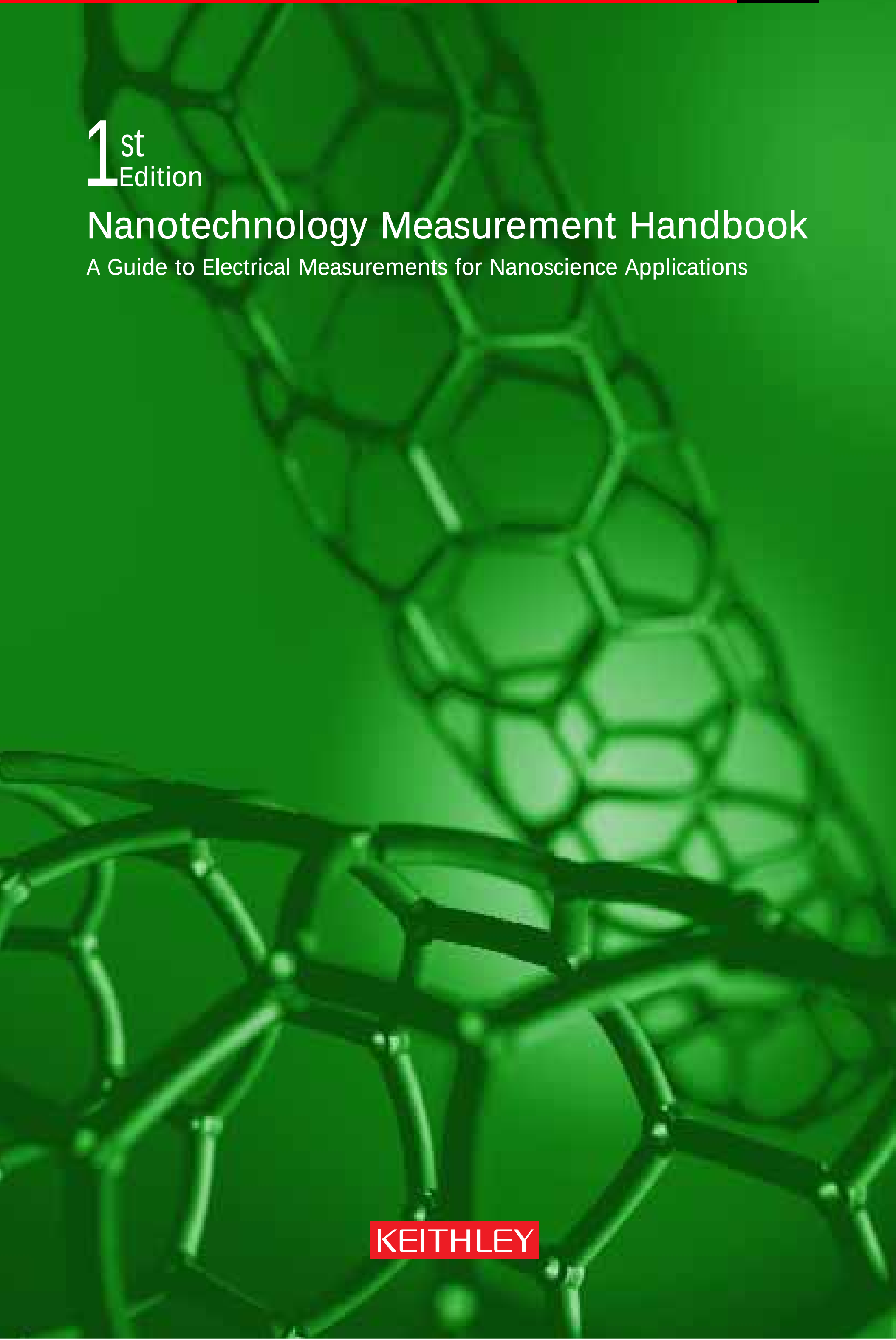

1st Edition

Nanotechnology Measurement Handbook

A Guide to Electrical Measurements for Nanoscience Applications

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Foreword

Nanotechnology research often demands skills in multiple disciplines, from physics and materials science to chemistry and measurement system design. Although it would be impossible to predict all the technical innovations that nano research will offer, it's already clear that nanoscience will be a major driver of the economy of the future. However, characterizing tomorrow's nanoscale components and materials will be far from trivial because many of their electrical properties lie at the very edge of the measurement envelope.

To unravel tiny mysteries and turn nanoscale materials and devices into commercial products, researchers must have tools with the flexibility to handle a variety of electrical measurements, including current vs. voltage (I-V) characterization, resistance, resistivity and conductivity, differential conductance, transport, and optical spectrum and energy. They must also gain an in-depth understanding of the principles and pitfalls associated with low-level electrical measurements.

Nanotechnology Measurement Handbook: A Guide to Electrical Measurements for Nanoscience Applications offers practical assistance in making precision low-level DC and pulse measurements on nanomaterials and devices. It is useful both as a reference and as an aid to understanding low-level phenomena observed in the lab. It provides an overview of the theoretical and practical considerations involved in measuring low currents, high resistances, low voltages, and low resistances.

I hope you find this handbook helpful in your nanoscience research efforts.

Dr. Meyya Meyyappa
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NASA Ames Research Center, Moffett Field, California
IEEE Distinguished Lecturer on Nanotechnology
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SECTION I
Introduction

Nanotech Innovations Hinge on Measurement Technology and Close Alliances Between Researchers and Instrumentation Designers

Nanotechnology has the potential to improve our quality of life in diverse ways, such as faster electronics, huge memory/storage capacities for PCs, cheaper energy through more efficient energy conversion, and improved security through the development of nanoscale bio- and chemical-detection systems. Before these become commercial realities, researchers must be able to characterize nano material and device properties quickly and accurately.

Optical and electro-optical characterization techniques, such as scanning electron microscopy (SEM), emission microscopy, atomic force microscopy, and ultra-violet microscopy provide valuable information on nanostructures. However, electrical characterization is essential to gain insight into phenomena that occur beneath the surface of nanomaterials. For example, gate dielectrics in advanced semiconductors can have a physical thickness of less than one nanometer; the performance of these dielectrics can only be predicted by evaluating their equivalent electrical thickness. Similar considerations apply to carbon nanotubes and silicon wires, which are the basis for many nano innovations.

Alliances Shorten Time to Market

While government funding provides essential support for nano research, it is also crucial to form alliances between industry and university researchers with complementary areas of expertise. This is especially true in testing, where complex devices and materials present unique measurement challenges. Historically, many scientific advances occurred only after suitable investigative instruments became available. Nanotechnology is following the same path. Nano researchers must either rely on instrumentation companies or take time away from R&D to develop their own measurement systems. Typically, researchers know the material and device physics intimately, but often lack measurement expertise. Moreover, the pressure to commercialize research results as quickly as possible and conserve resources means that researchers can't spare the time needed to develop in-depth measurement expertise.

However, instrument companies need the insights only researchers can provide in order to develop measurement technologies that will advance the state of the art. Nanotechnology research spans multiple scientific disciplines, including electrical and electronic engineering, computer science, biotechnology, materials engineering, chemistry, and physics. The commercial pressures instrumentation manufacturers face make it all but impossible for any one company to develop equal levels of expertise in all these disciplines. Alliances with instrumentation companies allow leveraging the expertise of individuals and organizations to create better solutions for researchers.

Measurement Complexities

The essence of nanotechnology research is to work at the molecular level, atom by atom, to create structures with fundamentally new properties. Some of the current research involves:

- Carbon nanotube materials and field emission devices
- Semiconducting nanowires of silicon and other materials
- Polymer nanofibers and nanowires
- Nano and molecular electronics
- Single electron devices

One of the main challenges in electrical characterization of these materials and structures is dealing with ultra-low signal levels. Another challenge is the wide range of behavior that these materials and components can exhibit. For example, polymer materials can have resistances greater than one gigaohm. However, when drawn into fibers less than 100nm in diameter and doped with various nanoparticles, a polymer may be changed from a superb insulator into a highly conductive wire. The result is an extremely wide range of test signals. Detecting tiny electrical signals at the low end of the range requires high sensitivity, high resolution instruments such as electrometers, picoammeters, and nanovoltmeters. Also using one of these instruments for high level signals as well demands an instrument with a very wide dynamic range. Instrumentation designers require insight from researchers to tailor measurement solutions to this wide range of needs.

In addition to DC measurements, some devices and structures may need to be characterized with RF signals. Testing some nanoscale structures may involve measurements of multiple RF harmonics far higher than 20GHz. This requires rigorous instrumentation design with reliable low-loss RF connections in the test head and dedicated electronic circuitry for each individual signal path. Otherwise, it becomes impossible to achieve the resolution required for precision measurements that reveal subtleties in nanometer structures.

Probing and Manipulation Tools Are Key to Nano Measurements

Still, a sensitive instrument has limited value if it can't be connected to a device under test properly. For nanoscale devices, the instrument must be connected to a probing system through a high quality signal path that allows rapid, low noise measurements. Therefore, alliances between instrumentation designers and manufacturers of nano-manipulation and nanoprobing tools are essential in constructing a complete measurement solution.

By working together closely, nano researchers and instrumentation manufacturers can create innovative and comprehensive measurement solutions that are essential for developing the next generation of nanostructures, nanomaterials, MEMS (Micro-Electro-Mechanical Systems), and semiconductor devices. These alliances will also be instrumental in speeding up the transfer of nanotechnology from the research lab to the production environment.

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