The Emerging Challenges of Nanotechnology Testing

John Tucker, Keithley Instruments, Inc.

Introduction

Nanotechnology is an important new area of research that promises significant advances in electronics, materials, biotechnology, alternative energy sources, and dozens of other applications.

Understanding how new building-block materials like nanocrystals, nanotubes, nanowires, and nanofibers will perform in the electronic devices of tomorrow demands instrumentation that can characterize resistance and conductivity over wide ranges. Often, this requires the measurement of very small currents and voltages.

Nanotechnology research is advancing rapidly. In fact, many scientists and engineers find their existing measurement tools simply lack the sensitivity or resolution needed to effectively characterize the low-level signals associated with research in nanotech materials. Meanwhile, others are scrambling to keep up with the rapid changes in measurement requirements that new discoveries create.

The ability to create accurate and repeatable measurements at the nano-scale level is critical to engineers seeing to develop these next generation materials.

The Challenges of Nanotech Testing

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

An equally important if often overlooked factor is that research tools and instruments must be easy to use and cost-effective. The importance of these characteristics will grow as industry employment grows. Some of the present tools are unnecessarily complex, with too many buttons on front displays that confuse users and make the learning curve steeper. Also, data transfer mechanisms are often tedious and can require extensive amounts of storage media. And graphical analysis can take too long, while programming steals time away from research. Department heads and managers who must make hard choices about equipment investments should examine these issues carefully, and compare instrument features before committing funds.

To advance the state of the art rapidly, researchers can't be bogged down with programming chores and arcane details of instrument operation. User-friendly instruments are important, not only to researchers and technicians, but also to design engineers and manufacturing specialists who must take new discoveries and convert them into practical products. To meet this challenge, state-of-the-art electrical characterization systems must now be PC-based with the familiar point-and-click, cut-and-paste, and drag-and-drop features of the Windows® operating system. These system features make test setup, execution, and analysis more time efficient by shortening the learning curve.

There are also many difficulties when testing at the nanoscale level. For instance, it is incredibly complex to probe down to the device level for failure analysis and other testing. This requires new testing equipment, probers, and new nanotech measurement standards.

The Need for Standards

With the proliferation of nanotechnology devices comes the need for quality standards for these devices. Specifically, when it comes to testing, recently a new standard was worked out and approved by the Institute of Electrical and Electronic Engineers (IEEE).

The recently approved IEEE 1650™-2005 standard, known as "Standard Methods for Measurement of Electrical Properties of Carbon Nanotubes," gives the burgeoning nanotechnology industry one uniform and common set of recommended testing and data reporting procedures for evaluating the electrical properties of carbon nanotubes.

A carbon nanotube is a tubular structure that has become a major focus of nanomaterials research because it displays a variety of exciting properties for creating nanoscale, low power consumption electronic devices. A nanotube can even act as a biological or chemical sensing device in some applications, or as a carrier for individual atoms.

The new standards contain a variety of testing apparatus recommendations and measurement practices for making electrical measurements on carbon nanotubes in order to minimize and/or characterize the effect of measurement artifacts and other sources of measurement error encountered when making measurements on carbon nanotubes. The new testing standard should aid in the commercialization of nanotubes by providing uniformity between lab researchers and design engineers eager to put lab results into commercial use on the production line. Recommended measurement data to report as specified in the new standard include electrical resistivity, conductivity, carrier mobility, and non-linear behaviors.

The new standard promises to greatly aid in accelerating the commercialization of nanoscale materials and electronic devices for the semiconductor industry, along with many other industries. The new standard lets those buying carbon nanotubes speak the same language as the manufacturers when it comes to the electrical properties and quality of the products they're purchasing.

The Need for Pulse Testing

During device development, structures like single electron transistors (SETs), sensors, and other experimental devices often display unique properties. Characterizing these properties without damaging one-of-a-kind structures requires systems that provide tight control over sourcing to prevent device self-heating.

With more devices shrinking in size, the demand for new kinds of test techniques increases. Namely, as devices get smaller, the method of testing changes. No longer can you send sizable currents through devices in order to test them. A current too large can irreversibly damage a component.

What is needed are shorter bursts of energy. This comes in the way of pulse testing. An instrument that can deliver an extremely short duration pulse, on the order of a few nanoseconds wide, with tight control over parameters such as rise time, fall time, pulse width, voltage and current levels is a great asset to engineers and scientists doing cutting edge research.

In addition, voltage pulsing can produce much narrower pulse widths than current pulsing, so its often used in experiments such as thermal transport, in which 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.

Consequently, the need for pulsed sources has been growing over time. This need is driven, in part, by the higher operating speeds of today's electronic circuits. The higher operating speed requires test equipment that can produce simulated clock and data signals at the rate that the circuits will actually perform. Also, analog components used in these circuits behave differently at higher speeds, so they can't be characterized at DC using traditional DC methods.

As components have become smaller, the need for pulsed testing techniques becomes more critical. Smaller devices are more susceptible to self-heating, which can destroy or damage the part of change its response to test signals, masking the response the user is seeking. Pulse testing is commonly used when characterizing nanoelectronic devices.

Pulse generators are especially helpful for material characterization in nanotechnology, which includes transient analysis and stress testing. KEITHLEY

KEITHLEY INSTRUMENTS, INC. ■ 28775 AURORA ROAD ■ CLEVELAND, OHIO 44139-1891 ■ 440-248-0400 ■ Fax: 440-248-6168 ■ 1-888-KEITHLEY ■ www.keithley.com

BELGIUM
Sint-Pieters-Leeuw
Ph: 02-363 00 40
Fax: 02-363 00 64
www.keithley.nl

CHINA
Beijing
Ph: 8610-82255010
Fax: 8610-82255018
www.keithley.com.cn

FINLAND
Espoo
Ph: 09-88171661
Fax: 09-88171662
www.keithley.com

FRANCE
Saint-Aubin
Ph: 01-64 53 20 20
Fax: 01-60-11-77-26
www.keithley.fr

GERMANY
Germering
Ph: 089-84 93 07-40
Fax: 089-84 93 07-34
www.keithley.de

UNITED KINGDOM
Theale
Ph: 0118-929 75 00
Fax: 0118-929 75 19
www.keithley.co.uk

INDIA
Bangalore
Ph: 080 22 12 80-27/28/29
Fax: 080 22 12 80 05
www.keithley.com

ITALY
Milano
Ph: 02-553842.1
Fax: 02-55384228
www.keithley.it

JAPAN
Tokyo
Ph: 81-3-5733-7555
Fax: 81-3-5733-7556
www.keithley.jp

KOREA
Seoul
Ph: 82-2-574-7778
Fax: 82-2-574-7838
www.keithley.co.kr

MALAYSIA
Kuala Lumpur
Ph: 60-3-4041-0899
Fax: 60-3-4042-0899
www.keithley.com

NETHERLANDS
Gorinchem
Ph: 0183-63 53 33
Fax: 0183-63 08 21
www.keithley.nl

SINGAPORE
Singapore
Ph: 65-6747-9077
Fax: 65-6747-2991
www.keithley.com.sg

SWEDEN
Solna
Ph: 08-50 90 46 00
Fax: 08-655 26 10
www.keithley.com

TAIWAN
Hsinchu
Ph: 886-3-572-9077
Fax: 886-3-572-9031
www.keithley.com.tw

Printed in the U.S.A. No. 2782 0906