Overview of Metrology for the Semiconductor Industry at the National Institute of Standards and Technology

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Abstract

Semiconductor metrology developments at NIST have been conducted since the 1950s, covering a wide range of topics, including investigation of the causes of second breakdown in bipolar transistors, development of the four point probe technique for resistivity measurements, the production of Standard Reference Materials (SRM™) for resistivity, film thickness, and ion implant, to calorimetry for deep ultraviolet (DUV) and extreme ultraviolet (EUV) laser radiation. Currently the total effort of relevance to the semiconductor manufacturing industry and its supporting infrastructure is approximately $31M per year. This overview presentation covers the major programs underway, and highlights the various ways industry can partner with NIST to obtain critically needed metrology techniques, artifacts, calibration services, and results.

1. Semiconductor Manufacturing Metrology Developments at NIST

The major activities are divided into program areas [1]. These are described in brief below, with a short list of references.

1.1 The Lithography Metrology Program

The Lithography Metrology Program is designed to support the developers of Next Generation Lithography tools. Examples of the results include the discovery of intrinsic birefringence in the CaF_2 and other cubic crystalline materials contemplated for use as lenses for optical lithography at 157 nm [2], the construction and use of the extreme ultraviolet reflectometer for characterizing EUV lenses and mask blanks [3], and the characterization of experimental resists for DUV and EUV lithography [4].

1.2 The Critical Dimension and Overlay Metrology Program

The Critical Dimension and Overlay Metrology Program explores the various techniques for the length and placement measurements necessary for advanced integrated circuit manufacture. Michael Postek and Marilyn Bennett will discuss much of this program in one of the subsequent presentations in this session. One project is to provide single crystal silicon artifacts for calibrating critical dimension metrology instruments. NIST is working closely with International SEMATECH and a commercial supplier of calibration artifacts to develop this technique and make it broadly available [5,6].

1.3 The Thin Film and Shallow Junction Metrology Program

The Thin Film and Shallow Junction Metrology Program covers metrology in the vertical dimension, including thickness, composition, and electrical characterization of gate dielectrics [7,8], profiling of junctions [9], and the fabrication of implantation reference materials [10]. These projects involve extensive interactions with industry, consortia, and academic partners.

1.4 The Interconnect and Packaging Metrology Program

The Interconnect and Packaging Metrology Program spans a wide range of projects covering metrology of the various materials used in packaging and chip interconnect. An excellent example of a cooperative project recently completed is the measurement of the frequency dependence of the dielectric constants, including loss tangents, up to 60 GHz [11]. This project was a cooperative project between International SEMATECH and NIST. NIST provided the test structure designs and the measurements on the finished structures, while International SEMATECH provided the test structure fabrication. David Read in a subsequent presentation in this session will describe several projects involving extensive interactions with industry partners to evaluate the mechanical properties of interconnect materials and packaging materials.

1.5 The Wafer Characterization and Process Metrology Program

The Wafer Characterization and Process Metrology Program covers the application of a broad range of techniques to provide process control and materials and defect analysis. Examples of projects include the thermophysical characterization of process gases such as WF_6 so that flow meters can be accurately calibrated [12], and the development of accurate thermometry for rapid thermal processing [13]. Mechanisms for collaborating with industry include convening common interest groups and participating in SEMI Standards task forces. George Mulholland, Thom Germer, and John Stover will describe in a subsequent presentation in this session a project involving extensive interactions with SEMI Standards and industry collaborators to develop particle sizing metrology.

1.6 The Modeling and Design Metrology Program

The Modeling and Design Metrology Program projects focus on calibration of device models and characterization of devices. A number of industry participants are developing high voltage devices that are characterized at NIST using specialized test equipment [14]. Curt Richter and Duncan Stewart in a subsequent presentation in this session will describe their collaboration to begin to develop molecular electronic device metrology.

1.7 The Test Metrology Program

The Test Metrology Program at NIST is relatively new but growing rapidly. Emphasis is on testing high-speed digital circuits [15] and testing of complex circuits [16].

1.8 The Manufacturing Support Program

Finally, the **Manufacturing Support Program** consists of a joint project between NIST and International SEMATECH to provide a web-based engineering statistics handbook. It is available at http://www.itl.nist.gov/div898/handbook/.

2. KEYS TO SUCCESS

NIST researchers across a broad range of disciplines collaborate extensively with industry, academia, and consortia partners to develop metrology for the semiconductor manufacturing industry and its supporting infrastructure industries. Successful collaborations involve (1) the identification of a worthy problem; (2) complementary assets from the set of collaborators sufficient to solve the problem; (3) and a worthwhile outcome for all the collaborators.

Industry and industry consortia participants bring insights on what is relevant, sample fabrication capabilities, and access to advanced processing and testing equipment. Academic participants have the freedom to work on longer range and riskier solutions and problems. NIST provides unique laboratory facilities, such as the Cold Neutron Source and the Synchrotron Ultraviolet Radiation Facility (SURF III), and has the expertise necessary for precise calibrations. Industry and industry consortia, in turn, can gain solutions to problems faster by leveraging academic and NIST resources. Academia gains access to relevant problems for research for faculty and students, and are exposed to "real world" industry problems. Through collaboration, NIST succeeds in achieving its mission of developing and promoting measurement, standards, and technology to enhance productivity, facilitate trade, and improve the quality of life.

3. REFERENCES

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