NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards was established by an act of Congress March 3, 1901. The Bureau's overall goal is to strengthen and advance the Nation's science and technology and facilitate their effective application for public benefit. To this end, the Bureau conducts research and provides: (1) a basis for the Nation's physical measurement system, (2) scientific and technological services for industry and government, (3) a technical basis for equity in trade, and (4) technical services to promote public safety. The Bureau consists of the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, the Institute for Computer Sciences and Technology, and the Office for Information Programs.

THE INSTITUTE FOR BASIC STANDARDS provides the central basis within the United States of a complete and consistent system of physical measurement; coordinates that system with measurement systems of other nations; and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. The Institute consists of a Center for Radiation Research, an Office of Measurement Services and the following divisions:

- Applied Mathematics
- Electricity
- Mechanics
- Heat
- Optical Physics
- Nuclear Sciences
- Applied Radiation
- Quantum Electronics
- Electromagnetics
- Time and Frequency
- Laboratory Astrophysics
- Cryogenics

THE INSTITUTE FOR APPLIED TECHNOLOGY provides technical services to promote the use of available technology and to facilitate technological innovation in industry and Government; cooperates with public and private organizations leading to the development of technological standards (including mandatory safety standards), codes and methods of test; and provides technical advice and services to Government agencies upon request. The Institute consists of a Center for Building Technology and the following divisions and offices:

- Engineering and Product Standards
- Weights and Measures
- Invention and Innovation
- Product Evaluation Technology
- Electronic Technology
- Technical Analysis
- Measurement Engineering
- Structures, Materials, and Life Safety
- Building Environment
- Technical Evaluation and Application
- Fire Technology

THE INSTITUTE FOR COMPUTER SCIENCES AND TECHNOLOGY conducts research and provides technical services designed to aid Government agencies in improving cost effectiveness in the conduct of their programs through the selection, acquisition, and effective utilization of automatic data processing equipment; and serves as the principal focus within the executive branch for the development of Federal standards for automatic data processing equipment, techniques, and computer languages. The Institute consists of the following divisions:

- Computer Services
- Systems and Software
- Computer Systems Engineering
- Information Technology

THE OFFICE FOR INFORMATION PROGRAMS promotes optimum dissemination and accessibility of scientific information generated within NBS and other agencies of the Federal Government; promotes the development of the National Standard Reference Data System and a system of information analysis centers dealing with the broader aspects of the National Measurement System; provides appropriate services to ensure that the NBS staff has optimum accessibility to the scientific information of the world. The Office consists of the following organizational units:

- Office of Standard Reference Data
- Office of Information Activities
- Office of Technical Publications
- Library
- Office of International Relations.

1 Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
2 Part of the Center for Radiation Research.
3 Located at Boulder, Colorado 80302.
4 Part of the Center for Building Technology.
Semiconductor Measurement Technology:
Spreading Resistance Symposium

Proceedings of a Symposium
Held at the National Bureau of Standards
Gaithersburg, Maryland
June 13-14, 1974

James R. Ehrstein, Editor

Electronic Technology Division
Institute for Applied Technology
National Bureau of Standards
Washington, D.C. 20234

Under the Sponsorship of
Committee F-1 of the
American Society for Testing and Materials

and

The National Bureau of Standards
This Symposium on Spreading Resistance measurements was held on June 13-14, 1974 at the National Bureau of Standards under the cosponsorship of this Bureau and Committee F-1 of the American Society for Testing and Materials. It consisted of three sessions as detailed in the Contents on pp. vi to viii.

The objective of the Symposium was to expose the state of the art with respect to the theory, practice and applications of the electrical spreading resistance measurement technique. This technique which has seen rapidly increasing interest and use over the last 10 or more years, has noteworthy versatility for profiling dopant concentrations over many orders of magnitude in multiple layer semiconductor structures. Nevertheless, the ever increasing demand on all measurement methods, caused by device fabrication utilizing active regions often less than 1 μm in thickness, taxes the theory, practice and successful application of all techniques, including the electrical spreading resistance.

It is hoped that this symposium, by illustrating the successful applications which have been made of the technique, and by indicating some of the areas where limitations have been found to exist, will encourage further effort by interested parties, to find solutions to those limitations.

Finally, by compiling a store of well documented measurement practice in one volume, it is hoped that the beginner in this technique will find rapid solutions to possible basic problems, so that he too may make rapid and successful use of this technique.

James R. Ehrstein
Editor
SPREADING RESISTANCE SYMPOSIUM

ABSTRACT

This Proceedings contains the information presented at the Spreading Resistance Symposium held at the National Bureau of Standards on June 13-14, 1974.

This Symposium covered the state of the art of the theory, practice and applications of the electrical spreading resistance measurement technique as applied to characterization of dopant density in semiconductor starting materials and semiconductor device structures. In addition to the presented papers, the transcripts of the discussion sessions which were held directly after the Theory, Practice and Applications sessions are also included. These transcripts, which were reviewed by the respective respondents for clarity, are essentially as presented at the symposium.

Key words: Dopant concentration, dopant profiles, metal-semiconductor contacts, resistivity, semiconductor surface preparation, silicon, spreading resistance.
SYMPOSIUM COMMITTEE

P. LANGER, Symposium Chairman
Bell Telephone Laboratories
Allentown, Pennsylvania

K. E. BENSON, Cochairman - Theory Session
Bell Telephone Laboratories
Allentown, Pennsylvania

F. VIEWEG-GUTBERLET, Cochairman - Theory Session
Wacker Chemitronic
Burghausen, West Germany

B. MORRIS, Cochairman - Practice Session
Bell Telephone Laboratories
Allentown, Pennsylvania

P. LANGER, Cochairman - Practice Session
Bell Telephone Laboratories
Allentown, Pennsylvania

A. MAYER, Cochairman - Application Session
RCA Corporation
Somerville, New Jersey

F. PADOVANI, Cochairman - Application Session
Texas Instruments, Inc.
Dallas, Texas

J. R. EHRSTEIN, Chairman - Publicity, Arrangements, Publication
National Bureau of Standards
Washington, D. C. 20234
CONTENTS

Paper No.                          Page No.

I-1.  Welcome from NBS            1
      Judson C. French, Chief, Electronic Technology Division
      National Bureau of Standards, Gaithersburg, Maryland

I-2.  Welcome from ASTM           3
      Robert I. Scace, Chairman, ASTM Committee F-1
      General Electric Company, Syracuse, New York

I-3.  Keynote Address             5
      Robert G. Mazur
      Solid State Measurements, Monroeville, Pennsylvania

SESSION I - THEORY

T-1.  The Physics of Spreading Resistance Measurements
      S. J. Fonash, Engineering Science Department
      Pennsylvania State University
      University Park, Pennsylvania 17

T-2.  Formal Comparison of Correction Formulae for Spreading Resistance Measurements on Layered Structures
      P. J. Severin, Philips Research Laboratories
      Eindhoven, The Netherlands 27

T-3.  Two-Point Probe Correction Factors
      D. H. Dickey, Bell and Howell Research Laboratory
      Pasadena, California 45

T-4.  On the Validity of Correction Factors Applied to Spreading Resistance Measurements on Bevelled Structures
      P. M. Pinchon, R. T. C. La Radiotechnique Compelec
      14 Caen, France 51

T-5.  SRPROF, A Fast and Simple Program for Analyzing Spreading Resistance Profile Data
      B. L. Morris and P. H. Langer, Bell Telephone Laboratories
      Allentown, Pennsylvania 63

T-6.  Multilayer Analysis of Spreading Resistance Measurements
      Gregg A. Lee, Texas Instruments Incorporated
      Dallas, Texas 75

SESSION II - PRACTICE

P-1.  An Automated Spreading Resistance Test Facility
      J. C. White, Western Electric Company
      Allentown, Pennsylvania 95

P-2.  Angle Bevelling Silicon Epitaxial Layers, Technique and Evaluation
      P. J. Severin, Philips Research Laboratories
      Eindhoven, The Netherlands 99

P-3.  Spreading Resistance Measurements on Silicon with Non-blocking Aluminum-Silicon Contacts
      J. Krausse, Siemens AG
      Munich, F. R. Germany 109
<table>
<thead>
<tr>
<th>Paper No.</th>
<th>Title</th>
<th>Authors</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-5.</td>
<td>Spreading Resistance Correction Factors for (111) and (100) Samples</td>
<td>H. Murrmann and F. Sedlak, Siemens AG Munich, F. R. Germany</td>
<td>137</td>
</tr>
<tr>
<td>P-6.</td>
<td>On the Calibration and Performance of a Spreading Resistance Probe</td>
<td>H. J. Ruiz and F. W. Voltmer, Texas Instruments Incorporated Dallas, Texas</td>
<td>145</td>
</tr>
<tr>
<td>P-7.</td>
<td>Comparison of the Spreading Resistance Probe with Other Silicon Characterization Techniques</td>
<td>W. J. Schroen, G. A. Lee, and F. W. Voltmer, Texas Instruments Incorporated, Dallas, Texas</td>
<td>155</td>
</tr>
</tbody>
</table>

SESSION III - APPLICATIONS

<table>
<thead>
<tr>
<th>Paper No.</th>
<th>Title</th>
<th>Authors</th>
<th>Page No.</th>
</tr>
</thead>
</table>
A-7. The Experimental Investigation of Two-Point Spreading Resistance Correction Factors for Diffused Layers  
N. Goldsmith, R. V. D'Aiello, and R. A. Sunshine, RCA Laboratories  
Princeton, New Jersey  

A-8. Applications of the Spreading Resistance Technique to Silicon Characterization for Process and Device Modeling  
W. H. Schroen, Texas Instruments Incorporated  
Dallas, Texas  

LATE NEWS PAPER  

Improved Surface Preparation for Spreading Resistance Measurements on p-Type Silicon  
J. R. Ehrstein, National Bureau of Standards  
Gaithersburg, Maryland  

DISCUSSION SESSION  

List of Participants  

Discussion - Theory  

Discussion - Practice  

Discussion - Applications  

Concluding Remarks  
P. H. Langer - Symposium Chairman  

Appendix - Bibliography  

---  

Certain commercial materials and equipment are identified in this paper in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.
<table>
<thead>
<tr>
<th>Author</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assour, J.</td>
<td>201</td>
</tr>
<tr>
<td>Deines, J. L.</td>
<td>169</td>
</tr>
<tr>
<td>Dickey, D. H.</td>
<td>45</td>
</tr>
<tr>
<td>Ehrstein, J. R.</td>
<td>249</td>
</tr>
<tr>
<td>Edwards, J. R.</td>
<td>179</td>
</tr>
<tr>
<td>Fonash, S. J.</td>
<td>17</td>
</tr>
<tr>
<td>Goldsmith, N.</td>
<td>223</td>
</tr>
<tr>
<td>Gruber, G.</td>
<td>209</td>
</tr>
<tr>
<td>Krausse, J.</td>
<td>109</td>
</tr>
<tr>
<td>Lee, G. A.</td>
<td>75</td>
</tr>
<tr>
<td>Mayer, A.</td>
<td>123</td>
</tr>
<tr>
<td>Morris, B. L.</td>
<td>63</td>
</tr>
<tr>
<td>Murrmann, H.</td>
<td>137</td>
</tr>
<tr>
<td>Murrmann, H.</td>
<td>217</td>
</tr>
<tr>
<td>Pinchon, P. M.</td>
<td>51</td>
</tr>
<tr>
<td>Ruiz, H. J.</td>
<td>145</td>
</tr>
<tr>
<td>Schroen, W. J.</td>
<td>155</td>
</tr>
<tr>
<td>Schroen, W. J.</td>
<td>235</td>
</tr>
<tr>
<td>Severin, P. J.</td>
<td>27</td>
</tr>
<tr>
<td>Severin, P. J.</td>
<td>99</td>
</tr>
<tr>
<td>Vieweg-Gutberlet, F.</td>
<td>185</td>
</tr>
<tr>
<td>Voltmer, F. W.</td>
<td>191</td>
</tr>
<tr>
<td>White, J. C.</td>
<td>95</td>
</tr>
</tbody>
</table>
Spreading Resistance Symposium, National Bureau of Standards, 1974. / Spreading Resistance Sym

DATE DUE
Cryogenic Data Center Current Awareness Service bibliographies are issued periodically by the Bureau:

- **Physics and Chemistry (Section A)**
  Papers of interest primarily to scientists working in these fields. This section covers a broad range of physical and chemical research, with major emphasis on standards of physical measurement, fundamental constants, and properties of matter. Issued six times a year. Annual subscription: Domestic, $17.00; Foreign, $21.25.

- **Mathematical Sciences (Section B)**
  Studies and compilations designed mainly for the mathematician and theoretical physicist. Topics in mathematical statistics, theory of experiment design, numerical analysis, theoretical physics and chemistry, logical design and programming of computers and computer systems. Short numerical tables. Issued quarterly. Annual subscription: Domestic, $3.00; Foreign, $4.00.

**DIMENSIONS/NBS (formerly Technical News Bulletin)**—This monthly magazine is published to inform scientists, engineers, businessmen, industry, teachers, students, and consumers of the latest advances in science and technology, with primary emphasis on the work at NBS.

**DIMENSIONS/NBS** highlights and reviews such issues as energy research, fire protection, building technology, metric conversion, pollution abatement, health and safety, and consumer product performance. In addition, **DIMENSIONS/NBS** reports the results of Bureau programs in measurement standards and techniques, properties of matter and materials, engineering standards and services, instrumentation, and automatic data processing.

**NONPERIODICALS**

- **Monographs**—Major contributions to the technical literature on various subjects related to the Bureau's scientific and technical activities.
- **Handbooks**—Recommended codes of engineering and industrial practice (including safety codes) developed in cooperation with interested industries, professional organizations, and regulatory bodies.
- **Special Publications**—Include proceedings of high-level national and international conferences sponsored by NBS, precision measurement and calibration volumes, NBS annual reports, and other special publications appropriate to this grouping such as wall charts and bibliographies.
- **Applied Mathematics Series**—Mathematical tables, manuals, and studies of special interest to physicists, engineers, chemists, biologists, mathematicians, computer programmers, and others engaged in scientific and technical work.

**BIBLIOGRAPHIC SUBSCRIPTION SERVICES**

The following current-awareness and literature-survey bibliographies are issued periodically by the Bureau:

- **Cryogenic Data Center Current Awareness Service** (Publications and Reports of Interest in Cryogenics). A literature survey issued weekly. Annual subscription: Domestic, $20.00; foreign, $25.00.
- **Liquefied Natural Gas**. A literature survey issued quarterly. Annual subscription: $20.00.
