NBS TECHNICAL NOTE

445

# A Bibliography on Methods For the Measurement of Inhomogeneities in Semiconductors (1953–1967)


U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards

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[2] Located at Boulder, Colorado, 80302.

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C. R. Smith, Secretary
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# TECHNICAL NOTE 445

ISSUED MAY 1968

## A Bibliography on Methods for the Measurement of Inhomogeneities in Semiconductors (1953–1967)

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and Susan Gayle Needham

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# A BIBLIOGRAPHY ON METHODS FOR THE MEASUREMENT OF INHOMOGENEITIES IN SEMICONDUCTORS (1953-1967)

Harry A. Schafft
Susan Gayle Needham

About 130 papers which deal with the measurement techniques useful in detecting the type and location of various inhomogeneities, primarily in germanium and silicon, are listed with key words. The types of inhomogeneities considered are those in impurity concentration, resistivity, mobility, diffusion length, lifetime, surface conditions, crystal perfection, and p-n junctions. Some of the twenty-two effects or methods used to detect these inhomogeneities are: photovoltaic, electron-voltaic, photoconductivity, one-, two- and four-point probe, spreading resistance, and voltage breakdown. There are three indexes: a reference tabulation according to key words, a reference tabulation according to methods or effects used to detect an inhomogeneity, and an author index.

Key Words: bibliography; semiconductor material inhomogeneities; measurement methods: photovoltaic, electron voltaic, photoconductivity, point potential probe, spreading resistance, voltage breakdown.

## 1. INTRODUCTION

Inhomogeneities in semiconductors cause many diverse problems in the measurement of transport properties and in the fabrication, operation, and reliability of semiconductor devices. Troublesome inhomogeneities include variations in the distribution of impurities; clusters of impurities, voids, second phase precipitates, and clusters of crystal defects such as dislocations, lineage, or strain fields.

Among the transport properties affected are the resistivity, lifetime, and mobility. These appear to be most affected by nonuniform impurity distributions, including clusters. In fabrication, both solid-state diffusion and alloying steps are affected by the presence of voids or clusters of crystal defects. As a result, poor junction geometry and nonuniform current distributions frequently appear in devices fabricated from inhomogeneous material. These faults often lead to such causes of failure as hot spots, thermal runaway, and second breakdown. Anomalous diffusion of impurities along crystal defects may also occur during operation of devices at high power. In addition, gross variations in properties over a slice often causes wide variations in device characteristics and poor yields. This problem is particularly serious in large area power devices and large scale integrated circuits.

One crucial aspect of the general problem of inhomogeneities in semiconductors is the detection and location of these inhomogeneities. This is the subject of the bibliography, which is the result of a literature survey of measurement techniques useful in detecting the type and location of various inhomogeneities, primarily in germanium and silicon. The sources used in this survey were: personal files, subject indexes of Science Abstracts since 1960, literature citations in papers collected, and journal issues not yet abstracted. To keep within the bounds of manageability without sacrificing utility, the size of the bibliography was limited by applying three sets of boundary conditions. These boundary conditions determined the kinds of inhomogeneities considered, the kinds of measurement techniques described, and the intent of the paper.

The following types of crystal inhomogeneities were selected because of their relevance to the electrical properties of semiconductor devices:

1. Resistivity
2. Impurity concentration
3. Diffusion length
4. Lifetime
5. Surface recombination velocity
6. Surface conditions (inversion layers, surface states, etc.)
7. Mobility
8. Crystal perfection
9. Junction conditions (doping profile, physical location or extent).

The 22 techniques listed below are included in the bibliography. The first 16 of these, which involve electrical and optical interactions, are emphasized. An effort was made to obtain complete coverage of the literature dealing with these techniques. A few representative papers describing the remaining techniques are also included.

1. Photovoltaic
2. Surface photovoltage
3. Electron-voltaic
4. Photoconductivity
5. Two- and one-point probe
6. Four-point probe
7. Spreading resistance
8. Voltage breakdown
9. Internal injection-extraction

10. Capacitance vs voltage

11. Impedance

12. Reflectivity (plasma edge)

13. Absorption

14. Refractive index

15. Birefringence

16. Microwave diode

17. Neutron activation

18. Radioactive tracer

19. Electron microprobe analysis

20. Light microprobe analysis

21. X-ray topography

22. Electrochemical analysis (etching and electroplating).

With regard to the intent of the paper, only those papers were included which dealt directly with one of the listed measurement techniques even though the use of the technique may not have been the major subject of the paper. Those papers which describe results of measurements that can be affected by inhomogeneities were usually excluded.

## 2. ORGANIZATION AND USE OF THE BIBLIOGRAPHY

Each paper has been given an identification code which consists of a sequence of two digits, a letter, and another digit. The first two digits indicate the year of publication and the letter is the initial of the first author's surname. The last digit is used to distinguish those papers which would otherwise have the same code. No rule was used in the assignment of the last digit.

Five major topic headings, each divided into sub-topics and assigned key words, are used to indicate the contents and the approach of each paper. The major topic headings are: (1) the type of inhomogeneity considered, (2) the material examined, (3) the method used or effect measured to detect the inhomogeneity, (4) the special techniques used, and (5) the type of paper. These topics and key words (in capital letters) are listed in the Index According to Key Words. Also included is a tabulation of codes by the appropriate key words.

The papers in the bibliography are arranged according to their codes. The codes are grouped first by year, then in alphabetical order by letter, and then in numerical order by the last digit. Appropriate key words of each topic are arranged in a column just below each reference in order of their listing in the first index.

Of the papers which deal with a given measurement technique to detect a particular type of inhomogeneity, there are some which are sufficiently important that they should be given special attention. The key word for the measurement technique in each of these papers has been bracketed in the bibliography. The codes for these papers have also been underlined in the Index According to Methods or Effects Used to Detect Inhomogeneities.

Each reference citation in the bibliography is followed by an abstract identification code, in parenthesis, if one was available. The code begins with either PA, EA, or CA to indicate that the abstract may be found in Series A, Physics, of Science Abstracts, Series B, Electrical and Electronics (formerly Electrical Engineering) of Science Abstracts, or Chemical Abstracts, respectively. Following these letters are two digits which indicate the year the paper was abstracted if it appears in Science Abstracts or the volume in which the abstract may be found in Chemical Abstracts. The remaining code is the one assigned by the abstracting journal.

If the reference citation is followed by a number preceded by the letters AD then the paper may be obtained from the Clearinghouse for Federal Scientific and Technical Information, Department of Commerce, Sills Building, 5285 Port Royal Road, Springfield, Virginia 22151, by using the AD number.

Journal abbreviations follow those of Science Abstracts. One exception was made in the case of publications of the Institute of Electrical and Electronics Engineers, which is abbreviated IEEE. For those publications which are not listed no abbreviations were made where confusion might arise.

ACKNOWLEDGMENT

The authors wish to thank Dr. W. Murray Bullis for his generous encouragement and valuable guidance throughout the preparation of the bibliography and for the use of his extensive personal files of papers. The personal files of papers on X-ray topography techniques and on electron microprobe analysis techniques which Dr. Richard Deslattes and Dr. Kurt Heinrich, respectively, made available were very useful. The secretarial assistance of Miss Juanita Seal was of considerable help in the final stages of the preparation of the bibliography. The final draft was expeditiously typed by Mrs. Gail Crum.

This work was supported by the Rome Air Development Center, U. S. Air Force, under contract F30602-67-C-0105.

## 3. INDEX ACCORDING TO KEY WORDS

### I. Type of Inhomogeneity

#### 1. RESISTIVITY

55T1, 56F1, 56H1, 56T1, 57T1, 58B1, 58R1, 58S1, 59D1, 59O1, 59Z1, 60B1, 60B2, 60C1, 60H3, 60L1, 60O1, 60S1, 61B2, 61K1, 61S1, 61T1, 61V1, 62B1, 62K1, 63C1, 63G1, 63H1, 63K2, 63L2, 63P1, 63S2, 63T1, 64A1, 64B1, 64B2, 64D1, 64I1, 64L2, 64S1, 64S2, 65B1, 65G2, 65I1, 65M1, 65M2, 65M3, 65M4, 65M5, 65P1, 65S2, 65W2, 65W3, 66A2, 66B1, 66G1, 66M1, 66M2, 66M3, 66M4, 66S1, 66Z2, 67A3, 67D1, 67H1, 67L1, 67M1

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#### 3. DIFFUSION LENGTH

61G1, 63S1, 64M4, 66C2

#### 4. LIFETIME

54A1, 56H1, 60S1, 61R1, 62T2, 63W1, 64B1, 66B1, 67E1

#### 5. SURFACE RECOMBINATION VELOCITY

60S1

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63L1, 65H1, 65W1, 66E1, 66N1, 66Z1, 67H2, 67P1, 67T1, 67T2

#### 7. MOBILITY

54A1

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53B1, 54A1, 55T1, 56F1, 56H1, 56T1, 57T1, 58B1, 58R1, 59D1, 59L1, 59O1, 60B1, 60C1, 60H1, 60H2, 60O1, 60S1, 61B2, 61R1, 61S1, 62B1, 62H1, 62K1, 62P1, 62S1, 62T2, 63H1, 63L2, 63M1, 63S1, 63W1, 64I1, 64L1, 65B1, 65G3, 65I1, 65M1, 65M2, 65M3, 65M4, 66A2, 66B1, 66C1, 66M1, 66M2, 66M3, 67E1, 67H1

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61G1, 62H1, 63K1, 65G3, 65Z1, 66D1, 66H1, 66L2, 66W1, 67C2, 67D1, 67F1, 67L1

4. InSb

61A1, 62H1, 64B2, 65G3

5. InAs

62E1, 62H1

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66C2, 66H1

7. GaAs-InAs, Ge-Si

66H1

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1. PHOTOVOLTAIC

55T1, 56F1, 56T1, 57T1, 59O1, 59Z1, 60B5, 60C1, 60O1, 60S1, 61S1, 62K1, 63P1, 63S1, 64B2, 65M4, 65P1, 66B1, 66S1, 67E1

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61G1

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65M2, 65M3, 66M1, 66M2

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58B1, 58R1, 60L1, 61B2, 63L2, 64I1, 65I1, 67A3, 67D1, 67L1

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Ge, Si
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Ge
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Ge, Si
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