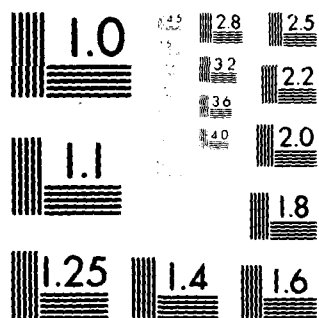


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FINAL REPORT

ELECTRICAL CHARACTERIZATION OF GERMANIUM
IMPLANTED GALLIUM ARSENIDE

Work performed under AFOSR Grant No. 79-0113
During the period June 1, 1979 to May 31, 1980

under the USAF scientific directorate of
Dr. Y. S. Park, AFWAL/AADR, Wright Patterson AFB

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June 2, 1980

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (18) AFOSR-TR-80-0462	2. GOVT ACCESSION NO AD-A086632	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ELECTRICAL CHARACTERIZATION OF GERMANIUM IMPLANTED GALLIUM ARSENIDE		5. TYPE OF REPORT & PERIOD COVERED FINAL 6-1-79 to 5-31-80
7. AUTHOR(s) (10) FRANK L. PEDROTTI		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Frank L. Pedrotti / Physics Department, Marquette University Milwaukee, Wisconsin 53233		8. CONTRACT OR GRANT NUMBER(s) AFOSR-79-0113 ^{new}
11. CONTROLLING OFFICE NAME AND ADDRESS AIR FORCE OFFICE OF SCIENTIFIC RESEARCH BOLLING AIR FORCE BASE, DC 20332		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102 F 2306/D9
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (16) 23061 (17) D9L (18) 81		12. REPORT DATE June 2, 1980
		13. NUMBER OF PAGES 8
		15. SECURITY CLASS. (of this report) unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) approved; distribution unlimited (11) 2 Jun 80		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) (9) Final rept. 1 Jun 79-31 May 80		
18. SUPPLEMENTARY NOTES (15) ✓ AFOSR-79-0113		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Ion Implantation Gallium Arsenide Double Implantation		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

20.

The amphoteric electrical properties of germanium single implants into gallium arsenide, and of dual implants of germanium with either gallium or arsenic into gallium arsenide, have been studied. Room temperature implantation was performed for all implanted ions at 120 keV, with doses ranging from 5×10^{12} to 3×10^{15} ions per square centimeter. Implanted samples were annealed with pyrolytic silicon nitride encapsulants at temperatures ranging from 700 to 1000 degrees Celsius. Both p- and n-type layers were observed. Type of conductivity, electrical activation, and carrier mobility were found to depend critically upon ion dose and anneal temperature. The general electrical behavior suggests that in samples of lower dose and anneal temperature, the implanted Ge ions go into As sites preferentially, producing p-type activity, whereas in samples of higher dose and anneal temperature, more Ge ions go into Ga sites, producing n-type activity. Conductivity was found to change from p- to n-type at an intermediate dose of 3×10^{14} ions per square centimeter and at an anneal temperature between 900 and 950 degrees Celsius. It has been determined that additional implantation of As into GaAs:Ge favors Ge occupancy of Ga sites and an enhancement of n-type activity, whereas the additional implantation of Ga encourages Ge occupancy of As sites and an enhancement of p-type activity. Enhancement factors of as much as 8 for p-type activations, and as much as 50 for n-type activations have been measured.

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Research Objectives

This work represents an experimental study of the electrical properties of the semiconductor GaAs which has been doped in thin layers with germanium by the method of ion bombardment. The specific objectives include

- (a) complete characterization of the electrical activation and mobility of Ge-implanted GaAs by the method of Hall/resistivity measurements
- (b) relation of such properties to conditions of implantation and thermal anneal treatment
- (c) determination of conditions which result in n- and p-type conductivity for the amphoteric dopant, germanium
- (d) determination of the benefits to electrical activation to be derived from sequential double implantation of germanium with gallium and arsenic ions, respectively.

Status of the Research

The amphoteric electrical properties of germanium single implants into gallium arsenide have been studied. The amphoteric behavior of germanium implants into gallium

arsenide (reported, Appl. Phys. Lett. 35(2), 197, 1979), where both p- and n-type layers were observed, was found to depend critically upon ion dose and anneal temperature. The general electrical behavior suggests that in samples of lower dose and annealing temperature, the implanted Ge ions go into As sites preferentially, producing p-type activity, whereas in samples of higher dose and annealing temperature, more Ge ions go into Ga sites than into As sites, producing n-type activity. Room temperature implantation was performed at 120 keV with doses ranging from 5×10^{12} to 3×10^{15} ions/cm². Implanted samples were annealed with pyrolytic Si₃N₄ encapsulants at temperatures ranging from 700 to 950 deg. C. For doses of 1×10^{14} /cm² or below, the implanted layer was p-type at anneal temperatures up to 950 deg. C, with electrical activation up to 38%. For doses of 1×10^{15} /cm² or above, the implanted layer is n-type at all anneal temperatures, with activation up to 5%. For the intermediate dose of 3×10^{14} /cm², the conductivity changes from p- to n-type at an anneal temperature between 900 and 950 deg. C. Dual implantation into gallium arsenide with either Ge + Ga or Ge + As has also been investigated (reported at the American Physical Society Meetings in New York City, March, 1980). It has been determined that the additional implantation of Arsenic into GaAs:Ge favors germanium occupancy of gallium sites and an enhancement of n-type activity, whereas the additional implantation of gallium

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into GaAs:Ge encourages germanium occupancy of arsenic sites and an enhancement of p-type activity. In all cases, both ion species of the dual implants were implanted at the same ion energy of 120 keV and at the same dose to maintain stoichiometry, with doses ranging from $1\text{E}13$ to $3\text{E}15$ ions/cm². Implanted samples were annealed with pyrolytic Si₃N₄

encapsulants at temperatures ranging from 700 to 1000 deg.

C. The amphoteric behavior of germanium in gallium arsenide was enhanced significantly when arsenic ions were added, but the addition of gallium ions resulted in p-type conductivity for all doses up to the anneal temperature of 900 deg. C.

The n-type electrical activity of germanium implants in GaAs:Ge+As was found to increase significantly over that of GaAs:Ge for ion doses of $1\text{E}15/\text{cm}^2$ or above, while the p-type activity was not significantly affected by the dual implants for doses of $3\text{E}13/\text{cm}^2$ or below. Also the original p-type activity of germanium single implants was found to convert to n-type for intermediate doses of $1\text{E}14$ and $3\text{E}14$ ions/cm².

The p-type electrical activity of germanium implants in GaAs:Ge+Ga was found to increase significantly over that of GaAs:Ge for doses of $3\text{E}14/\text{cm}^2$ or below, while the original n-type activity of Ge single implants was found to change to p-type for doses of $1\text{E}15/\text{cm}^2$ or above.

Associated Research Publications

Y.K.Yeo, J.E.Ehret, F.L.Pedrotti, Y.S.Park, and W.M.Theis, "Amphoteric behavior of Ge Implants in GaAs," Appl. Phys. Lett. 35(2), 197(1979)

F.L.Pedrotti, Y.K.Yeo, J.E.Ehret and Y.S.Park, "Dual Implants of Ga and Ge into GaAs," submitted to J. Appl. Phys, April 1980

Y.K.Yeo, F.L.Pedrotti, Y.S.Park and J.E. Ehret, "Dual Implants of As and Ge into GaAs," in preparation, to be submitted to J. Appl. Phys., summer 1980

Associated Papers Presented

"Electrical Properties of Ge-Implanted GaAs," American Physical Society Meetings, Chicago, January 1980. Abstracted in Bull. Am. Phys. Soc. 24, 314(1979).

"Electrical Properties of GaAs with Dual Implants of Ge+Ga and Ge+As," American Physical Society Meetings, New York City, March 1980. Abstracted in Bull. Am. Phys. Soc. 25, 202(1980).

"Dual Implantation and Amphoteric Behavior of Ge Implants in GaAs,"
to be presented at the Ion Implantation Conference, Albany, New York,
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Summer, 1980. Thesis title: "Investigation of the electrical
activity of Ge implanted into GaAs amorphous layers"