SemiSouth's transistors boost photovoltaic system efficiencies

Solar power is still too expensive to compete in free market economies. However, improvements in inverter efficiency, which could be driven by an uptake of SiC JFETs with lower conduction and switching losses than incumbent silicon IGBTs, could change that, says SemiSouth's **Jeff Casady**.

FIRST SOLAR

First Solar's CdTe panels have enjoyed substantial deployment in the German solar farms that receive generous financial subsidies. One of the company's goals is to reduce the cost of its CdTe panels so that they can compete in free markets within five years. This goal will be aided by improvements in solar-inverter efficiencies.

The credit crunch is unlikely to thwart growth of the solar-cell market. Although the financial crisis has led The Information Network to downgrade its growth forecast for this year's installed capacity of solar panels by 23%, this market analyst still expects global photovoltaic deployment to rise by 26% in 2009. And next year should be even better, with installations soaring by 48% to hit 10.5 GW.

Although this figure sounds large, it is only equivalent to the output of a handful of nuclear reactors. The reality is that the vast majority of today's electricity is generated through the burning of fossil fuels, and solar-power's success has predominantly come from subsidized markets, such as those in Germany, Spain and Japan. However, if photovoltaic energy is to move on and become a serious contender in global energy markets, then electrical generation costs must fall so that this technology can compete in free market economies.

There are many ways to cut the costs of solar systems. One obvious route is to decrease the cell's cost per watt, which can be done by improving device efficiencies, reducing material consumption and streamlining manufacturing processes. However, savings can also result from reductions in installation costs, which typically account for half of the total cost of the build, and improvements to the efficiency of the inverter that converts the DC output from the cells into the AC form that is needed by individual customers and national grids.

The leading manufacturers of solar inverters, such as SMA Solar Technology, Fronius and Xantrex, use silicon MOSFETs or insulated gate bipolar transistors (IGBTs) in their circuits, alongside silicon or SiC diodes. These inverters deliver typical conversion efficiencies of 94–97%, but a switch from silicon to SiC transistors could lead to even smaller losses. At SemiSouth in Starkville, MS, we are developing a SiC FET for this purpose, which has delivered excellent results in solar-inverter trials by the Fraunhofer Institute of Technology, Germany.

We selected SiC because it has the potential to produce efficient transistors that operate at high voltages and currents. These strengths stem from the excellent intrinsic properties of this wide-bandgap semiconductor, which has an electric field strength 10 times that of silicon and a thermal conductivity that is three times higher. Power devices built with SiC have switching losses that are 1000 times lower than silicon equivalents and feature an on-resistance per unit area that is 100 times smaller than the incumbent technology.

Many of today's inverters are designed to operate at input voltages of more than 600 V and are based on the silicon IGBT. One of the major weaknesses of this bipolar device is its slow switching speed, which is limited by the time that it takes for the stored minority charge to be swept out of the drift region. Improving the IGBT's switching speed is a significant challenge, which explains why inverters typically operate at just 16–20 kHz – a frequency that minimizes switching losses, but requires deployment of expensive and bulky inductors and

FRAUNHOFER ISE

The Fraunhofer Institute for Solar Energy has demonstrated that the efficiency of advanced solar inverters can be improved by replacing Infineon's silicon IGBT with SemiSouth's JFET.

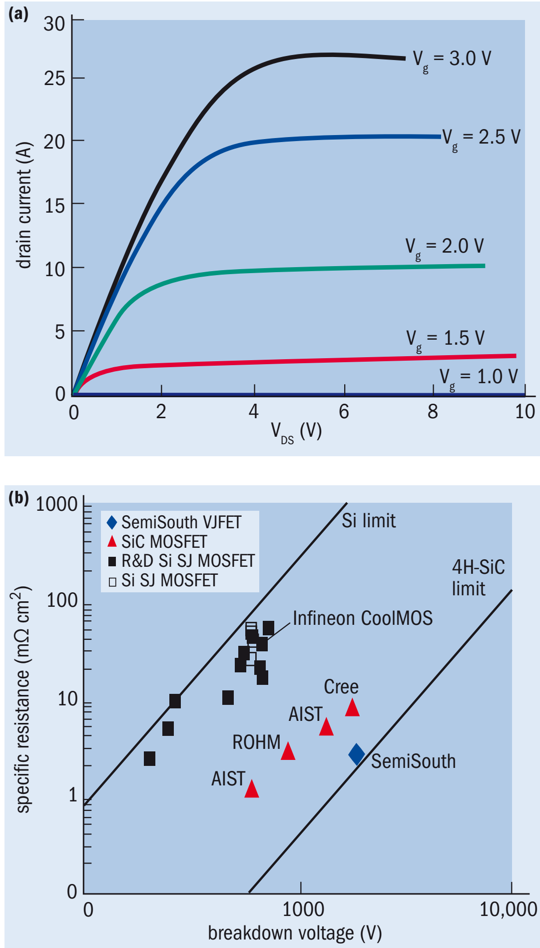

Fig. 1. SemiSouth's normally off SiC JFET, which was released in June 2008, has a threshold voltage of 1.0 V and can block 1200 V with no gate voltage **(a)**. It has a saturation current of more than 25 A. The set of DC curves were taken at room temperature, with the gate voltage (V_g) decreased from a 3.0 V maximum in 0.5 V increments. SemiSouth's JFET operates at very close to the limit for 4H-SiC **(b)**.

capacitors. SiC transistors deliver far higher switching speeds and they should allow the use of smaller, lower-cost passive components.

IGBTs also suffer from power losses during conduction, which impact inverter efficiency. Moving to larger devices can increase the conduction efficiency, but this comes at the expense of a lower switching efficiency. SiC JFETs avoid this compromise because they operate without a constant voltage drop across the device – the root cause of IGBT conduction inefficiencies.

If higher inverter efficiencies are realized, the benefits are not just restricted to a lower cost per watt. Greater efficiencies also lead to less heating, which increases component reliability and reduces thermal management demands.

The inverter's input voltage is governed by the photovoltaic panels, which each produce an output of tens of volts. The US silicon solar-cell manufacturer SunPower, for example, produces 1.6 by 1.0 m panels with a 55 V output and smaller 40 V versions, while the clear-cut leader of CdTe photovoltaics, First Solar, makes 1.2 by 0.6 m panels with 62–71 V output. These panels can be linked together in parallel and deliver outputs of several hundred volts.

The high field strength of SiC makes it ideal for producing high-voltage devices for inverters. These can operate at higher voltages, which leads to cuts in the solar-system costs and efficiency improvements. These gains are a result of a reduction in ohmic losses in panel wiring, which is cheaper to install because it carries less current. Up to 1000 V DC input inverters are currently under development and revisions to electrical code legislation could lead to even higher input voltages.

Realizing the potential of SiC

The merits of SiC have been appreciated for many years, but fabricating reliable devices that fulfill the semiconductor's potential has not been easy. A great deal of effort has been channeled at the development of a high-quality substrate and substantial progress has been made during the last two decades. The first commercial SiC substrates were launched in 1991 and today it is possible to obtain 100 mm material with a very low defect density, no micropipes, and few particles, basal plane defects and dislocations. The extremely low density of all of these types of defects is important for delivering a high yield with power devices, which typically have large chip sizes.

Another milestone for SiC came in 2001, thanks to Infineon's launch of the first SiC Schottky diodes. Since then other companies, including ourselves, have unveiled similar products with 600 and 1200 V ratings. But the market is eagerly awaiting the release of a SiC power transistor.

If this device is to enjoy commercial success, it will have to be reliable, normally off and cost no

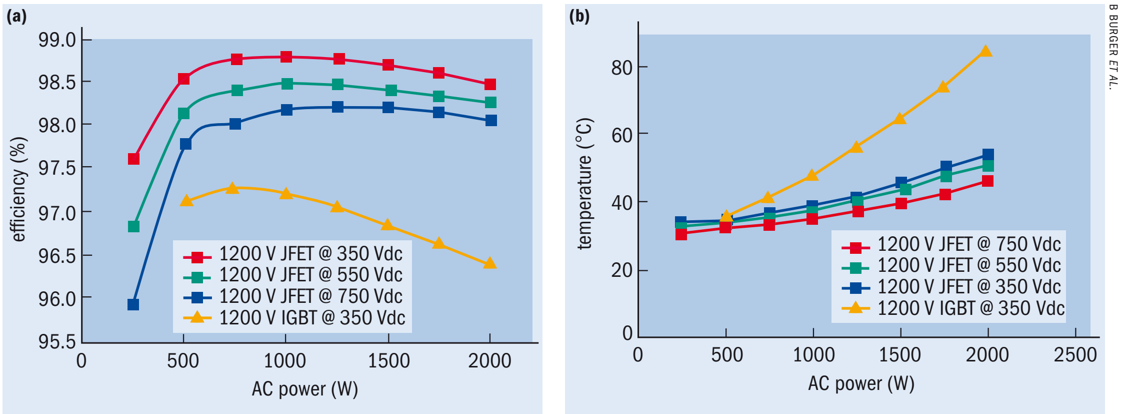

Fig. 2. Tests by the Fraunhofer Institute for Solar Energy reveal the higher efficiencies **(a)** and lower device temperature **(b)** that result from replacing Infineon's fourth-generation silicon IGBT with a SemiSouth 63 mΩ, normally off SiC JFET.

Table 1. Material properties

Material property	*Silicon*	*4H-SiC*	*GaN*
Bandgap (eV)	1.12	3.25	3.4
Breakdown field (MV/cm)	0.25	~3	~3
Thermal conductivity (W/cm K)	1.5	4.9	1.3
Electron mobility (cm^2/V s)	1200	800	900
Dielectric constant	11.7	9.7	9.0

more than four times that of a silicon equivalent. We are hitting these targets and we face competition from several companies around the globe, including Infineon, Cree, TranSiC, Rohm and Microsemi. Our contender is a SiC JFET – a cost-effective, normally off device, which we have shipped to a limited number of customers since June 2008.

Our initial products are 1200 V JFETs with 125 and 63 mΩ resistance, which are offered as bare die or as a TO-247 package. These transistors have saturation currents exceeding 25 A and threshold voltages of 1 V (figure 1, p19).

Our JFET's performance is unrivaled, thanks to its combination of a high breakdown voltage and low on-resistance (figure 1, p19). Device operation is very close to the 4H-SiC limit, a target that leads to SiC power transistors that are highly cost-effective and capable of delivering high performance.

Outperforming other silicon and SiC transistors can't guarantee long-term success for our JFET. This device will have to see off the threat posed by another wide-bandgap semiconductor – GaN. However, this rival is a more immature technology for power device manufacture and we believe that the production costs for these transistors will be higher than those for our SiC JFETs. Nitride devices are also hampered by poor thermal conductivity, high defect densities that impact reliability and yield, and the need for relatively large die sizes compared with SiC.

The contribution that our SiC JFETs can make on a state-of-the-art solar-inverter system has been assessed by the Fraunhofer Institute for Solar Energy Systems. The Fraunhofer team replaced a fourth-generation Infineon silicon IGBT with our JFET and observed a 1.6% increase in DC to AC conversion efficiency at an input of 350 V DC (figure 2). Higher inputs of up to 750 V DC led to a slight decline in efficiency from the peak of 98.8%, but this SiC-based inverter always delivers a superior performance to the silicon-based version. The higher efficiencies lowered the inverter's operating temperature, and at a 5 kW output up to 80% of the heat sink could be removed.

We believe that SiC devices can target a $2 billion slice of the power-semiconductor market, which is worth $14 billion according to market analyst IMS Research. The sales opportunities for SiC devices should increase over the next few years because the power semiconductor market is expected to increase at a compound annual growth rate of 15%.

Potential sales of SiC devices for solar inverters are a small fraction of that market, but success promises to highlight the benefits of wide-bandgap electronics and bring down the costs of solar energy. We believe that SiC will play a key part in generating new efficiency and cost records, which will help to drive up solar-system deployment.

In the past it has not been possible to enjoy all of the benefits of SiC because devices have been unreliable, expensive and unavailable in high volumes. However, our release of the normally off JFET will address all of these weaknesses. Solar inverters will benefit first, followed by power supplies and electric drive markets.

About the author
Jeff Casady is SemiSouth's chief technology officer, vice-president of business development and a co-founder of the company. He has previously held a faculty position at Mississippi State University, working in SiC power transistor development, and prior to that he was employed by Northrop Grumman.

Further reading

B Burger *et al.* (2008) *23rd Annual Photovoltaic Conference.*