

Easy I-V Characterization of Diodes Using the Model 2450 SourceMeter[®] SMU Instrument

Introduction

Diodes are two-terminal electronic devices that typically enable current to flow in one direction (forward bias) and block the current from flowing (reverse bias) in the opposite direction. However, there are many types of diodes that perform various functions such as Zener, light emitting (LEDs), organic light emitting (OLEDs), Shockley, avalanche, photodiode, etc. Each of these specific types of diodes can be differentiated by their current-voltage (I-V) characteristics. I-V testing of diodes is performed in research labs as well as in a production environment on packaged devices or on a wafer.

I-V characterization of a diode typically requires a sensitive ammeter, voltmeter, voltage source, and current source. Being able to program, synchronize, and connect all these separate instruments can be cumbersome and time consuming, as well as require a considerable amount of rack or bench space. To simplify testing and reduce rack space, a single unit, such as Keithley's Model 2450 SourceMeter SMU Instrument, is ideal for diode characterization because it can source and measure both current and voltage. The Model 2450 can sweep the source voltage and measure current over many decades (10^{-11} A to 1A), which is required for diode testing. These measurements can be generated automatically over the bus or just as easily via the large touchscreen, which enables the user to set up tests and graph them on the screen. The Model 2450 is pictured in *Figure 1* sourcing voltage and measuring current on a red LED that is connected to its inputs in a four-wire configuration.



Figure 1. Model 2450 SourceMeter SMU Instrument measuring the I-V characteristics of a red LED.

This application note explains how to perform I-V characterization on diodes easily using the Model 2450 SourceMeter SMU Instrument. In particular, it describes how to take, graph, and store measurements using the front panel user interface, as well as how to automate the measurements over the bus.

Diode I-V Tests

In general, the parameter testing of diodes typically involves being able to source and measure both current and voltage over a wide range. For example, while sweeping a forward voltage from 0V to about 1V, the resulting measured current can range from 10^{-12} A to 1A. However, the actual magnitudes, the types of I-V tests, and the parameters extracted are dependent on the particular diodes to be tested. To test an LED, the user will want to measure the luminous intensity as a function of an applied current, whereas an engineer testing a Zener diode will want to know the “clamped” or Zener voltage at a particular test current. However, there are many common tests among the various types of diodes.

A typical diode I-V curve is shown in *Figure 2* indicating the forward, reverse, and breakdown regions, as well as common test points, the forward voltage (V_F), leakage current (I_R), and the breakdown voltage (V_R). The forward voltage test (V_F) involves sourcing a specified forward bias current within the normal operating range of the diode, then measuring the resulting voltage drop. The leakage current test (I_R) determines the low level of current that leaks across the diode under reverse voltage conditions. This test is performed by sourcing a specified reverse voltage, then measuring the resulting leakage current. In the reverse breakdown voltage test (V_R), a specified reverse current bias is sourced and the resulting voltage drop across the diode is measured.

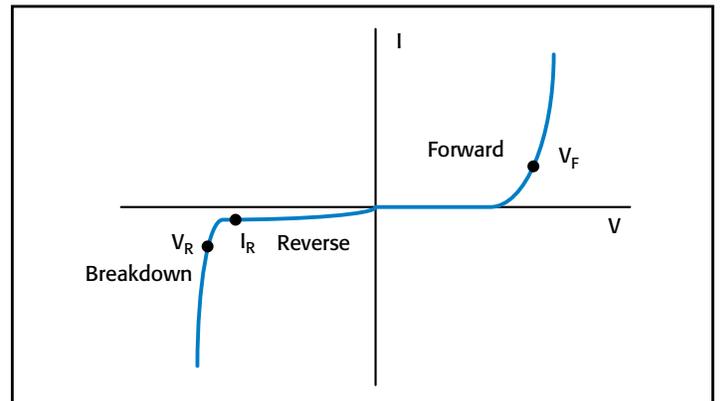


Figure 2. Current-voltage curve of a typical diode showing the forward, reverse, and breakdown regions.

Making Connections from the Diode to the Model 2450

The diode is connected to the Model 2450 as shown in *Figure 3*. A four-wire connection is made to eliminate the effects of lead

resistance. When connecting the leads to the diode, notice that the Force HI and Sense HI leads are connected to the anode terminal of the diode, and the Force LO and Sense LO leads are connected to the cathode. Make the connections as close as possible to the device to keep the lead resistance from affecting the measurement accuracy. This is especially true when sourcing or measuring high current or low voltage.

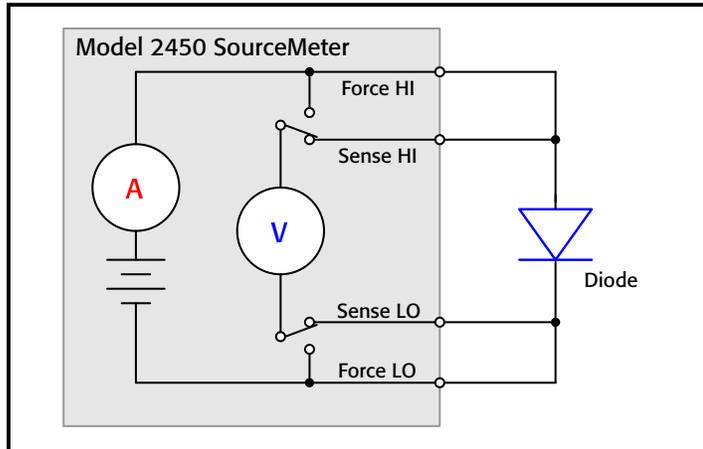


Figure 3. Connections of the Model 2450 to a diode.

When measuring low-level current ($<1\mu\text{A}$), it is recommended to use the four rear panel triax connectors with triax cables instead of using the front panel banana jacks. Triax cables are shielded and will reduce the effects of electrostatic interference, which may cause noisy readings. Figure 4 shows the rear panel triax connections to a diode.

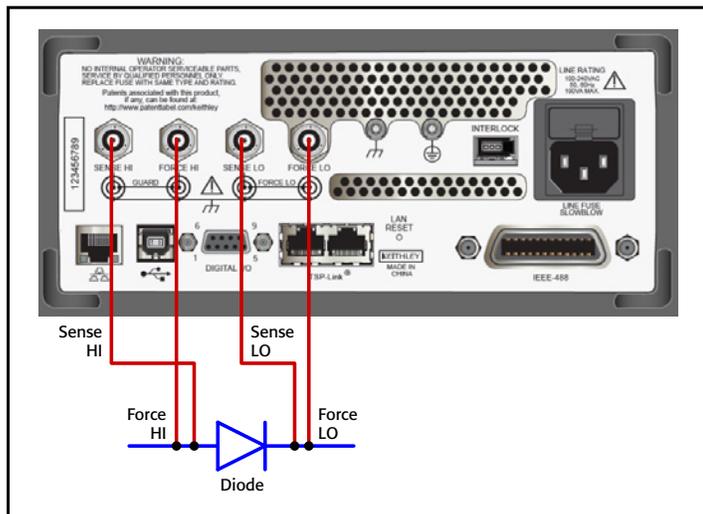


Figure 4. Model 2450 rear panel triax connections to diode.

In addition to using triax cables, the diode should be placed in a light-tight metal shielded enclosure. Proper shielding and other low current measuring techniques should be applied. Information on these topics can be found in Keithley's *Low Level Measurements* handbook, which can be downloaded from Keithley's website at www.keithley.com.

Generating Sweeps and Plotting Graphs on the User Interface

Diode tests and sweeps can be easily performed via the front panel user interface of the Model 2450. Just a few key strokes are needed to generate and view an I-V curve. Here are the easy steps to do this:

Steps to Generate, Execute, and View I-V Curve

Step	Key Strokes
Reset instrument to default state	Menu key → Manage System → System Reset
Set for rear terminals	Press Rear Terminal button if measuring from rear
Set to Source V and Measure I (this should be default state after Reset)	Home key → Function key → Source V Measure I
Set to 4-Wire Sense	Menu key → Measure Settings → Sense Mode → 4-Wire Sense
Set-up V sweep	Menu key → Source Sweep – Set desired Start, Stop, and Step V – Set Source Limit (scroll down) – Set a Source Delay Press Generate to create sweep
View Graph	Menu key → Views Graph – Change to log scale by pressing Scale tab and press Scale Format and select Log
Execute Sweep	Press TRIGGER key

Figure 5 shows the results of graphing the 1N3595 diode from 0V to 0.9V in 181 steps (5mV steps). Notice that 12 decades of current are plotted on the large display. The I-V sweep can be repeated by simply pressing the TRIGGER key.

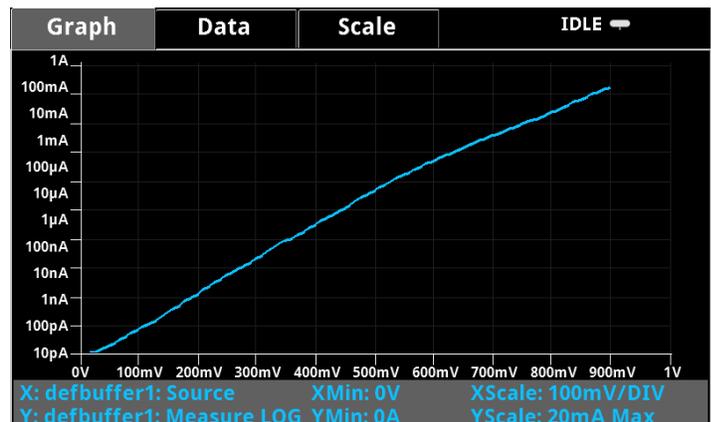


Figure 5. Model 2450 screen capture of I-V curve of diode.

Saving Data to a USB Drive

The generated sweep data can be saved as a .csv file to a USB drive. Simply insert a USB drive into the front panel USB port, press the MENU key, press Data Buffers, select the correct data buffer (defbuffer1 is the default), and press Save to USB. If you want to change the file name, enter the new file name and press Enter. Press Yes to confirm the file save. The data is now saved on the USB drive.

Automating Measurements Using the Model 2450

The Model 2450 can be remotely controlled by using either SCPI or Test Script Processor (TSP®) commands with the flexibility of a LAN, USB, or GPIB interface. An example of how to program the Model 2450 to automate the I-V sweeps was performed using the 1N3595 diode. For this particular test, the Model 2450 was programmed to sweep voltage from 0V to 0.9V in 181 steps (5mV steps) and measure the resulting current with a 100ms time delay. The actual TSP code to perform this test is in Appendix A. The results of plotting the generated I-V measurements into a spreadsheet are shown in *Figure 6*.

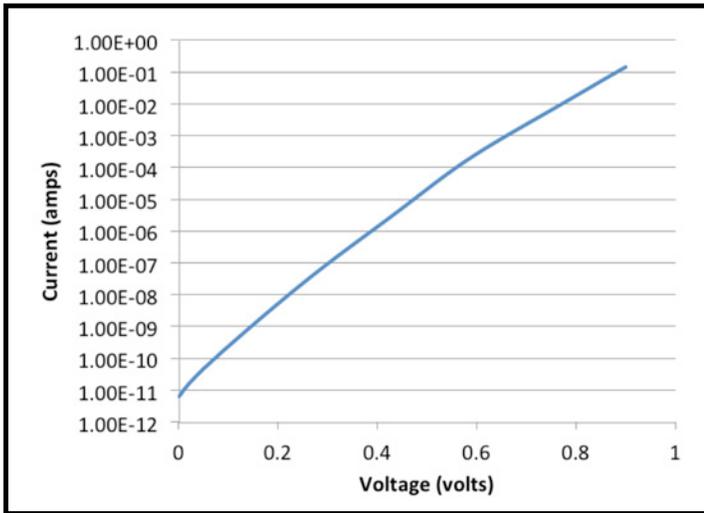


Figure 6. Forward voltage I-V sweep of 1N3595 diode generated by a Model 2450.

Appendix A: Example TSP Code to Generate I-V Sweep

The following example TSP code is designed to be run from Keithley Instruments' Test Script Builder (TSB) software. TSB is a software tool included with the Model 2450. To use other programming environments, you will need to change the example TSP code. For this particular test, the Model 2450 is programmed to sweep voltage from 0V to 0.9V in 181 steps and to measure the resulting current using a four-wire configuration. The time delay is set to 100ms.

```
--Reset the instrument
reset()
defbuffer1.clear()

--Measure Settings
smu.measure.func = smu.FUNC_DC_CURRENT
smu.measure.autorange = smu.ON
smu.measure.nplc = 1
smu.measure.sense=smu.SENSE_4WIRE
smu.measure.terminals = smu.TERMINALS_REAR

--Source Settings
smu.source.func = smu.FUNC_DC_VOLTAGE
smu.source.ilimit.level = 0.3
smu.source.sweeplinear('diode', 0, 0.9, 181, 0.1)

--Run trigger model and wait for it to complete
trigger.model.initiate()
waitcomplete()

--Print Results
if defbuffer1.n == 0 then
    print("Buffer is empty\n")
else
    print("Voltage\tCurrent\tTime")
    for i=1,defbuffer1.n do
        print(string.format("%g\t%g\t%g",
defbuffer1.sourcevalues[i], defbuffer1.readings[i],
defbuffer1.relativetimestamps[i]))
    end
end
end
```

Appendix B: Example SCPI Code to Generate I-V Sweep

The example sequence of SCPI commands is designed to generate an I-V sweep on a diode. You must make the appropriate changes so it will run in your programming environment. In this particular example, the voltage is swept from 0V to 0.9V in 181 steps (5mV steps) and the resulting current is measured. The current and voltage readings are stored in the buffer, defbuffer1.

SCPI Command	Description
*RST	Reset the instrument.
SENS:FUNC "CURR"	Set to measure current.
SENS:CURR:RANG:AUTO ON	Turn on measure autorange.
ROUT:TERM REAR	Set to rear terminals.
SYST:RSEN ON	Turn on 4-wire sense.
SOUR:FUNC VOLT	Set to source voltage.
SOUR:VOLT:ILIM 300e-3	Set the source limit level to 300mA.
SOUR:SWE:VOLT:LIN 0, 0.9, 181, 0.1	Set up a linear sweep from 0 to 0.9V in 181 steps with 100ms delay
INIT	Initiate the sweep.
*WAI	Wait for the sweep to complete.
TRAC:DATA? 1, 181, "defbuffer1", READ, SOUR, REL	Get the readings, source values and relative timestamps from the buffer.

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