

Pulse Testing for Nanoscale Devices

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Introduction

Nanotechnology research works with matter at the molecular level, atom by atom, to create structures with fundamentally new properties. In particular, the field of nanoelectronics is developing especially rapidly with potential impact across a wide range of industries. Nanoelectronics research today includes devices that utilize carbon nanotubes, semiconductor nanowires, molecular organic-based electronics, and single-electron devices.

Unfortunately, these smaller devices can't be tested using standard test techniques for a number of reasons. One key reason is the physical size of the devices. The nanoscale dimensions of some of the new 'beyond CMOS' devices can be susceptible to damage from even small amounts of current used in the measurement process. In addition, traditional DC test techniques are not always adequate to reveal how devices really operate. Consequently, designers need new testing techniques and test tools. One such technique is pulse testing, and it is essential for the new generation of nanoelectronic devices.

Pulse Testing Techniques

Pulsed electrical testing is a measurement technique that reduces the total energy dissipated in a device. It reduces the joule heating effects (such as I^2R and V^2/R) that could potentially damage small nanoscale devices. The device under test (DUT) is excited for a very short interval with a source high enough to produce a quality measurable signal, and then the source is removed.

Pulsing also gives engineers more data about the device, allowing for better characterization and understanding of device behavior. For example, pulse testing can be used for transient testing of a nanodevice to determine its transfer function and thereby characterize the material under test. Pulse test measurements are essential for devices with isothermal limitations, such as SOI devices, FinFETs, and nano devices, in order to avoid self-heating effects that could mask the response that the researcher is seeking. Pulsing also helps the device engineer to understand charge trapping effects. The effect of charge trapping is decreased drain current after a transistor is turned on. As charges are trapped in the gate dielectric, the threshold

voltage of the transistor increases due to the built-in voltage in the gate capacitor; therefore, the drain current decreases.

Pulse testing can be one of two different types: voltage or current pulsing.

Voltage pulsing produces much narrower pulse widths than current pulsing. This makes it more suitable for experiments in thermal transport where the time frame of interest is shorter than a few hundred nanoseconds. High amplitude accuracy and programmable rise and fall times are necessary to control the amount of energy delivered to a nanodevice. Voltage pulsing is useful for transient analysis, charge trapping, and AC stress tests during reliability testing, as well as generating clock signals and simulating repeating control lines such as in memory read and write cycles.

Current pulsing is very similar to voltage pulsing. In this method, a specified current pulse is applied to the DUT and the resulting voltage across the device is measured. Current pulsing is often used to measure very low resistances or to obtain an I-V curve without putting significant power levels into the DUT that would otherwise damage or destroy a nanoscale device.

Both voltage and current pulse testing have many benefits but are not without some drawbacks. For example, the speed characteristics of an ultra-short voltage pulse are in the radio frequency (RF) domain, so it is very easy to introduce errors in the measurement if the test system is not optimized for high bandwidth. There are three main sources of errors: signal losses due to cables and connectors, losses due to device parasitics, and contact resistance.

Current pulsing is usually subject to slower rise times, perhaps as low as a few hundred nanoseconds. This is usually limited by the inductance and capacitance in the experimental setup.

Pulse I-V Testing

Performing current versus voltage (I-V) pulse characterization on nanoscale devices often requires measuring very small voltages or currents due to the necessity of applying a very small current or voltage, respectively, to control power or to reduce the joule heating effects. Here, lowlevel measurement techniques become important, not only for I-V characterization of devices but

also for resistance measurements of highly conductive materials. For researchers and electronic industry test engineers, this power limitation makes characterizing modern devices and materials, as well as future devices, challenging.

Unlike I-V curve generation on micro-scale components and materials, measurement on nanoscale materials and devices requires special care and techniques. I-V DC characterizations are typically performed using a two-point electrical measurement technique. The problem with this method is that if sourcing a current and measuring voltage, the voltage is measured not only across the device but includes the voltage drop across the test lead and contact, as well. If the goal is to measure the resistance of a device using a typical ohm meter to measure resistance greater than a few ohms, this added resistance is usually not a problem. However, when measuring low resistances on conductive nanoscale material or components, obtaining accurate results with a two-point measurement can be a problem even when using pulse testing.

If the Pulse I-V characterization or resistance measurement involves low voltage or low resistance, such as with molecular wires and semiconducting nanowires, a four-wire or Kelvin measurement technique with a probe station will yield more accurate results. With a Kelvin measurement, a second set of probes is used for sensing. Negligible current flows in these probes due to the high impedances associated with the sensing inputs; therefore, only the voltage drop across the DUT is measured. As a result, the resistance measurement or I-V curve generation is more accurate. Source and measurement functions for this measurement technique are typically provided by source measure units (SMUs), electronic instruments that source and measure DC voltages and currents.

Pulse testing can benefit from other basic low-level measurement techniques that are used with DC measurements. To make pulse

measurements effectively at low levels, pulse testing techniques should be used in combination with line frequency synchronization. By synchronizing the pulse measurement with the line frequency, any 50/60Hz line frequency noise is eliminated.

With applications requiring greater voltage sensitivity, even small errors can become important. One common way of avoiding these errors is to use a delta method. This is the difference between “before” and “during” readings, which corrects for DC offsets. Unfortunately, DC offsets tend to drift. This problem can be corrected with a similar technique known as the three-point delta method. Here, taking a third measurement after the pulse can correct for the drift.

Tools for Nano Testing

With nanoelectronic and semiconducting materials and films, sensitive electrical measurement tools are essential. They provide the data needed to fully understand the electrical properties of new materials and the electrical performance of new device and components. Instrument sensitivity must be much higher because electrical currents and voltages are much lower and many nanoscale materials exhibit significantly improved properties such as conductivity. The magnitude of measured current may be in the femtoamp range, voltage in the nanovolt range, and resistance as low as micro ohms. Therefore, measurement techniques and instruments must minimize noise and other sources of error that might interfere with the signal.

One such solution is the Keithley Model 4200-SCS Semiconductor Characterization System with 0.1fA (or 100attoamps) and 1μV resolution. A special Pulse I-V Package provides dual-channel pulse generation and measurement for making pulse I-V measurements. Combined with an internally installed high-speed pulse generator and scope, the Model 4200 with the PIV Package offers the ability to perform both DC and Pulse I-V testing together.

To minimize the signal reflections due to poor impedance matching that often plague custom built pulse testing systems, Keithley’s Model 4200 Pulse I-V Solution includes a system interconnect box, a Remote Bias-Tee or ‘RBT’ that provides AC/DC coupling to connect the pulse generator, and the DC instrumentation illustrated in *Figure 1*.

With this package, the researcher can perform both DC and Pulse IV testing together to understand device behavior, such as the

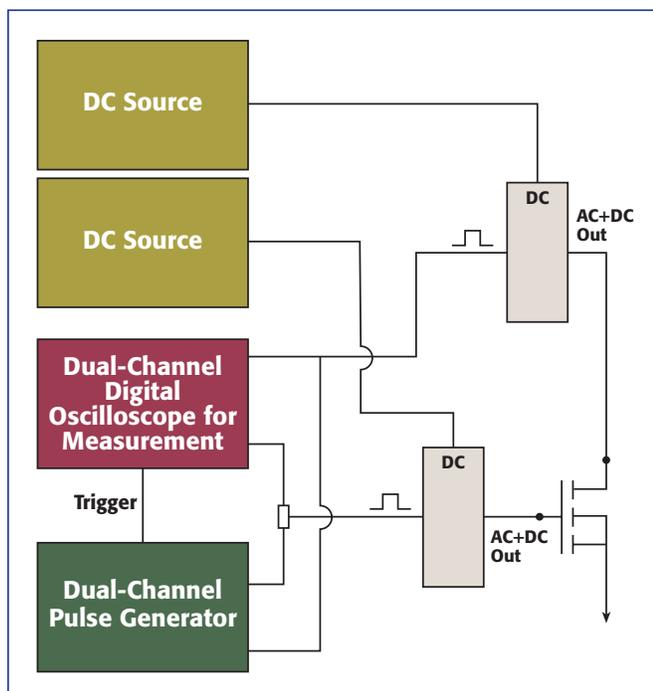


Figure 1. Schematic diagram of the Keithley Model 4200-PIV test system.

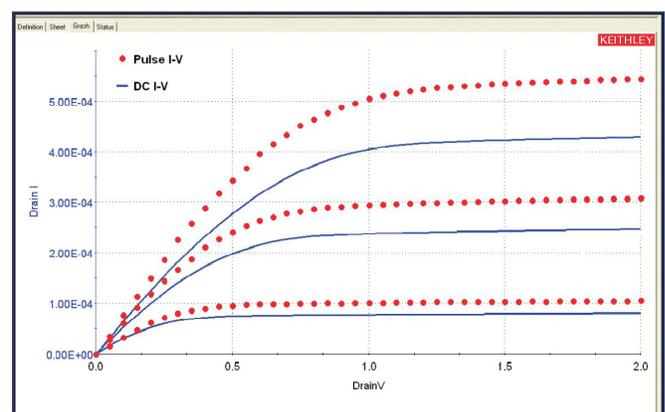


Figure 2. Pulse I-V versus DC I-V characterization of a family of FET curves.

family of curves for a FET device shown in *Figure 2*.

For very conductive materials or devices where a large magnitude change of resistance is involved, Keithley's Model 6221/2182A combination minimizes the amount of power dissipated into a DUT by allowing users to program the optimal pulse current amplitude, pulse interval, pulse width, and other pulse parameters. The Model 6221 makes short pulses (and reductions in heat dissipation) possible with microsecond rise times on all ranges. The Model 6221/2182A combination synchronizes the pulse and measurement—a measurement can begin as soon as 16 μ s after the Model 6221 applies the pulse. The entire pulse, including a complete nanovolt

measurement, can be as short as 50 μ s. Line synchronization between the Model 6221 and Model 2182A also eliminates power line related noise.

Lastly, Keithley's Series 3400 Pulse/Pattern Generators provide nanotechnology researchers the flexibility needed to handle varying application needs. Users can program pulse parameters such as amplitude, rise and fall time, pulse width, and duty cycle and can choose from several operating modes including pulse and burst modes for material and device characterization. A simplified user interface accelerates the learning curve, allowing users to set up and execute tests much quicker than competitive products.

Conclusion

Pulse testing provides a key capability for the investigation of nanomaterials, nanoelectronics, and today's semiconducting devices. Pulsing a voltage while simultaneously measuring the DC current is the basis for charge pumping, which is valuable for measuring inherent charge trapping in semiconducting and nanoscale materials. Pulsing current and measuring voltage gives the researcher the best opportunity for measuring very low resistances or performing I-V characterization on next generation devices while protecting these valuable devices from damage.

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