-conversion system, which in turn greatly reduces turn-ON losses in the associated switch that has to commutate the reverse recovery currents associated with Si PiN devices. Because of this increased efficiency and performance, SiC Schottky diodes are the ideal solution for solar-energy systems. The consensus estimate from available sources shows that electricity accounts for 39 percent of the world's energy use. In the United States, convert it to a positive DC voltage. This voltage varies with the intensity of the sun's rays to which the panels are exposed. That voltage is boosted to a fixed DC voltage by means of a boost converter switching at high frequency (Figure 3). Cree's SiC Schottky diodes eliminate the boost diode switching losses and greatly reduce the MOSFET or IGBT turn-on loss. This significantly improves the boost section efficiency. An inverter then converts the fixed DC voltage to a usable AC voltage of fixed frequency (typically 220 V, 50 Hz for Europe and 110 V, 60 Hz for North America). The SiC Schottky diodes eliminate diode-switching losses in the freewheeling diodes of this section along with reducing IGBT turn-ON losses. Inverter efficiency is significantly improved. Silicon-based inverters typically operate at close to 96-percent average efficiency. With a more efficient system, more of the energy delivered by the solar panels gets converted to usable electricity. With SiC devices, the inverter's average efficiency can be boosted up to 97.5%. This represents up to 25% reduction in inverter losses. Considering that these solar systems are designed to operate for at least 30 years, this represents a considerable improvement in energy savings, and by virtue of reduced temperatures, the system will have higher reliability.

Solar-power systems available today are generally divided into two categories, grid-tied and off-grid. The grid-tied system, as its name implies, is tied to the utility grid. Power for the end-user originates either from the solar panels of the system or the grid, depending on load demands, time-of-day, etc. These systems have a metering capability whereby power from the solar system can be delivered back to the grid during low-demand periods. Off-grid systems are standalone and contain batteries and sometimes a back-up generator as well. The solar panels charge up a bank of batteries through a charge controller, and the batteries provide input power to the inverter that in turn supplies power to the end-user. Typically a system today will cost about $10 per watt, so a 3-kW system should cost approximately $30,000. Obviously, a more-efficient system will mean a faster payback to the consumer. Again, global energy concerns are driving the adoption of alternative energy sources and silicon carbide provides an additional benefit.

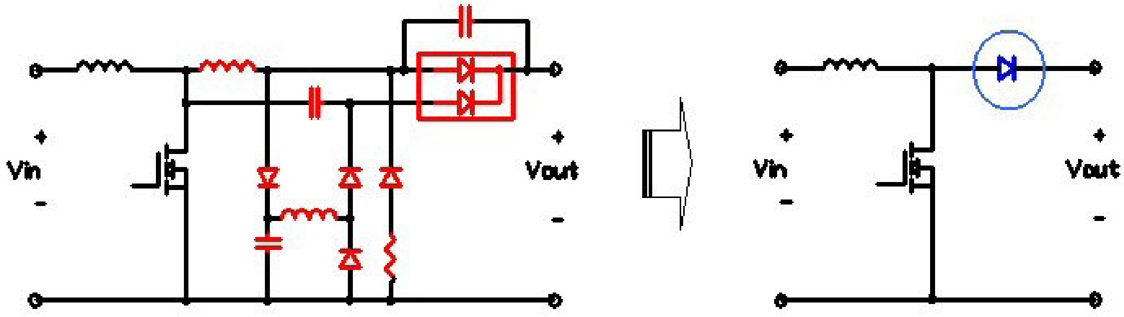

Figure 3. *Boost Converter simplicity with SiC diode*

The largest solar market in the world right now is in Germany, in part because its utilities offer the incentive of buying excess power back from customers at three times the rate at which it charges for delivering it. When a customer generates power from a solar system, if he's not using that power himself, the utility's metering system allows the customer to generate that power back on to the grid. The utility will pay the customer for the power he's given them. Because of this, in Germany, the payback period for a solar system is considerably shorter than in other countries. Although the largest market for solar power right now is in Europe, it is expanding worldwide. Many developing countries are turning to solar as a viable source for energy. With increased environmental regulations and rising energy costs, solar energy may see widespread adoption in the United States, sooner rather than later. California, Arizona and Nevada already offer incentives for converting to solar power, and these three states stand to gain significantly from such programs due to the amount of sunshine they enjoy. Cree has been providing high-voltage SiC Schottky diodes to this and other markets for about four years, and we are working to expand the line of offered devices to address future needs as well. Solar-panel makers are continually striving to design a more-efficient product, as they typically run at 15 to 20% efficiency. Given that statistic, it is the boost converter and the inverter that have the greatest impact presently on the system's overall energy efficiency, which is why SiC diodes play such an important role. Research into development of more-efficient materials for photovoltaic panels is ongoing. With more-efficient panels, much higher power ratings will be delivered for a much smaller area of paneling. At that point, SiC diode manufacturers should see a shift in their customers' needs, from the 10-amp to 20-amp ratings of today to 50-amp, 100-amp and higher current-rated devices. In fact, Cree has a commercially available 1200-V 50-amp device today. With further advances in SiC material technology and the move to larger-diameter wafer, Cree is well positioned to be a leading provider of these future devices.