

# TESTING HIGH POWER SEMICONDUCTOR DEVICES FROM INCEPTION TO MARKET

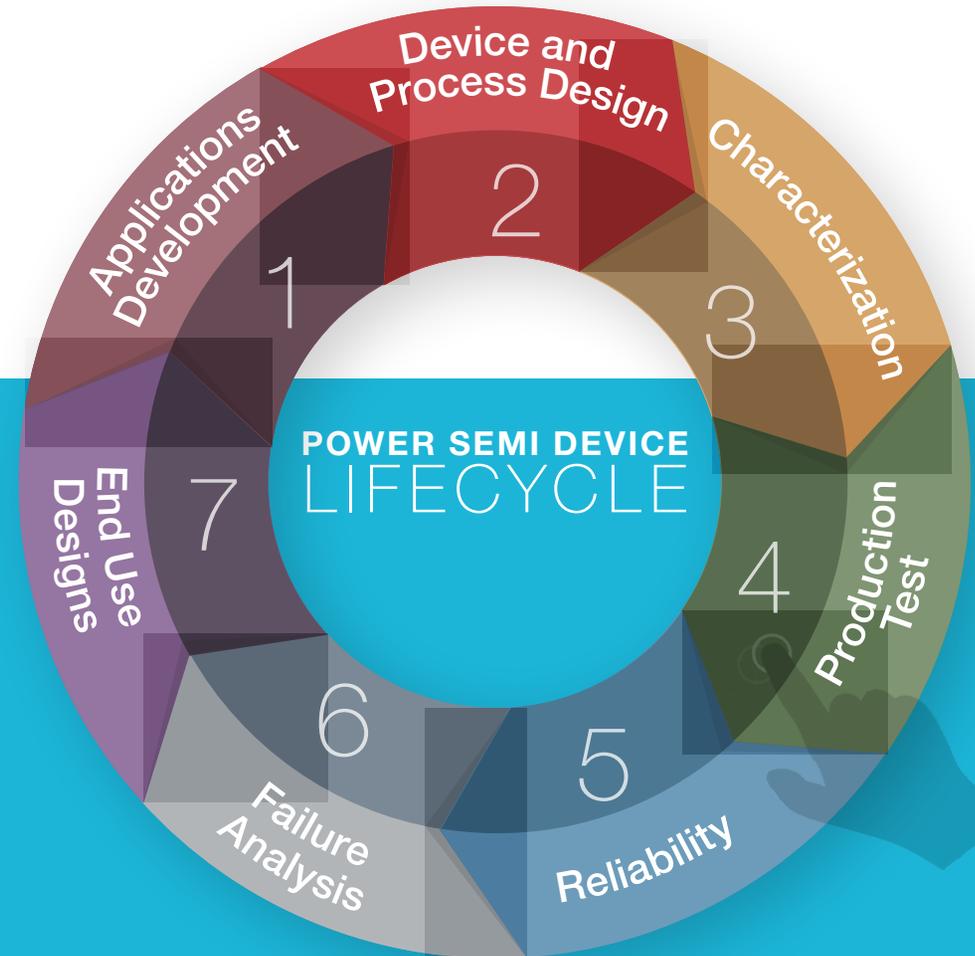
Methods for Efficient, Flexible Test and Characterization  
Throughout the Life Cycle of a Power Semi Device



## Introduction

This e-guide examines the life cycle of a power semiconductor device and the tremendous variety of test and characterization activities and measurement challenges faced by the engineers involved in each stage throughout the cycle. From the early stages of designing a new power device to the point where it's ready for market. Keithley's flexible set of high power characterization tools are ideal for testing across the entire life cycle of a power device.

- For basic curve tracing measurements, perhaps a single source measure unit (SMU) instrument with Android-based curve tracer app is sufficient.
- When more meticulous curve tracing is required, a SMU instrument with semiconductor I-V characterization software may be the solution.
- For detailed on-state, off-state, or capacitance-voltage characterization, a full parametric curve tracer (PCT) allows both easy data acquisition and detailed parameter extraction.
- The flexible instrumentation used for curve tracing can also be configured in a racked system for simple functional test, process monitoring, or other higher volume characterization.

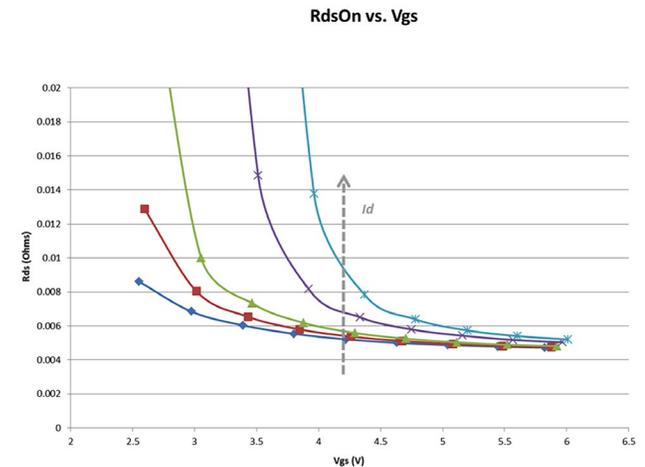
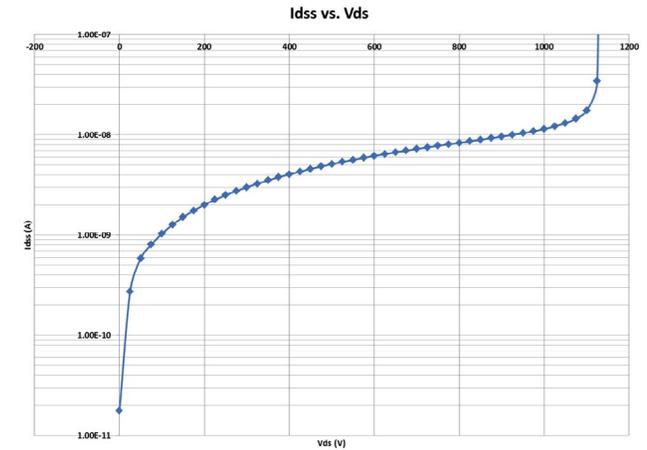


## Evaluating Existing Devices and Designs for New Application Requirements

Applications engineers work with customers who are constantly stressing, testing, or stretching a design to maximize efficiency. These customers need detail beyond what is noted in the device specification. Requirements are continually changing, so what needs to be measured can vary on a daily basis. How can measurements be made quickly and easily without time being wasted to relearn software or instrumentation?



The IVy Android App works with Series 2600B SourceMeter® SMU Instruments to perform I-V characterization. Pinch and zoom for deeper insight into device performance.



Keithley offers a wide range of test capabilities, including pulse, DC, and C-V. Our ACS Basic Software uses device-specific – not instrument-specific – vocabulary to simplify measurements. It also simplifies the interaction between multiple source measurement unit (SMU) instruments, so users can focus on the device rather than the instrumentation. The Ivy Android App works with Series 2600B SourceMeter® SMU Instruments to perform I-V characterization, including two- and three-terminal device testing and trend monitoring, and enables interactive analysis and insight into your device without programming! Or, use the Model 2450 Interactive SourceMeter SMU Instruments with KickStart I-V Characterization Software to perform current versus voltage (I-V) testing on a variety of materials, two terminal and multi-terminal semiconductor devices, solar cells, embedded systems, and much more.

[Read the Article](#)

## Source Measurement Unit Instruments Simplify Characterizing a Linear Voltage Regulator's DC Performance

### Source Measurement Unit (SMU) Instruments Simplify Characterizing a Linear Voltage Regulator's DC Performance

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Linear voltage regulators (LVR) are essential elements of power management systems. They provide the constant voltage rails required by any electronic circuit designed to operate at specific DC levels. A properly designed voltage regulator will maintain the specified output voltage continuously, regardless of changes in the input voltage or load current.

The two main types of LVRs, conventional and low dropout (LDO), function on the same principle, but an LDO requires a lower input voltage in excess of the output voltage to operate than a conventional type does, thereby reducing the amount of power needed to operate it. As a result, low dropout regulators are better suited for battery-powered electronics and portable handheld communication devices.

This article discusses how to characterize some common DC electrical characteristics of LVRs, including line regulation, load regulation, dropout voltage and open-circuit current. These parameters are applicable to qualifying both conventional and LDO LVRs for specific applications.

Testing an LVR requires a variable power source for the input side and a variable load for the output side. Source Measurement Unit (SMU) instruments are excellent candidates for these applications because voltage and current measurements must be made on both sides of the regulator. One SMU instrument can act as a power source on the input side; a second SMU instrument on the output side can act as a load. A growing

number of test equipment vendors have begun offering system-level SMU instruments that house multiple SMU instrument channels in a single enclosure. For applications like these, a dual-channel SMU instrument like Keithley's Model 2602A System SourceMeter® instrument (Figure 4), could serve as an economical substitute for two separate SMU instruments.

#### Configuring an LVR Characterization System

As illustrated in Figure 2, SMU\_1 is connected to the input side of the regulator and is configured to source voltage and measure current (VME). The voltage source is the desired input voltage applied to the regulator. The compliance, or the current limit, is set to a value higher than the maximum output current of the voltage regulator in order to account for the LVR's current consumption.

SMU\_2 is connected to the output side of the regulator. It also sources voltage and measures current (VME). However, the voltage is configured to a fixed value that's lower than the expected output voltage of the regulator. SMU\_2 automatically switches to sink- ing, or drawing, current from the regulator, thereby acting as a load. The compliance current, or the current limit, is set to the desired load current. Given that an SMU instrument operates on the principle of amp, it is important to ensure that SMU\_2 voltage range encompasses the expected output voltage of the regulator to ensure the regulator output voltage is measured correctly.

LVRs may require external capacitors to ensure stable operation of the voltage



Figure 2. Series 2600B Dual Channel System SourceMeter instruments.

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## 7 Keys to Detecting Potential DUT Issues Minimize Troubleshooting Time and Boost Productivity

Perform these seven easy tests on your battery, diode, LED, FET, or other DUT to identify potential issues early, avoid extensive troubleshooting, and have confidence that the DUT is safe to use in your circuit.

- I-V Characterization with Real-time Control**  
I-V characterization is performed on a variety of electronic products. Typical I-V characterization requires writing programs or configuring test software to source voltage/current in a certain range, then the measured current/voltage will be displayed after you run the testing program. But, real-time control eliminates the delayed visualization that may cause you to miss some critical device behavior, providing further insight into your DUT.
- Monitor I-V Trends over Time**  
It's especially important to monitor device behavior over time to identify DUT problems that occur with changes in ambient conditions, such as temperature, lighting, and humidity. Use Keithley Ivy to provide a time mode to monitor your devices.
- Understand Measurement Results from Different Perspectives**  
You know your measurement fits a noise at a random point, but do you know how to determine the measurement? Measurement data makes more sense when you look at it from different perspectives.
- Share Measurement Results for Collaborative Work**  
If you're having trouble understanding the device's behavior, share a screenshot and the actual data with your colleagues to ensure collaborative work.
- Stimulus-Response Behavior over Time**  
Have you tested your component's stimulus-response behavior? The test results may surprise you! Typically, you need to program the stimulus activities into your test program and then observe the responses. If you see some unexpected behavior after the measurement is completed, go back to the test program and try to make any adjustments with the device behavior. Ideally, you can change device state in real time. Use the DUT response directly. When you are collecting data in time mode, you can remain in control of your source by changing the source level.
- Compare Your Device to a "Golden Device"**  
A "golden device" is a "known good" device that is often used when testing components. Compare test results of an unknown device against a characterized, known good device to determine if it is operating normally. This module allows you to compare test results, so you can remain in control of your source by changing the source level.

The Keithley Ivy Android™ App lets you perform these tests on your DUT with a couple of touches and just seconds of your time.



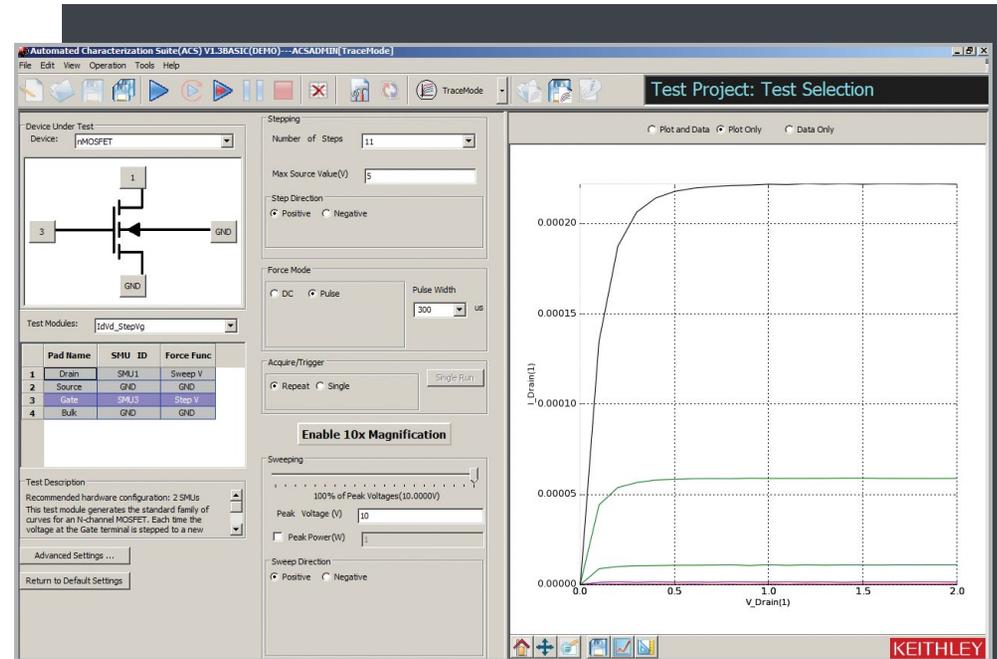
## 7 Keys to Detecting Potential DUT Issues: Minimize Troubleshooting Time and Boost Productivity



## Designing New Devices to Meet Evolving Needs

To effectively design devices to meet their customer's latest requirements, power device design engineers and process engineers must understand how to tweak the process to produce the desired device performance. There must be confidence that the device models are fairly accurate, and changing a particular process step must produce the necessary change in the device measurement parameter. Therefore, the device engineer must perform preliminary verification of key device parameters.

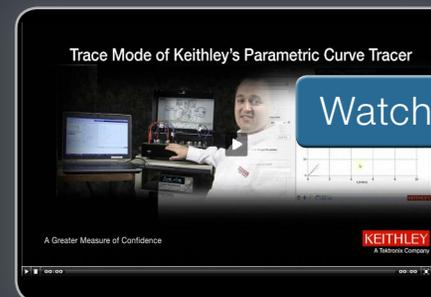
With its trace mode, ACS Basic Edition Software allows quick verification of key device parameters, including family of curves, bias voltage, etc. In addition to being intuitive, it's designed from the device perspective and includes scores of device libraries and a built-in formulator to quickly relate measurement to device parameters. Parametric Curve Tracer (PCT) Configurations and the Model 8020 Probe Station Interface simplify a wide range of tests that must be performed on-wafer for DC, CV, and pulsed test.



*Trace Mode supports interactive testing of a device.*

Testing Modern Power Semiconductor Devices Requires a Modern Curve Tracer

Watch the Webinar



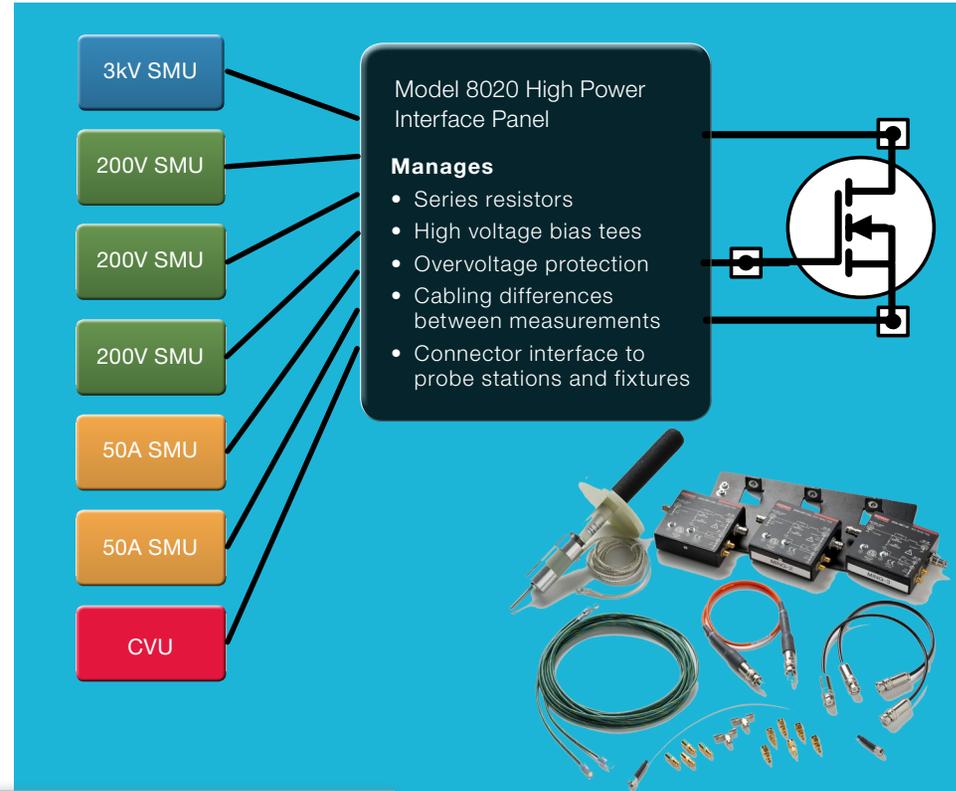
Watch the On-line Demo

*PCT Configuration in Trace Mode*

# Characterizing Full Performance of New Device Design

A characterization engineer provides the necessary measurement expertise and understanding of how measurement anomalies can impact non-targeted areas of device performance. It's imperative to get results fast to enable multiple iterations with device or process engineers and quickly convert measurements to device parameters.

For on-wafer characterization, the Model 8020 High Power Interface Panel minimizes connection changes between major measurement types. I-V and C-V measurements can be made through bias tees without connection changes. ACS Basic Edition Software allows users to quickly calculate desired parameters.



**KETHELEY** Application Note Series

### Solving Connection Challenges in On-Wafer Power Semiconductor Device Test

Introduction  
 Measuring DC and capacitance parameters for high power semiconductor devices requires sufficient expertise to optimize the accuracy of various measurements. Even for those with this level of expertise, managing setup changes between ON-state, OFF-state and capacitance-voltage (C-V) measurements can be time consuming and prone to errors, this is especially true in the on-wafer environment.

This application note provides an overview of how the Keithley Model 8020 High Power Interface Panel greatly simplifies the user's test experience by:

- Integrating key measurement-enabling accessories for ON-state, OFF-state and C-V measurements.
- Enabling all C-V measurement parameters, at both the component level and on-wafer level, with minimal connection changes at the device under test (DUT).
- Building in flexibility with a variety of connector options.
- Expanding easily to support future measurement requirements and new device terminals.

**Configuring Common Semiconductor Device Measurements using Traditional Accessories and Standalone Instrumentation**  
 A review of the requirements for the DC and capacitance measurements to be made on the DUT is an important first step.

**ON-State Measurements**  
 Characteristic curves for a power transistor, I<sub>CE</sub> or I<sub>DM</sub>, include a plot of its typical output characteristics. Output characteristics for some power devices can involve tens to hundreds of amps. Therefore, creating these curves requires a high current instrument, such as the Keithley Model 2615A High Power System SourceMeter® instrument, when two Model 2615As are configured in parallel, they can generate up to 300A in pulsed current. This SMU instrument is coupled with a lower power SMU instrument, such as Keithley's Model 2656B, to drive the control terminal (e.g., gate) of a three-terminal device.

To produce optimal high current measurements, managing the resistance and inductance in the cabling is imperative. This can be achieved using low inductance, constant Kelvin connections and minimizing the inductive loop area at the DUT. (Probe station geometries often dictate this inductive loop area.) The gate SMU instrument also requires Kelvin connections so that high current pulses at the FEET source terminal don't affect the gate voltage and change the operating point of the device.

High power devices often exhibit gate and may be prone to oscillate during testing. Adding series resistors helps eliminate such oscillations. In test systems, the resistor is inserted between the lower power SMU and the gate terminal. This resistor is housed in a shielded enclosure to minimize electronic interference is not needed when characterizing other parameters, such as gate leakage. Otherwise, the series resistor would have to be removed for those other tests. Series resistance values can vary between devices and it may be necessary to try several values in order to select the appropriate value. It can be a design challenge to house and connect to these resistors properly when performing on-wafer measurements. Figure 4 illustrates the typical setup for high current ON-state measurements.

**OFF-State Measurements**  
 OFF-state characterization includes measurement of the breakdown voltage and leakage current of the device. These parameters are typically tested at the

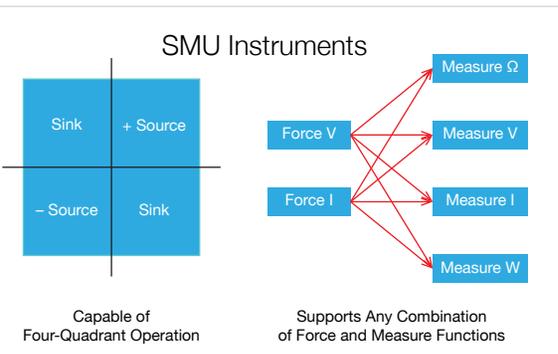
Figure 3. Typical ON-state measurement setup.

Read the Application Note

Solving Connection Challenges in On-Wafer Power Semiconductor Device Test

## Preparing the Device for Production

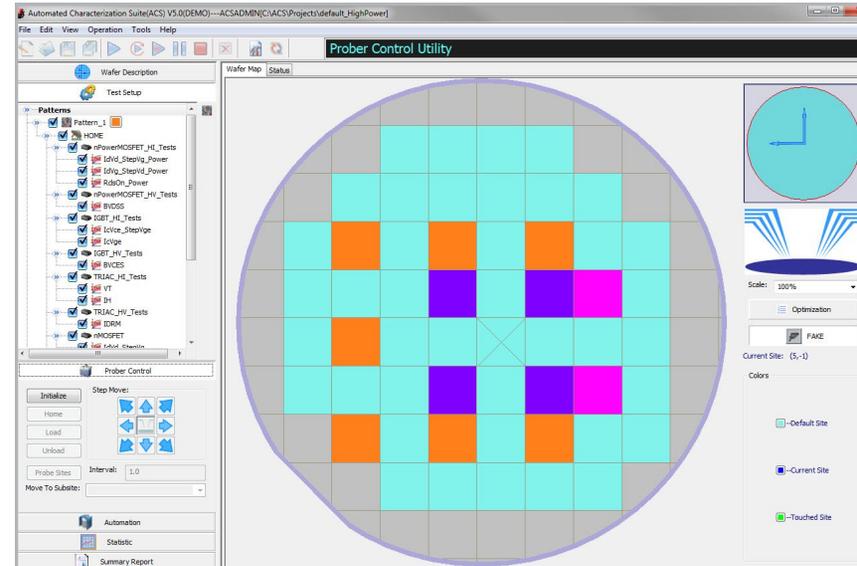
To properly prepare a device for production, the production test engineers must prove if the device can be produced reliably. Measurements must be gathered for statistical setting of device specifications, and test times must be optimized to meet required production throughput.



Multi-functional instruments offer the best way to obtain measurements quickly with minimal connection changes and switching.

Source measure unit (SMU) instruments are multi-functional instruments that are proven for use in semiconductor applications. SMU instruments with Test Script Processor (TSP®) technology are primed for throughput because of their tight synchronization, built-

in processors for complex operations, and decision-making performed within the instrument, thus minimizing communication times. These SMUs instruments are used in PCT configurations for interactive testing and also in S500 Parametric Test Systems for automated production testing. Automated Characterization Suite (ACS) Software combines advanced semiconductor test capabilities along with prober control, data reporting, and statistics.



*ACS maps devices and tests to sites and subsites, eliminating the need to duplicate each test for each subsite and reducing test development time.*

Optimizing Semiconductor Measurements and Test Times



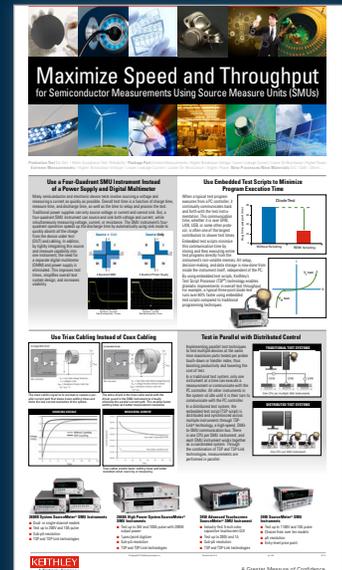
Read the White Paper

Gearing Up for Parametric Test's High Voltage Future

Maximize Speed and Throughput for Semiconductor Measurements Using Source Measure Unit (SMU) Instruments

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## Meeting Reliability Standards for Commercial Use

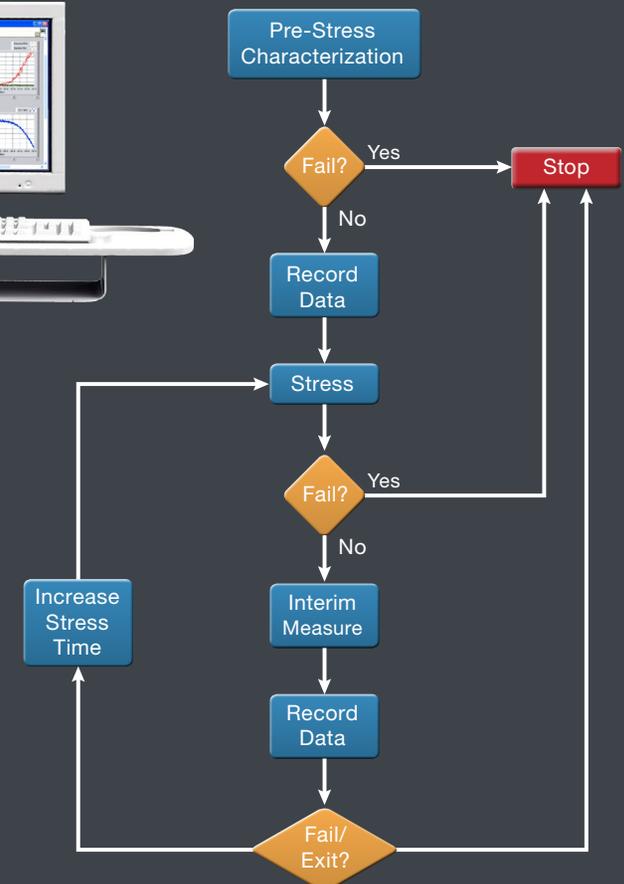
To conclude that a device meets reliability standards for commercial use, reliability test engineers have several responsibilities:

- Determining if a device will survive environmental stresses and continue to meet specifications
- Answering customer questions about device lifetime (MTBF, MTTF)
- Providing key insight into device fit for certain high reliability applications (mil/aero, automotive, etc.)

Creating statistically relevant results requires sufficient sample sizes of the test devices. The nature of stress-measure cycling over many devices necessitates multi-channel parallel test with automated data evaluation.



*Process flow for HCI/NBTI/constant current EM tests.*



S500 Integrated Test Systems are reliability test systems that can be custom built to accommodate from small to large number of devices. ACS features stress measure loop cycling with integrated decision making. Keithley also provides a wide range of power supply and SMU instrument solutions to permit simultaneous power and testing of any number of devices.

## Optimizing Reliability Testing of Power Semiconductor Devices and Modules with Keithley SMU Instruments and Switch Systems

application brief



### Optimizing Reliability Testing of Power Semiconductor Devices and Modules with Keithley SMU Instruments and Switch Systems

**Introduction**

To minimize early defect rates and to continuously improve the overall reliability and lifetime of power semiconductor, a variety of important tests are performed by both manufacturers and end-use designers. Many of these tests are outlined in JEDEC standards such as JESD22-A110D "Temperature, Bias, and Operating Life," JESD22-A110D "Highly Accelerated Temperature and Humidity Stress Test (HAST), or HAST2," Reliability Qualification of Power Amplifier Modules," This application brief discusses methods to optimize reliability testing of silicon and wide band gap (WBG) power semiconductor devices, modules, and materials by using Keithley SourceMeter® Source Measure Unit (SMU) Instruments and Switch Systems (Figures 1 and 2).

**Typical Reliability Tests**

Typical reliability tests involve stressing a batch or batches of sample devices for hundreds or thousands of hours with bias voltages that are greater than or equal to their normal operating voltages while subjecting them to temperatures that are well beyond normal operating conditions. During this stress, a variety of key operating parameters are measured at specific time intervals. Some of the more popular reliability tests for power semiconductor are HTDB (High Temperature Operating Life, HTRB (High Life Failure Rate), HTRF (High Temperature Forward Bias), HTRB (High Temperature Reverse Bias), and HAST (Highly Accelerated Temperature & Humidity Stress Test). These tests will either use a continuous bias (Figure 1) or a cyclic bias (Figure 2). A continuous bias can be a fixed voltage or a staircase ramp. A cyclic bias will typically vary the duty cycle and/or frequency of the bias voltage. In both cases, key device parameters will be tested continuously or at specific time intervals.

**Reliability Testing Challenges**

Reliability testing of today's WBG power semiconductor presents several key challenges for engine designers. Most importantly, since most being targeted for energy efficiency apply much lower leakage and on-resistance to traditional silicon. The test instrument is capable of providing the necessary stability to meet the electrical requirements. In addition, since WBG devices exhibit characteristics that are different from silicon, effective JEDEC standards require larger sample sizes. Another to adequately profile important reliability parameters. This requires test instrumentation that is capable of supplying enough power to test many devices in parallel while maintaining the accuracy and resolution mentioned above. Finally, the test instrumentation must be able to respond to the high speed behavior associated with these devices and produce the masses of data associated with testing devices in parallel. Each instrument in the system must be fast, and all units must operate in a highly synchronized manner.

The  $V_{DS}$  ramp and the High Temperature Reverse Bias (HTRB) tests are among the most common reliability tests for power devices. In a  $V_{DS}$  ramp test, the drain-source voltage is swept from a low voltage to a voltage that is higher than the rated maximum drain-source voltage, specified device parameters are evaluated. The test is useful for testing the design and power conditions, as well as verifying that devices deliver the performance specified on their data sheets. For example, Dynamic  $R_{DS(on)}$  monitored using a  $V_{DS}$  ramp test, provides a measurement of how much a device's effective resistance increases after being subjected to a drain bias [1]. Although a  $V_{DS}$  ramp test is generally used as a quick form of parameter verification, an HTRB test evaluates long-term stability under high drain-source bias. During an HTRB test, the device samples are stressed at or slightly less than the maximum rated reverse breakdown voltage (usually 90% or 80% of  $V_{BR}$ ) at an ambient temperature close to their maximum rated junction temperature ( $T_{Jmax}$ ) over a



Figure 1. Keithley Series 2550A High Power SourceMeter SMU Instruments.



Figure 2. Keithley Series 3300A and 3370B Series Switch Systems.

## $V_{DS}$ Ramp and HTRB Reliability Testing of High Power Semiconductor Devices with Automated Characterization Suite (ACS) Software

Keithley  
Application Note Series

Number 220

### $V_{DS}$ Ramp and HTRB Reliability Testing of High Power Semiconductor Devices with Automated Characterization Suite (ACS) Software

**Introduction**

Wide bandgap semiconductor materials such as silicon carbide (SiC) and gallium nitride (GaN) offer physical properties superior to those of silicon (Si) for power device applications, enabling devices based on these materials to withstand high voltages and temperatures, as well as providing higher frequency response, greater current density, and faster switching [1]. These emerging power devices have great potential; however, the technologies necessary to create and refine them are still under development and therefore less mature than silicon technology. This creates some key challenges associated with designing and characterizing these devices, as well as process monitoring and reliability issues [2].

Before they can gain commercial acceptance, the reliability of wide bandgap devices must be proven and there is a demand for higher reliability requirements. The continuous drive for greater power density at the device and package levels creates consequences in terms of higher temperatures and temperature

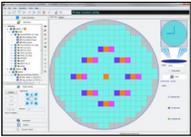


Figure 1. Automated Characterization Suite (ACS) graphical user interface period of time (usually 1,000 hours)[3][5][6][7]. The leakage current is continuously monitored throughout the test and a

instrumentation with higher voltage as well as most sensitive current measurement capability than ever before [2]. During operation, the device undergoes both electrical and thermal stress when in the ON state, they have to pass on or hundreds of amps with minimal loss (low voltage, high current) when they are OFF, they have to block thousands of volts with minimal leakage current (high voltage, low current). Additionally, during the switching transient, they are subjected to a brief period of both high voltage and high current. The high current experienced during the ON state generates a large amount of heat, which may degrade device reliability if it is not dissipated efficiently [1].

Reliability tests typically involve high voltage, long test times, and often multiple devices under test (multi-test) testing. As a result, well-designed test systems and measurement plans are essential to avoid breaking devices, damaging equipment, and losing test data. Consider the following factors when executing  $V_{DS}$  ramp and HTRB reliability tests:

## Breakdown and Leakage Current Measurements on High Voltage Semiconductor Devices

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Number 220

### Breakdown and Leakage Current Measurements on High Voltage Semiconductor Devices Using Keithley Series 2290 High Voltage Power Supplies and Series 2600B System SourceMeter® Source Measure Unit (SMU) Instruments

Increased attention to energy efficiency has resulted in electronics with higher power density. In grid-connected and industrial applications, such as AC motor control, uninterruptible power supplies (UPS), and traction control (large hybrid and electric transport vehicles), the need to keep manageable cable sizes pushes power conversion to higher voltages. For such voltages, the semiconductor device of choice has historically been the thyristor. Technological advances in device fabrication and material processing is making the development of IGBTs and MOSFETs with voltage ratings of thousands of volts. In applications where possible, using IGBTs or even MOSFETs in place of thyristors permits power conversion at high switching frequencies. The migration to higher frequency reduces the size of power components used in the design and, thereby, improves energy efficiency.

Keithley has long had a strong presence in high power semiconductor device test with its high voltage source-measure products, including the Models 257, 2410, and 2670A SMU instruments. Most recently, Keithley released the Model 2290-A SMU and Model 2290-B 10kV High Voltage Power Supplies. This note considers the application of these power supplies to high voltage semiconductor device testing.

**High Voltage Device Tests**

Basic characterization of high voltage semiconductor devices typically involves a study of the breakdown voltage and leakage current. These two parameters help the device designer to quickly determine whether the device was correctly manufactured and whether it can be effectively used in the target application.

**Breakdown Voltage Measurements**

Measuring breakdown voltage is done by applying an increasing reverse voltage to the device until a certain test current is reached that indicates that the device is in breakdown. Figure 1 depicts a breakdown measurement on a high voltage diode using a Series 2290 High Voltage Power Supply. Note that the Series 2290 Power Supplies are unipolar supplies and must be connected to the diode's cathode in order to apply a reverse voltage.

In qualifying breakdown voltage, measurements are typically made well beyond the expected rating of the device to ensure

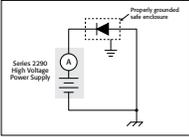


Figure 1. Typical breakdown voltage measurement of a high voltage diode using the Series 2290 High Voltage Power Supply.

**Safety Considerations**

When testing at high voltage, safety is of utmost concern. The Series 2290 Power Supplies generate voltage up to 10kV, so precautions must be taken to ensure that the operator is not exposed to unsafe voltage.

- Enclose the device under test (DUT) and any exposed connections in a properly grounded fixture.
- Use the safety interlock. The Series 2290 Power Supplies are fully interlocked so that the high voltage output is turned off if the interlock is not engaged (interlock switch closed). The interlock circuit of the power supply should be connected to a normally-open switch that closes only when the user access point in the system is closed to ensure that operators cannot come in contact with a high voltage connection to the DUT. For example, opening the lid of the test fixture should open the switch.
- Use cables and connectors rated to the maximum voltage in the system. Series 2290 Power Supplies provide a number of appropriately-rated accessories that the test system designer can use in addition to the device under test (DUT).

**Leakage Current Measurements**

In a typical power conversion application, the semiconductor device is used to convert AC to DC. The current measurements are performed on the DC side of the device.

Learn More from these Application Resources

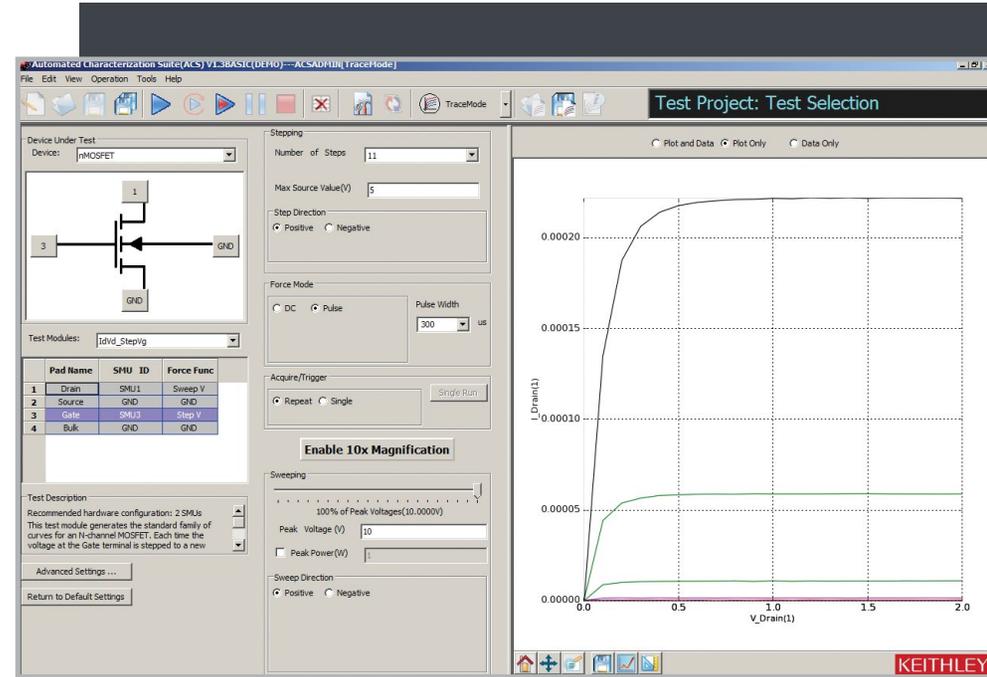


## Implementing the Device in Actual Designs

Failure analysis engineers must determine whether a failure has been caused by end-product use or by a design flaw that was previously overlooked. Once this determination has been made, design and process engineering must be made aware of the cause of the failure, so that either process or design changes can be implemented to prevent future failures.

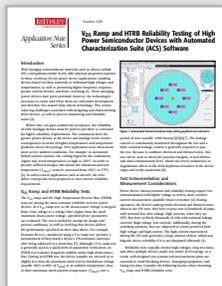
It's important that basic device specifications, both static and dynamic, can be measured quickly. The end use application is mimicked in an effort to reproduce the failure.

Parametric Curve Tracer Configurations feature trace mode, which provides quick device analysis. Additionally, Keithley's Automated Characterization Suite (ACS) has several built-in stress-measure tests that can be used until a device reaches the desired level of degradation.

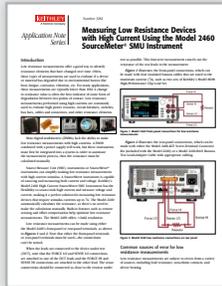


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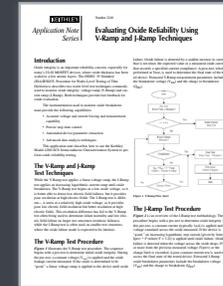
**V<sub>DS</sub> Ramp and HTRB Reliability Testing of High Power Semiconductor Devices with Automated Characterization Suite (ACS) Software**



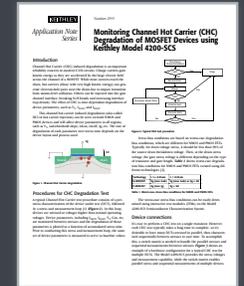
**Measuring Low Resistance Devices with High Current Using the Model 2460 SourceMeter® SMU Instrument**



**Evaluating Oxide Reliability Using V-Ramp and J-Ramp Techniques**



**Monitoring Channel Hot Carrier (CHC) Degradation of MOSFET Devices using Keithley Model 4200-SCS**



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Keithley Instruments hosts an online applications forum to encourage idea exchange, discussions among users. Join the discussion today.