

MEASUREMENTS OF RESISTIVITY
IN POLYCRYSTALLINE THIN FILMS
OF GERMANIUM

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By

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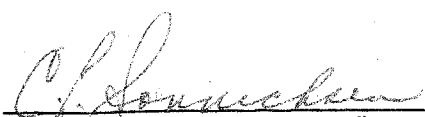
MEASUREMENTS OF RESISTIVITY
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OF GERMANIUM

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ABSTRACT

Thin films of amorphous germanium were prepared by evaporating 99.999% pure germanium in a vacuum of 10^{-5} torr. Thickness was the only parameter knowingly varied from one evaporation to the next. Resistance measurements were made over a temperature range of 173°K to 373°K. From electron microscope transmission studies, the films were found to contain a large density of grain boundaries. Assuming grain boundary scattering to be the predominant scattering mechanism in films thicker than 800°A, the grain boundary density is found to be 2.59×10^{12} per cm^2 . Resistivity versus thickness studies of the films revealed that a thickness dependent scattering mechanism predominated in films thinner than 700°A.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	iii
ABSTRACT	iv
TABLE OF CONTENTS	v
LIST OF ILLUSTRATIONS	ix
I. INTRODUCTION	1
The purpose of the thesis is stated.	
The resistivity terms are given and summed to give a total expression of resistance.	
II. THEORETICAL DEVELOPMENT	4
A discussion is given for each of the resistivity terms plus the basic assumptions made in the derivation.	
Several other thin film parameters and their significance are discussed.	
Theoretical considerations that are original in this thesis are made interconsistent with experimental data.	
III. EXPERIMENTAL PROCEDURE	27
A. Handling and Cleaning of Vacuum Working Areas	

TABLE OF CONTENTS

Page

A discussion of the vacuum system, its components and the cleaning procedure is presented.

Methods of cleaning and handling the substrates are listed.

B. Evaporation Procedure

A general outline of the procedure used in doing any evaporation is offered.

C. Materials Evaporated and the Characteristics of Their Evaporation

Different materials used as electrodes, semiconductors, protective coatings, and reflective coatings are discussed as to their behavior during evaporation.

The materials are also discussed in relation to their relative merit for performing the desired function.

D. Evaporation Parameters: Control and Measurement

TABLE OF CONTENTS

Page

The relative merit and the use of the Sloan OMNI rate and thickness control unit are discussed.

The principle of operation of the Angstromer thickness measuring unit is given.

E. Preparation and Measurement of Thesis

Samples

The step-by-step procedure used for the fabrication of the thesis samples is presented.

Calibration methods are discussed for the samples.

IV. RESULTS.....52

The results are stated.

The significance of the results and their application are discussed.

Possible correction factors are offered for consideration.

TABLE OF CONTENTS

	Page
Future investigations are suggested.	
V. CONCLUSION	65
BIBLIOGRAPHY.....	66
APPENDIX	68
Table [1-A]	
N_{ex} , N_{in} , and N_T between 4°K and 1000°K	
Table [2-A]	
$T^{3/2}$, $T^{-3/2}$, and T^{-1} between 4°K and 1000°K	
Table [3-A]	
ρ_L , ρ_I , ρ_N , ρ_{GB} , and ρ_{Th} between 4°K and 1000°K	
Table [4-A]	
$\frac{1}{\mu_L}$, $\frac{1}{\mu_I}$, $\frac{1}{\mu_N}$, $\frac{1}{\mu_{GB}}$, and $\frac{1}{\mu_{Th}}$ between 4°K and 1000°K	
Table [5-A]	
Conversion of units.	

LIST OF ILLUSTRATIONS

Figure	Page
1 Lattice deformation potential diagram.....	11
2 Vacuum system diagram.....	31
3 Angstrometer operation diagram.....	44
4 Angstrometer fringe pattern.....	44
5 Filament and boats.....	46
6 Film mask.....	46
7 Schematic of testing circuit.....	49
8 Temperature-Resistance calibration apparatus.....	50
9 Vacuum system and evaporation apparatus.....	51
10 Jigging, mask, and crystal thickness monitor.....	51
11 Theoretical curve of resistivity as a function of temperature from 4°K to 1000°K	53
12 Electron microscope diffraction patterns of germanium.....	56
13 Electron microscope transmission picture of germanium.....	56
14 Experimental and theoretical comparisons of resis- tivity as a function of temperature for films approx- imately 1000°A thick.....	57

LIST OF ILLUSTRATIONS

Figure		Page
15	Experimental and theoretical comparison of resistivity as a function of temperature for a film 643 ^o A thick.....	59
16	Experimental curve of resistivity as a function of thickness.....	60
17	Reciprocal mobility as a function of temperature over the range of 4 ^o K to 1000 ^o K.....	62

I. INTRODUCTION

The purpose of this thesis is twofold: first, to describe evaporation techniques for the films and, second, to evaluate the significance of the following temperature dependent scattering mechanisms on the current carriers in a thin film sample:

- (1) Lattice scattering
- (2) Ionized impurity scattering
- (3) Grain Boundary scattering
- (4) Thickness dependent scattering

as well as the one temperature independent scattering mechanism:

- (1) Neutral impurity scattering.

The samples for which the resistance versus temperature characteristics were studied were thin films of amorphous germanium. The only parameter that was knowingly varied in the samples was thickness, which varied from 100°\AA to $10,000^{\circ}\text{\AA}$. The theoretical approach used for this thesis is based upon the band theory⁺ of semiconductors

+

For the reader unfamiliar with the theory used in the physics of semiconductors, an excellent treatment of the basic measurable parameters can be found in Physics of Semiconductors, by A. F. Ioffe, (8) chapter one. Another detailed approach to basic parameters and a good treatment of the band theory of solids can be found in Introduction to Solid State Physics, by Charles Kittel (10).

which applies not only to single crystal samples but also to polycrystalline and amorphous films (8, p. 132)[†]. Many correlative examples between theoretical and experimental results for thin film parameters can be found in The Hall Effect and Related Phenomena, a Semiconductor Monograph by E. H. Putley (15).

As will be shown in the theoretical development, the effective relaxation time due to the different scattering mechanisms is given by

$$\frac{1}{\tau} = \frac{1}{\tau_{\text{Lattice}}} + \frac{1}{\tau_{\text{Ionic}}} + \frac{1}{\tau_{\text{Neutral}}} + \frac{1}{\tau_{\text{Grain Boundary}}} + \frac{1}{\tau_{\text{thickness}}}$$

The mechanisms are usually present in varying degrees in thin film samples. Since mobility and relaxation time are directly proportional, the total mobility can be written as⁺

$$\frac{1}{\mu} = \frac{1}{\mu_L} + \frac{1}{\mu_I} + \frac{1}{\mu_N} + \frac{1}{\mu_{GB}} + \frac{1}{\mu_{Th}}$$

When this expression for mobility is substituted into the equation for resistivity, one obtains the following expression

$$\rho_{\text{total}} = \frac{1}{q [N_{\text{ex}} e^{-\epsilon_{\text{ex}}/2kT} + N_{\text{in}} e^{-\epsilon_{\text{in}}/2kT}]} \frac{1}{\mu}$$

[†]
+ First number refers to bibliographical index, second, to page number.

+ For a quick reference of the final equations of mobility and a brief discussion of their significance, one should consult Solid State Physics by Adranus J. Dekker (3, pp. 329-334).

$$\rho_{\text{total}} = \rho_L + \rho_I + \rho_N + \rho_{\text{GB}} + \rho_{\text{Th}}$$

and since

$$R = \frac{\rho_{\text{total}} L}{A} = \frac{L}{A} [\rho_L + \rho_I + \rho_N + \rho_{\text{GB}} + \rho_{\text{Th}}]$$

$$\text{letting } N_T = N_{\text{ex}} e^{-\epsilon_{\text{ex}}/2kT} + N_{\text{in}} e^{-\epsilon_{\text{in}}/2kT}$$

the above expression can be written to show its temperature dependence in the following form

$$R = \frac{L}{AN_T} [\alpha_L T^{3/2} + \alpha_I T^{-3/2} + \alpha_N + \alpha_{\text{GB}} T^{-1} + \alpha_{\text{Th}} \frac{1}{(\text{thick})} 4T^{-1}] .$$

Many characteristics of the thin films and the procedures used in preparing them have been left unexplored in this thesis. Possibilities for future investigations will be suggested in the section on results.

II. THEORETICAL DEVELOPMENT

The first part of the introduction deals with the development and discussion of several basic parameters used in the study of thin films. The bulk of the theoretical development is devoted to the scattering mechanisms and their evaluation. The mechanisms discussed are lattice scattering, ionic impurity scattering, neutral impurity scattering, grain boundary scattering, and thickness dependent scattering. In the last part of the theory, the expressions for the total effects on resistivity and reciprocal mobility are developed.

It is of interest to the reader to understand the units and their conversions used in this thesis; therefore, a short section has been included in the appendix listing some of the basic parameters in the practical and c. g. s. systems.

Theoretical Parameters

Starting with the electrical definition of force being equal to the charge times the electric field and integrating this expression, one obtains the velocity that an electron acquires in the period of time between collisions.

$$m \frac{dv}{dt} = q E$$

$$\int_0^v dv = \frac{q E}{m} \int_0^\tau dt$$

$$\bar{v} = \frac{q E}{m} \tau .$$

When the average values of velocity and life time are used, the expression can be written as

$$\bar{v} = \frac{q E}{m} \bar{\tau} .$$

Now by using the definition of mobility as the ratio of average velocity to electric field

$$\mu = \frac{\bar{v}}{E} = \frac{q}{m} \bar{\tau} .$$

The average life time $\bar{\tau}$ can also be defined as the mean free path \bar{L} divided by the average velocity \bar{v}

$$\bar{\tau} = \frac{\bar{L}}{\bar{v}}$$

which when substituted into the equation of mobility yields,

$$\mu = \frac{q}{m} \frac{\bar{L}}{\bar{v}}$$

substituting the life time dependent mobility term into the equation for conductivity yields

$$\sigma = N_T q \mu$$

$$\sigma = N_T q \frac{q \bar{\tau}}{m} = \frac{N_T q^2 \bar{\tau}}{m} .$$

The average life time for a typical film 1/6-A whose thickness is 2120°A and conductivity is $0.5(\text{ohm-cm})^{-1}$ can be calculated as follows:

$$\sigma(\text{esu}) = \sigma(\text{pract}) \times 9 \times 10^{11}$$

$$\sigma(\text{esu}) = 4.5 \times 10^{11} \text{ sec}^{-1}$$

$$\bar{\tau} = \frac{\sigma m}{N_T q^2} \quad \text{Assuming } N_T = 10^{18} \text{ carriers/cm}^3$$

$$\bar{\tau} = \frac{(4.5 \times 10^{11}) (9 \times 10^{-28})}{(1.0 \times 10^{18}) (5.0 \times 10^{-10})^2}$$

$$\bar{\tau} = 1.62 \times 10^{-15} \text{ sec.}$$

This value can be understood physically if one assumes that an electron moving with thermal velocity at room temperature is scattered by two grain boundaries every 100°A . Using these physical assumptions