



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 semiconductors, 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-A108D “Temperature, Bias, and Operating Life,” JESD22-A110D “Highly Accelerated Temperature and Humidity Stress Test (HAST),” or JESD236 “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**).



Figure 1. Keithley Series 2650A High Power SourceMeter SMU Instruments.



Figure 2. Keithley Series 3700A and 707B Series Switch Systems.

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 semiconductors are HTOL (High Temperature Operating Life), ELFR (Early Life Failure Rate), HTFB (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 3**) or cycled bias (**Figure 4**). A continuous bias can be a fixed voltage or a staircase ramp. A cycled 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 semiconductors presents several key challenges for engineers and test system designers. Most importantly, since most of these devices are being targeted for energy-efficiency applications, they have much lower leakage and on-resistance specifications compared to traditional silicon. The test instrumentation must therefore be capable of providing the necessary accuracy, resolution, and stability to meet the electrical requirements of these devices. In addition, since WBG devices exhibit failure mechanisms that are different from silicon, effective reliability testing per JEDEC standards requires larger sample sizes and longer stress durations to adequately predict 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 behaviors 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.

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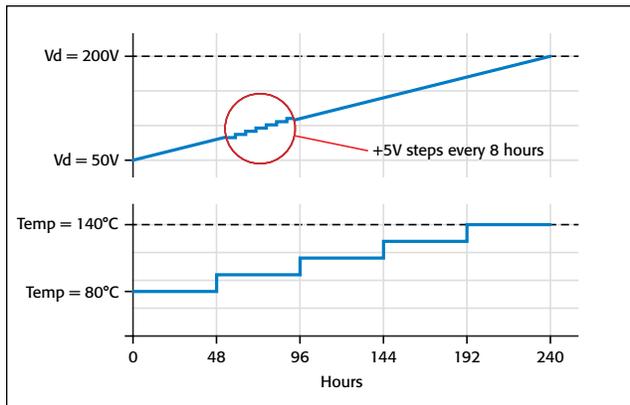


Figure 3. Continuous Bias Test. Vd=50V. Step temperature 15°C every 48 hours from 80°C to 140°C. Step Vd 5V every 8 hours from 50V to 200V. Collect I-V curve data before and after each voltage step. Test 72 devices per batch.

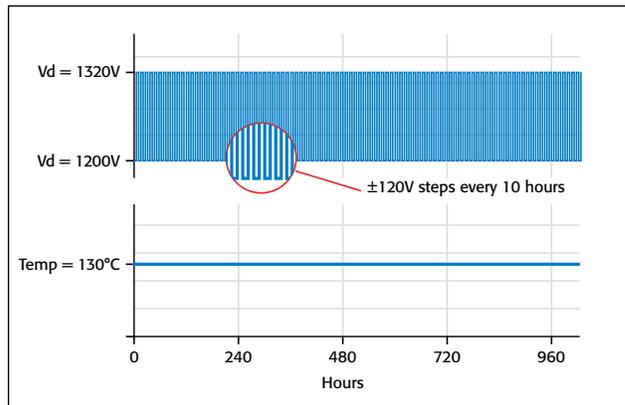


Figure 4. Cycled Bias Test. Vd cycles between 1200V to 1320V every 10 hours with a 50% duty cycle. Maintain temperature of 130°C for 1000 hours, and continuously measure Id. Test 240 devices per batch.

Keithley Solutions

Keithley reliability test solutions based on the Series 2600B and 2650A System SourceMeter SMU Instruments meet these demanding requirements (**Figure 5**). Keithley's Series 2600B and 2650A are modular, independent, isolated SMUs that provide up to 200W per channel with measurement resolutions to sub-pA levels.

In addition, all Series 2600B and 2650A SMU Instruments contain Keithley's Test Script Processor (TSP®) and TSP-Link® technology for ultra- high speed operation and parallel test. Keithley's TSP technology enables the instrument to perform advanced tests without PC intervention through the use of embedded test scripts. These scripts are complete test subroutines executed from the instrument's non-volatile memory that can perform conditional branching, flow control, advanced calculations, pass-fail testing, and more. On-board memory buffers can store over 140,000 readings, and can be queried while data is being written to them. For larger, multi-channel applications, Keithley's TSP-Link technology

works together with TSP technology to enable high-speed, multi-channel, SMU-per-pin parallel testing or seamless integration with Keithley's Series 3700A or Series 700 Switch Mainframes (**Figure 6**). The Keithley Series 3700A Mainframes also have a temperature measurement option that can be used for monitoring internal oven temperature at multiple locations. Synchronization with external equipment such as temperature chambers is enabled by the built-in digital I/O capability. Because Series 2600B and 2650A instruments have fully isolated channels that do not require a mainframe, they can easily be reconfigured and re-deployed as reliability test requirements evolve.

Solution Details

Reliability test algorithms are typically very specific to the device under test (DUT) and its market requirements. In this application brief, we are referring to the cycled bias test example in **Figure 4**. This test cycles the drain voltage (Vd) from 1200V to 1320V every 10 hours with a 50% duty cycle, and maintains a temperature of 130°C for 1000 hours while



Model 2657A: 180W, High Voltage

- Source and measure up to 3000V @ 20mA or 1500V @ 120mA.
- Basic voltage source accuracy of 0.03% with 5mV programming resolution.
- Basic current measure accuracy of 0.02%. 1fA resolution.



Model 2636B: Dual Channel, Low Current

- Source and measure up to 200V @ 100mA or 20V @ 1.5A per channel.
- Basic voltage source accuracy of 0.03% with 5µV programming resolution.
- Basic current measure accuracy of 0.02%. 0.1fA resolution.



Model 2651A: 200W, High Current

- Source and measure up to 40V @ 5A or 10V @ 20A
- Basic voltage source accuracy of 0.02% with 5µV programming resolution.
- Basic current measure accuracy of 0.02%. 1pA resolution.

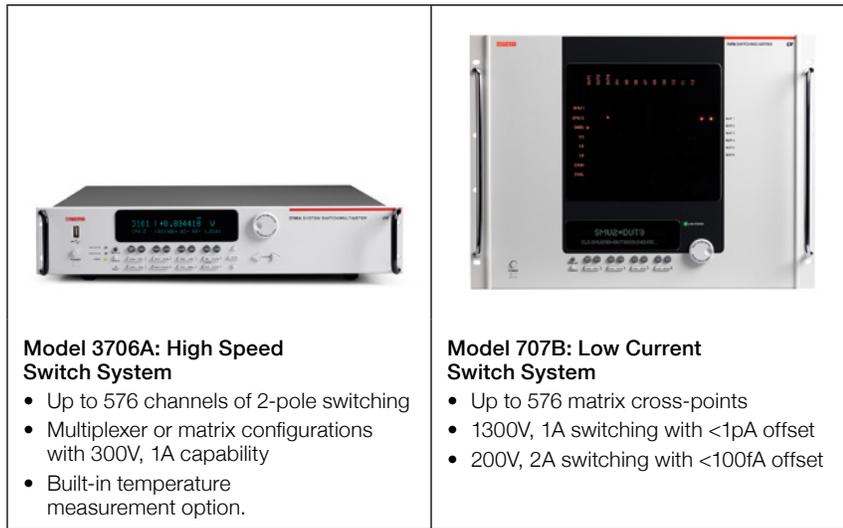


Figure 6. Key specifications of Keithley switch systems.

continuously measuring the devices' off-state leakage current (I_d). A batch size of 240 is tested, so the most economical approach is to use a switch system to route the power of one SMU instrument to all DUTs.

An example system block diagram is shown in **Figure 7***. The Keithley Model 2657A High Voltage SMU Instrument provides power to the drain terminal of all 240 DUTs, which are connected in parallel. Maximum current available from the Model 2657A at voltages of 1200V–1320V is 120mA, so there is plenty of capacity. In fact, the Model 2657A can supply power to multiple batches. Current limiting resistors are placed in series with each DUT in case of device failure.

The Keithley Model 2635B SMU Instrument is used to measure the leakage current (I_d) of each device at the source terminal, and is connected to each device through the Keithley Model 3706A Switch System with Model 3720 Switch Cards.

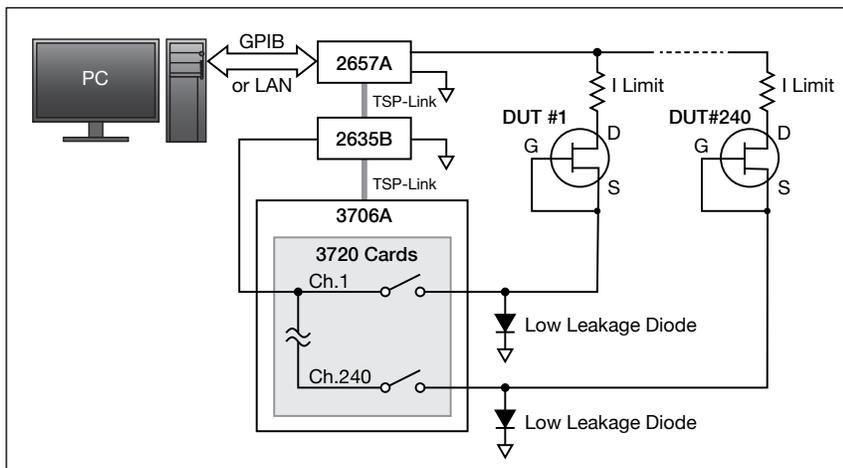


Figure 7.

*This example is for illustrative purposes only. Full test system design and adherence to proper safety guidelines and procedures are the responsibility of the designer and operator.

A low-leakage diode is also placed at the source terminal in parallel with each switch. When a given switch is open, any leakage current from the DUT will flow through this diode. When a given switch is closed, the leakage current for that DUT will flow through the Keithley Model 2635B (since its output is 0V when measuring current). The Model 3720 Switch Cards are configured for single-pole switching, and each card has a 60-channel capacity; therefore, four switch cards are used (the Model 3706A Switch System chassis has a total capacity of six switch cards). The scanning speed of the Model 3720 Switch Card is 120 channels per second.

For maximum system speed and programming simplicity, the TSP-Link intercommunication bus is used to connect the three instruments together. Only one connection is needed to the PC controller, and this is through the Model 2657A over GPIB or LAN (LXI). The PC controller contains the main test program that calls the TSP scripts (subroutines) that reside inside the Model 2657A's non-volatile memory. Keithley's TSP technology enables all instrument control and most data management to be performed at the instrument level, thus eliminating the typical GPIB or LAN traffic delays that slow system-level throughput in instrument-based systems.

In this example, Keithley's Series 2600B and 2650A System SourceMeter SMU Instruments and Series 3700A Switch Systems are used to meet the accuracy, resolution, power, and speed requirements of today's semiconductor reliability test applications.

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