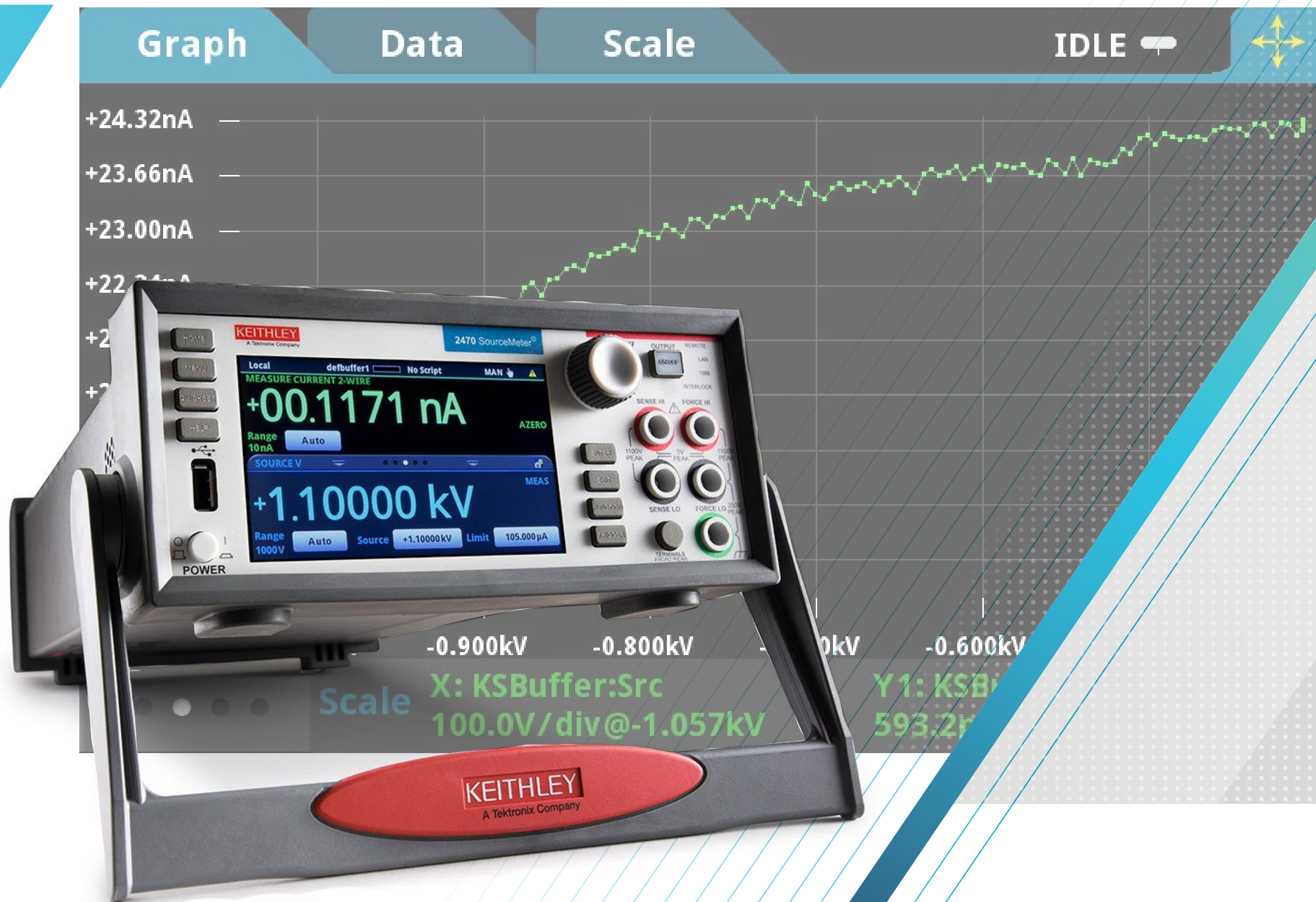
Breakdown and Leakage Current Measurements on High Voltage Semiconductor Devices Using the Keithley 2470 SourceMeter® Source Measure Unit (SMU) Instrument and KickStart Software

APPLICATION NOTE



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Introduction

After years of research and design, Silicon Carbide (SiC) and Gallium Nitride (GaN) power devices are becoming more viable. The shift to SiC and GaN is driving new designs from the ground up. SiC, with its capability of driving high power at high voltages for high power applications, and GaN, with its super high-power density for medium to low power applications, are pushing the limits of what is possible with silicon-based designs in efficiency and power density. For example, SiC is finding applications in higher power, higher voltage designs such as motor drives in automobiles, locomotives, and PV inverters. GaN technology is also shaking up the world of RF power amplifiers, thanks to many of the same attributes that make it well-suited for power conversion. GaN is carving its niche in data-center power, wireless power, consumer power supplies, and automotive and military/government power electronics.

These devices, though high performance, come with challenges. Setting cost and reliability aside, these power devices are not drop-in replacements for their silicon counterparts. Semiconductor R&D engineers are working to validate and characterize new components. Driver manufacturers are developing new gate drivers to withstand the demands of faster switching, EMI management, and more sophisticated topologies. Manufacturing engineers in these companies are dealing with wafer testing challenges – having to thoroughly test smaller devices over wider voltage and current ranges than ever. Manually characterizing wafer and package-part level devices for electrical performance requires learning new techniques, equipment, and probing infrastructure for low level measurement (e.g., pA of leakage current measurement in the presence of high breakdown voltage).

Some of the biggest challenges working with SiC and GaN devices are the gate drive requirements. SiC requires much higher gate voltage (V_{gs}) with a negative bias for turn off. GaN, on the other hand, has much lower threshold voltage (V_{th}), requiring tight gate drive designs. Wide band gap (WBG) devices, by the nature of their physics, also have a higher body diode voltage drop that requires much tighter control of dead-time and turn-on/turn-off transitions. Solving these challenges are not trivial. It's critical that you have accurate electrical source and measure testing when characterizing these high voltage devices so that the right design decisions can be made in a timely fashion. Increasing design margins and overdesigning will only drive costs up and bring performance down. And, due to the high voltages involved - usually >200 V, keeping the scientist and engineer safe from harmful voltage is very important.

Keithley has long had a strong presence in high power semiconductor device test. Most recently, Keithley introduced the 2470 1.1kV Graphical SourceMeter® Source Measure Unit (**Figure 1**) to address challenging measurements for SiC and GaN device testing. This application note considers the application of this new source measure unit with Keithley's KickStart software for high voltage semiconductor device testing.

Figure 1: Keithley's high voltage 2470 Graphical SMU

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 2** depicts a breakdown measurement on a high voltage diode using a source measure unit like the 2470. Note how the SMU is connected to the diode's cathode 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 2470's 1100-volt sourcing capability is typically high enough to test many SiC and GaN devices today and future device designs.

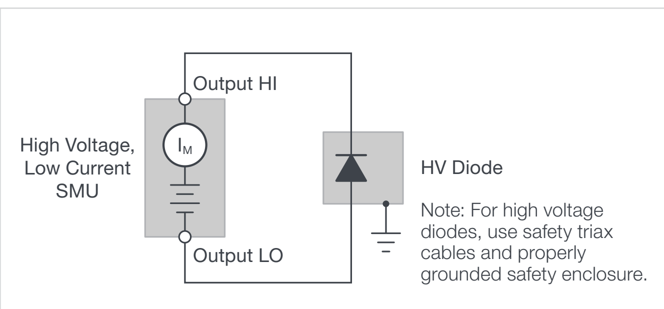

Figure 2. Typical breakdown voltage measurement of a high voltage diode using the 2470 High Voltage SMU.

Safety Considerations

When testing at high voltage, safety is of utmost concern. The 2470 SMU can generate voltage voltage up to 1.1 kV, 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 such as the fixture shown in **Figure 3**.
- Use the safety interlock provided on the rear panel of the 2470 SMU as shown in **Figure 4**. The 2470 is fully interlocked so that the high voltage output is turned off if the interlock is not engaged. The interlock circuit of the SMU 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 meet 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 2470 SMU.
- Use cables and connectors rated to the maximum voltage in the system. Keithley's TRX-1100V-* high voltage triax cables are designed for the 2470 which meet today's high voltage safety standards.
- Always use the proper safety gloves when working with high voltages on energized components as shown in **Figure 5**.

Figure 3: Properly grounded testing fixture

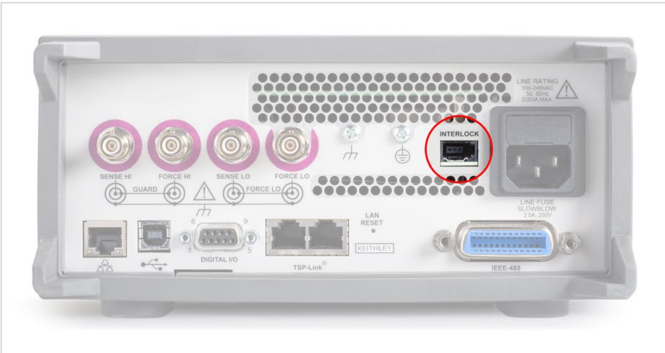

Figure 4: Location of safety interlock connection on rear panel of 2470 SMU

Figure 5. Using proper safety gloves when working with high voltages on energized components.

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 high power devices with very small leakage currents. SMUs like the 2470 offers precision low current measurement capabilities with measurement resolution as low as 10 fA.

To prevent unwanted measurement error when measuring currents less than 1 µA, 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*.

Characterizing a SiC Power Diode with KickStart Software

Keithley's KickStart software can be used to quickly run breakdown and reverse leakage current testing with the 2470. KickStart simplifies what you need to know about the instrument so that in just minutes you can take the instrument out of the box and get real data on your device. By plotting data immediately and offering quick statistical summaries of the data in the reading table, KickStart allows you to gather insights faster and make the decisions you need to move on to the next stage of device development. The software saves you time by facilitating quick replication of tests and comparison of results using convenient export features.

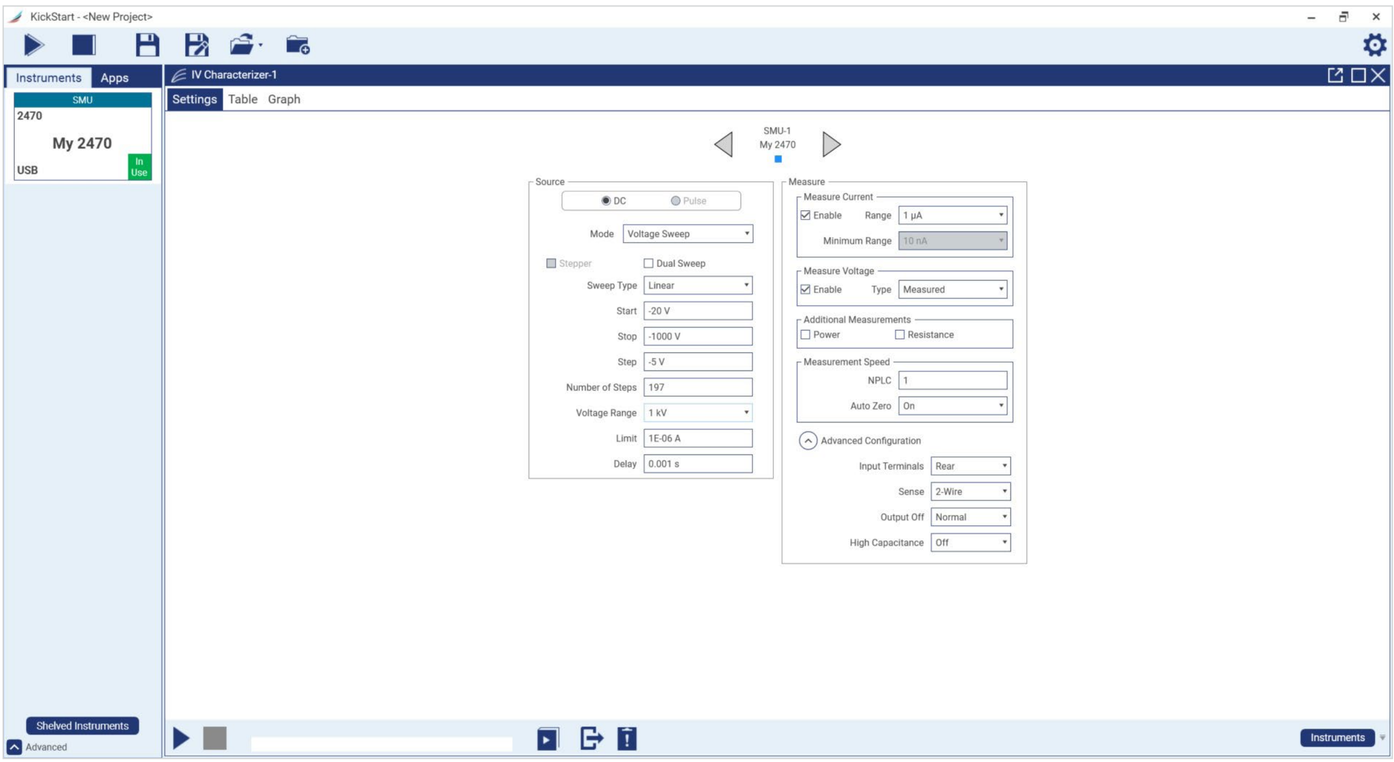

Figure 6. KickStart software and IV Characterizer App

For this example, we will measure the leakage current on a high voltage ultrafast soft recovery silicon carbide rectifier diode. The diode has a maximum specified reverse current of 100 µA when 1000 V of reverse voltage is applied at room temperature. To set up the test, the diode is inserted into a test fixture as shown in **Figure 7**. The test fixture also incorporates a safety interlock using a magnetic relay switch to ensure that if the top cover is off the fixture, the SMU output turns off to prevent someone from coming in contact with high voltages.

Figure 7. Test Fixture for testing the high voltage diode which includes a safety interlock relay system.

The key test parameters are as follows:

- Linear Sweep
- Start Point: –20 V
- Stop Point –1000 V
- Step: –5 V
- Current Limit: 1 µA
- Measure Current Range: 1 µA
- Source Voltage Range: 1 kV
- Measurement Speed: 1 NPLC
- Auto Zero: On

The 2470's rear inputs will be used since the test required the use of high voltage triax connections. The test parameters are set up as shown in **Figure 8**.

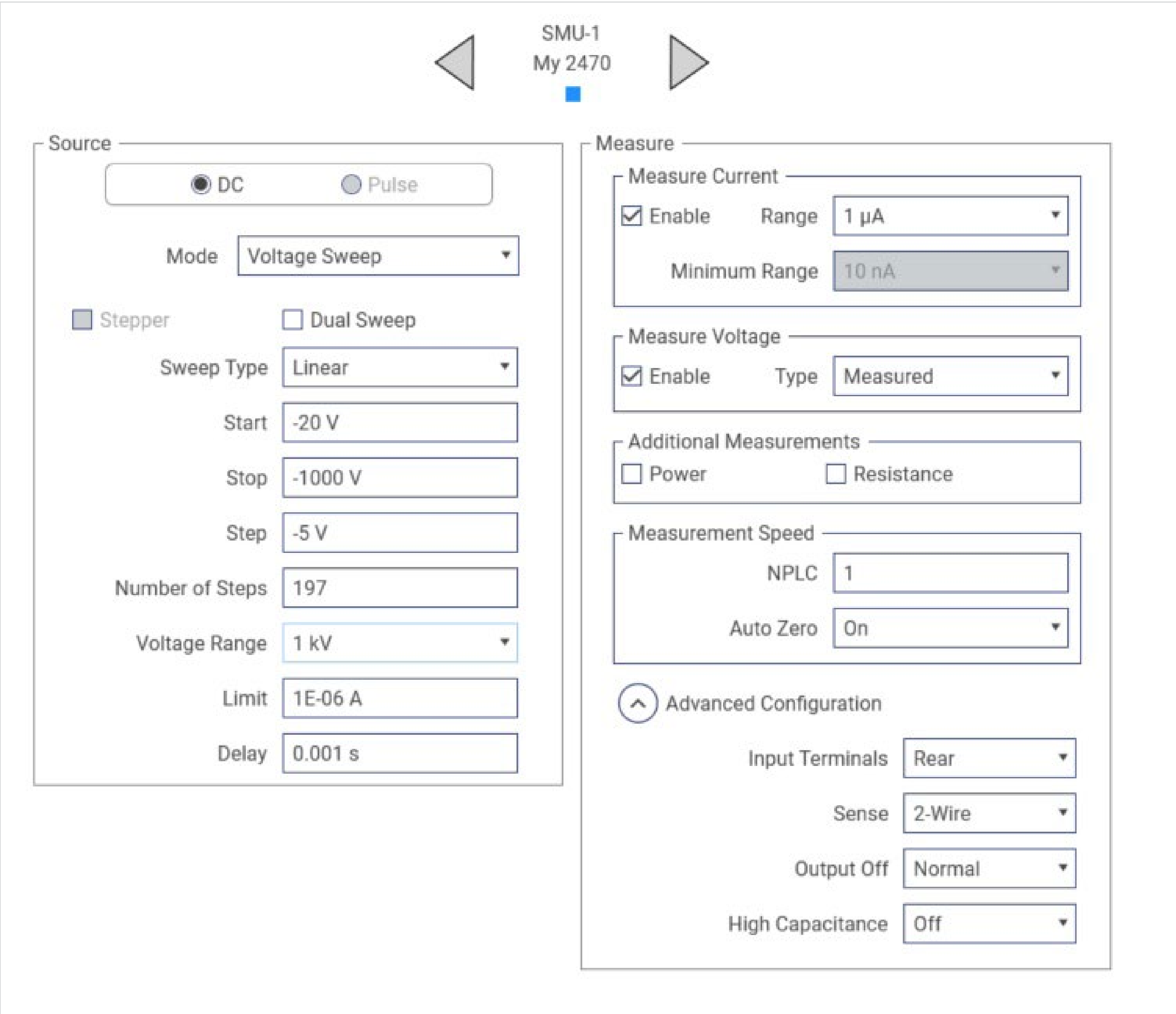

Figure 8: Test setup using Kickstart.

The KickStart test can now be initiated and viewed on the Graph Screen. The results of the test are shown in Figure 9.

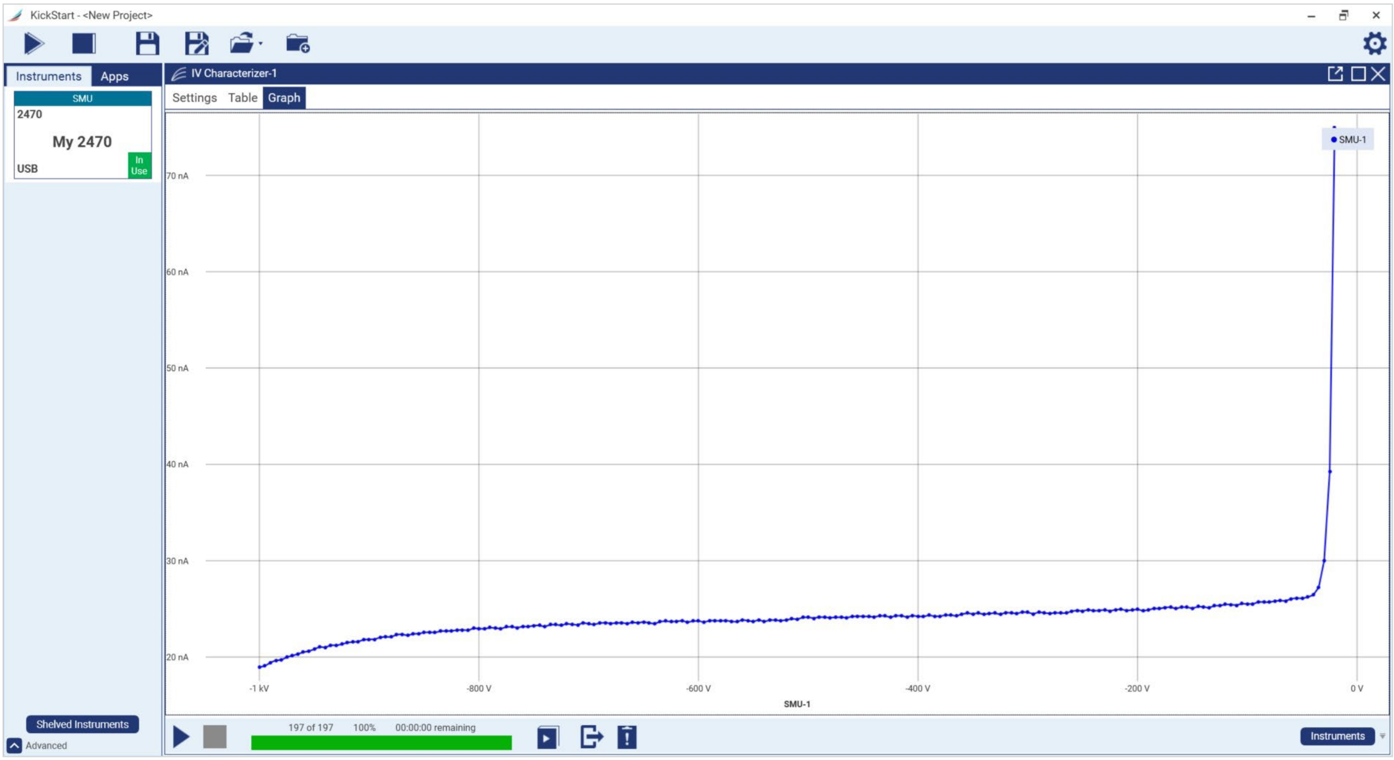

Figure 9: Leakage current results of High Voltage Diode using 2470 and KickStart

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. With KickStart, we can zoom in on the area of the chart to show the reverse current growing fast as the test voltage increases as shown in **Figure 10**.

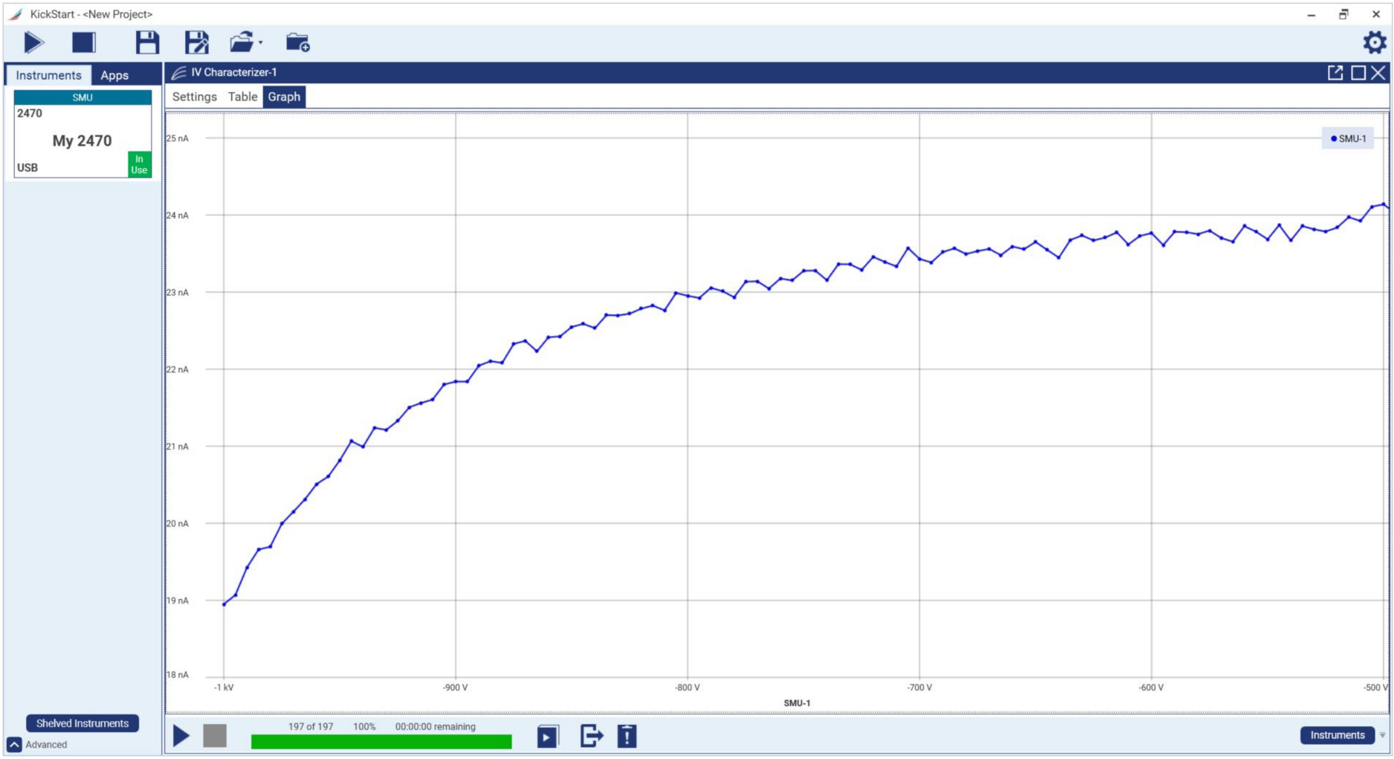

Figure 10: Zooming in with Kickstart.

The 2470 can also plot the results in real time and screen shot capture the plot. The results of the test as graphed and zoomed in on the 2470 are shown in **Figure 11**.

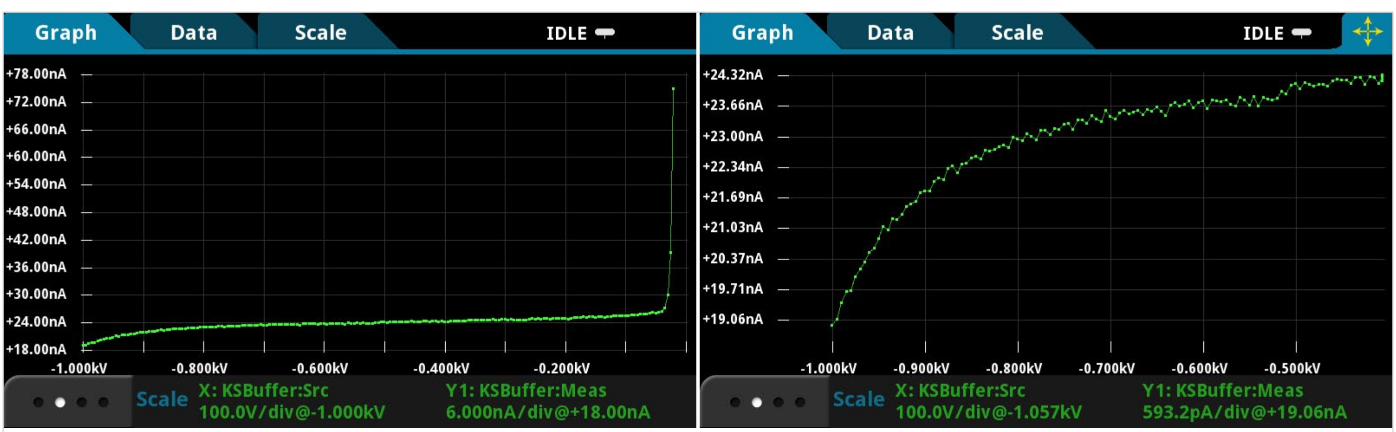

Figure 11: Screen captures from the 2470.

Conclusion

Testing new silicon carbide and gallium nitride high voltage, high power semiconductor devices involves a consideration of test system safety, wide voltage range, and accurate current measurement. Coupling a Keithley SourceMeter SMU instrument like the 2470, KickStart software, and their associated accessories meets all these needs and further facilitates research of high voltage materials and semiconductor devices.

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