Demand for Higher Power Semi Devices Will Require Pushing Instrumentation to New Extremes

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A VARIETY of market trends are contributing to the development and direction of the latest generation of test and measurement products. Many segments of the electronics industry, including the semiconductor industry, are focused on increasing energy efficiency, including boosting the efficiency of energy generation, transmission, and consumption. Device manufacturers have traditionally relied on silicon technology for creating many of the devices used to control motors, regulate voltages, convert power, etc. Given that most power semiconductor devices are used as switches or blocking devices in these applications, this translates into creating "greener" devices that offer lower leakage, lower ON resistance, or both.

At the same time, semiconductor technology is evolving to create devices that can operate at much higher levels of voltage, current, power, and frequency. This holds the promise of higher growth for device manufacturers, as silicon-based devices increasingly replace the electro-mechanical technology once so prevalent in energy generation and transmission applications. This becomes particularly evident when comparing industry forecasts for these types of power devices with those of other discrete semiconductor devices. Power transistors are expected to be the largest and fastest growing segment of the discrete semiconductor industry, with much of this growth being driven by energy efficiency-related applications and technologies.

High power semiconductor end applications are becoming increasingly demanding, requiring test instrumentation capable of characterizing significantly higher rated voltages and peak currents than ever before (***Table 1***). Even more significant, breakdown and leakage test are typically performed at 2–3 times the level of the rated or operating voltage, making the need for instrumentation capable of sourcing and measuring ever-high voltages increasingly obvious. When the devices are in the ON state, they have to pass through tens or hundreds of amps with minimal loss; when they are OFF, they have to block thousands of volts with minimal leakage currents.

Many power device manufacturers are turning to new compound materials, such as silicon carbide (SiC) and gallium nitride (GaN), to create high power semiconductor devices. These newer materials typically have much higher power density, smaller size, better high temperature performance, higher frequency response, lower leakage, and lower ON resistance than silicon, all of which add up to greater operating efficiency. In turn, devices based on SiC and GaN have far lower leakage than silicon, so at the same time as

Table 1. High power semiconductor end applications.

	High–End Power Supplies, Servers, etc.	UPSs	HEVEV	Solar Panel Inverters	Wind urbines	Industrial Motors	Electronic Transmission, Rail Traction, Ships
Main Devices	FETs, Diodes	FETs, IGBTs, Diodes	FETs, IGBTs, Diodes	FETs, IGBTs, Diodes	IGBTs, Diodes	FETs, IGBTs, Diodes	IGBTs, Diodes
Rated Voltage	600V	600V–1200V	650V–2000V	600V–1200V	Today: 690V, Trend: 3kV–4kV	600V–1200V	>5kV
Peak Current	0.5A–10A	2A–100A	50A–200A	75A	>150A	3A–100A	>200A

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. In most cases, special triaxial cables are required to provide sufficient noise immunity to allow characterizing these low currents.

Silicon carbide, gallium nitride, and other compound semiconductor materials are more difficult to work with and more difficult to control from a processing standpoint than traditional silicon. These technologies are simply not as mature as silicon technology, which creates some big challenges for the engineers responsible for designing and characterizing these devices, as well as for those involved in quality assurance, failure analysis, and process monitoring. The higher cost of dealing with these challenges, as well as the cost of the materials themselves, also means that the prices of these devices are generally higher than their silicon equivalents. That puts pressure on the cost of test, especially final test, which these manufacturers can't afford to short-change due to the reliability requirements of their end-user customers.

As a result, the challenge for power semiconductor manufacturers is to develop and produce devices that operate at both higher power levels and with lower leakage levels and to do so quickly and profitably. And that's where the need for new approaches to test instrumentation becomes particularly urgent. When power semiconductors were typically manufactured using only silicon-based technologies, the measurement ranges involved were not nearly as challenging as they are today. The relatively slow rate of change in the power semiconductor industry for a number of years meant that existing equipment types largely met power semi manufacturers' test requirements, so instrument manufacturers had little motivation to innovate and develop new, more capable solutions. The manufacturers of some of these test solutions allowed them to become obsolete due to a fall-off in demand, rising support costs, and reduced profitability.

However, the recent worldwide thirst for more energy-efficient, environmentally conscious, and "green" products is breathing new life into the power semiconductor industry. Innovation is surging again as power semi devices manufacturers push to improve the efficiency of their products by squeezing every last drop of efficiency and performance from new devices, whether they're based on silicon, silicon carbide, or gallium nitride.

Unfortunately, after returning to growth after years of stagnation, semi power device manufacturers now realize the T&M equipment they've been using for so long is no longer capable of meeting the requirements of their new product development initiatives. Moreover, these older solutions simply can't provide the low current measurement capability or accuracy required to characterize next-generation devices and materials. In addition, in many cases, they lack the necessary power to support today's operating or characterization levels. As a result, the T&M industry is being forced to play catch-up to serve these test needs, and many of the traditional vendors simply aren't up to speed yet.

Although some new parameter analyzer products have entered the market to serve certain niche applications (such as R&D characterization), their prices are often beyond the means of many of today's cost- and ROI-conscious equipment buyers. Moreover, they don't address the broader application requirements for production test and quality assurance/failure analysis (QA/FA). Similarly, integrating a system that combines high power capability with low current measurements is a big technical challenge and such custom-designed systems typically require large test engineering teams to develop and maintain them, so they're practical only for production test applications. Traditional curve tracers, although suitable for some lower power R&D and QA/FA applications, lack low current measurement capability and can only be found in the used equipment marketplace. The newer models on the market still lack the necessary low current capabilities, precision, power levels, and affordable price points that today's power semi manufacturer customers demand. Although commercial ATE systems have always been used for power semi production test applications, their cost, size, and lack of characterization and low current measurement capabilities make them impractical for R&D and QA/FA applications. As single-quadrant devices, power supplies cannot sink power; therefore, they require several seconds for the capacitance charge to bleed off after testing, which slows the test process, which is particularly problematic in production applications.

Safety is another area of major concern when configuring high voltage test systems, which require safety interlocks, double grounds, and other safety features to protect operators and sensitive system instrumentation. Particularly in Europe, safety standards like IEC 60601 will be of importance in guiding system design.

In light of these shortcomings, manufacturers have been seeking a new approach to high power semi material and device testing. In response, a number of T&M manufacturers, including Keithley Instruments, have begun applying the integrated sourcing and measurement capabilities of SMU (source measurement unit) instruments to this challenge. Essentially, SMUs are fast-response, read-back voltage and current sources with high accuracy measurement capabilities, all tightly integrated in a single enclosure. In the early stages of this effort, the major shortcoming of these instruments was their limited range – existing SMUs simply couldn't deliver the power levels required to characterize high power semi devices accurately. As the first step in their effort to correct these limitations, Keithley introduced the Model 2651A High Power System SourceMeter® instrument in 2011, which was specifically designed for high current characterization of high power electronics.

Like all of Keithley's Series 2600A SMUs, the Model 2651A combines the capabilities of a semiconductor parametric analyzer, precision power supply, true current source, DMM, low-frequency ARB, pulse generator, electronic load, and trigger controller – all in one full-rack, four-quadrant instrument. It also has the widest current range available in the industry, with 2000W (40V@50A) of pulsed power capability and 200W of continuous DC power (***Figure 1***). It can source and measure currents from 1pA to 50A; the top end of the current pulsing range can be expanded to 100A by linking two units together.

Although the Model 2651A addresses many high power semiconductor test applications, it's only half of the story. In response to the need for higher voltage testing of these materials and devices, Keithley developed a

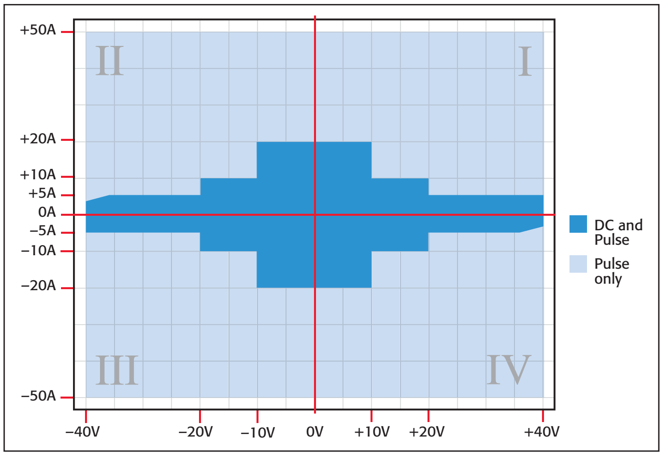

Figure 1. The Model 2651A has the widest current range available in the industry, with 2000W of pulsed power (40V@50A pulsed) capability and 200W of continuous DC power.

Figure 2. Model 2657A High Power System SourceMeter instrument is designed for high voltage/low current sourcing and measurement in high power semiconductor characterization.

companion product optimized for applications that demand a combination of high voltage sourcing, fast response, and precise voltage and current measurements. The Model 2657A High Power System SourceMeter instrument (***Figure 2***) is tailored to the needs of power semiconductor designers and manufacturers, researchers working with power semi devices and materials, and those developing precision electronics, especially those in the military/aerospace, automotive, and medical markets. Together, the Model 2651A and Model 2657A address the needs of many of today's power semiconductor applications and can be used across multiple departments within a single organization. This provides the added benefit of measurement correlation at various stages throughout the commercialization process, which helps resolve problems faster and enables quicker time to market.

With the capability to source up to 180 watts of either continuous DC or pulsed power, the Model 2657A offers the highest power level available in the industry at such a high voltage (3,000V). This wide range makes it possible to capture important parametric data that competitive systems can't. Competitive source measurement unit solutions that offer up to 3kV are limited to just 12 watts of power. The Model 2657A also offers the speed necessary to source high voltage pulses quickly, like a 3000V pulse in less than 15 milliseconds or a 500V pulse in less than 2 milliseconds (***Figure 3***).

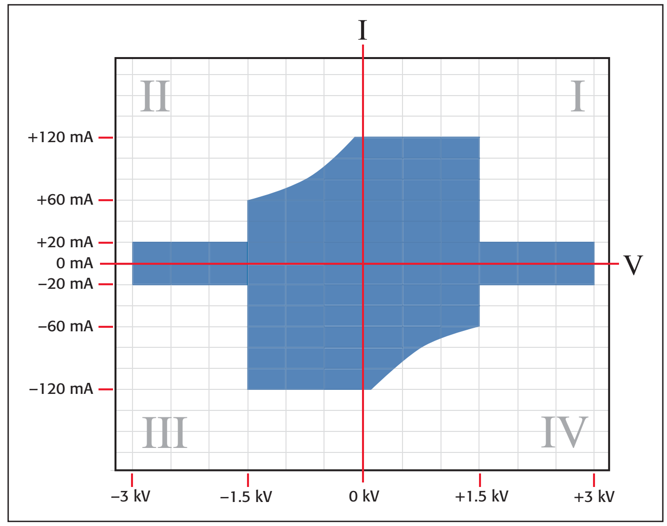

Figure 3. The Model 2657A offers the highest power available in the industry (up to 180W of either continuous DC or pulsed power) at such a high voltage (3,000V).

With two sets of high speed, high accuracy A/D converters built in, and one-microsecond per point sampling, the Model 2657A allows characterizing transient and steady-state behavior precisely, including rapidly changing thermal effects. Its one femtoamp-level resolution supports measuring the very low leakage currents common in next-generation devices.

The Model 2657A's TSP-Link® virtual backplane makes it easy to create high speed, scalable integrated systems with up to 32 nodes. System builders can create powerful multi-channel power semi test systems that rival the speed of large ATE systems that cost tens of thousands of dollars more. Built-in 500ns trigger controllers enable precision timing and tight channel synchronization between instruments.

For benchtop or R&D applications, an optional high power device test fixture provides connections for testing packaged high power devices at up to 3000V or 100A, making it safer and simpler to configure a device test system that includes both high and low power SMUs. The Model 2657A can be combined with other Series 2600A and Model 4200-SCS SMUs to support multi-terminal test capability. Optional protection and interconnect modules simplify connecting multiple instruments to a prober, handler, or custom fixture safely. A unique rear access port enables DUT access for an oscilloscope or temperature probe.

TSP® Express, an LXI-based I-V test software utility, supports basic device characterization with no need for software installation or programming. Users can simply connect a PC to the LXI LAN port and access TSP Express with any Java-enabled web browser. ACS Basic Edition software is also available as an option for component characterization. The measurement libraries included address a variety of power devices, including FETs, BJTs, diodes, IGBTs, etc., with tests that include input, output, and transfer characteristics on most devices.

Conclusion

Although no one can know exactly what the next generation of power semiconductor devices will look like, it's absolutely certain they will require instrumentation with a broad dynamic range and exceptional low-level leakage measurement capabilities to characterize and test them. As new devices evolve, their manufacturers will continue to explore their options, seeking the best combination of power, performance, and cost-effectiveness available. KEITHLEY

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