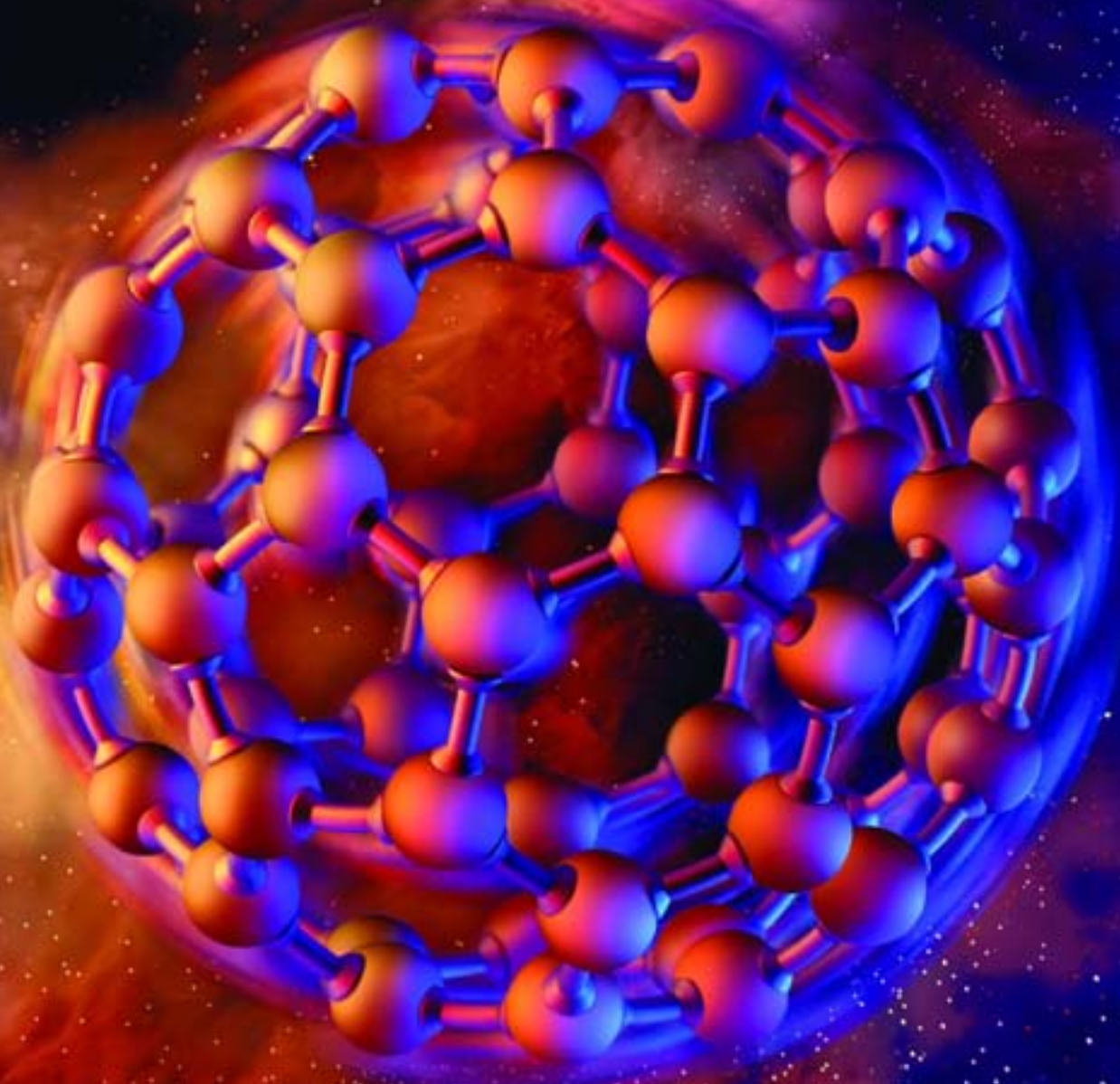


Measurement solutions for nanoscale device and materials characterization



KEITHLEY

A G R E A T E R M E A S U R E O F C O N F I D E N C E

The background of the slide is a blue-tinted molecular structure, possibly a protein or a complex polymer, with white text overlaid. The text is centered and reads:

Mapping the boundaries of nanotechnology from research to production

At nanoscale dimensions, some materials exhibit entirely new properties associated with quantum physical phenomena. These properties have applications in biotechnology, molecular electronics, alternative energy sources, and dozens of other disciplines. Although important breakthroughs have been made, a lot of uncharted territory remains. Keithley is helping to advance nanotechnology with sensitive instruments optimized for measuring the extremely small electrical signals associated with nanoscale devices and materials.

Keithley helps you gather data quickly, accurately, and with greater confidence

Why choose Keithley instrumentation for your nanotechnology application?

We're low level measurement instrumentation experts.

We bring more than a half-century of experience to our low level measurement solutions, so you can be confident of the accuracy of the results you get from Keithley instruments. We also design measurement solutions so that you don't have to be a measurement expert to use them. Just as important, our applications engineers are trained to help you choose the most cost-effective solution for your application.

We can help you transfer your discoveries from the lab to the fabrication environment. Keithley measurement solutions aren't confined to the R&D lab—they also offer the speed, robustness, and communications capabilities that high throughput production environments demand. We also have decades of experience in transferring measurement technologies from the lab to the production floor. That ensures you'll get high correlation in your test results.

We partner with other industry leaders. Keithley has developed working partnerships with leading suppliers of nanotech fixturing, probing, and scanning hardware so we can provide you with more complete test and measurement solutions.



I-V CHARACTERIZATION of nanoelectronics



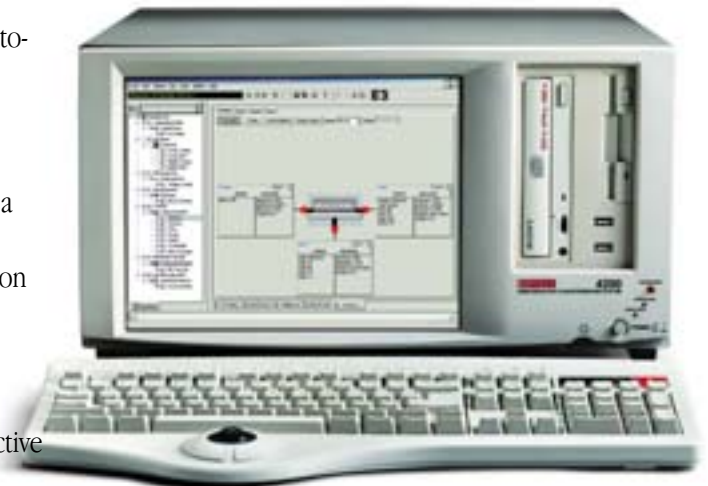
Helping nanotech pioneers around the world characterize next-generation electronics

Just imagine what you could discover about Carbon Nanotubes (CNTs), Single Electron Transistors (SETs), and other exotic nano-scale devices if you weren't limited by your instrumentation. Keithley's I-V characterization tools offer wide sourcing and measurement ranges to help you unlock the secrets of next generation components like these, accelerating the jump from the research lab into commercial production.

For further reading, download the Keithley White Paper, "*Improving Low Current Measurements on Nanoelectronic and Molecular Electronic Devices*," from www.keithley.com.

Model 4200-SCS Semiconductor Characterization System

- Fully integrated characterization system combines precision voltage and current sourcing and measurement in one easy-to-operate package.
- Built-in Project Navigator organizes tests and automates test sequencing, eliminating the need to write code.
- System connects directly to the DUT or can be interfaced to a variety of nanotech probe stations, nanomanipulators, Transmission Electron Microscopes (TEMs), Scanning Electron Microscopes (SEMs), etc.
- Optional preamps provide sub-femtoamp sensitivity for characterizing experimental devices.
- Nanotech Toolkit for the Model 4200-SCS includes 16 interactive test modules for characterizing the seven most common nanodevice structures. Available at www.keithley.com.
- Intuitive Windows®-based GUI minimizes system-specific training requirements and allows even first-time users to acquire data quickly.



Device Under Test	Application Needs	Keithley's Solutions
Carbon nanotube transistors, switches, and arrays Nano-bioelectronics Molecular electronic cells Molecular transistors	I-V measurements	Model 4200-SCS Semiconductor Characterization System Model 6430 Sub-Femtoamp Remote SourceMeter Instrument Series 2400 SourceMeter Instruments
Single electron transistors	Ultra-sensitive I-V measurements	Model 4200-SCS Model 6430
Molecular diodes	Breakdown voltage, I-V curves, conductance	Model 4200-SCS Model 6430 Series 2400
Nano-photovoltaics	I-V, C-V measurements	Model 4200-SCS Model 590 C-V Analyzer Model 6430 Series 2400

“The Model 4200-SCS makes it simple to obtain and analyze data, so we can learn the electronic characteristics of nano-devices almost immediately. It’s a very user-friendly design—it’s easy to set up and operate with no training needed.”

Dr. Iwao Ohdomari, Professor of Science & Engineering, Waseda University, Japan

SourceMeter® Instruments

- Each SourceMeter instrument is a complete, single-channel DC parametric tester.
- Tightly coupled source/measure engine minimizes test station development, set-up, and maintenance time.
- Choose from a variety of measurement ranges and functions to suit specific application needs: Model 2400 (general-purpose), Model 2410 (high voltage), Model 2420 (3A), Model 2425 (100W), Model 2430 (pulse mode), Model 2440 (5A), Model 6430 (sub-femtoamp resolution).
- Free LabTracer software (downloadable from www.keithley.com) can coordinate the operation of up to four Series 2400 SourceMeter instruments at once, and collect voltage and/or current readings from any of the instruments, as well as a timestamp for each measurement set.



For more information on *characterization of nanoelectronics*, look on the back cover for the Keithley nanotechnology expert in your area.

CONDUCTIVITY AND TRANSPORT of nanotubes and



Image courtesy of Zyvex Corporation.

Ensuring high integrity resistance measurements

Understanding how nanotubes, nanowires, and nanofibers will perform in tomorrow's electronic interconnections demands instrumentation that's optimized for making measurements over a wide range of resistances and conductivities. Whether you're measuring nano-ohms or tera-ohms, Keithley's line of resistance measurement tools ensures greater accuracy by reducing or eliminating common sources of error at these extremes.

For further reading, download Keithley Application Note #312, "High Resistance Measurements," from www.keithley.com.

Model 6517A Electrometer/High Resistance Meter

- Built-in 1kV source and low current sensitivity make it ideal for measuring high resistance nanomaterials.
- 1fA–20mA current measurement range, with $<20\mu\text{V}$ burden voltage on lowest current ranges.
- 200T Ω input resistance ensures high accuracy voltage and resistance measurements.
- Measures resistances up to $10^{16}\Omega$.
- Voltage reversal technique enhances the accuracy of extremely high resistance measurements and volume and surface resistivity measurements.
- Optional software simplifies remote programming via a computer and simplifies optimizing test parameters for the material or device under test.



nanowires

Device Under Test	Application Needs	Keithley's Solution
Carbon nanotube wires	I-V measurements, conductivity, low resistance measurements ($1\Omega \rightarrow 100k\Omega$)	Model 4200-SCS Semiconductor Characterization System Series 2400 SourceMeter Instruments
Semiconductor nanowires	($1\Omega \rightarrow 100\Omega$)	Models 6220/6221 Current Sources/Model 2182A Nanovoltmeter Combo
Copper nanowires	($1\mu\Omega \rightarrow 10\Omega$)	
Polymer nanofibers and nanowires	I-V measurements, conductivity/resistivity, high resistance measurements, low current measurements ($1M\Omega \rightarrow 1 \times 10^{14}\Omega$)	Model 4200-SCS Model 6430 Sub-Femtoamp Remote SourceMeter Instrument Model 6487 Picoammeter/Voltage Source Model 6517A Electrometer/High Resistance Meter Models 6220/6221 current sources/Model 2182A Nanovoltmeter Combo

For further reading, download the Keithley White Paper, "*Achieving Accurate and Reliable Resistance Measurements in Low Power and Low Voltage Applications*," from www.keithley.com.

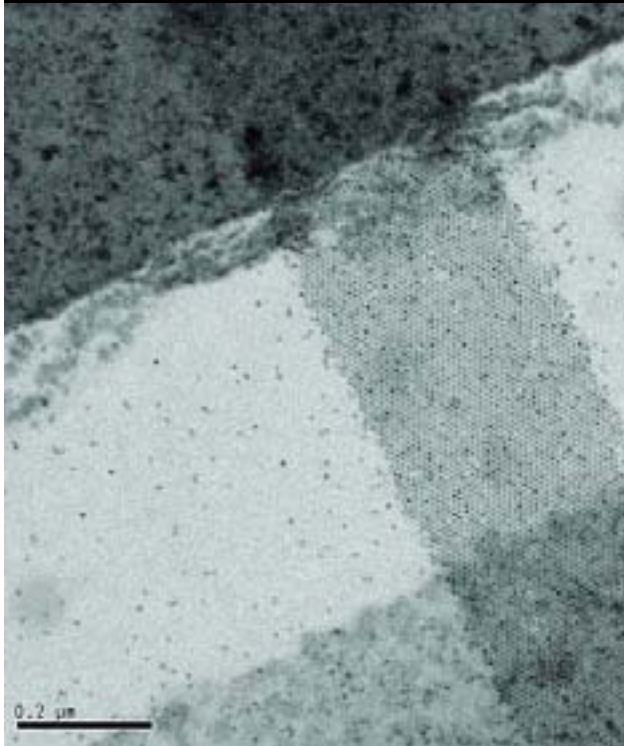


Models 6220/6221 Current Sources and Model 2182A Nanovoltmeter Combination

- Measure resistances from $10n\Omega$ to $100M\Omega$.
- High performance alternative to AC resistance bridges and lock-in amplifiers for measuring resistances.
- Industry's first turn-key differential conductance measurement solution.
- Measure differential conductance up to 10X faster and with lower noise than traditional, user-assembled setups based on lock-in technology.
- Perform pulsed I-V measurements, reducing the likelihood of damaging heat-sensitive devices.
- Current noise as low as $400fA$ p-p.
- Source AC currents from $1pA$ to $100mA$ over a frequency range of $1mHz$ to $100kHz$ (6221 only).

To learn more about solutions for testing the conductivity and transport of nanotubes and nanowires, look on the back cover for the Keithley nanotechnology expert in your area.

MATERIALS RESEARCH on nanoparticles and comp



Gold nanoparticle array forms device structure photo courtesy of K. Ehlers and X.M. Liu, The University of Chicago

Instruments that expand your field of creative vision

Keithley's innovative instruments and systems reveal the unique properties of carbon nanotubes, nanoparticles, and advanced composites. Characterizing properties like thermal conduction, electrical conductivity, and mechanical performance helps researchers create the next generation of materials with capabilities never before imagined.

“The capabilities of the 6430 allow us to measure with a resolution and ease that was previously unavailable in this type of experiment.”

—Heinrich Jaeger, Professor of Physics, The University of Chicago

Model 6430

Sub-Femtoamp Remote SourceMeter

- Four-quadrant sourcing plus measurement sensitivity down to sub-femtoamp and micro-volt levels.
- Industry-leading low noise and drift performance make it ideal for studying highly resistive nanowires.
- Remote PreAmp design minimizes cable and noise effects that reduce measurement accuracy.
- Offers sensitivity, noise, and input resistance specifications superior to electrometers.
- Measures currents with 400aA (400×10^{-18} A) sensitivity.
- Allows measuring resistance with either the constant-voltage or constant-current method.
- Measures resistances from $1 \mu\Omega$ to $> 1 \text{T}\Omega$.
- Compatible with free Keithley LabTracer software.



Materials	Application Needs	Keithley's Solution
Carbon nanotube (CNT) composites and structures Nanoparticles, composites, and structures	I-V measurements, conductivity, resistivity, thermal conduction Nanomanipulation, elastic constants, Young's Modulus, cantilever force, I-V characteristics	Model 4200-SCS Semiconductor Characterization System Model 6430 Sub-Femtoamp Remote SourceMeter Instrument Series 2400 SourceMeter Instruments Model 6485 Picoammeter Model 6487 Picoammeter/ Voltage Source Model 6517A Electrometer/ High Resistance Meter Models 6220/6221 Current Sources/Model 2182A Nanovoltmeter Combo *Zyvex S100 Nanomanipulator
Self assembly	Source V, measure I Source I, measure V	Model 4200-SCS Model 6430 Series 2400

*Zyvex Corporation is a Keithley nanotechnology solutions partner.

For further reading, download Keithley Application Note #2481, "I-V Measurements of Nanoscale Wires and Tubes with the Model 4200-SCS and Zyvex S100 Nanomanipulator," from www.keithley.com.

Zyvex S100 Nanomanipulator

- Positioning and testing tool for micro- and nano-scale R&D, device quality/failure analysis, MEMS/IC or microstructure R&D, surface science experiments, assembly, and manipulation.
- Ideal test fixture for use with the Model 4200-SCS.
- Accommodates up to four positioners, which grasp, move, test and position samples in Scanning Electron Microscopes (SEMs) and Focused Ion Beam systems (FIBs).
- 5nm positioner resolution.
- Supports probe diameters <20nm.

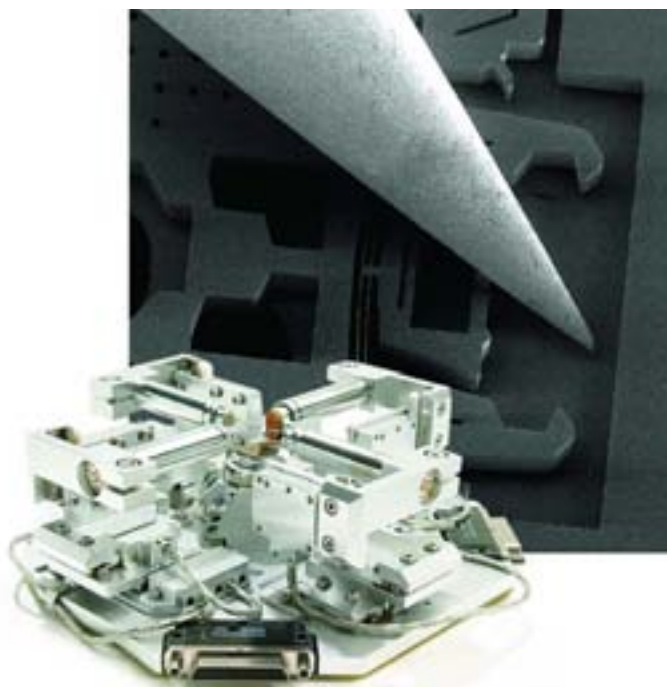


Image courtesy of Zyvex Corporation.

See the back cover for the Keithley nanotechnology experts in your area. They'll help you select instrumentation that's ideal for materials research on nanoparticles and composites.

SOLUTIONS for tomorrow's nanotech challenges

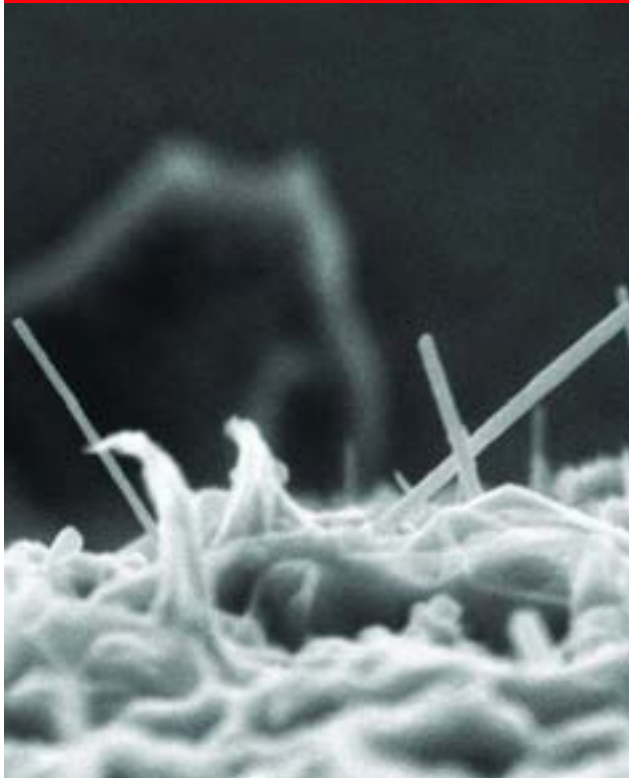


Image courtesy of Zyve Corporation.

Making the leap from imagination to commercialization

Whether you're developing the next generation of displays, exploring exotic energy sources, or refining hazard alert sensors, Keithley's measurement solutions for I-V characterization and optical measurements turn today's ideas into tomorrow's commercial technologies. Our advanced research products are engineered for reliability and flexibility, so you can transform the products of your imagination into the products of the future.

Model 6485 Picoammeter/**Model 6487** Picoammeter/Voltage Source

- Cost-effective, low current measurement solution with 20fA RMS noise.
- $<200\mu\text{V}$ burden voltage ensures accurate low current measurements, even in circuits with very low source voltages.
- An analog output that's compatible with chart recorders and other plotters makes it easy to spot kinks or other anomalies in a device's output.
- High accuracy, 2nA–20mA measurement range, and 5½-digit resolution make the Model 6485 ideal for SEM beam current experiments and use in focused ion beam systems (FIBSs) for nano-scale imaging, micromachining, and mapping.
- The Model 6487 adds a 500V bias source to all the capabilities of the Model 6485 for use in high resistance and resistivity measurements. An Alternating Voltage method supports resistance measurements to $10^{16}\Omega$.



Device Under Test	Application Needs	Keithley's Solution
Carbon nanotube (CNT) field emission	I-V measurements, high voltage sourcing	Model 4200-SCS Semiconductor Characterization System Model 6430 Sub-Femtoamp Remote SourceMeter Instrument Series 2400 SourceMeter Instruments Model 6485 Picoammeter Model 6487 Picoammeter/Voltage Source Model 6517A Electrometer/High Resistance Meter
Nanobatteries, energy	I-V measurements, charging/discharging	Model 4200-SCS Model 6430 Series 2400
Quantum scale sensors and detectors, nanobiosensors	I-V measurements	Model 4200-SCS Model 6430 Series 2400
Quantum dot light sources, nanophotonics	I-V measurements, optical power measurements Pulsed I-V	Model 4200-SCS Series 2400 Models 6220/6221 Current Source Model 2520 Pulsed Laser Diode Test System Model 2520INT Integrating Sphere Model 2502 Photodiode Meter

For further reading, download Keithley Application Note #2428, "Pulsed LIV Testing of Low Power Optical Devices with an Amplified Integrating Sphere and the Model 2520," from www.keithley.com.

Model 2520 Pulsed Laser Diode Test System

- Combines high speed, precision pulsing and measurement capabilities to prevent destructive device self-heating.
- Remote test head minimizes cable effects and maximizes the signal-to-noise ratio for greater pulse measurement accuracy.
- Programmable pulse on time from 500ns to 5ms up to 4% duty cycle.
- Pulse capability up to 5A, DC capability up to 1A.



See the back cover for the Keithley nanotechnology expert near you for assistance in choosing solutions to tomorrow's nanotech challenges.

LET KEITHLEY HELP YOU set new standards for nanotech measurements

FREE Keithley handbooks

Want a fast refresher on test and measurement techniques? Request your **FREE** copies of Keithley's handbooks on low level measurements, switching, and data acquisition and control by calling your local sales engineer or visiting our website at **www.keithley.com**.



Check something out of our library

We invite you to visit www.keithley.com to download materials from our growing library of **FREE** nanotech literature, including articles, application notes, white papers, online demonstrations, and webcasts.



Need somebody to talk to?

There's a Keithley applications engineer ready with advice on configuring a test system for your nanotechnology application. Call us toll free at **1-888-KEITHLEY (534-8453)** (US only) or call your local Keithley sales office and ask to speak with one of our nanotech instrumentation specialists.

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All other trademarks and trade names are the property of their respective companies.

For Keithley's help with *measurement solutions for nanoscale device and materials characterization*, contact one of the experts listed below.

KEITHLEY

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