Standards Will Help Ensure Order in Nano-Enabled Industries

Jonathan L. Tucker

Chairman, IEEE Nanotechnology Council Standards Committee

and

Senior Marketer, Nanotechnology, Research, and Education, Keithley Instruments, Inc.

Industry-wide standards are a vital early step in exploiting nanotechnology

Like the California gold rush of 1849, the emergence of nanotechnology presents both an enormous opportunity and enormous risks. Just as new techniques, rewards, and challenges emerged during the gold rush era, nanotechnology exploration will inevitably lead to the development of new tools to achieve new breakthroughs, the opportunity for creating enormous wealth, and unfortunately, the potential for environmental, health, and safety disasters. Although nanotechnology undoubtedly will create disruptive technologies that will spin off many new jobs, it also has the potential for displacing existing workers unprepared to take on these new technologies.

The first fruits of nano R&D are already being harvested as disciplines as diverse as materials, electronics, biotechnology, and computing rush to exploit nanotechnology's potential. Many consumers have already become familiar with nano-derived products, such as improved types of cosmetics, fabrics, paints, plastics, or personal electronics.

Nanotechnology offers all-but-unlimited opportunities for those who can develop the next exotic material or electronic component that is cheaper, better, and faster than today's CMOS devices. It also holds huge promise for those who will create the tools needed to produce these materials and devices. Despite the recession, corporate and government labs around the world continue to invest billions in nanoscience research. Unfortunately, unless the public and private sectors work in cooperation to develop standardized test methods and guidelines, the transition from the laboratory to the marketplace could create many of the same problems as the California gold rush did, particularly for the environment. However, with careful planning, we can have the appropriate terminology, test measurement methods, reporting, and environmental, safety, and health safeguards in place early enough to ward off serious consequences.

Why Are Standards So Important?

Very simply, standards are crucial to achieving a high degree of interoperability, creating order in the marketplace, simplifying production requirements, managing the potential for adverse environmental impacts, and most important, ensuring the safety and health of those developing and using the next generation of materials and devices.

Standards for nano terminology, materials, devices, systems, and processes will help establish order in the marketplace. For R&D researchers and engineers, standards make it possible to make measurements and report data consistently in a way that others can understand clearly. Those responsible for developing standards will be at the forefront in understanding the need for, and creation of, new characterization tools, processes, components, and products to help jump-start this emerging field. This kind of approach can represent a competitive tool in global markets. Creating a standard in advance of the release of a new technology allows both manufacturers and consumers to gain greater confidence in it, promoting greater acceptance and faster adoption.

The following examples illustrate the importance of early standards development.

Carbon Nanotubes

Although some of the more sophisticated electronics and medical advances scientists have envisioned are still years down the road, the development of some nanoscale raw materials, particularly carbon nanotubes (CNTs), is already well underway. Years before CNTs were commercially available, industry observers heard how they would bring significant performance advantages to electronics, enhance materials to make them stronger and lighter, and might even be part of the solution to our energy problems. This industry buzz, plus the massive private and public sector investments in nano research, built interest at every level. In 2000, the late Dr. Richard Smalley spun off his work to form Carbon Nanotechnologies Inc. (now Unidym) with the goal of commercializing his method of producing large batches of high-quality nanotubes. Unfortunately, at that point, there were no manufacturing standards or guidelines for ensuring the reproducibility of the company's manufacturing process. There were also no known test and measurement guidelines for verifying the reproducibility and proving results on a large scale. Given this, how would the company have assured its customers of the quality of its products? Or just as important, how could customers choose confidently among various manufacturers' CNTs based on their product description?

Buying carbon nanotubes isn't like buying baseballs or bananas—it's impossible to judge their quality just by looking at them. *En masse*, CNTs basically look like a pile of soot (***Figure 1***). How can incoming inspectors verify what they have received? How do they know whether they are single-walled or multi-walled tubes? Given the different species of carbon nanotubes now available (tubes that are metal or semiconducting, based on their chirality), most companies looking to purchase nanotubes would have had no basis on which to ensure that what they received is what they ordered. However, with a standard in place, customers have the tools needed to verify the materials they are purchasing.

Materials Characterization Techniques

Characterizing the specific properties of raw CNTs or other nanoscale materials is obviously important, but what about nanoscale materials intended to enhance bulk materials or to create new materials with enhanced properties? What kinds of testing and reporting standards are needed? Must both mechanical and electrical testing be included when designing new materials?

Probing and microscopy are used routinely to uncover new materials properties, but probe force should also be considered. What happens to the electrical properties of a nanoscale material under a particular probe force? Some very thin materials can exhibit localized phase transformations at the probing location, which can change their electrical characteristics. What kind of testing standards and guidelines are necessary to support probe force?

Nanomechanical testing has become a popular way of determining quantitative, small volume mechanical properties. Conceptually, nanoindentation is a relatively straightforward technique in which an indenter probe of a well-known geometry is pushed into and withdrawn from the material's surface while the force and displacement are continuously recorded. Conductive nanoindentation, a new technique, combines nanoindenter hardware with a conductive probe and voltage/current source-and-measure instrumentation to produce a time-based correlation of force, displacement, voltage, and current. When used in tandem, nanomechanical and electrical measurements have proven highly sensitive to probe/sample contact conditions, as well as to material deformation behavior, which adds important information to that obtainable from nanoscale point measurements.

From a standards perspective, the most important question becomes whether a broader audience would find this testing method acceptable. Would the nanomaterials community accept this as a best practice measurement method and as a potential standard test methodology?

Figure 1. Carbon nanotubes (CNTs) in bulk. Photo credit: Jes Sherman.

IEEE's Nanotechnology Standards Development Efforts

The IEEE has assumed a leadership position in the development of nanoelectronics standards. The factors driving the development of these standards are the need for reproducibility of results, international collaboration, and a common means of communicating across traditional scientific disciplines. This activity is driven by the IEEE Nanotechnology Council (NTC), an interdisciplinary group with members representing 21 IEEE societies. NTC is currently involved in a variety of standards efforts and activities.

IEEE 1650-2005

IEEE std. 1650™-2005, "IEEE Standard Test Methods for Measurement of Electrical Properties of Carbon Nanotubes" was one of the first nanotechnology standards with which the IEEE became involved. This effort was driven by the need for a way to reproduce and prove lab results on a much larger scale and to establish common metrics and a minimum requirement for reporting. The standard's main purpose is to establish methods for the electrical characterization of carbon nanotubes and the means of reporting performance and other data. These methods enable the creation of a suggested reporting standard that are used from the research phase through manufacturing as the technology is developed. Moreover, the standard recommends the necessary tools and procedures for validation.

It took more than two years to complete development of the IEEE 1650 standard, which was approved in December 2005. Since then, other standards bodies have been busy developing their own standards. In addition, the IEEE Standards Association (IEEE-SA) has been exploring support for the adoption of IEEE 1650 by several international bodies. For example, in collaboration with the NTC, IEEE-SA pursued a dual-logo agreement for the 1650 standard with the International Electrotechnical Commission (IEC) Technical Committee 113, Working Group 3 *Performance of Nanomaterials for Electrotechnical Components and Systems*. Last November, the IEC TC 113 decided to adopt ANSI/IEEE Std1650™-2005 as a dual logo.

IEEE P1690

Breakthroughs in nanotechnology have received greater attention during the past few years, in part due to significant advances in materials performance and processing techniques. One potential impediment to widespread introduction of carbon nanotubes used as additives in bulk materials is the lack of defined standards for their characterization. Also, methods for reporting performance and other data have not been established; each scientist or engineer has independently developed measurement procedures that may or may not be definitively comparable with the results of others. To address these concerns, IEEE-SA approved the creation of the IEEE P1690TM Working Group in late 2005. A team was tasked with developing "Standard Methods for the Characterization of Carbon Nanotubes Used as Additives in Bulk Materials." The standard will suggest procedures for characterizing and reporting data that will be used by research through manufacturing; methods will be independent of processing routes used to fabricate the carbon nanotubes. The standard will recommend the necessary tools and procedures for validation.

The NESR Initiative

The NanoElectronics Standards Roadmap (NESR) Initiative is working to create a framework through which the IEEE-SA and the nanoelectronics community can work in cooperation to define a roadmap for nanoelectronics standards that will:

- Identify high-value standards opportunities
- Frame near-term standards
- Leverage, not duplicate, existing sources
- Stimulate industry collaboration
- Accelerate nanoelectronics standards development
- Establish a framework for proactive management of standards

Those involved in the NESR Initiative are responsible for developing and driving a standards roadmap that will help electronic nanotechnology innovations make a smooth transition from the laboratory to the marketplace in the communications, information technology, consumer products and optoelectronics sectors. The NESR roadmap has gained considerable interest from representatives of the International Technology Roadmap for Semiconductors and the International Electronics Manufacturing Initiative. Members are currently focusing on nanomaterials and devices that will have a short-term impact on industry, while also assessing the long-term needs of an electronics industry based on nanoelectronic architectures. Within these areas, standards have been prioritized by testing them against four criteria:

- **Technology maturity:** Is the technology well enough understood to standardize?
- **Clear near-term applications:** Does the standard eliminate near-term roadblocks, ensuring a rapid payback for the effort involved?
- **High business value:** Does the standard offer multiple device-circuit-application "threads"?
- **Fits IEEE role – Nanoelectronics:** Does the definition of electronics stretch a bit at the nanoscale level?

On March 28, 2008, IEEE-SA approved the first NESR Project Authorization Request (PAR) to create a standards working group on "Nanomaterials Characterization and Use in Large Scale Electronics Manufacturing." The PAR is denoted PAR1784. The purpose of this standard is to enable the quick, low-risk adoption of nanomaterials into large-scale electronics manufacturing. In addition, a best set of common practices will be delineated for use in semiconductor fabs.

Efforts in nanomaterial research and development for use in semiconductor VLSI technology are increasing exponentially. The common availability of nanomaterials is allowing engineers to explore new methods to exploit the mechanical, electromagnetic, and quantum properties of nanotubes, nanowires, and nanoparticles—not just theoretically but experimentally. To exploit the enhanced properties of new nano-scale materials fully, industries (including the semiconductor industry) that use nano-enhanced materials must embrace a new set of best practices for large-scale manufacturing.

What Benefits Do Standards Offer?

Standards offer a major benefit to a technology by supporting its evolution. In fact, standards are the defining precursor of products whose intended performance they prescribe. A variety of benefits are attributable to standards:

- They give end users confidence that products are safe and reliable, and that they will perform as they are intended. Standards establish consistent expectations and help ensure those expectations are met.
- Standards create a common language that manufacturers and end users can use to communicate on issues like quality and safety.
- Standards help promote product compatibility and interoperability.
- Standards help overcome trade barriers for global markets.
- Standards foster the diffusion and adoption of new technologies. In addition to giving participants in the development process early access to technical know-how, participants can influence how certain test or measurement guidelines can be documented, thereby affecting the content of the standard.

Keithley's participation in the development of IEEE 1650 offers a good example of how companies can gain a competitive advantage by participating in the development of standards. As a representative of Keithley Instruments, I had the opportunity to help develop the Electrical Characterization overview section of the standard (Section 1.3), which addresses testing apparatus and measurement techniques, including the definition of the measurement equipment specifications for the testing guidelines. It includes guidelines for handling ohmic contacts, and making both low (<100kΩ) and high (>100kΩ) resistance measurements.

The standard also created a business opportunity for Keithley. Because our Model 4200 Semiconductor Characterization System (***Figure 2***) meets the equipment specification requirements of IEEE 1650-2005, we can include this fact in our product literature, which has led to increased sales and greater customer confidence when using this product in their applications for measuring the electrical properties of CNTs.

Participation in standards development also offers advantages for the public sector by spurring improved national competitiveness, education, and job creation.

Figure 2. The Model 4200-SCS Semiconductor Characterization System meets the equipment specification requirements of IEEE 1650-2005.

The Expanding Standards Community

Participants from the public and private sectors have traditionally written most of the standards because they tend to derive the greatest benefit from them. Although the academic community has been relatively slow to get involved in standards development, the public and private sectors have often called upon them to provide expertise because of their experience in validating applications-oriented research. Having the public, private, and academic communities unite together to develop standards for international adoption is in everyone's best interests.

Thinking Globally

Speaking as an active participant in the IEEE 1650, IEEE 1690, NESR, and ISO efforts, I can attest to how rewarding participating in standards development can be as an engineer, but it can also provide a competitive advantage to companies by offering early access to information and technical know-how. Standards development must be a global effort. Certain countries around the world are making it a primary part of their own research plans. For example, the Chinese Ministry of Science and Technology has made the drafting of nanotechnology research standards part of its national basic research plan. Other countries are striving for leadership positions within standards organizations so that they can help shape the standards to which everyone must adhere.

One of the many challenges that must be overcome is how to prioritize which standards to develop next, based on measurement best practices and characterization processes. We need to understand whether the measurement tools available today are the right tools from an international perspective.

Although international barriers must be taken into account, creating an international working collective will simplify the development of standards and allow for broader acceptance. Currently, no one country is in complete control nor is there one standard that predominates, but global agreements will be necessary if nano standards development is to stay in synch with the technologies themselves. This need creates opportunities for everyone. Standard development is a people project and virtually every standards development organizations could put your efforts to good use, whether you're an engineering student, an academic, or someone who works in the public or private sectors. Participating in standards development is an excellent way to begin to establish oneself as an expert. While it doesn't take up much time, your reward can be increased visibility for you and your organization.

Acknowledgement

Jonathan Tucker (jtucker@keithley.com) is the Senior Marketer for Nanotechnology, Research and Education and Sensitive Measurements Product Line Manager at Keithley Instruments in Cleveland, Ohio. He joined Keithley Instruments in 1987 and has held numerous positions including Test Engineer, Applications Engineer, Applications Manager, and Product Marketer. He chairs the IEEE Nanotechnology Council Standards Committee and co-chairs the IEEE Nanoelectronics Standards Roadmap Initiative. John is also the IEEE-SA primary member of the US Technical Advisory Group (TAG) to the International Organization for Standardization technical committee on nanotechnologies (ISO TC229). He is also a recipient of a Nano Science and Technology Institute Fellow Award for outstanding contributions towards the advancement of the international NSTI Nanotechnology, Microtechnology, and Biotechnology Community. He holds a Bachelors of Electrical Engineering degree from Cleveland State University and an MBA from Kent State University.

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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: 02-3630040
Fax: 02-3630064
info@keithley.nl
www.keithley.nl

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

FINLAND
Espoo
Ph: 358-40-7600-880
Fax: 44-118-929-7509
finland@keithley.com
www.keithley.com

FRANCE
Saint-Aubin
Ph: 01-64532020
Fax: 01-60117726
info@keithley.fr
www.keithley.fr

GERMANY
Germering
Ph: 089-84930740
Fax: 089-84930734
info@keithley.de
www.keithley.de

INDIA
Bangalore
Ph: 080-26771071, -72, -73
Fax: 080-26771076
support_india@keithley.com
www.keithley.com

ITALY
Peschiera Borromeo (Mi)
Ph: 02-5538421
Fax: 02-55384228
info@keithley.it
www.keithley.it

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

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

MALAYSIA
Penang
Ph: 60-4-643-9679
Fax: 60-4-643-3794
chan_patrick@keithley.com
www.keithley.com

NETHERLANDS
Gorinchem
Ph: 0183-635333
Fax: 0183-630821
info@keithley.nl
www.keithley.nl

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

SWEDEN
Stenungsund
Ph: 08-50904600
Fax: 08-6552610
sweden@keithley.com
www.keithley.com

SWITZERLAND
Zürich
Ph: 044-8219444
Fax: 044-8203081
info@keithley.ch
www.keithley.ch

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

UNITED KINGDOM
Theale
Ph: 0118-9297500
Fax: 0118-9297519
info@keithley.co.uk
www.keithley.co.uk

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