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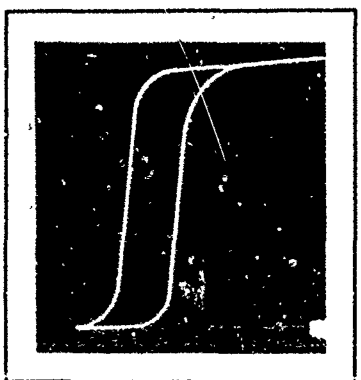
CONTRACT AF 33(616)—8438,
PROJECT 7381; TASK 738103

SILICON: ELECTRICAL CONDUCTIVITY

Data Sheets

M. Neuberger

DS-126
June 1963



EPIC

HUGHES
HUGHES AIRCRAFT COMPANY
CULVER CITY CALIFORNIA

CONTRACT AF 33(616)—8438
PROJECT 7381, TASK 738103

SILICON: ELECTRICAL CONDUCTIVITY

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DS-126
June 1963

EPIC

HUGHES
HUGHES AIRCRAFT COMPANY
CULVER CITY CALIFORNIA

DS-12

FOREWORD

This report was prepared by Hughes Aircraft Company under Contract No. AF 33(616)-8438. The contract was initiated under Project No. 7381, Task No. 738103. The work was administered under the direction of the Directorate of Materials and Processes, Aeronautical Systems Division, with Mr. R.F. Klinger acting as Project Engineer.

Many persons have contributed to the program which this report represents. The author wishes especially to acknowledge the contributions of the following: J.J. Anders, J.W. Atwood, C.L. Blocher, D.L. Grigsby, J.J. Grossman, F.S. Harter, D.H. Johnson, H.T. Johnson, J.T. Milek, G.S. Picus, and E. Schafer.

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ABSTRACT

The Electronic Properties Information Center has been established to collect, index and abstract the literature on the electrical and electronic properties of materials and to evaluate and compile the experimental data from that literature. A modified coordinate index to the literature is machine stored and printed for manual use. The Center publishes data sheets, summary reports, thesauri, glossaries, and similar publications as sufficient information is evaluated and compiled. This report consists of the compiled data sheets on Silicon: Electrical Conductivity.

This report has been reviewed and is approved for publication.

H. Thayne Johnson, Supervisor
Electronic Properties Information Center

John W. Atwood
Project Manager

INTRODUCTION

In June 1961, a program was initiated under the direction of the Air Force to collect, index and abstract the literature on the electrical and electronic properties of materials and to evaluate and compile the experimental data from that literature. Placed at Hughes Aircraft Company in Culver City, California, the program, now called the Electronic Properties Information Center, was originally intended to cover ten major categories of materials: Semiconductors, Insulators, Ceramics, Ferroelectrics, Metals, Ferrites, Ferromagnetics, Electroluminescent Materials, Thermionic Emitters, and Superconductors.

During the first year, studies were completed on the Semiconductor and Insulator categories; and Ceramics was discontinued as a separate category and subsumed under the other nine. Vocabulary studies have now been completed on all categories, and retrospective documentation is virtually complete for Semiconductors and Insulators. A full index to the literature is maintained; and publications such as data sheets, summary reviews, glossaries, and thesauri are periodically issued. The use of the Center and these publications are available to anyone wishing information within the scope of the Center's objectives. A full list of publications to date appears at the end of this report.

This report contains data sheets on Silicon: Electrical Conductivity. The data sheets have been compiled direct from the literature. Articles are allowed to accumulate in the system until it is judged that a sufficient number are available on one material for adequate evaluation.

The manual modified coordinate index is then used to retrieve all literature on the material to be compiled. Bibliographies are checked to make sure that valuable and relevant literature is not overlooked. Then the assembled literature is given to the specialist doing the evaluation and compilation.

Evaluation is confined to primary source data except when only secondary citations are available. If equally valid data are available from several sources, all are given. Data are rejected when judged questionable because of faulty or dubious measurements, unknown sample composition, or if more reliable data are available from another source. Selection of data is based upon that which is judged most representative, precise, reliable, and covers the widest range of variables. The addition of new data to a previously evaluated property requires a reappraisal of the reported values. Older data may be deleted if the new data are judged more accurate or representative.

After a thorough analysis and evaluation, the data is compiled into data sheets which present it in its most optimum form. This will be, primarily, but not limited to, curves or tabular form. Where possible, graphs are adapted directly from the original sources. If this is not possible, they are drawn from data compiled from the articles. Where thought important, notes are entered with each graph to help the user.

The references, from which the data are drawn, are shown by reference number below each graph with the full bibliographic information at the end of the data sheets. The bibliography is referred to and listed in the order of entry into the Center (accession number). This provides a quick cross reference into the index used with the literature.

This compilation deals only with Silicon: Electrical Conductivity as a Semiconductor. Non-semiconductor data will be included in a future revision.

DATA SHEET

ELECTRICAL AND ELECTRONIC PROPERTIES

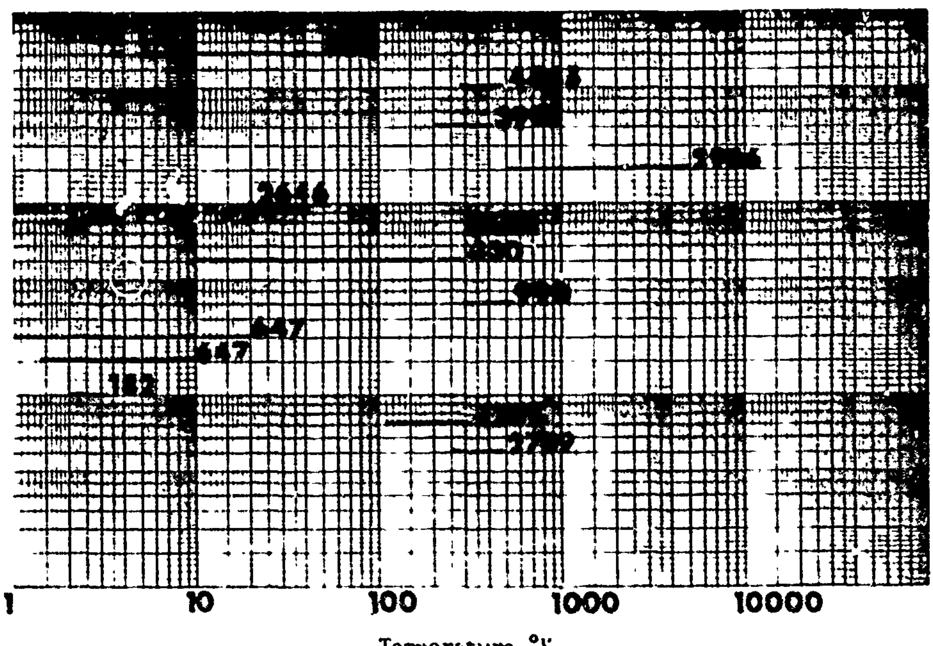
MATERIALS CENTRAL
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND

SEMICONDUCTOR MATERIALS

June 1963

SILICON

Electrical Conductivity



Temperature ranges for electrical conductivity measurements shown on following pages. Numbers at the end of each line are the reference numbers.

DATA SHEET

ELECTRICAL AND ELECTRONIC PROPERTIES

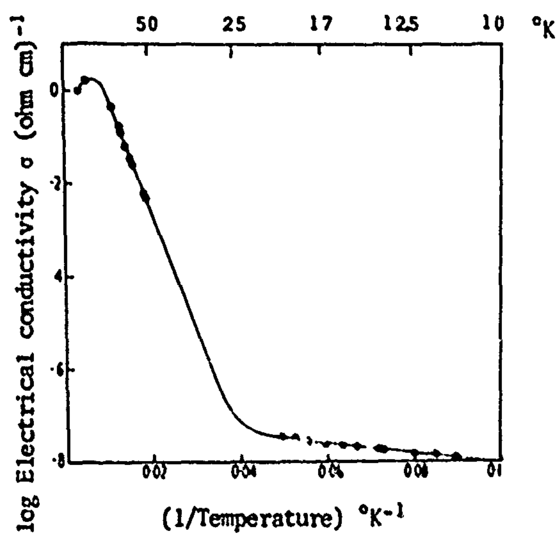
MATERIALS CENTRAL
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND

SEMICONDUCTOR MATERIALS

June 1963

SILICON

Electrical Conductivity



log Electrical conductivity of single crystal, p-type silicon as a function of temperature.

[Ref. 532]

DATA SHEET

ELECTRICAL AND ELECTRONIC PROPERTIES

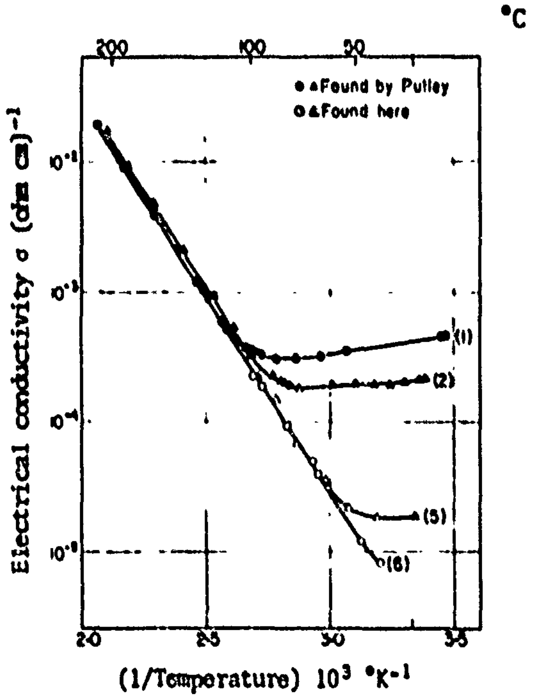
MATERIALS CENTRAL
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND

SEMICONDUCTOR MATERIALS

June 1963

SILICON

Electrical Conductivity



Electrical conductivity of p-type silicon single crystals as a function of the temperature. The curves (1) and (2) are taken from a paper by Putley and Mitchell. Samples 5 and 6 are intrinsic. Boron impurity level reduced to 10^{11} cm^{-3}.

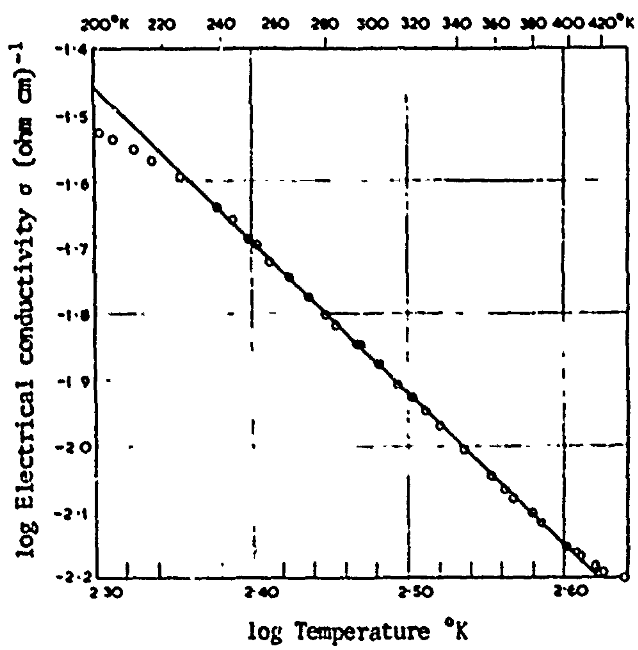
[Ref. 4465]

SEMICONDUCTOR MATERIALS

June 1963

SILICON

Electrical Conductivity



Electrical conductivity of p-type, single crystal silicon as a function of temperature. ρ = 74 ohm cm at 300° K.

[Ref. 3901]

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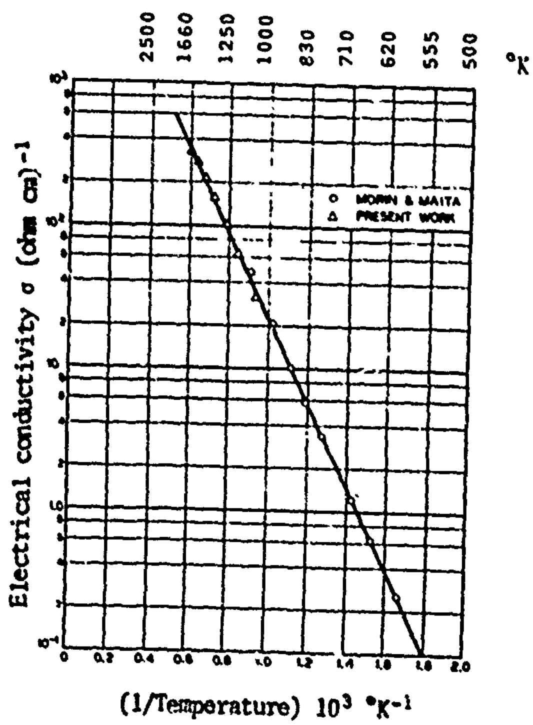
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND

SEMICONDUCTOR MATERIALS

June 1963

SILICON

Electrical Conductivity



Electrical conductivity as a function of temperature for intrinsic, single crystal, n-type silicon.

[Ref. 2956]

DATA SHEET

ELECTRICAL AND ELECTRONIC PROPERTIES

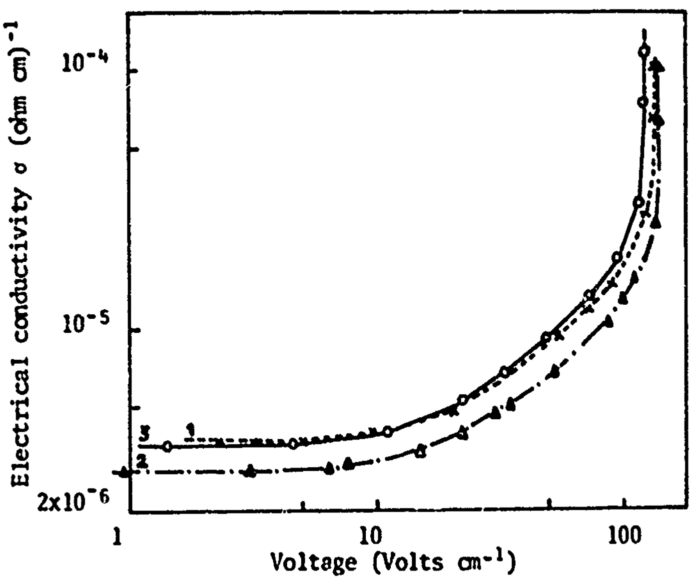
MATERIALS CENTRAL
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND

SEMICONDUCTOR MATERIALS

June 1963

SILICON

Electrical Conductivity

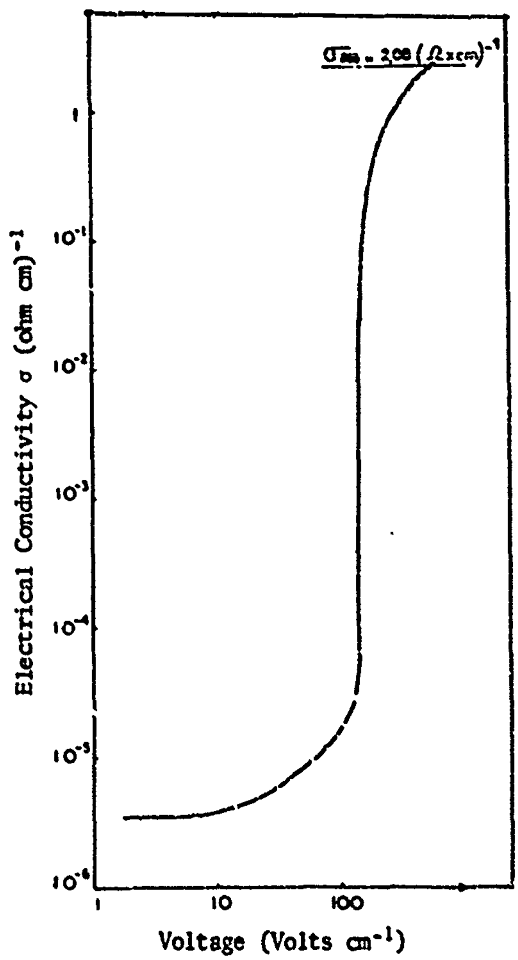


Electrical conductivity of single crystal silicon as a function of field at 20.75°K. Sample is n-type. $n_D = 8.2 \times 10^{15}$ cm^{-3}; $n_A = 1.6 \times 10^{12}$ cm^{-3}.

[Ref. 2646]

SILICON

Electrical Conductivity



Electrical conductivity of single crystal silicon as a function of field at 20.75°K. Conductivity of sample at 300°K = 2.08 (ohm cm)$^{-1}$.

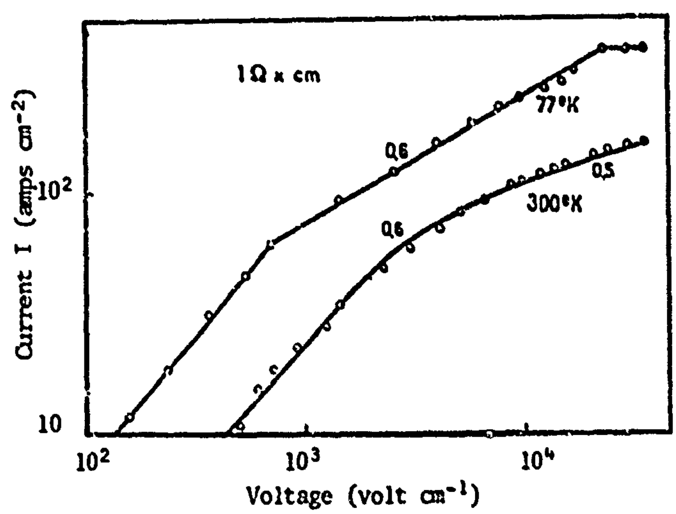
[Ref. 2646]

SEMICONDUCTOR MATERIALS

June 1963

SILICON

Electrical Conductivity



Current - Voltage relation for single crystal, n-type silicon; $n = 3 \times 10^{15}$ cm^{-3} at 300°K. 0.5 and 0.6 show slope of curve at two points.

[Ref. 3012]

DATA SHEET

ELECTRICAL AND ELECTRONIC PROPERTIES

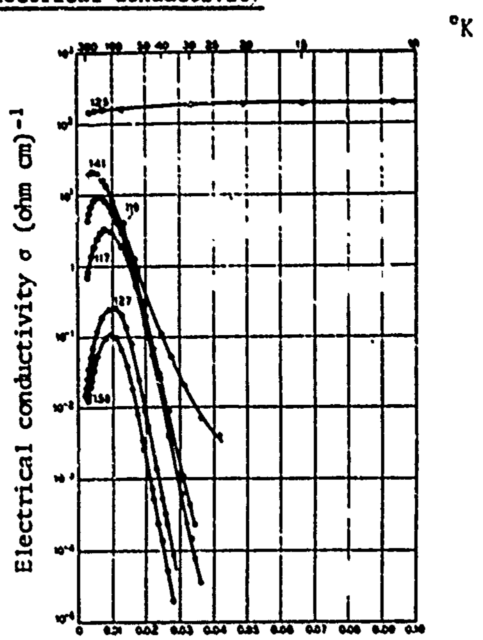
MATERIALS CENTRAL
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND

SEMICONDUCTOR MATERIALS

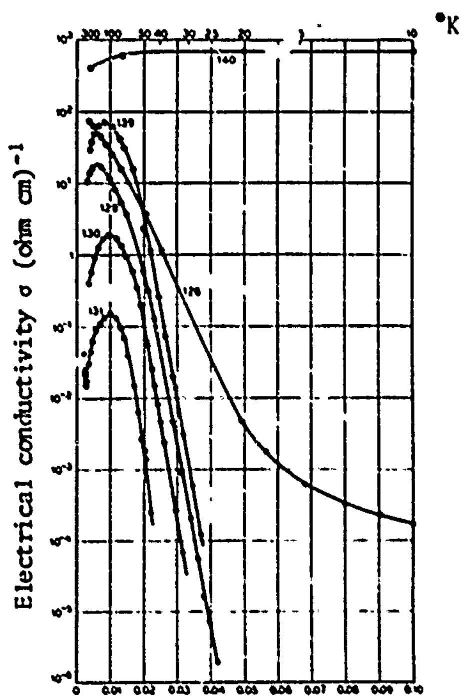
June 1963

SILICON

Electrical Conductivity



Electrical conductivity of single crystal boron-doped silicon as a function of temperature. Sample data given in Table below.



Electrical conductivity of single crystal, arsenic-doped silicon as a function of temperature. Sample data given below.

Sample No.	Majority impurity ionization energy ev	Net impurity concentration cm^{-3}	Minority impurity concentration cm^{-3}	Mass parameter	Added impurity
		n type			
131	0.056	1.75 X10[illegible]	1.0 X10[illegible]	0.5	arsenic
130	0.049	2.1 X10[illegible]	5.25 X10[illegible]	1.0	arsenic
129	0.048	1.75 X10[illegible]	1.68 X10[illegible]	1.2	arsenic
139	0.046	1.3 X10[illegible]	2.2 X10[illegible]	1.0	arsenic
126	?	2.2 X10[illegible]			arsenic
140	degenerate	2.7 X10[illegible]			arsenic
		p type			
159	0.045	3.1 X10[illegible]	4.1 X10[illegible]	0.4	none
127	0.045	7.0 X10[illegible]	2.2 X10[illegible]	0.4	boron
117	0.043	2.4 X10[illegible]	2.3 X10[illegible]	0.5	boron
119	0.043	2.0 X10[illegible]	4.9 X10[illegible]	0.7	boron
141	?	1 X10[illegible]			boron
125	degenerate	1.5 X10[illegible]			boron

[Ref. 430]

DATA SHEET

ELECTRICAL AND ELECTRONIC PROPERTIES

MATERIALS CENTRAL
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND

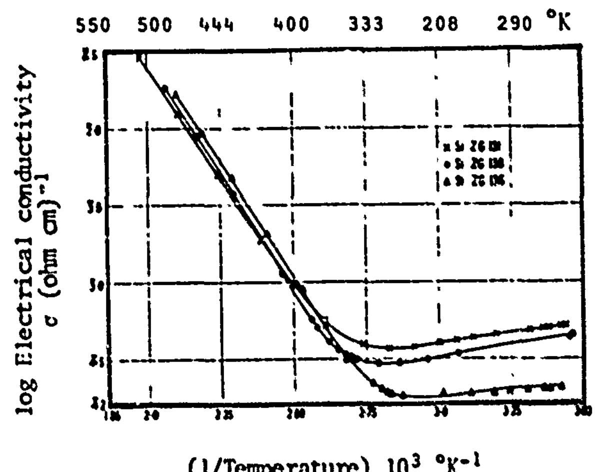
SEMICONDUCTOR MATERIALS

June 1963

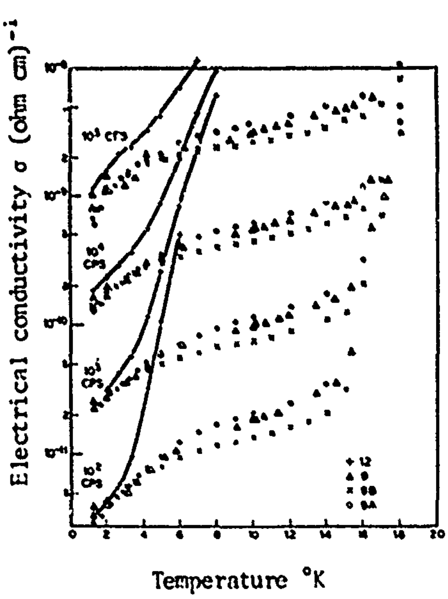
SILICON

Electrical Conductivity

Electrical conductivity as a function of temperature for single crystal silicon. ZG 131: n-type, phosphorus-doped, $N_A=1.8\times10^{13}$; $N_D=2\times10^{13}$. ZG 133: p-type, boron-doped, $N_A=3.5\times10^{13}$; $N_D=3.3\times10^{13}$. ZG 136; p-type, boron-doped, $N_A=5.3\times10^{13}$; $N_D=4.7\times10^{13}$.



[Ref. 990]



Electrical conductivity as a function of temperature for single crystal silicon. Boron-doping is same for all samples, $N_A = 0.8\times10^{15}$ cm^{-3}. Phosphorus-doping:
12) $N_D = 1.1 \times 10^{17}$ cm^{-3}
9) $N_D = 1.4 \times 10^{16}$ cm^{-3}
9B) $N_D = 1.2 \times 10^{16}$ cm^{-3}
9A) $N_D = 1.6 \times 10^{16}$ cm^{-3}

[Ref. 647]

DATA SHEET

ELECTRICAL AND ELECTRONIC PROPERTIES

MATERIALS CENTRAL
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND

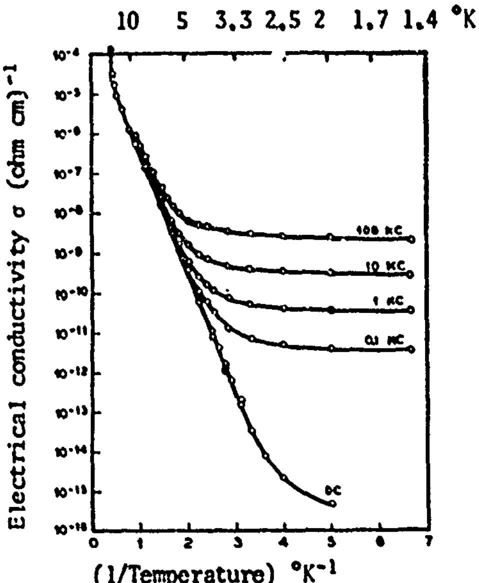
SEMICONDUCTOR MATERIALS

June 1963

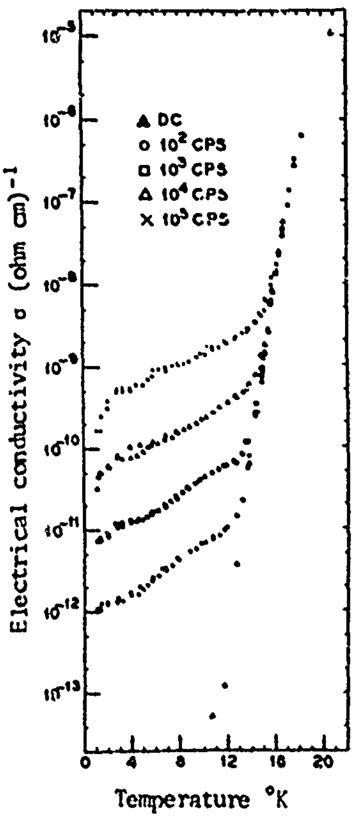
SILICON

Electrical Conductivity

Electrical conductivity as a function of temperature for single crystal silicon, boron and phosphorus-doped, $N_A = 0.8 \times 10^{15}\ cm^{-3}$; $N_D = 2.7 \times 10^{17}\ cm^{-3}$.



[Ref. 647]



Electrical conductivity as a function of temperature for single crystal silicon, phosphorus-doped, $N_D = 1.5 \times 10^{16}\ cm^{-3}$.

[Ref. 647]

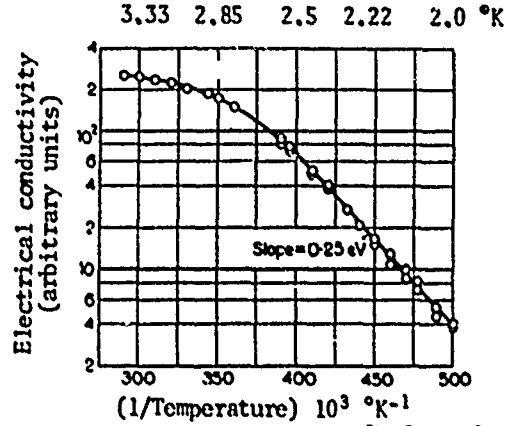
SEMICONDUCTOR MATERIALS

June 1963

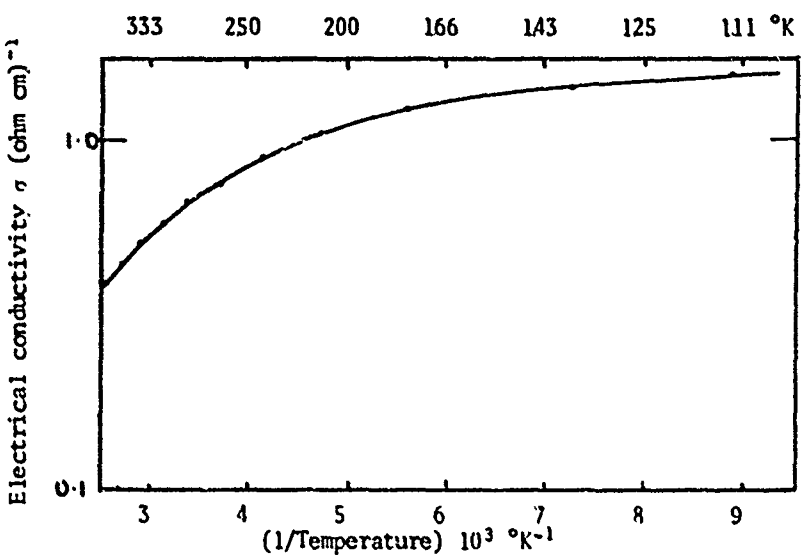
SILICON

Electrical Conductivity

Electrical conductivity as a function of temperature for single crystal, p-type, thallium-doped silicon. ρ = 50 ohm cm.



[Ref. 182]



Electrical conductivity as a function of temperature for single crystal, copper-doped silicon. Original sample, ρ = 1 ohm cm at 300°K, n-type, $n_D = 2.7 \times 10^{15}$ cm^{-3}.

[Ref. 2769]

DATA SHEET

ELECTRICAL AND ELECTRONIC PROPERTIES

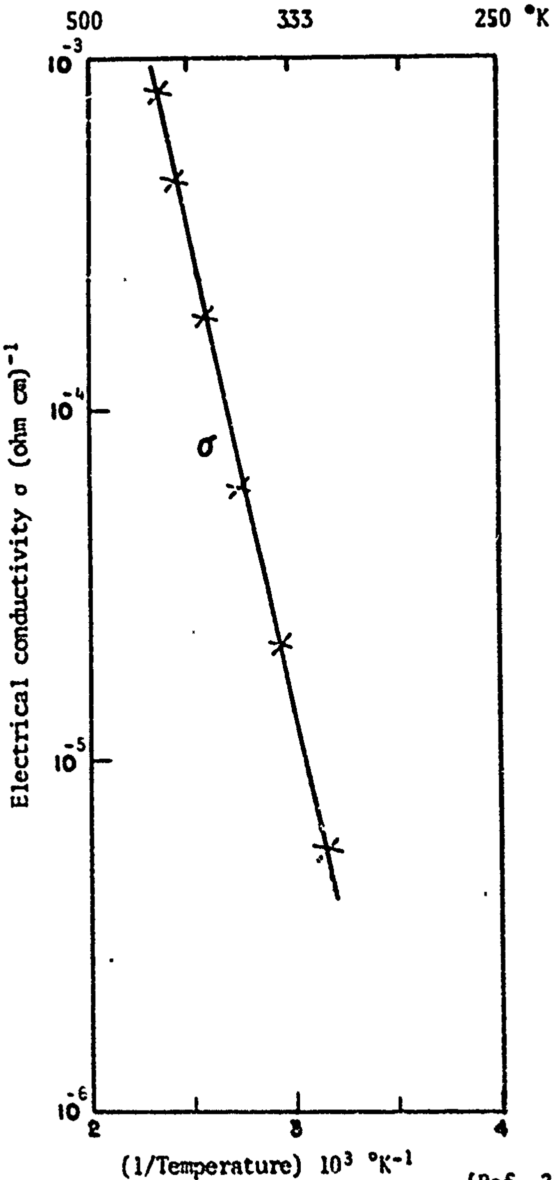
MATERIALS CENTRAL
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND

SEMICONDUCTOR MATERIALS

June 1963

SILICON

Electrical Conductivity



Electrical conductivity as a function of temperature for gold-doped, single crystal silicon. Original sample, ρ = 1 ohm cm, n-type, $n = 2.3 \times 10^{14}$ cm^{-3}.

[Ref. 2769]

DATA SHEET

ELECTRICAL AND ELECTRONIC PROPERTIES

MATERIALS CENTRAL
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND

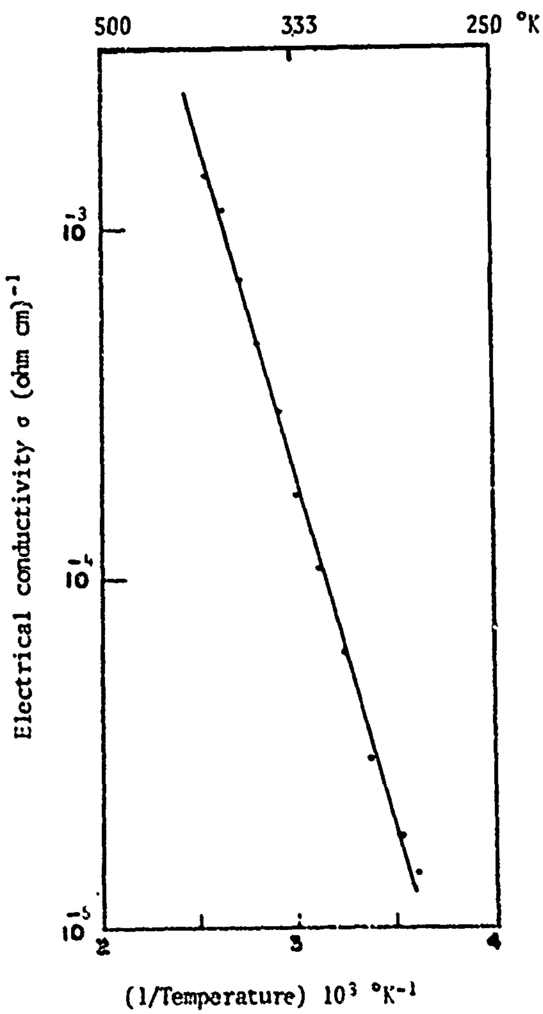
SEMICONDUCTOR MATERIALS

June 1963

SILICON

Electrical Conductivity

Electrical conductivity as a function of temperature for single crystal, copper-doped, p-type silicon, n = 2.3 to 6 x 10^{14} cm^{-3}. Original sample; n-type, ρ = 1 ohm cm, n = 2.3 x 10^{14} cm^{-3}.



[Ref. 2769]

DATA SHEET

ELECTRICAL AND ELECTRONIC PROPERTIES

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AIR FORCE SYSTEMS COMMAND

SEMICONDUCTOR MATERIALS

June 1963

SILICON

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SILICON

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Summary Reviews and Data Sheets

DS-101. Cadmium Telluride - Data Sheets. M. Neuberger. June 1962.

DS-102. Indium Phosphide - Data Sheets. M. Neuberger. June 1962.

DS-103. Indium Telluride - Data Sheets. M. Neuberger. June 1962.

DS-104. Magnesium Silicide - Data Sheets. M. Neuberger. June 1962.

DS-105. Polyethylene Terephthalate - Data Sheets. John T. Milek. June 1962.

DS-106. Polytetrafluoroethylene Plastics - Data Sheets. Emil Schafer. June 1962.

DS-107. Polytrifluorochloroethylene Plastics - Data Sheets. Emil Schafer. June 1962.

DS-108. Zinc Telluride - Data Sheets. M. Neuberger. June 1962.

DS-109. Indium Arsenide - Data Sheets. M. Neuberger. July 1962.

DS-110. Aluminum Antimonide - Data Sheets. M. Neuberger. September 1962.

DS-111. Gallium Phosphide - Data Sheets. M. Neuberger. September 1962.

DS-112. Gallium Antimonide - Data Sheets. M. Neuberger. October 1962.

DS-113. Lead Telluride - Data Sheets. M. Neuberger. October 1962.

DS-114. Magnesium Stannide - Data Sheets. M. Neuberger. October 1962.

DS-115. Gallium Arsenide - Data Sheets. M. Neuberger. November 1962.

DS-116. Lead Selenide - Data Sheets. M. Neuberger. December 1962.

DS-117. Silicon: Absorption - Data Sheets. M. Neuberger. December 1962.

DS-118. Silicon: Debye Temperature - Data Sheets. M. Neuberger. January 1963.

DS-119. Silicon: Dielectric Constant - Data Sheets. M. Neuberger. January 1963.

DS-120. Silicon: Mean Free Path - Data Sheets. M. Neuberger. January 1963.

DS-121. Indium Antimonide - Data Sheets. M. Neuberger. February 1963.

DS-122. Steatite - Data Sheets. John T. Milek. February 1963.

DS-123. Beryllium Oxide - Data Sheets. John T. Milek March 1963.

DS-124. Cadmium Sulfide - Summary Review and Data Sheets. M. Neuberger. April 1963.

DS-125. Magnesium Oxide - Data Sheets. John T. Milek. June 1963.