The National Institute of Standards and Technology was established in 1988 by Congress to “assist industry in the development of technology . . . needed to improve product quality, to modernize manufacturing processes, to ensure product reliability . . . and to facilitate rapid commercialization . . . of products based on new scientific discoveries.”

NIST, originally founded as the National Bureau of Standards in 1901, works to strengthen U.S. industry’s competitiveness; advance science and engineering; and improve public health, safety, and the environment. One of the agency’s basic functions is to develop, maintain, and retain custody of the national standards of measurement, and provide the means and methods for comparing standards used in science, engineering, manufacturing, commerce, industry, and education with the standards adopted or recognized by the Federal Government.

As an agency of the U.S. Commerce Department’s Technology Administration, NIST conducts basic and applied research in the physical sciences and engineering, and develops measurement techniques, test methods, standards, and related services. The Institute does generic and precompetitive work on new and advanced technologies. NIST’s research facilities are located at Gaithersburg, MD 20899, and at Boulder, CO 80303. Major technical operating units and their principal activities are listed below. For more information contact the Public Inquiries Desk, 301-975-3058.

Office of the Director
• Advanced Technology Program
• Quality Programs
• International and Academic Affairs

Technology Services
• Manufacturing Extension Partnership
• Standards Services
• Technology Commercialization
• Measurement Services
• Technology Evaluation and Assessment
• Information Services

Materials Science and Engineering Laboratory
• Intelligent Processing of Materials
• Ceramics
• Materials Reliability
• Polymers
• Metallurgy
• Reactor Radiation

Chemical Science and Technology Laboratory
• Biotechnology
• Chemical Kinetics and Thermodynamics
• Analytical Chemical Research
• Process Measurements
• Surface and Microanalysis Science
• Thermophysics

Physics Laboratory
• Electron and Optical Physics
• Atomic Physics
• Molecular Physics
• Radiometric Physics
• Quantum Metrology
• Ionizing Radiation
• Time and Frequency
• Quantum Physics

Manufacturing Engineering Laboratory
• Precision Engineering
• Automated Production Technology
• Intelligent Systems
• Manufacturing Systems Integration
• Fabrication Technology

Electronics and Electrical Engineering Laboratory
• Microelectronics
• Law Enforcement Standards
• Electricity
• Semiconductor Electronics
• Electromagnetic Fields
• Electromagnetic Technology
• Optoelectronics

Building and Fire Research Laboratory
• Structures
• Building Materials
• Building Environment
• Fire Safety
• Fire Science

Computer Systems Laboratory
• Office of Enterprise Integration
• Information Systems Engineering
• Systems and Software Technology
• Computer Security
• Systems and Network Architecture
• Advanced Systems

Computing and Applied Mathematics Laboratory
• Applied and Computational Mathematics
• Statistical Engineering
• Scientific Computing Environments
• Computer Services
• Computer Systems and Communications
• Information Systems

1 At Boulder, CO 80303.
2 Some elements at Boulder, CO 80303.
The Journal of Research of the National Institute of Standards and Technology features advances in measurement methodology and analyses consistent with the NIST responsibility as the nation’s measurement science laboratory. It includes reports on instrumentation for making accurate and precise measurements in fields of physical science and engineering, as well as the mathematical models of phenomena which enable the predictive determination of information in regions where measurements may be absent. Papers on critical data, calibration techniques, quality assurance programs, and well-characterized reference materials reflect NIST programs in these areas. Special issues of the Journal are devoted to invited papers in a particular field of measurement science. Occasional survey articles and conference reports appear on topics related to the Institute’s technical and scientific programs.

ISSN 1044-677X  Coden: JRITEF  Library of Congress Catalog Card No.: 89-656121

The Gaseous Electronics Conference Radio-Frequency Reference Cell

Preface

One of the most important commercial applications of low-temperature, radio-frequency (rf) glow discharges is the fabrication of microelectronic circuitry. However, many plasma-based production processes suffer from reliability problems. A process may work well for some time and then fail mysteriously, or a process may yield certain results in one plasma reactor, and completely different results in another. These types of uncertainties in process and reactor performance cause decreased manufacturing efficiency, increased costs, and limit the development of increasingly complex semiconductor devices.

The unpredictability of semiconductor fabrication processes has been attributed to subtle differences in reactor conditions that could not easily be detected, such as feed gas impurities, surface conditioning, surface charging, and minor variations in electrical circuits. However, progress in isolating the effects of these conditions was slowed by the fact that the plasma reactors used by many researchers were so vastly different in design from one another, that differences in experimental data due to reactor conditions could not be separated from the effects of different reactor geometries.

An attempt to formally address this problem at the 1988 Gaseous Electronics Conference (GEC) resulted in the design of the GEC RF Reference Cell: a parallel plate, capacitively-coupled, rf plasma reactor that, in principle, is suitable for studies of basic discharge phenomena, investigation of industrial-type plasmas, and theoretical modeling. The use of several of these chambers to perform similar experiments in different laboratories, with subsequent comparison of results, was proposed to isolate the effects of reactor geometry from other experimental variables. Over the years, the number of GEC Cells has increased from 6 to 25, and they are now found in 19 different laboratories throughout the United States and Europe. Work performed on GEC Cells has resulted in the publication of over 75 articles and reports, and has been presented at numerous conferences.

At the 1993 Gaseous Electronics Conference, it was determined that a sufficient amount of research had been performed on GEC Cells that a review of the available data would be useful, and so it was decided that a Special Issue of the Journal of Research of the National Institute of Standards and Technology would be dedicated to work performed on GEC RF Reference Cells. Submission of articles to this Special Issue corresponded to the hosting of the 1994 Gaseous Electronics Conference by NIST. The issue before you is the result of that decision. This issue contains 12 articles that review nearly all of the experiments and theoretical modeling efforts that have been performed over the last 5 years using GEC Cells. While the emphasis of these articles is on the comparison of data obtained on different GEC Cells, together they serve as a "users’ guide" to the operation and performance of the GEC Cell. Hopefully, this makes this issue useful to both novices and experts in the plasma processing community.

All of the articles in this issue have been reviewed, and I am grateful to the many scientists at NIST and elsewhere who served as referees. I also wish to thank Julian Ives for his invaluable assistance in the production of this Special Issue.

James K. Olthoff
Editor
Contents

The Gaseous Electronics Conference Radio-Frequency Reference Cell

Preface

Articles

The Gaseous Electronics Conference RF Reference Cell—An Introduction
J. K. Olthoff and K. E. Greenberg

Current and Voltage Measurements in the Gaseous Electronics Conference RF Reference Cell
Mark A. Sobolewski

Optical Emission Spectroscopy on the Gaseous Electronics Conference RF Reference Cell
J. R. Roberts

Optical Diagnostics in the Gaseous Electronics Conference RF Reference Cell
G. A. Hebner and Kenneth E. Greenberg

Studies of Ion Kinetic-Energy Distributions in the Gaseous Electronics Conference RF Reference Cell
J. K. Olthoff, R. J. Van Brunt, and S. B. Radovanov

Microwave Diagnostic Results from the Gaseous Electronics Conference RF Reference Cell
Lawrence J. Overzet

Langmuir Probe Measurements in the Gaseous Electronics Conference RF Reference Cell
M. B. Hopkins

An Inductively Coupled Plasma Source for the Gaseous Electronics Conference RF Reference Cell
Paul A. Miller, Gregory A. Hebner, Kenneth E. Greenberg, Paul D. Pochan, and Ben P. Aragon

Reactive Ion Etching in the Gaseous Electronics Conference RF Reference Cell

Dusty Plasma Studies in the Gaseous Electronics Conference RF Reference Cell
H. M. Anderson and S. B. Radovanov

One-Dimensional Modeling Studies of the Gaseous Electronics Conference RF Reference Cell
T. R. Govindan and M. Meyyappan

Two-Dimensional Self-Consistent Radio Frequency Plasma Simulations Relevant to the Gaseous Electronics Conference RF Reference Cell
Dimitris P. Lymberopoulos and Demetre J. Economou

Conference Reports

Forty-Seventh Annual Gaseous Electronics Conference
Richard J. Van Brunt and Jean W. Gallagher
News Briefs

GENERAL DEVELOPMENTS

New Web Site Serves as Guide to NII
Photovoltaic Hot Water System Exceeds Expectations
Stress Measurements Assess Railroad Wheel Safety

August Conference Focuses on Diamond Applications
Accurate Prices Goal of New NCWM Procedure
USDA Adopts Updated Versions of Two NIST Handbooks
Energy-Related Inventions Program Recommendations

NIST Helps Company with Measurement of Pulse Energy for Inkjet Print-Heads
Bioelectrical Impedance Analyzers Studied
Partial Discharge Measurement Laboratory Established

NIST Facilitates International Workshop on Ultra-Shallow Profiles in Semiconductors
NIST Testing Machining Centers for Industry
NIST and Private Company Collaborate in Presenting the Practical Application of
  Scanned Probe Microscopy
NIST’S Participation in the Newly Launched Apparel Research Network Program

X-Ray Spectrometry in Electron Beam Instruments
New Publication Focuses on Analytical Methods for Cancer Chemopreventive Agents
Workshop on the ‘‘Treatment of Gaseous Emissions via Plasma Technology’’
  Hosted by NIST
NIST Parallel Applications Development Environment (PADE) Released

Nanodetector Produces First Images
CRADA Signed with Private Company to Share Parallel Computing Software
NIST and the Council on Ionizing Radiation Measurements and Standards Host
  Workshop on Radiation Protection
Photonic Films

Workshop on Materials Property Measurements
X-Ray Diffraction Imaging of ZnSe Substrates for Blue-Green LEDs
Thermal Barrier Coatings Workshop
NIST Work Featured at Automotive Conference

Thermal Behavior of Polymer Ultrathin Films
Thermal Diffusivity Measurements in Multilayer Thermal Barrier Coatings
NSF Renews Support for the Center for High Resolution Neutron Scattering

NIST Develops New Method for Measuring Refrigerant Flammability
NIST Participates in Development of Remote Database Access Standard
Secretary of Commerce Approves Federal Information Processing Standard (FIPS) for
  Document Application Profile

New Publication Looks at Object-Oriented Technology
Information Security Training Attracts Large Federal Audience
NVCA SE Public Workshop Held
Calibration Accreditation
Cryptographic Module Validation
<table>
<thead>
<tr>
<th>Patent Issued on the Application of Arrays of Miniature Hotplates to Materials Processing</th>
<th>511</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latest Gage Block Calibration System at NIST</td>
<td></td>
</tr>
<tr>
<td>NIST Asserts New Approach to Unifying Rockwell Hardness Standards</td>
<td></td>
</tr>
<tr>
<td>First Technical Meeting of Computer-Aided Manufacturing Forum Held</td>
<td>512</td>
</tr>
<tr>
<td>International Comparison of Humidity Standards at NIST</td>
<td></td>
</tr>
<tr>
<td>Synthesis and In Situ Characterization of Superparamagnetic Nanocomposites from Vapor Phase Condensation in a Flame</td>
<td></td>
</tr>
<tr>
<td>Computational Thermochemistry of Si, H, O, Reactions</td>
<td>513</td>
</tr>
<tr>
<td>Role of Radiocarbon Measurement Technology in Meeting Urban Air Quality Standards</td>
<td></td>
</tr>
<tr>
<td>Eighth Annual Workshop on Secondary Ion Mass Spectrometry</td>
<td></td>
</tr>
<tr>
<td>Workshop on Infrared Microspectroscopy With Synchrotron Radiation Sources</td>
<td>514</td>
</tr>
<tr>
<td>Ocean Radiometry Workshop at NIST</td>
<td></td>
</tr>
<tr>
<td>CRADA Investigates Radiation Engineering for Environmental Cleanup</td>
<td></td>
</tr>
<tr>
<td>NIST Assists Industry in Thermoplastics Engineering Design</td>
<td>515</td>
</tr>
<tr>
<td>Method Developed to Measure Material Density at Surfaces</td>
<td></td>
</tr>
<tr>
<td>Micromagnetic Modeling Workshop</td>
<td></td>
</tr>
<tr>
<td>NIST Researchers Receive Patent for a Welding Control System</td>
<td>516</td>
</tr>
<tr>
<td>NIST Hosts Joint Meeting with NSF Center for Science and Technology of Advanced Cement-Based Materials</td>
<td></td>
</tr>
<tr>
<td>NIST Models Radon Transport in Large Multizone Buildings</td>
<td></td>
</tr>
<tr>
<td>Fault Detection and Diagnosis Using Artificial Neural Networks</td>
<td></td>
</tr>
<tr>
<td>Proceedings of Text Retrieval Conference Published</td>
<td>517</td>
</tr>
<tr>
<td>New Publication Gives Blueprint for Electronic Access to Historical Information</td>
<td></td>
</tr>
<tr>
<td>Report Details Benefits of Electronic Workshop</td>
<td></td>
</tr>
<tr>
<td>Commerce, Energy Join Forces to Aid Manufacturers</td>
<td></td>
</tr>
<tr>
<td>First Full-Scale Fire Tests for High Ceilings Done</td>
<td>518</td>
</tr>
<tr>
<td>Distribution Amplifiers Yield Low Noise, High Isolation</td>
<td></td>
</tr>
</tbody>
</table>

**STANDARD REFERENCE MATERIALS**

SRM 2391—PCR-Based DNA Profiling Standard

Eight Thousand Series RMs for Fine Gold, Fine Silver, and Gold Bullion from the Royal Canadian Mint (RCM)

SRM 1632b, 1635 Trace Elements in Coal

SRM 656—Silicon Nitride Powders for Quantitative Analysis by Powder Diffraction

NIST Issues Radiopharmaceutical SRM for Health Care Providers

NIST Sets Standard for Domestic Sludge