PHOSPHORUS DIFFUSION IN GALLIUM ARSENIDE

by

Devendra Kumar Sadana

A THESIS SUBMITTED TO THE
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
FOR THE AWARD OF THE DEGREE OF
Doctor of Philosophy
in
Physics

National Physical Laboratory
New Delhi-110012

August, 1974

Thesis Supervisors:

Prof. G. C. Jain
Head, Materials Science
& Technology Division
National Physical Laboratory
New Delhi-110012

and

Prof. K. L. Chopra
Department of Physics
Indian Institute of
Technology
New Delhi-110016.

ABSTRACT

PHOSPHORUS DIFFUSION IN GALLIUM ARSENIDE

Devendra Kumar Sadana

The diffusion of phosphorus in gallium arsenide has been studied with the purpose of understanding the kinetics and mechanism of the diffusion process. The gallium arsenide phosphide formed after diffusion may then be used for the fabrication of various devices, e.g., light emitting diodes, power rectifiers, etc.

The conversion of gallium arsenide into gallium arsenide phosphide after phosphorus diffusion, was confirmed by Debye-Scherrer X-ray analysis of the diffused powder specimen. The Laue back reflection pattern of the surfaces of the diffused specimens showed that the diffused layer retains the crystallinity of the parent specimens.

The junction depth measurements taken on the diffused specimens prepared under different conditions, revealed that the diffusion process is suppressed considerably, when the diffusion is carried out under an overpressure of arsenic. This indicated that the

diffusion process is aided by vacancies on arsenic sites in gallium arsenide. The energy of formation of a vacancy at arsenic or phosphorus site in gallium arsenide phosphide was then estimated to be (1.06 ± 0.54) eV from these measurements. The behaviour of arsenic vacancies in gallium arsenide was also studied. It was found that these vacancies are electrically active.

The distribution of phosphorus atoms was determined by taking reflectance measurements at different depths of the diffused region. The activation energy and the pre-exponential factor of phosphorus diffusion in GaAs, as computed from the knowndistributions of phosphorus atoms in the specimens, were found to be (0.90 ± 0.04) eV and 7.0×10^{-9} $cm^2/sec.$ for GaAs and (1.51 ± 0.26) eV and 8.0×10^{-6} $cm^2/sec.$ for GaP, respectively. A diffusion mechanism has been postulated on the basis of the results obtained.

The changes occurring in electrical parameters, such as resistivity, mobility and carriers concentration; at different compositions of gallium arsenide phosphide (prepared by diffusion), were also measured. The ohmic contacts made on the surfaces of the specimens for electrical measurements showed dependence on the thickness of the alloy used for the purpose and also on the annealing temperature.

It was concluded that gallium arsenide phosphide prepared by diffusion at temperatures $\leqslant$ 800°C, may be suitable for the fabrication of various devices.

ACKNOWLEDGMENTS

The author wishes to acknowledge with the deepest sense of gratitude the guidance provided to him by Prof. G.C. Jain, Head, Materials Science & Technology Division, National Physical Laboratory, New Delhi and Prof. K.L. Chopra, Dean, Faculty of Science, Indian Institute of Technology, New Delhi, who served as the major advisors during the course of this work. The author has greatly benefitted from their vast and versatile knowledge of the subject. The association of Dr. B.K. Das, N.P.L. has been the constant source of inspiration. The author wishes to record his great appreciation and indebtedness to Dr. B.K. Das for the numerous stimulating and helpful discussions. Dr. R. Bhattacharya of Thin Film Section, N.P.L. deserves special thanks for reading the final draft and making the necessary corrections.

The author is indebted to Prof. R.K. Mishra, late Dr. J.S. Chowdhury, Mr. Ashok Sood and Mr. Indrajeet Gupta of the All India Institute of Medical Sciences, New Delhi, who, in spite of all the difficulties, made it possible for him to take the reflectance measurements. The help rendered by Mr. K.C. Nagpal, N.P.L. in taking the X-ray measurements and the contributions of Mr. Risal Singh, Radio Science Division, N.P.L. in programming the IBM 360

computer, to calculate the correction factors for resistivity measurements, are gratefully acknowledged.

Thanks are also due to author's many colleagues for their cooperation during this work.

Finally, the author is grateful to Prof. A. R. Verma, Director, National Physical Laboratory, New Delhi for permitting him to work in this Laboratory and also to the Council of Scientific & Industrial Research (India) for providing the financial assistance throughout the course of this work.

CONTENTS

TITLE PAGE i

ABSTRACT ii

ACKNOWLEDGEMENTS v

CONTENTS vii

LIST OF FIGURES AND TABLES ix

I. INTRODUCTION 1

II. KINETICS OF DIFFUSION (a general description) 6

2.1 Fick's Laws 6

2.2 Concentration Dependent Diffusion 11

2.3 Modes of Diffusion 17

2.4 Impurity Diffusion 46

2.5 Determination of Diffusion Mechanism 51

2.6 Some Empirical Relations 55

III. CONVERSION OF GaAs TO $GaAs_{1-x}P_x$ 57

3.1 Experimental Procedure 58

3.2 Results 60

3.3 Discussion 66

3.4 Conclusions 75

IV. COMPOSITION DETERMINATION BY REFLECTIVITY MEASUREMENTS 76

4.1 Composition Determination 77

4.2 Results 82

4.3 Discussion 86

4.4 Conclusions 97

V. ARSENIC VACANCIES IN GALLIUM ARSENIDE 98

5.1 Experimental Procedure 98

5.2 Results 100

5.3 Discussion 102

5.4 Conclusions 109

VI. ELECTRICAL PROPERTIES 110

6.1 Experimental Procedure 111

6.2 Results 111

6.3 Discussion 112

6.4 Conclusions 121

VII. CONCLUSIONS 123

A.I. OHMIC CONTACTS ON GaAs AND $GaAs_{1-x}P_x$ 126

A.II. CORRECTION FACTORS IN RESISTIVITY MEASUREMENTS 132

A.2.1 Theoretical Analysis 132

REFERENCES 155