Designation: ~~E3001 – 15~~ E3001 – 20

Standard Practice for Workforce Education in Nanotechnology Characterization[1]

This standard is issued under the fixed designation E3001; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice describes a procedure to provide the basic education of characterization methods for nanometer-scale materials, to be taught at an undergraduate college level. This education should be broad and include a suite of characterization methods to prepare an individual to work in various capacities within one of the many areas in nanotechnology research, development, or manufacturing.

1.2 This practice may be used to develop or evaluate an education program for characterization in the nanotechnology field. It provides listings of key methods that are relevant to such a program, with a minimum number of these methods to be taught as a requirement for such an education. This practice does not provide specific course material to be used in such a program.

1.3 While no units of measurements are used in this practice, values stated in SI units are to be regarded as standard.

~~1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*~~

1.4 *This standard does not purport to address all of the characterization methods for nanometer-scale materials, nor is it meant for use in certification processes. It is the responsibility of the user of this standard to utilize other knowledge and skill objectives as applicable to local conditions or required by local regulations.*

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E2456 Terminology Relating to Nanotechnology

E2996 Guide for Workforce Education in Nanotechnology Health and Safety

E3089 Guide for Nanotechnology Workforce Education in Material Properties and Effects of Size

[1] This practice is under the jurisdiction of ASTM Committee E56 on Nanotechnology and is the direct responsibility of Subcommittee E56.07 on Education and Workforce Development.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

2.2 ~~*Other*~~*ISO Standards:*

~~BSI PAS 133 Terminology for Nanoscale Measurement and Instrumentation~~[33]

ISO/TS ~~27687~~80004-1 Nanotechnologies – ~~Terminology and Definitions for Nano-Objects – Nanoparticle, Nanofibre, and Nanoplate~~Vocabulary – Part 1: Core terms

ISO/TS 80004-6 Nanotechnologies – Vocabulary – Part 6: ~~Nano-Object Characterization~~Nano-object characterization

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms related to nanotechnology in general, refer to Terminology E2456 and ISO/TS ~~27687.~~80004-1.

3.1.2 For definitions of terms related to measurement methods and instrumentation used, refer to ~~BSI PAS 133 and~~ ISO/TS 80004-6.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *characterization, n*—measurement(s), using one or more methods, to determine the structure and composition of a material as well as its physical or chemical properties.

~~3.2.2 *education, n*—the teaching of specific topics as part of a degree or certificate program, or as training to provide additional skills and knowledge.~~

4. Summary of Practice

4.1 This practice designates a list of nineteen characterization methods to be relevant to nanotechnology workforce education. Methods are grouped into two tiers, with five methods classified as Tier 1 and the others as Tier 2. Method selection and tier classification are based on inputs from industry, nanotechnology educators, and subject matter experts.

4.2 For each characterization method in the list, important topics to be covered are listed specifically.

4.3 From this list, five methods have been classified as Tier 1. An educational program is to select at least three Tier 1 methods to be taught in detail, and to teach the remaining two Tier 1 methods plus a minimum of five Tier 2 methods at an introductory level.

NOTE 1—Tier 1 methods are considered key. This requirement ensures that all Tier1 methods are taught, even when there are practical time constraints on the quantity of instructional material that can be covered in an undergraduate-level program.

4.4 This approach provides both a broad education as well as in-depth emphasis for key subjects within the time constraints of an instructional course or program.

5. Significance and Use

5.1 This practice establishes the basic structure for education in the characterization of nanoscale materials at the undergraduate college level. The approach taken is to classify specific characterization methods into two tiers, with a minimum number of methods to be selected from each tier and taught at an in-depth or introductory level. This offers the flexibility of tailoring to regional industry needs while still retaining a high degree of equivalency in educational depth and breadth across geographical boundaries.

5.2 Workers may transition in their roles in the workplace. Participants in such education will have a broad understanding of a complement of characterization methods, thus increasing their marketability for jobs within as well as beyond the nanotechnology field.

5.3 This practice is intended to be one in a series of standards developed for workforce education in various aspects of

[3] ~~Available from British Standards Institution (BSI), 389 Chiswick High Rd., London W4 4AL, U.K., http://www.bsigroup.com.~~

[3] Available from International Organization for Standardization (ISO), ~~1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20,~~ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

nanotechnology. It will assist in providing an organization a basic structure for developing a program applicable to many areas in nanotechnology, thus providing dynamic and evolving workforce education.

6. General Background Knowledge and Skills

6.1 Introductory algebra, chemistry, physics, and statistics at the college level.

6.2 The environmental, health and safety (EHS) hazards presented by nanoscale materials can be very different from those presented by bulk materials. Students should have a basic understanding of the unique EHS factors when handling nanoscale materials.

NOTE 2—See Guide E2996 for details.

6.3 Students should also have a basic knowledge of the unique physical and chemical properties of nanoscale materials as compared to their bulk equivalents.

NOTE 3—See Guide E3089 for details.

7. Concepts and Skills to be Covered

7.1 Characterization methods covered should include ones based on electron beam, scanning probe, optical, ion beam, and X-ray techniques, as well as electrical, mechanical and thermal measurements. Method selection is based on inputs from industry, nanotechnology educators and subject matter experts.

7.2 Usage of the appropriate methods for a given type and quantity of material or sample will also be covered, together with sample preparation and data analysis methodology.

7.3 The methods relevant for workforce education in nanotechnology characterization are given in Section 8, with important topics to be covered for each method listed specifically. Additional methods or topics, or both, may be added on an as-needed basis.

8. Characterization Methods Relevant to Nanotechnology Workforce Education

8.1 *Scanning ~~Electron Microscopy~~electron microscopy (SEM) or ~~Field Emission~~field emission (FE) SEM, or ~~Both:~~both:*

8.1.1 Vacuum system ~~operation,~~operation.

8.1.2 Appropriate materials to be ~~analyzed,~~analyzed.

8.1.3 Magnification ~~range,~~range.

8.1.4 Sample ~~preparation,~~preparation.

8.1.5 Care of biological ~~samples,~~samples.

8.1.6 Types of ~~emission,~~emission.

8.1.7 Impact of beam energy and spot ~~size,~~size.

8.1.8 Detection of secondary ~~electrons,~~electrons.

8.1.9 Detection of backscattered ~~electrons, and~~electrons.

8.1.10 Corrections for astigmatism and aberration.

8.2 *Transmission ~~Electron Microscopy~~electron microscopy (TEM):*

8.2.1 Vacuum system ~~operation,~~operation.

8.2.2 Appropriate materials to be ~~analyzed,~~analyzed.

8.2.3 Magnification ~~range,~~range.

8.2.4 Sample preparation and sample thinning ~~methods,~~methods.

8.2.5 Care of biological ~~samples,~~samples.

8.2.6 Bright field ~~mode,~~mode.

8.2.7 Diffraction ~~contrast,~~contrast.

8.2.8 Impact of beam ~~energy, and~~energy.

8.2.9 Corrections for astigmatism and aberration.

8.3 *Energy ~~Dispersive X-Ray Spectroscopy~~dispersive X-ray spectroscopy (EDS):*

8.3.1 Vacuum system ~~operation,~~operation.

8.3.2 Appropriate materials to be ~~analyzed,~~analyzed.

8.3.3 Electron beam ~~source,~~source.

8.3.4 X-ray ~~detector,~~detector.

8.3.5 Spectrum and data ~~analysis,~~analysis., and

8.3.6 Detection limit.

8.4 *Scanning ~~Probe Microscopy~~probe microscopy (SPM):*

8.4.1 *Atomic ~~Force Microscopy~~force microscopy (AFM):*

8.4.1.1 AFM tip technology and tip ~~construction,~~construction.

8.4.1.2 Vibration isolation needs and ~~solutions,~~solutions.

8.4.1.3 Optical ~~lever,~~lever.

8.4.1.4 Photodiode ~~detector,~~detector.

8.4.1.5 Probe positioning ~~mechanism,~~mechanism.

8.4.1.6 Cantilever spring constant and resonance ~~frequency,~~frequency.

8.4.1.7 Sample preparation and ~~mounting,~~mounting.

8.4.1.8 Laser alignment on ~~cantilever, and~~cantilever.

8.4.1.9 Modes of operation: contact, tapping, and non-contact.

8.4.2 *Scanning ~~Tunneling Microscopy~~tunneling microscopy (STM):*

8.4.2.1 Tip and sample ~~conductivity,~~conductivity.

8.4.2.2 Vibration isolation needs and ~~solutions,~~solutions.

8.4.2.3 Sample ~~flatness,~~flatness.

8.4.2.4 Probe positioning ~~mechanism,~~mechanism.

8.4.2.5 Probe tip ~~construction,~~construction.

8.4.2.6 Piezoelectric tube ~~scanner,~~scanner.

8.4.2.7 Feedback loop proportional-integral-derivative (PID) ~~control,~~control.

8.4.2.8 Cases needing ultra high vacuum ~~measurements, and~~measurements.

8.4.2.9 Range of operation.

8.5 ~~*Profilometry:*~~*Stylus profilometry:*

8.5.1 Appropriate materials to be ~~analyzed,~~analyzed.

8.5.2 Range of ~~operation,~~operation.

8.5.3 ~~Calibration, and~~Calibration.

8.5.4 Stylus designs and stylus force.

8.6 *Raman ~~Spectroscopy:~~spectroscopy:*

8.6.1 Concept of ~~operation,~~operation.

8.6.2 Appropriate materials to be ~~analyzed, and~~analyzed.

8.6.3 Chemical bonds and Doppler interactions.

8.7 *Fourier ~~Transform Infrared Spectroscopy~~transform infrared spectroscopy (FTIR):*

8.7.1 Appropriate materials to be ~~analyzed,~~analyzed.

8.7.2 Sample ~~preparation,~~preparation.

8.7.3 Infrared ~~emitter,~~emitter.

8.7.4 Michelson interferometer ~~operation,~~operation.

8.7.5 Overview of the theory of Fourier ~~transforms, and~~transforms.

8.7.6 Interferogram analysis.

8.8 *Spectrophotometry:*

8.8.1 Appropriate materials to be ~~analyzed,~~analyzed.

8.8.2 Transmittance and reflectance ~~mode, and~~mode.

8.8.3 Sample preparation and cuvettes.

8.9 *Optical ~~Microscopy:~~microscopy:*

8.9.1 *Light ~~Microscopy:~~microscopy:*

8.9.1.1 Appropriate materials to be ~~analyzed,~~analyzed.

8.9.1.2 Magnification range and resolution ~~limits, and~~limits.

8.9.1.3 Brightfield and darkfield illumination.

8.9.2 *Fluorescence ~~Microscopy:~~microscopy:*

8.9.2.1 Light ~~sources,~~sources.

8.9.2.2 Application to biological ~~samples, and~~samples.

8.9.2.3 Limitations.

8.9.3 *Scanning ~~Confocal Microscopy:~~confocal microscopy:*

8.9.3.1 Scanning modes: laser scanning and spinning ~~disc, and~~disc.

8.9.3.2 3-dimensional image reconstruction and multi-channel image overlay.

8.10 *Ellipsometry:*

8.10.1 Appropriate materials to be ~~analyzed,~~analyzed.

8.10.2 One-angle verses two-angle ~~measurements, and~~measurements.

8.10.3 Stoichiometric information.

8.11 *Contact ~~Angle Measurement:~~angle measurement:*

8.11.1 Appropriate materials to be ~~analyzed,~~analyzed.

8.11.2 Surface ~~energy, and~~energy.

8.11.3 Relationship of surface energy for water and protein adhesion and implications for biocompatibility.

8.12 *Auger ~~Electron Spectroscopy~~electron spectroscopy (AES):*

8.12.1 Vacuum system ~~operation,~~operation.

8.12.2 Electron transitions and the Auger ~~Effect,~~effect.

8.12.3 Spectrum and data ~~analysis,~~analysis.

8.12.4 ~~Instrumentation,~~Instrumentation.

8.12.5 Quantitative ~~analysis, and~~analysis.

8.12.6 Depth profile.

8.13 *~~Secondary-Ion Mass Spectroscopy~~Secondary-ion mass spectroscopy (SIMS):*

8.13.1 Vacuum system ~~operation,~~operation.

8.13.2 Appropriate materials to be ~~analyzed,~~analyzed.

8.13.3 Element sensitivity ~~range,~~range.

8.13.4 *Ion source:*

8.13.4.1 Ion beam selection and interaction with ~~surface,~~surface.

8.13.4.2 Gaseous ionization by electron ~~ionization,~~ionization.

8.13.4.3 Surface ionization of Cs ~~ions, and~~ions.

8.13.4.4 Liquid metal ionization.

8.13.5 *Static versus dynamic measurement methods:*

8.13.5.1 Sputter rates.

8.13.6 Types of ~~emission,~~emission.

8.13.7 Impact of beam ~~energy, and~~energy.

8.13.8 Sample charging and reduction of negative charge.

8.14 ~~*X-Ray Photoelectron Spectroscopy*~~*X-ray photoelectron spectroscopy (XPS):*

8.14.1 Vacuum system ~~operation,~~operation.

8.14.2 Appropriate materials to be ~~analyzed,~~analyzed.

8.14.3 X-ray ~~source,~~source.

8.14.4 Electron ~~detector,~~detector.

8.14.5 Spectrum and data ~~analysis, and~~analysis.

8.14.6 Detection limit.

8.15 ~~*X-Ray Diffraction:*~~*X-ray diffraction (XRD):*

8.15.1 X-ray generation and ~~characteristics,~~characteristics.

8.15.2 Lattice planes and Bragg's ~~Law,~~law.

8.15.3 *Sample ~~Preparation:~~preparation:*

8.15.3.1 Diffraction of powder ~~samples, and~~samples.

8.15.3.2 Diffraction of thin film samples.

8.15.4 *Comparison with reference spectra:*

8.15.4.1 Elemental ~~composition, and~~composition.

8.15.4.2 Lattice parameter.