Application Note Series

Number 3249

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 enabling 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 passive 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 237, 2410, and 2657A SMU instruments. Most recently, Keithley released the Model 2290-5 5kV and Model 2290-10 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 that the device is robust and reliable. The models 2290-5 and 2290-10 Power Supplies have a voltage range wide enough to test many of the industry's future devices.

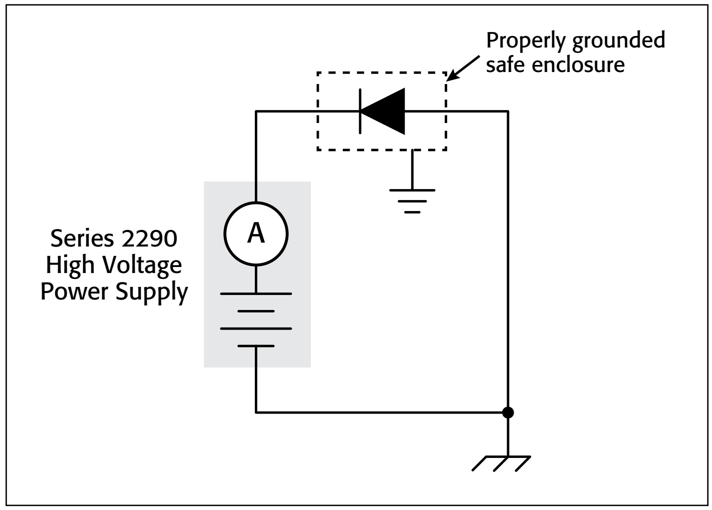

Figure 1. Typical breakdown voltage measurement of a high voltage diode using the Series 2290 High Voltage Power Supply.

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/relay that disengages the interlock of the Series 2290 Power Supply.
- 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 to interface to the device under test (DUT).

Leakage Current Measurements

In a typical power conversion application, the semiconductor device is used as a switch. Leakage current measurements indicate how closely the semiconductor performs to an ideal switch. Also, when measuring the reliability of the device, leakage current measurements are used to indicate device degradation and to make predictions of device lifetime.

Semiconductor researchers are finding materials to make higher quality switches and produce devices with very small leakage currents. Such currents may fall below the measurement capability of the Series 2290 Power Supplies. In such cases, couple the accurate sourcing ability of the Series 2290 Power Supply with the precision low current measurement ability of a Keithley SMU instrument. Using Keithley SMU instruments improves the low current measurement resolution and accuracy and also improves the accuracy of the current limit. As an example, Keithley Models 2635B and 2636B SourceMeter® SMU instruments have four current ranges at 1μA and below. The current limit of the Keithley SMU instrument can be configured as small as 10% of a range.[1]

To prevent unwanted measurement error when measuring currents less than 1μA, use triaxial cables and electrostatic shielding. Triaxial cables are essential in part because they permit carrying the guard terminal from the current measurement instrument. Guarding eliminates the effect of system leakage currents by routing them away from the measurement terminal. Use an electrostatic shield to shunt electrostatic charges away from the measurement terminal. An electrostatic shield is a metal enclosure that surrounds the circuit and any exposed connections. The safe test enclosure may serve as an electrostatic shield. For more tips on optimizing low current measurements, refer to Keithley's *Low Level Measurements Handbook, 7th Edition*.

Safety Considerations

Review system safety whenever a new element, in this case the SMU instrument, is added to the test circuit. In addition to the safety issues considered under the topic of breakdown voltage testing, the Series 2600B SMU Instrument is also capable of generating voltages up to 200V. Like the Series 2290 power supplies, Keithley Series 2600B SMU instruments have a safety interlock to ensure operator safety during changes in the test setup. For optimum system safety, the interlock of the Series 2600B SMU Instrument should be wired in parallel with the Series 2290 Power Supplies. An example of this is shown in ***Figure 2***.

As a part of the system safety review, consider all potential consequences of device failure. In a setup where both a Series 2290 Power Supply and a Series 2600B SMU Instrument are employed, a device breakdown could result in high voltage appearing at the input terminals of the SMU instrument. Because the SMU instrument is not designed to handle these higher voltages, it must be protected against possible damage by the high voltage power supply. The Model 2290-PM-200 Protection Module can be used for this purpose. The same module can be used regardless of whether a Model 2290-5 5kV or Model 2290-10 10kV High Voltage Power Supply is used in the test circuit (see

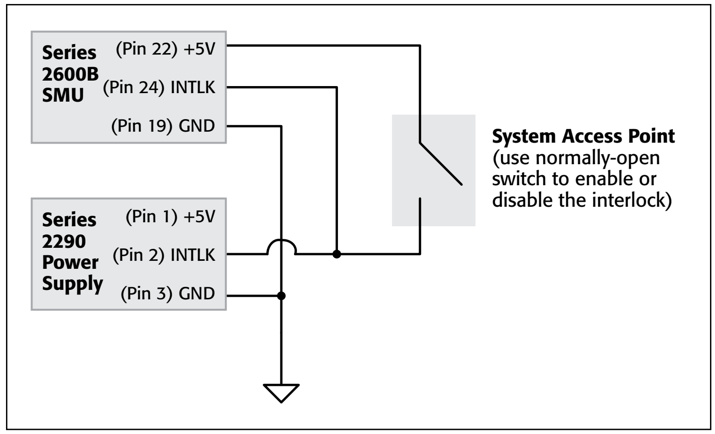

Figure 2. Correct wiring of interlocks from a Series 2600B SMU instrument and a Series 2290 Power Supply to a single system access point, e.g. test fixture lid.

Figure 3. The Model 2290-PM-200 Protection Module permits safe connection of a single 200V SMU instrument into the test circuit. It is designed to be used in a test circuit with either the Model 2290-5 5kV or the Model 2290-10 10kV Power Supply.

Figure 3). ***Figure 4*** illustrates the placement of the Model 2290-PM-200 in the test circuit.

Using the test setup shown in ***Figure 4***, the actual test results when measuring leakage current of a high voltage diode are displayed in ***Figure 5***. The diode has a maximum specified reverse current of 10μA when 3300V is applied at room temperature. The results show that the diode meets its specification. The reverse current grows at a faster rate as the reverse voltage increases, indicating that the diode is approaching breakdown.

Figure 6 depicts the actual test results when measuring the collector-emitter cutoff current of a 4000V IGBT. In this test, the gate and emitter terminals are shorted to ensure that the device remains off (***Figure 7a***). An SMU instrument can also be used to actively program the gate voltage. Using an SMU instrument is useful if the leakage current measurements are desired with the device in hard cutoff (with a bias less than 0V at the gate terminal). ***Figure 7b*** depicts the setup using two SMU instruments and a Series 2290 Power Supply.

This particular IGBT has a maximum specified cutoff current of 100μA at 4000V. The performance of this IGBT is much better

1 The current limit of an SMU instrument is an active current limit and has a finite response time. To limit the maximum possible current in a circuit, use a series resistor.

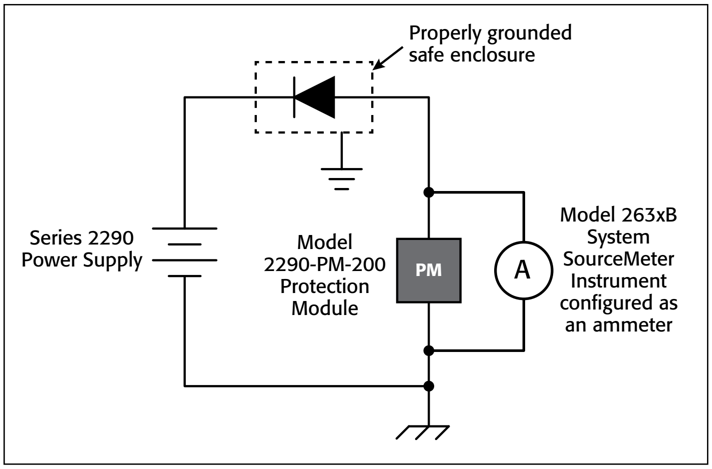

Figure 4. Characterizing the leakage current of a high voltage diode using a Series 2290 Power Supply with a Model 263xB SMU Instrument. Using the SMU instrument enhances the resolution and accuracy of both the current measurement and current limit.

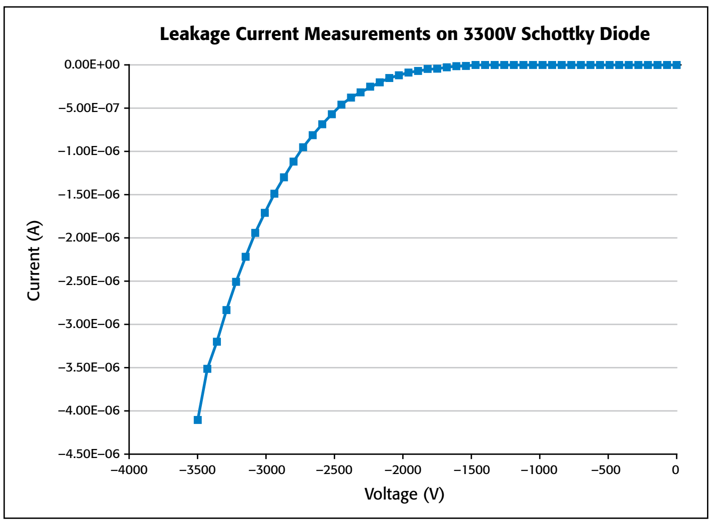

Figure 5. Measurements of 3300V Silicon Carbide Schottky diode. Voltage is applied with the Model 2290-5 5kV Power Supply and current is measured with the Model 2636B System SourceMeter SMU Instrument.

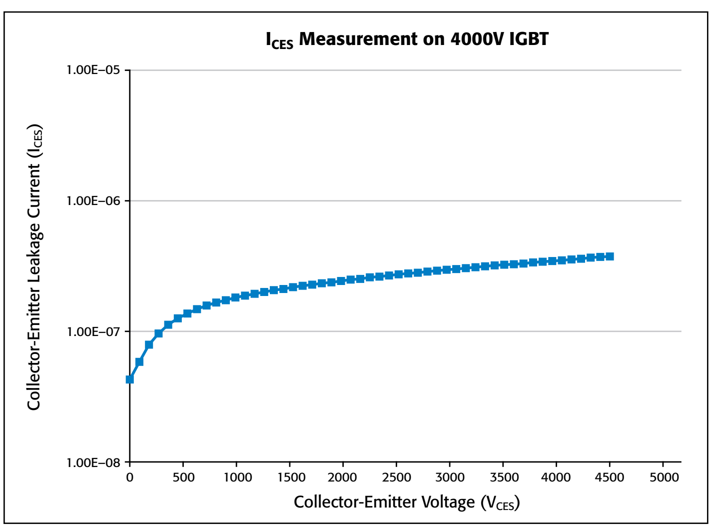

Figure 6. Ices measurements of 4000V IGBT. V_{CES} is applied with the Model 2290-5 Power Supply, and I_{CES} is measured with the Model 263xB SourceMeter SMU instrument. Gate and source terminals are shorted.

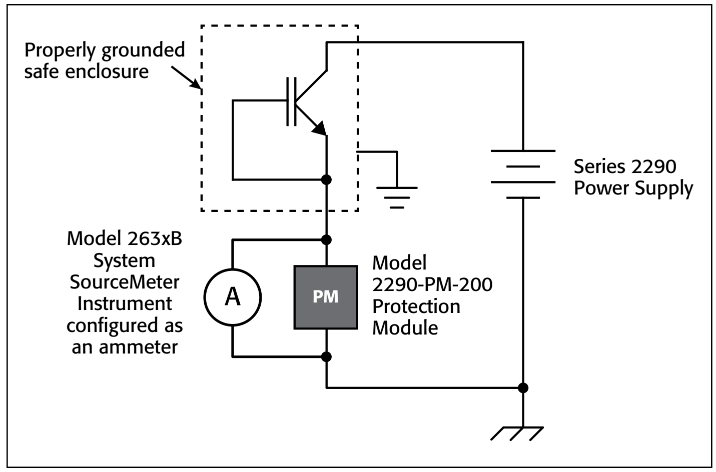

Figure 7a. Test setup using a Series 2290 Power Supply and the Model 263xB SourceMeter SMU Instrument to measure the cutoff current (I_{CES}) of an IGBT. The short between the gate and emitter terminals keeps the device in the off-state.

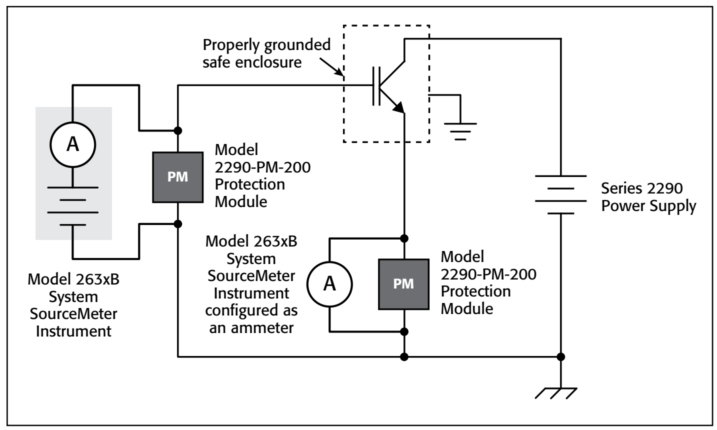

Figure 7b. Test setup using a Series 2290 Power Supply and two Model 263xB SourceMeter SMU instruments to measure the cutoff current (i_{CES}) of an IGBT. The SMU instrument connected to the gate terminal can be used to place a certain bias on the gate, e.g., to drive the device into hard cutoff.

than the specification. In fact, even at 4500V, the cutoff current is not increasing rapidly, thereby indicating that the device is not yet in breakdown.

The command sequence to generate the results shown in both ***Figures 5*** and *6* using either the Model 2290-5 or the Model 2290-10 and the Model 2636B SourceMeter SMU Instrument is included in the Appendix. Note that open source language Python™ [2] is used to send the information to the GPIB interface.

Conclusion

Testing high voltage semiconductor devices involves a consideration of test system safety, wide voltage range, and accurate current measurement. Coupling a Keithley Series 2290 Power Supply with a Keithley SourceMeter SMU instrument and their associated accessories meets all these needs and further facilitates research of high voltage materials and semiconductor devices.

2 Find out more about Python programming language at http://www.python.org

Appendix

```
# Import pyVisa and time modules into the Python
environment
import visa
import time

# Open a VISA session with the 2290 at GPIB address 14
# and 263xB at GPIB address 26
ki2290 = visa.instrument("GPIB::14")
ki263x = visa.instrument("GPIB::26")

# Reset and clear the status of the 263xB
ki263x.write("reset()")
ki263x.write("*CLS")

# Reset and clear any errors of the 2290
ki2290.write("*RST")
ki2290.write("*CLS")
ki2290.write("*RCL 0")

# Configure the 263xB as an ammeter, set the current
limit
# and current measurement range
ki263x.write("smua.source.rangev = 0.2")
ki263x.write("smua.source.levelv = 0")
ki263x.write("smua.source.limiti = 1e-3")
ki263x.write("smua.source.autorangei = 1")
ki263x.write("smua.measure.lowrangei = 100e-9")

# Configure the display of the 263xB and turn on the
output
ki263x.write("display.screen = display.SMUA")
ki263x.write("display.smua.measure.func = display.
MEASURE_DCAMPS")
ki263x.write("smua.source.output = smua.OUTPUT_ON")

# Define sweep variables for the programmed output
voltage
# and measured current readings
voltage = 0
currReading = ""
currRdgList = []
# Turn on the output of the 2290
time.sleep(1)
ki2290.write("HVON")

print "Running Sweep . . . "

# Perform a sweep from 0 to 4500V and make current
measurements
# at each point of the sweep
for n in range(0,51):
    ki2290.write("VSET " + str(voltage))
    time.sleep(2) # Allow new voltage level to stabilize
    currReading = ki263x.ask("print(smua.measure.i())")
    time.sleep(1) # Allow measurement to be taken
    currReading = float(currReading)
    currRdgList.append(currReading)
    voltage = voltage + 100

# Set the voltage of the 2290 to 0V and turn off its
output
ki2290.write("VSET 0")
ki2290.write("HVOF")

# Turn off the output of the Model 263xB
ki263x.write("smua.source.output = smua.OUTPUT_OFF")

# Print the current measurements
print "Sweep Complete. Current Measurements: ",
currRdgList
```


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