Challenges of Wide Bandgap Power Semiconductor Testing

Devices based on Silicon Carbide (SiC) and Gallium Nitride (GaN) can switch at much higher frequencies and also have far lower leakage than Silicon, so at the same time as there is a need for sourcing higher voltages in testing, there is also a need for greater current measurement sensitivity. It can be quite challenging to characterize these new devices at very low levels of current. DC instrumentation must be capable of characterizing significantly higher rated voltages and peak currents than ever before while providing the measurement resolution and accuracy characterizing these new materials demands.

Mark A.Cejer, Marketing Director, Tektronix/Keithley Instruments, Cleveland, USA

Wide bandgap semiconductor materials like Gallium Nitride (GaN) and Silicon Carbide (SiC) will be integral to the development of the next generation of power semi devices. Because they offer roughly a 10X advantage over traditional Silicon in terms of conduction and switching properties, they're ideal for creating power electronics, which are often used as switches or blocking devices. These advantages, in concert with their higher durability and reliability, make these devices invaluable for emerging applications that depend on power conversion efficiency, including hybrid electric and electric vehicles, alternative/renewable energy generation and storage, power supplies, motors and drives, lighting, consumer electronics, household appliances, and many others.

Devices like power diodes, thyristors, power MOSFETs, and IGBTs fabricated with these materials typically have higher power density, smaller size, and lower on-resistance than those made of Silicon, all of which add up to greater operating efficiency. They can also operate at higher temperatures, voltages, and frequencies with lower power loss than Silicon devices.

DC instrumentation must be capable of characterizing significantly higher rated voltages and peak currents than ever before while providing the measurement resolution and accuracy characterizing these new materials demands. When the devices are in the on-state, they have to pass through tens or hundreds of amps with minimal loss, which means the internal resistance ($R_{ds(on)}$) is very low; when they are off, they have to block thousands of volts with minimal leakage currents, so the drain currents will be very low. Consider that typical drain leakage currents on a SiC power FET might be on the picoamp range, but an automated power device tester might be limited only to resolving hundreds of nanoamps or even microamps. Meeting this challenge demands a new generation of test hardware that is both more powerful and more sensitive.

On-state characterization

A high current instrument capable of sourcing high levels of current and measuring low-level voltages or resistances is commonly used for on-state characterization. If the device under test (DUT) has three terminals, a second source measure unit (SMU) instrument is used at the device control terminal to place the device in the on-state. Figure 1 illustrates a typical configuration for characterizing the on-state parameters of a power MOSFET.

One of the most recognizable types of test results for a semiconductor device is a plot of its output characteristics, which

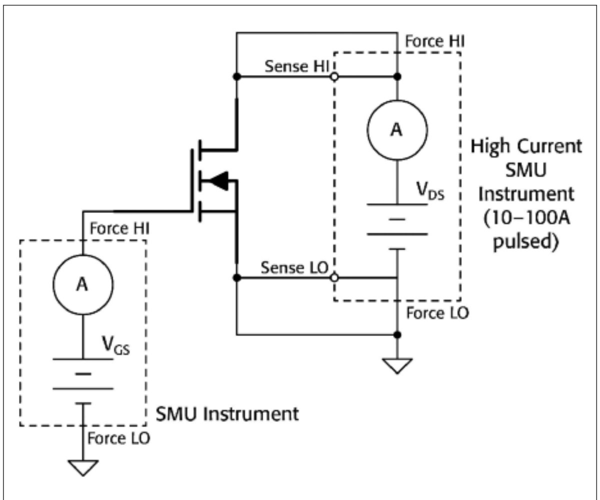


Figure 1: Typical SMU configuration for on-state characterization of power devices

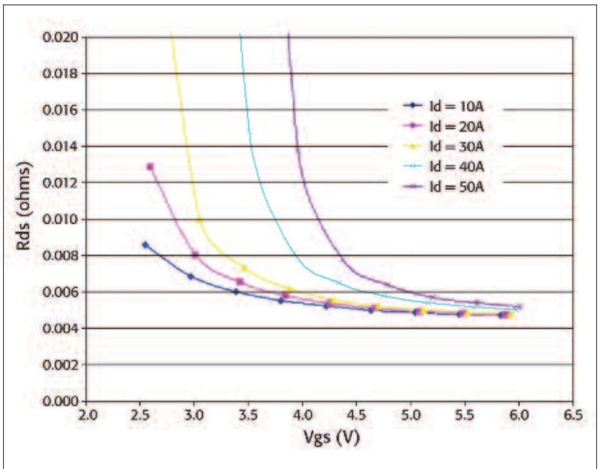


Figure 2: Results from performing a pulsed $R_{ds(on)}$ current sweep to test up to 50 A on a power MOSFET device using a high-power SMU instrument. It is possible to test up to 100 A by connecting two high-power SMU instruments in parallel

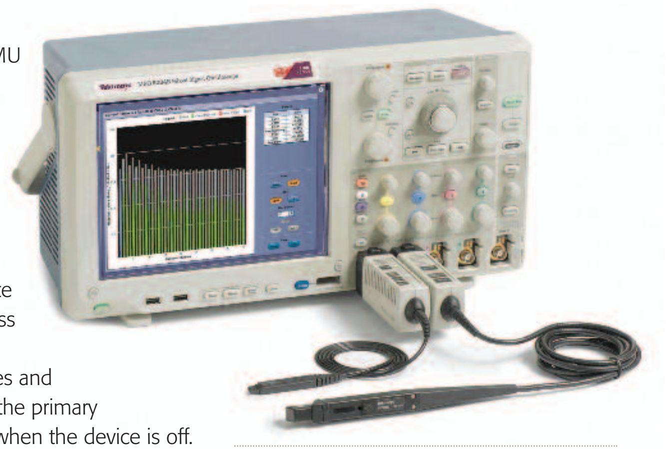
depicts the relationship between the output voltage and current. Figure 2 shows $R_{ds(on)}$ measurement data from a power MOSFET device by using a pulsed current sweep.

Power semiconductor devices are often high gain devices; oscillation is common when characterizing such devices, which can result in erratic measurements. Verifying the presence of oscillation demands source-and-measure instruments with high-speed A/D converters and the ability to characterize pulse transients accurately. Resolving this oscillation involves adding a resistor in series with the device control or input terminal, for example, the gate of a MOSFET or IGBT, so test engineers often choose test fixtures (Figure 3) that can handle the high-power signals involved as well as accommodate the addition of a discrete resistor.

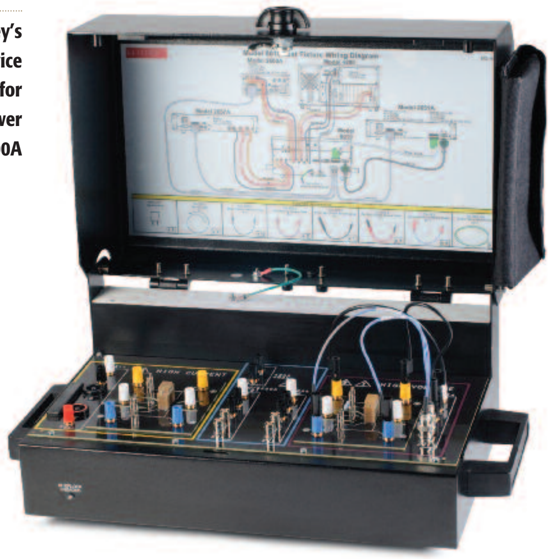
Off-state characterization

For power semiconductor devices, off-state characterization often involves the use of a high voltage instrument capable of sourcing hundreds or thousands of volts and measuring small currents. Because it's often performed between two device terminals, a single SMU instrument is often sufficient to perform the measurement. However, an additional SMU instrument can be used to force the device into its off-state or to add certain stress to certain terminals.

Breakdown voltages and leakage currents are the primary DC tests performed when the device is off. A device's off-state breakdown voltage determines the maximum voltage that can be applied to it. The primary withstanding voltage of interest to power management product designers is the breakdown voltage between drain and source of a MOSFET or between the collector and emitter of an IGBT or BJT. For a MOSFET, the gate can be either shorted or forced into a "hard" off-state, such as by applying a negative voltage to an n-type device or a positive voltage to a p-type device. This is a very simple test that can be performed using one or two SMU instruments. The lower power SMU instrument is connected to the gate and forces the transistor off. It can force 0 V for a gate shorted test or force a user-specified bias voltage. A high voltage SMU instrument, such as the Model 2657A, applies the necessary high voltage to the drain and measures the resulting drain current.

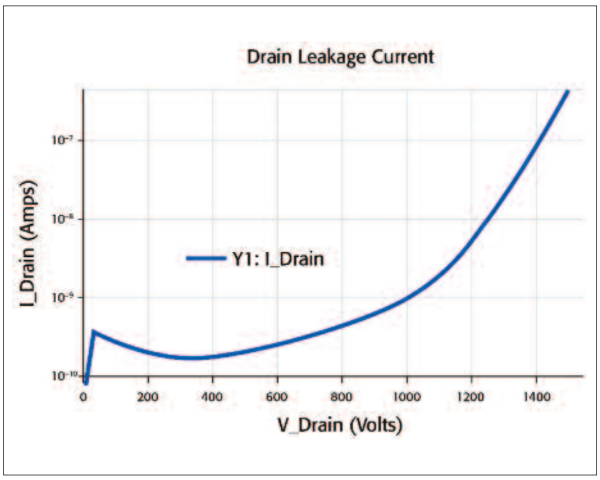


ABOVE Figure 5: With up to 2 GHz bandwidth and 10 GS/s real-time sample rate, Tektronix MSO/DPO5000B oscilloscopes offer the performance needed to handle the fast switching times seen in devices based on the newer compound processes, including GaN and SiC. MSO/DPO5000B oscilloscopes can be used with the full range of Tektronix voltage and current probes



RIGHT Figure 3: Keithley's Model 8010 High Power Device Test Fixture is designed for testing packaged high power devices at up to 3000V or 100A

Leakage current is the level of current that flows through two terminals of a device even when the device is off, so minimizing leakage current minimizes power loss. While testing a power device's off-state, it is generally desirable to test the drain or collector leakage current, the values of which are typically on the nanoamp, picoamp, or even sub-picoamp levels. Figure 4 is a plot of off-state drain voltage vs. drain current results for a commercially available SiC power MOSFET.



LEFT Figure 4: A look at the drain leakage current as the drain voltage is swept while the transistor is in the off-state

Future outlook

Switching power supplies are one of many power conversion technologies that are beginning to incorporate wide bandgap devices. Optimizing the designs of these products requires the use of higher-frequency tools. Oscilloscopes (Figure 5), high performance probes, and power analysis software are the AC tools of choice for characterizing components at high frequencies, analyzing the performance of a power conversion design, and understanding the source of problems. They make it possible to measure parameters like switching losses (turn-on, turn-off and conduction) and characterize the device's operating region (Safe Operating Area, SOA).

More technical details can be found in the 'Testing Power Semiconductor Devices application note' (www.keithley.com/data?asset=57464).