Integration, Interoperability, and Information Management: What are the key issues for Nanomanufacturing?

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ABSTRACT

Nanomanufacturing can be defined as all manufacturing activities that collectively support an approach to design, produce, control, modify, manipulate, and assemble nanometer scale objects and features for the purpose of fabricating a product or system that exploits properties seen at the nanoscale. This includes information technologies and systems that support each aspect of this collective approach. This paper focuses on research topics centered on information technology for nanomanufacturing and nanometrology applications that are broadly grouped into three categories: integration, interoperability, and information management.

Keywords: Nanomanufacturing, Integration, Interoperability, Information Management, Standards, Nanometrology, Information Technologies, IT

1.0 INTRODUCTION

Nanometrology is an integral part of the manufacturing processes for nanomaterials and products that incorporate nanometer scale elements and structures[1]. Nanomanufacturing (NM) measurement technology is critical in order that the billions of dollars of research be recovered through US leadership in bringing nanotech-enabled products to market. As efforts in nanotechnology, and in particular NM evolve and mature, there is increasing recognition that Information Technologies (IT) dealing with integration, interoperability, and information management[2] will be critical in effectively developing nanomanufacturing processes and ultimately products. There is a need to promote the research, development and application of measurement sciences to enable assessment of the performance of ultra-accurate, off-line, human-in-the-loop instrumentation, and automated production systems for monitoring and control of nanometer scale manufacturing systems. Further, the research outcomes must be responsive to production environments, requirements, and timeframes.

2.0 NANOMANUFACTURING PROGRAM AT NIST

The Nanomanufacturing Program within the Manufacturing Engineering Laboratory (MEL) at NIST has the mission to develop the measurement infrastructure for nanomanufacturing to reduce the barriers for technological innovation and successful commercialization of nano-based products. This will be accomplished through fundamental scientific research, theory, and experiments in precision metrology at the nanoscale in the manufacturing sector. The following focus areas are emphasized.

- Reliable, scaled-up, cost effective manufacturing of nanoscale materials, devices and systems
- Robust manufacturing practices coupled with the necessary standards and measurement infrastructure
- Development of the instrumentation, tools and processes needed to bridge the gap between discovery and commercialization.
- Development of the measurement infrastructure for nanomanufacturing to reduce the barriers for technological innovation and successful commercialization of nano-based products.

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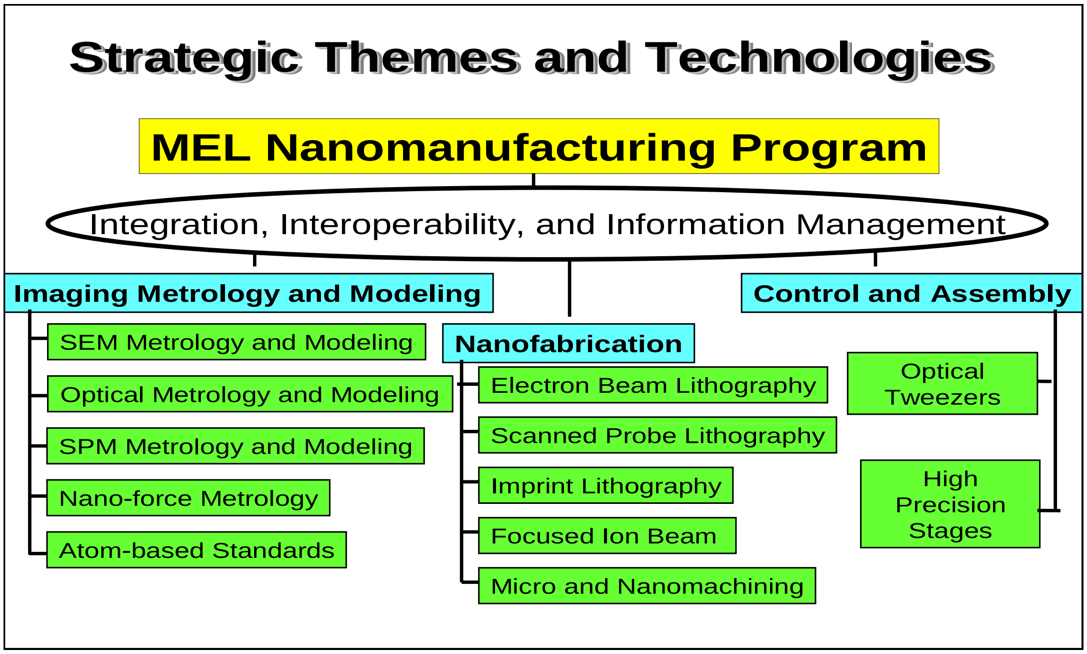
The Program is comprised of three themes: Imaging Metrology and Modeling, Nanofabrication, and Control and Assembly. Integration, interoperability, and information management have been defined as cross-cutting technologies.



<u>New measurement systems and Information Technologies</u>

The development of new measurement systems can evolve from existing measurement systems, fabrication processes, and fabrication system architectures or can involve the development of new nanomanufacturing systems, support tools, and new fabrication processes. To be suitable for plant floor deployment the systems must be production hardened to withstand the environmental conditions seen during manufacturing. Instruments must be designed to exist in a production environment and be capable of measuring product and process attributes required for conformance testing. Measurement technologies must provide production personnel with the necessary information to maintain control of the manufacturing process ensuring that the products produced will conform to desired specifications. This makes it necessary that control information be provided in the timeframes required by production and in formats suitable for production personnel. Particular emphasis is placed on technologies that promote low product costs and mass-production capabilities. It is important to establish traceability to basic and derived units of measure, including length, mass and force as traceability provides a direct and necessary link for verifying measurement accuracy.

The pursuit of standard processes and reference materials often times results in new fabrication processes and new measurement instruments such as Scanned Probe Oxidation (SPO) systems, Scatterfield Microscopes, Optical Tweezers Systems, and Chromium Deposition Directed Assembly Methods. The complexity of these new instruments and preciseness of measurements and methods is directing more attention to the development of open control architectures, user interfaces for instruments and other complex equipment, and an increased focus on models next to each other and simulation tools. This further underscores the importance of information technologies (IT) for nanomanufacturing and nanometrology advancement.

3.0 INTEGRATION

Integration technologies are key enablers for solution providers who design and produce measurement and production systems for nanotech manufacturers. These systems require the seamless integration of hardware and software together to achieve specific measurement functionality and performance. This functionality can be realized through software integration which incorporates algorithms and models that describe probe tip-to-feature interaction, material properties, material analysis results, tool-probe motion planning, forward-looking control approaches, process flows, and other relevant phenomenon. Adding to this complexity, the desired functionality will be reliant on knowledge/information exchange across a number of these models, further justifying an integrative solution to ensure measurement accuracy and efficiency. In addition, hybrid production systems that combine functionality of two or more tool technologies for measurement and deposition/removal of materials will require novel integration approaches. Coordination of measurements with control of production-level operations will set the stage for real-time integration within a single system and with clusters of loosely coupled production and measurement systems. An example of a loosely coupled system is an Atomic Force Microscope (AFM) and Scanning Electron Microscope (SEM) system that utilize a common pallet system for sharing of functionality between tools.

4.0 INTEROPERABILITY

Interoperability ensures that different metrology instrumentation (types and manufacturers) can exchange data and information in a useful and meaningful way in support of a system that works together effectively and in a predictable manner, without prior physical staging or communication. It is expected that as nanometer scale metrology sub-systems are incorporated into production systems they will increase in complexity as they become interwoven with existing engineering, manufacturing, and business software. In addition, there will likely be a mix of in-process and off-line measurements that will support production operations and actions. This will result in an urgent need to address the issue of interoperability and, equally important, a need to establish measures to determine the level of interoperability[3] of an implementation.

5.0 INFORMATION MANAGEMENT

Information management is simply the handling of information acquired by one or many disparate sources in a way to optimize access for all who have a share in that information or a right to that information[4]. Information management provides a structured approach to formatting, storing, transferring, and presenting product lifecycle information while maintaining security and data integrity requirements. This includes focus areas supporting measurement technologies which can be extensions to research areas such as database design and architectures, data mining, and data representations.

6.0 SUMMARY

Significant progress has been made in developing measurement models and algorithms that clearly demonstrate computational tractability and a path to their application in real-time monitoring and control of NM processes. Leveraging these advances with statistical methods and novel sampling strategies will further enhance this capability. New advances in interoperability technologies such as semantic-based knowledge representations will increase manufacturers capability to exchange process knowledge within its own enterprise and to work effectively, in real-time, with their extended supplier base. With the development of new information management architectures, combined with local production system functionality, processes will have ready access to relevant data and information stored remotely enabling processes to react to conditions beyond normal local response capabilities. IT plays a key role in creating this cohesive toolbox of technologies that will support metrology and instrumentation advances necessary for responsive and valued knowledge and information exchange. These recent advances in integration, interoperability, and information management technologies, and associated fields such as math and computational science and digital libraries, provide the essential ingredient for continuing U.S. leadership in this field.

Below are some key IT research areas that are reliant on integration, interoperability, and information management technologies. The research community's ability to overcome barriers in these areas will dictate the resulting outcomes for improved U.S. product quality and manufacturing process performance, reduced production costs and time-to-market, and increased competitiveness in international markets. One could ask "What are the new issues that NM is facing and how can one effectively use solutions from general manufacturing, if possible. What kind of new IT solutions should be worked out for NM?" The following listing of potential research topic areas is intended to introduce the reader to the diversity of IT for NM and is not intended to be complete.

- Advanced process modeling, simulation, and control technology
    - Utilities to support probe tip modeling and deconvolution algorithms
    - Model overlay and data fusion technologies

  - Real-time post-processing technologies (3-D model construction, surface weaving, etc.)
  - Efficient algorithms and portable, scalable software for the application of appropriate nanoscale instrumentation and in-process measurement procedures to industrial problems
  - Advanced algorithms to enable real-time assembly of libraries for physics-based simulation
    - Decision making from diverse data types that cross timescales and disciplines
  - New control system architectures which enable automated multi-tiered measurements that support low precision/high through-put and high precision/low through-put measurements.
    - Closed loop control with large uncertainties in relevant timeframes
  - Advanced performance modeling methodologies to quantify effectiveness of nanoscale measurement systems and human-metrology interfaces
  - Statistical methods and sampling strategies for product/process measurements
  - Generalized method to identify and define correlation models for indirect measurement/s
- Ultra-precision, fast registration and positioning approaches
  - SRMs (Standard Reference Materials) that provide a bridge between various measurement methods and imaging
  - Computer-interpretable descriptive registration targets, knowledge-encoded transfer pallets, substrates, tool holders, etc.
  - Fast transfer of data between measurement and manufacturing tools
- Nanometrology-unique knowledge representations, information and data architectures, and information management specifications
  - Tolerance and uncertainty representations
- Standardized method for encoding data (metadata sets, Standard Ref. Data)
- Standardized data model - shared understanding of semantic knowledge
  - For example, a knowledge cyberinfrastructure that clarifies semantics, disambiguates terminology, and provides a reservoir for organizing and classifying scientific concepts (ref. NASA Jet Propulsion Laboratory (JPL), Robert Raskin) could improve the accessibility of valued knowledge and information databases.
- Development and deployment of advanced information management and communications technology to support the education, research and manufacturing communities and to increase the electronic availability and use of scientific and engineering data at the appropriate content level and time;
- Support, promote, and coordinate the development of voluntary standards that provide interoperability and common user interfaces within the NM community, and increase industrial competitiveness.
- Common global language specification for metrology system interfaces[5]
- Industry-supported testbeds for validating performance of measurement systems

7. CONCLUSION

Nanomanufacturing is essential to product success in the marketplace, and to be a leading manufacturer one must implement processes that are well thought out in terms of both physical and software systems. Information technologies are playing a significant role in the success of new systems effectiveness and efficiency and must be considered early in the design cycle for maximum impact. In addition, measurements are critical to developing complete understanding of any new phenomena in nanomanufacturing and information technologies are key contributors to our success. Only those things that can be measured can be fully understood. Nanometrology is a critical component of nanomanufacturing that sets the stage for controlling fabrication and production of parts and ensuring product quality.

8.0 REFERENCES

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[3] NIST Systems Integration for Manufacturing Applications (SIMA) Program, Interoperability planning document, http://www.mel.nist.gov/div826/msid/sima/sima.htm

[4] Wikimedia Foundation, Inc., http://en.wikipedia.org/wiki/Information_management

[5] Similar in intent to dimensional markup language (DML) that supports the direct exchange of inspection results between multiple coordinate measuring machines (CMM)