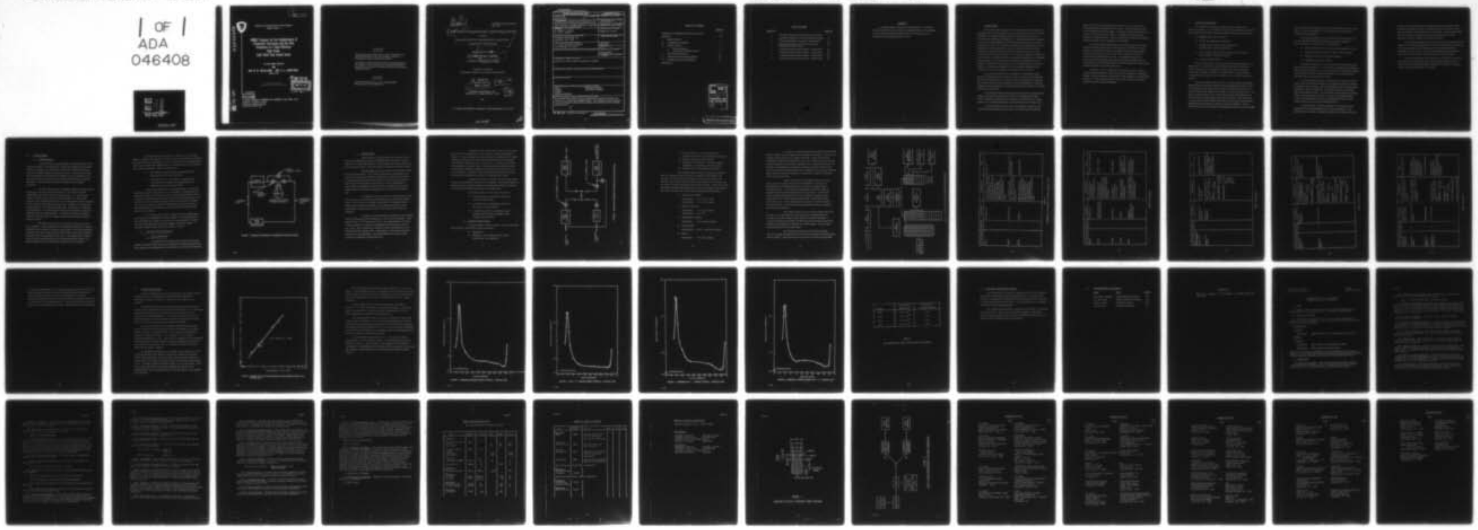
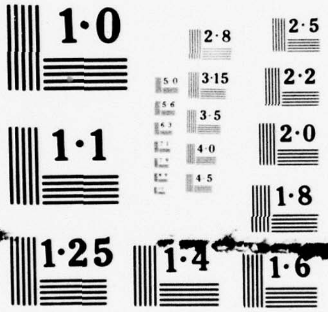
AD-A046 408 MICROWAVE ASSOCIATES INC BURLINGTON MASS F/G 9/1
MM AND T PROGRAM FOR THE ESTABLISHMENT OF PRODUCTION TECHNIQUES--ETC(U)
APR 77 R E WALLINE, J L HEATON DAAB07-77-C-0324
UNCLASSIFIED ECOM-0324-1 NL

1 OF 1
ADA
046408



END
DATE
FILMED
12-77
DDC



NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

12

Research and Development Technical Report

ECOM - 0324 - 1

MM&T Program for the Establishment of Production Techniques and the Pilot Production of a High Efficiency, High Power GaAs Read Type Impatt Diode

1ST QUARTERLY REPORT

By

DR. R. E. WALLINE DR. J. L. HEATON

APRIL 1977

DISTRIBUTION STATEMENT

Approved for public release, distribution unlimited.

Monitored by:

ECOM
US ARMY ELECTRONICS COMMAND • FORT MONMOUTH, NEW JERSEY 07703
CONTRACT DAAB07-77-C-0324
MICROWAVE ASSOCIATES, INC.
Burlington, Massachusetts 01803

Disclaimers

Disposition

⑱ ⑲

TR ECOM-0324-1
April 1977

REPORTS CONTROL SYMBOL
OSD-1366

⑥ and

MM~~&~~T PROGRAM FOR THE ESTABLISHMENT OF PRODUCTION TECHNIQUES AND THE PILOT PRODUCTION OF A HIGH EFFICIENCY, HIGH POWER GaAs READ TYPE IMPATT DIODE,

⑨

FIRST QUARTERLY REP~~OR~~T. no. 1,
29 Dec~~ember~~ ~~19~~76 ~~to~~ 29 Apr~~il~~ ~~19~~77,

⑮

CONTRACT NO. DAAB07-77-C-0324 new

Distribution Statement
Distribution unlimited: Approved for public release

⑩

Prepared By
Dr. Robert E. Walline
John ~~Dr. J.~~ L. Heaton

⑪ Apr 77

⑫ 48p.

MICROWAVE ASSOCIATES, INC.
BURLINGTON, MASSACHUSETTS 01803

FOR

U.S. ARMY ELECTRONICS COMMAND, FORT MONMOUTH, NJ 07703

229400

VB

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ECOM-0324-1	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Manufacturing Methods and Technology for the Establishment of Production Techniques and the Pilot Production of a High Efficiency, High Power GaAs Read Type IMPATT Diode		5. TYPE OF REPORT & PERIOD COVERED First Quarterly 29 Dec 1976 - 29 Apr 1977 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Dr. Robert E. Walline Dr. John L. Heaton		8. CONTRACT OR GRANT NUMBER(s) DAAB07-77-C-0324
9. PERFORMING ORGANIZATION NAME AND ADDRESS Microwave Associates, Inc. Burlington, MA 01803		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Electronics Command Fort Monmouth, NJ 07703		12. REPORT DATE April 1977 13. NUMBER OF PAGES 52
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

READ	PROCESS CONTROL
IMPATT	COMPUTER CONTROL
EPITAXY	
GALLIUM ARSENIDE	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An epitaxial GaAs system has been designed for growth of low-high-low GaAs for use in Read-type IMPATT diodes. This epitaxial system includes a computer control system for the operation and monitoring of the epitaxial growth process.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

An epitaxial GaAs system has been designed for the growth of low-high-low GaAs for use in Read-type IMPATT diodes. This epitaxial system includes a computer control system for the operation and monitoring of the epitaxial growth process.

I. INTRODUCTION

The purpose of this program is the establishment and verification of techniques to reduce the labor and increase control of processes used in the preparation of epitaxial GaAs and subsequent fabrication of Read-type, Low-High-Low (LHL) GaAs IMPATT diodes. The reduced labor and increased control will be demonstrated by improved manufacturing yields at reduced manufacturing cost. The mechanism by which these improvements are to be obtained is the automation of the epitaxial crystal growth process with appropriate feedback mechanisms which will regulate process variables in accordance with actual conditions. The system is required to control and respond rapidly to variation in wafer temperature, exposure time of the wafer to this temperature, the flow rate of the dopant and epitaxial gases, the chemical composition of these gases and the interrelationship of all these factors. In addition, the epitaxial crystal evaluation (routine) will be eliminated and crystal evaluation (non-routine) will be reduced.

The engineering effort will be restricted to the epitaxial crystal growth and epitaxial crystal evaluation required to produce high-efficiency Read-type IMPATT diodes plus sample diodes to demonstrate the progress. The success of these control programs will be demonstrated by a pilot line production demonstration of the required X-band diode as defined in SCS-481, dated 23 December 1974.

The epitaxial crystal evaluation will productionize the measurement methods specified for dislocation density of the substrates and buffer layers, doping and uniformity of the substrates and buffer layers, doping profile of the epitaxial LHL crystal, and the thickness of the buffer layer.

A suitable X-band test cavity shall be designed, fabricated, and used to test the performance of the diode. The cavity shall incorporate proper bias circuitry, shall provide easy access to the diode and fast interchangeability of diodes for quick testing. Parts and materials shall be in accordance with MIL-P-11268. Forced air or water cooling shall not be used. The output terminal shall be a standard waveguide terminal mating with flange UG-39/U. The cavity used to test engineering samples shall be identical to that supplied with the samples.

The required wafer yield is fifty percent (50%) of the wafers grown shall have eighty percent (80%) (minimum area 3.0 cm^2/wafer) of usable material. The term usable defines material which meets specifications for dislocation density, doping profile, and is capable of producing diodes meeting specification SCS-481. The required diode yield is forty percent (40%) of diodes produced and selected at random from any usable wafer and tested shall meet the cited specification for output power, operating frequency, and power efficiency.

In addition, for the X-band diode, performance curves shall be supplied showing typical min-max excursions for capacitance, breakdown voltage, thermal resistance, output power, power efficiency, and operating frequency. Diode design and process flow charts covering all process steps for the product shall be detailed.

II. SUMMARY OF APPROACH

The Microwave Associates' approach utilizes a maximum of existing technology. This technology results from an existing GaAs IMPATT diode production line and a complete epitaxial GaAs materials laboratory.

The epitaxial system will consist of:

1) Furnace and temperature controllers.
2) Epitaxial GaAs reactor including reactor tube, Ga source boat, and substrate holder.
3) Gas and vapor control system including flow controllers, doping system, and $AsCl_3$ bubblers.
4) Computer control system.

Of these subsystems, the furnace and temperature controllers, the reactor tube, Ga source boat, and substrate holder will be identical to those currently in use at Microwave Associates and which have been successfully utilized to provide LHL epitaxial GaAs. No development is required in these areas with the exception of the substrate holder drive system.

The gas and vapor control system is derived using an evolutionary approach from existing Microwave Associates epitaxial LHL GaAs systems. This proposed gas and vapor control system corrects deficiencies in the existing systems and improves the control of the gas and vapor flows. The basic concepts utilized in this system have all been demonstrated in the existing Microwave Associates crystal growth facility. The deficiencies in the existing systems manifest themselves as low yields of the requisite material and not as failure to produce the requisite material. These deficiencies have been analyzed and appropriate design and control changes have been made in the proposed system to correct these deficiencies and raise the yield to a projected 73% while meeting the uniformity and minimum area requirements.

The major improvements in the gas and vapor control system are the use of dynamic mass flow controllers for gas flow regulation. The result will be a system which is characterized by:

1) Constant reaction times in the source and deposition zones.
2) Dynamic doping gas dilution to control impurity doping.
3) Automatic control of all gases and vapors.
4) Capability of computer control.

When these characteristics are combined with already determined reactor operating conditions to insure Ga source saturation and scumming, and to insure and monitor in-situ substrate etching, the proposed epitaxial system fulfills all of the requirements imposed by the contract for the chemical synthesis and deposition system.

The entire epitaxial system is interfaced with a computer control system which calculates and programs the epitaxial deposition, performs all required control settings, monitors performance of all components and subsystems, times all operations, and records and prints all relevant data of the epitaxial system. The subsystems contain automatic dynamic control components and as a result, the system is manually operable in the event of computer or computer interface failure and for system trouble shooting in the event of component failure.

The minicomputer, computer interfaces, and computer control components are being purchased from the same manufacturer. This approach insures interface compatability between the components of the computer control system thereby eliminating engineering problems and/or development programs required to interface dissimilar components which can be expected if such an approach is not adopted. The proposed program does not, therefore, depend on the success and timeliness of such engineering programs to meet the required objectives.

The complete epitaxial system will meet all of the requirements of the contract. This system will demonstrate that the control and reproducibility of the proposed system when operated using existing processes and guarantee high yields (> 70%) of the requisite material and eliminates the necessity for routine and non-routine epitaxial crystal evaluation.

The device fabrication and testing will be performed in an existing GaAs IMPATT diode production area. All processes required for these devices have been developed and demonstrated at Microwave Associates and no engineering development is required.

III. SYSTEM DESIGN

A. Transport System

In order to insure the predictability and reproducibility of the chemical reactions, it is necessary to control and reproduce the concentrations of the reagents, the temperature at which the reactions take place, and the time interval allowed for reaction to occur. Implicit in the control and reproducibility of the reagent concentrations are the conditions of the Ga source itself, the condition of the substrate surface prior to epitaxial deposition, and the removal of unwanted impurities in the reagents themselves.

The only reagents which are handled outside the reactor are the hydrogen gas, the $AsCl_3$ and the doping gas. This system is further subdivided by the inlet in which the reagents enter, i.e., the transport system composed of $AsCl_3$ from the transport bubbler, the carrier gas, hydrogen, and a diluent hydrogen flow; and the doping/etch system composed of $AsCl_3$ from the etch bubbler, the carrier gas, hydrogen, the doping gas, hydrogen sulfide, and a diluent hydrogen flow. Since $AsCl_3$ is a liquid at room temperature, it is conventionally introduced by bubbling a carrier gas (hydrogen) through a liquid reservoir. The problem of control of external reagents is now reduced to the control of gases and the control of vaporization of a liquid.

The control of gas flow is accomplished by the use of mass flow controllers. These controllers are commercially available in a compact assembly which contains the sensors, control valve, and control electronics. An external set point is used to set the required flow and the self contained controller senses and regulates the gas flow. A DC output which is linear with flow rate is provided which may be interfaced with the operator by a digital voltmeter and a computer control system by an AD converter.

The control of the vaporization of a liquid is not as straightforward. Normally, the amount of vaporized liquid is controlled by controlling the flow of the carrier gas through a bubbler, maintained at a constant temperature, which contains the volatile liquid. The validity of this type of system rests on two assumptions. These assumptions are:

1) The efficiency of the bubbler is independent of the liquid level and the carrier flow rate.

2) The vapor pressure of the liquid is dependent only on the external temperature and independent of the liquid level and carrier gas flow rate.

What is being attempted in this reactor system is the actual control of the mass of $ASCl_3$ which enters the reactor. Conceptually, this system will operate in the same fashion as a conventional bubbler system if a temperature controlled condenser were applied to the bubbler outlet. This condenser, actually a simple distillation column would insure a constant mass of $AsCl_3$ entering the reactor by condensing a portion of the $AsCl_3$ vapor and returning it as a liquid to the bubbler while the remainder was carried into the reactor.

The system which is being installed will use modified mass flow controllers to accomplish this same purpose. These modified mass flow controllers will, however, have input and output signals like regular mass flow controllers and as such are capable of computer control. A schematic diagram of this subsystem is shown in Figure 1.

B. $AsCl_3$ Etch and Doping System

1. $AsCl_3$ Etch System

The portion of the system which is used for the in-situ etching is composed of the second $AsCl_3$ bubbler and a diluent hydrogen flow. This subsystem is constructed in the same fashion as the transport subsystem.

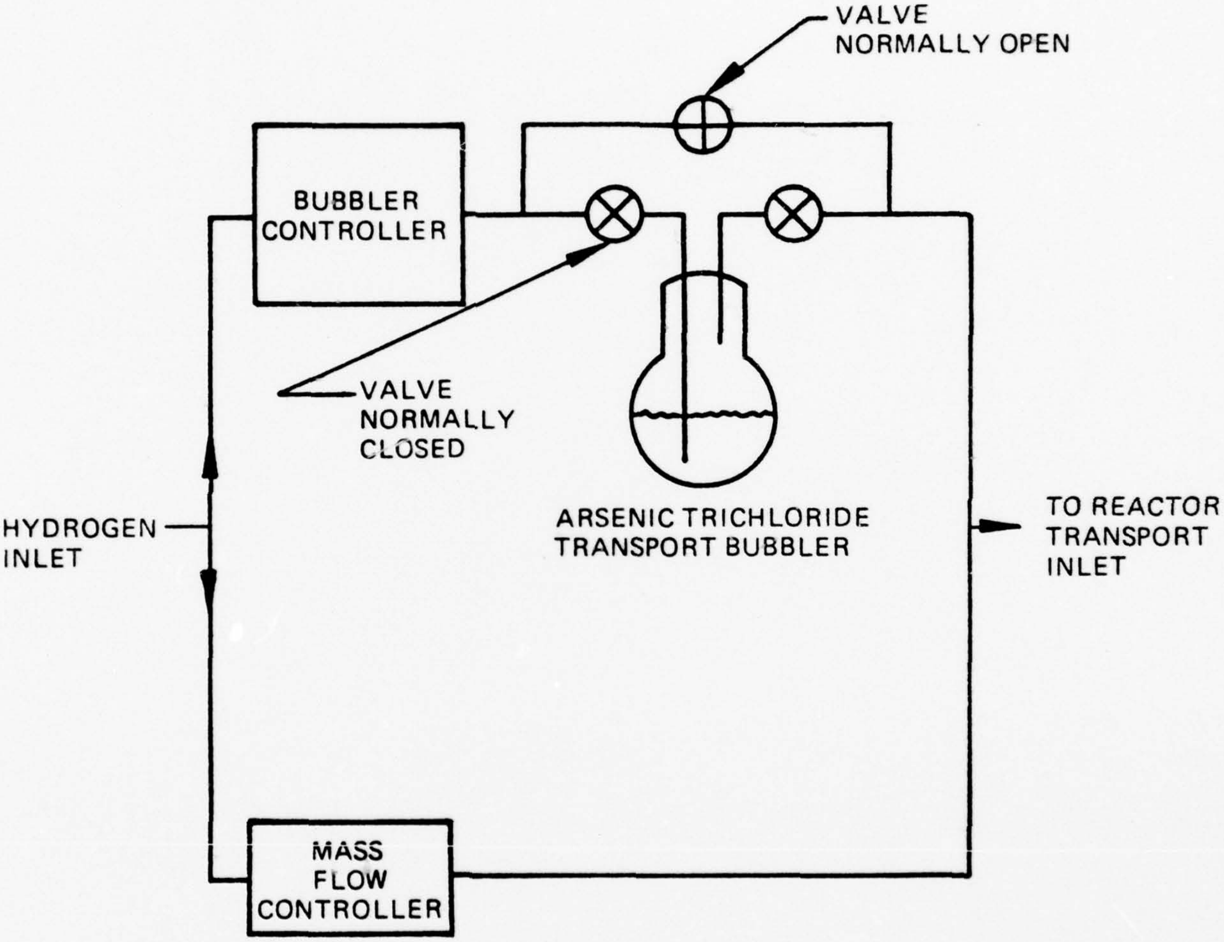


FIGURE 1 SCHEMATIC DRAWING OF TRANSPORT GAS INLET SYSTEM

D-15565

2. Doping System

There are two (2) methods which are commonly used to control carrier densities of the levels required for the drift region doping density of an X-band LHL structure. These methods are impurity doping and gas composition control. This system will use intentional impurity doping.

Impurity doping has been selected for the doping system for the following reasons: (1) in order to improve the reproducibility and control of the Ga source reaction by maintaining a constant concentration of reacting species in the transport reaction, (2) to allow the carrier gas flow of the transport vaporizer controller to be used as an indicator of normal bubbler performance, and (3) the desire to maintain the transport reaction products at constant concentrations in the epitaxial deposition zone.

An additional reason for the use of impurity doping arises from the nature of the species being controlled by gas composition doping control. This species is a residual contaminant in the epitaxial system. Improvements in the overall quality of the epitaxial system from purity considerations will thus have an effect on the doping levels which are obtainable.

In order to use doping gases to control the carrier density, dilute concentrations of the doping gas in a carrier gas are required. At the required levels for 10^{15} donors/cm^3 levels, gas concentrations well below 1 ppm are required. Dilute gas concentrations of doping gases such as H_2S, H_2Se, SiH_4 are unstable in cylinders at these concentrations due to reactions with the cylinder walls, decomposition, and reaction with trace contaminants during blending. More concentrated gases must be used and the gas dynamically diluted before use.

The dilution system which will be used is composed of three (3) mass flow controllers. This system is shown schematically in Figure 2. In use, the mass flow controller which is utilized for the control of doping gas flow and the mass flowmeter which controls the flow rate into the reactor utilize the same set point, i.e., the flows through these flow controllers are always equal. The other mass flow controller which is utilized thus controls and measures the amount of hydrogen which is used for dilution. This type of doping dilution system has been successfully utilized at Microwave Associates for epitaxial LHL crystals.

In order to increase the versatility of this basic system, a bypass for the dilution system has been included. This bypass allows the doping gas to be used and controlled directly which facilitates the growth of the more heavily doped buffer layers and doping peak.

The reagent handling system thus ensures that:

1) A regulated $AsCl_3$ concentration enters the Ga source reaction zone.

2) A regulated $AsCl_3$ concentration enters the etch inlet for in-situ etching.

3) A regulated doping gas concentration with a constant flow enters the etch/dopant inlet to control carrier density.

3. Computer Control System

From the outline of system operation, it can be seen that the functions of the computer control system are:

1) Programming,
2) Switching - motor control system, valves, control loops, and indicators,

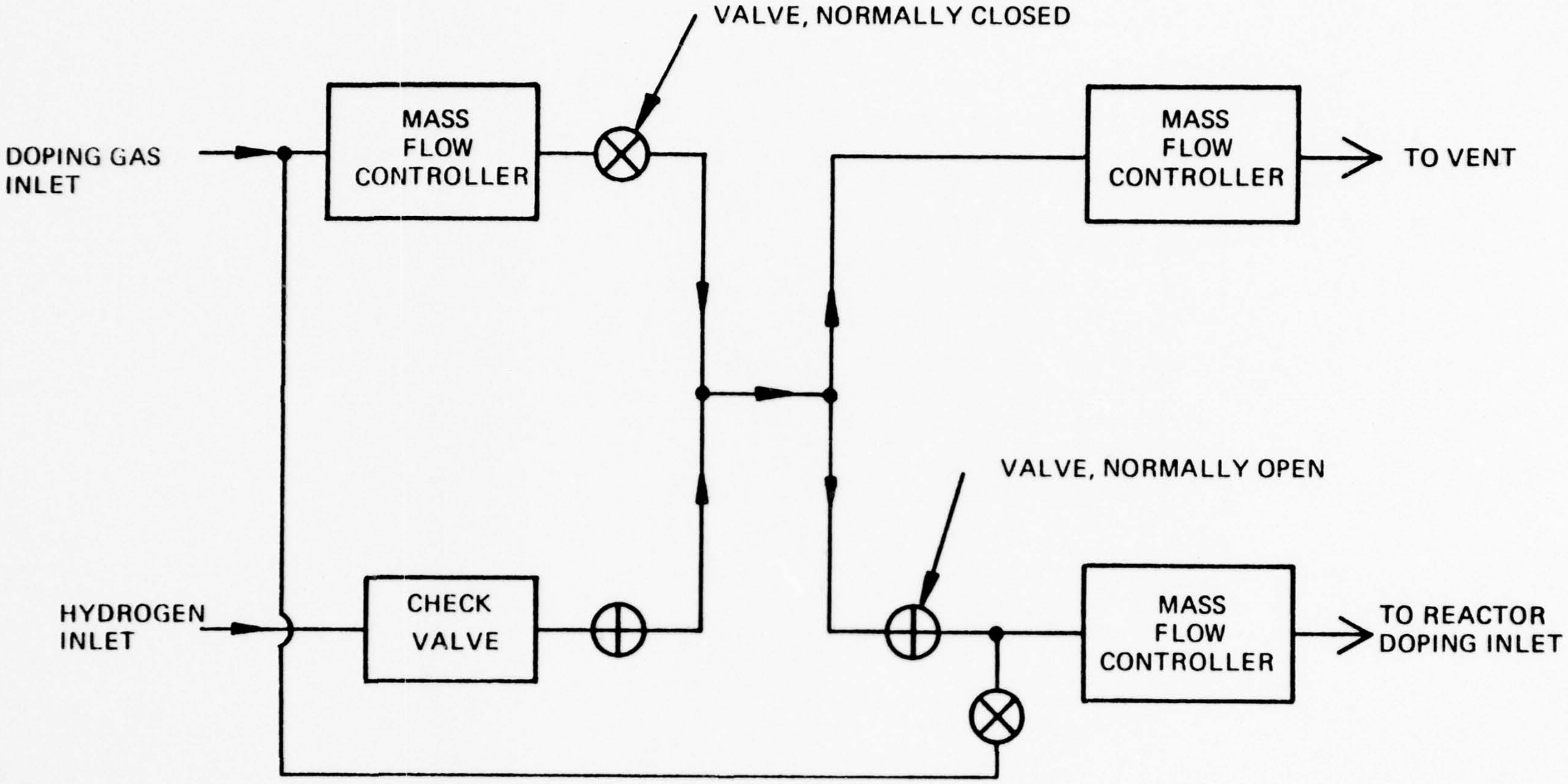


FIGURE 2 SCHEMATIC DRAWING OF DOPING GAS DILUTION SYSTEM

D 15562

3) Set point control - mass flow controllers, vaporizer controllers, and temperature controllers,
4) Timing - epitaxial run and cleaning,
5) Monitoring and comparing - flow and vaporizer controllers, thermocouples and control loops,
6) Record keeping - data storage and printing.

The computer control system is composed of interface units to couple the sensors and control elements of the system to the computer, the control processing computer, the computer memory, the interface unit to couple control elements and sensors to the computer, and the printer to provide permanent records for the operator. At this point, it is instructive to examine the interface units which are required. The sensors and control elements have the following input/output characteristics:

1) Mass Flow Controllers

   Input Signal: 0-5 V DC (3 units)
   Output Signal: 0-5 V DC (5 units)

2) Bubbler Controllers

   Input Signal: 0-5 V DC (2 units)
   Output Signal: 0-5 V DC

3) Temperature Controller

   Input Signal: 0-10.0 volts (3 units)

4) Thermocouples

   Output Signal: 6.000 - 9.000 mV (20 units)

5) Relays

   Input Signal: 5.0 V DC (8 units)

In general, a computer equipped with sufficient multiplexed analog to digital (A to D) converter input channels and digital to analog (D to A) channels could function as the required controller. Fixed gain amplifier or attenuator stages would convert to 0 to 5 V DC signals from mass flow and bubbler controllers to a computer compatable level. Switching functions and resistance programming for temperature controllers could be derived from a relay or opto-isolator matrix driven from the computer's D to A output channels. Timing sequences could be generated by performing a number of instruction loops of known cycle time.

Figure 3 shows the system configuration in final form. Table I lists the various items with brief descriptions. All items are manufactured by Hewlett Packard and as such form a reliable factory integrated system. A dual location configuration was chosen, with the computer located at some distance from the reactor room. An HP 9611R Remote Industrial Measurement and Control Station was chosen as the remote terminal and will be located together with a 2640B CRT terminal at the reactor site. This configuration allows use of a second terminal at the CPU location, to be used for program development without interfering with reactor room activity.

The system consists of an HP 2112A computer with 32 K memory, a 14.7 mbyte disc with one fixed and one removable section, 220 kbyte mini data cartridge system with two removable cartridges, a 200 lines per minute line printer, HP RTE II real time operating system with foreground and background capability, two CRT terminals, and the 9611R remote measurement and control station.

The 9611R will contain all of the analog to digital (A to D) and digital to analog (D to A) converters necessary for communicating with the reactor. Both high level and low level A to D inputs are provided

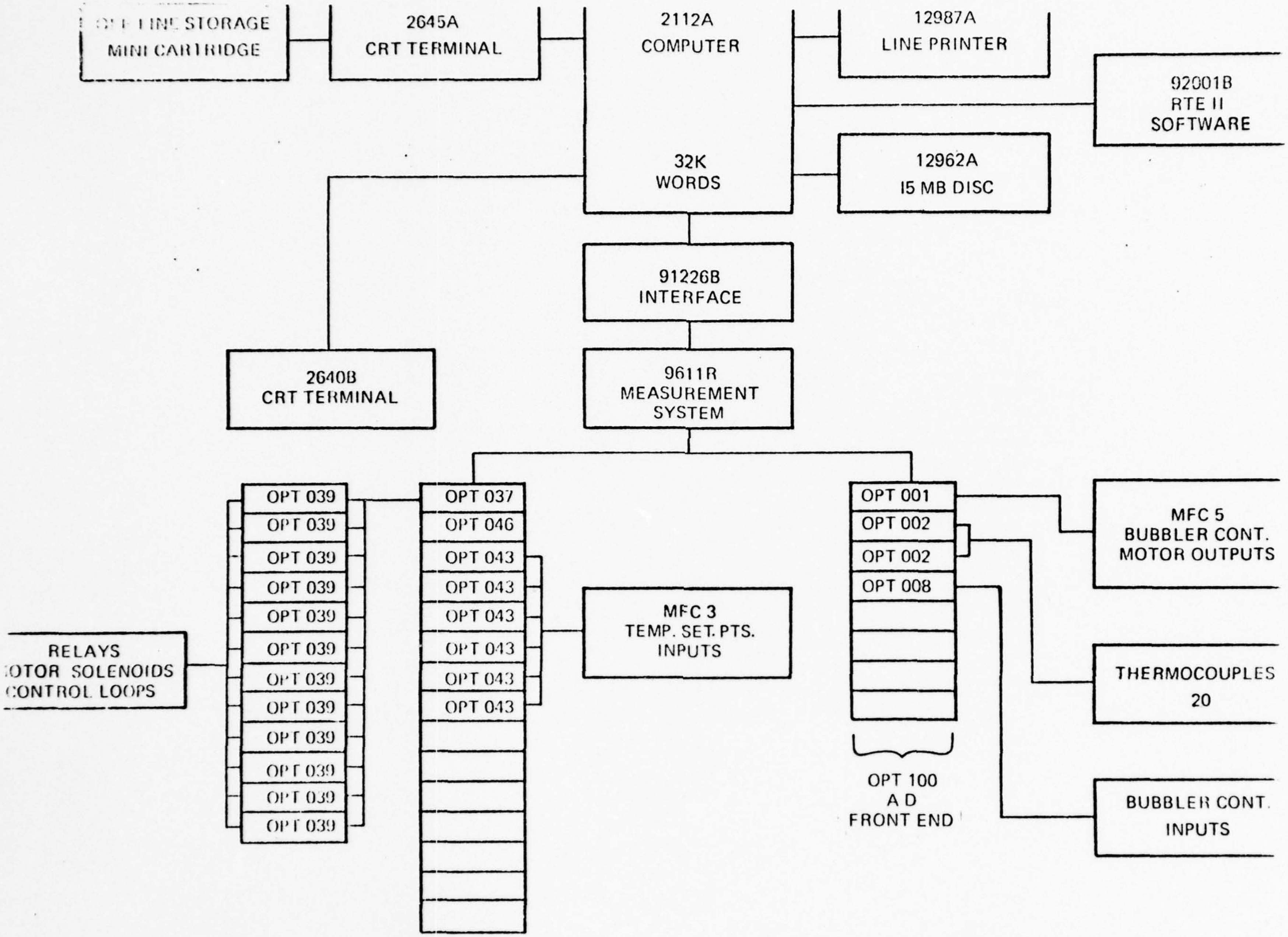


FIGURE 3 SCHEMATIC DRAWING OF COMPUTER CONTROL SYSTEM

HP Part Number	Quantity	Description	Specifications	Use
2112A	1	Computer CPU	32 K memory, 16 bit words, 650 nanosecond cycle time, includes HP 12892A Memory Protect, HP 2102A Memory Controller, HP 125396 Time Base Generator, HP 12991A Power Fail Recovery System and HP 12992A Binary Loader	System CPU
12962A	1	Disc Subsystem	14.7 mbytes capacity, 33.7 millisecond response time, 937.5 kbytes/second transfer rate	Operating System and Program Storage
92001B	1	Software	Real Time Executive II (RTE II) Operating System, features foreground and background multi-use swapping partitions, multi-terminal access, Fortran IV, and interactive editor	Operating System

TABLE I

SUMMARY OF AUTOMATIC CONTROL SYSTEM UNITS

HP Part Number	Quantity	Description	Specifications	Use
2640B	1	CRT Terminal	80 characters/line, 24 lines/display, 240 characters/second	Reactor Room Console
2645A	1	CRT Terminal with Mini Data Cartridge	80 characters/line, 24 lines/display, 240 characters/second, 220 kilobytes of on-line storage in two mini data cartridges	System Console
12987A	1	Line Printer	132 columns, 200 lines/minute, up to 5 copies	System Printer
91226B	1	Interface	Remote communications parallel to serial data transformation	Communication with Remote Data Acquisition Terminal
9611R	1	Industrial Measurement and Control Station	Up to 528 analog inputs, up to 900 digital I/O lines, operation up to 10,000 feet from computer	Reactor Room Measurement and Control Station

TABLE I (Continued)

HP Part Number	Quantity	Description	Specifications	Use
<u>9611R Options</u>:				
Option 100	1	Adds Analog I/O Subsystem	7 card capacity, 112 inputs	Accepts Analog Input Cards
Option 001 91110A	1	High Level Multiplexer	16 differential inputs per card, + 10.235 V to - 10.240 V , 45 KHz data rate, <u>Accuracy</u>: ± .09% fs ± 1/2 LSB <u>Temp Coefficient</u>: ± .0026% fs per °C <u>Long-Term Drift</u>: ± .66% fs max in 30 days 50 nsec aperture time	Accepts Analog Input Signals from Mass Flow Controllers, Bubbler Controllers, and Slice Insertion Motor

TABLE I (continued)

HP Part Number	Quantity	Description	Specifications	Use
Option 002 91111A	2	Low Level Multiplexer	16 differential inputs per card, Specifications for ± 10 mV range at 20 Hz sample rate: Accuracy: ± 0.33% fs ± 1/2 LSB Temp Coefficient: ±.0054% fs per °C	Accepts Analog Input Signals from Thermocouples
Option 008 91113A	1	D to A Converter	Two outputs per card, 12 bit accuracy, +10.235 volts to -10.240 volts, 0 to 20 mA, short circuit proof Regulation: .05% fs 0 to 20 mA Resolution: 5 mV Accuracy: (0 to 5 mA output) ±.025% fs Temp Coefficient: ±400 μV/°C max Stability: ± 1.5 mV drift/24 hours	Supplies Control Signal to Mass Flow Controllers

TABLE I (continued)

HP Part Number	Quantity	Description	Specifications	Use
Option 037 91223A-001	1	AC/DC Digital Output Controller	12 switch closures per card Used with Option 039 modules	Used with Option 39
Option 039 91212A	12	Solid State AC Relay Module	20 to 250 VAC switching 47 to 63 Hz, 10 mA to 2 A continuous 80 A surge for 16 millisec.	Provides Switch Closures for Solenoid Valves (8), Slice Insertion Motor (2), and Control Loop Switching (2)
Option 046 91123A	1	Voltage Regulator		Used with Option 043
Option 043 91207A-010	6	D to A Converter	One output per card +10.235 V to -10.240V 0 to 5 mA, short circuit proof <u>Regulation</u>: ± 3 mV max to 5 mA <u>Resolution</u>: 5 mV <u>Accuracy</u>: ± 5 mV, 0 to 5 mA Temp Coefficient: ±600 μV/°C Stability: ±1.5 mV in 24 hrs	Supplies Control Signals to Bubbler Controllers, Temperature Controllers and Mass Flow Controllers

TABLE I (continued)

in order to accomodate the 0 to 5 volt output signals from the mass flow and bubbler controllers, and the 10 millivolt signals from the thermocouples. Output signals for control of the mass flow controller and vaporizer controller set points as well as the furnace temperature controller set points are provided by 8 D to A output channels. Twelve solid state relays provide switch closures for operation of the slice insertion motor and solenoid valves.

IV. EXPERIMENTAL RESULTS

Most of the quarter was spent in designing the experimental system, obtaining delivery of equipment and beginning reactor construction. Experimental results are, therefore, minimal but some data have been obtained.

The variation of the infrared reflectance minimum with the doping density has been determined for Si-doped bulk GaAs crystals. The reflectance minimum was determined using a reflectance spectrum obtained with a Beckmann IR-20 spectrophotometer. The portion of the slice used for the reflectance pattern was used to prepare a van der Pauw Hall effect sample which was used to measure the corresponding donor density.

The log of the square of the reflectance minimum in wavenumbers (ν_m) was plotted versus the log of the carrier concentration in the fashion of Black, Lanning, and Perkowitz [1]. A least square fit was performed yielding the relationship $\log N = 0.81 \log (\nu_m)^2 + 14.04$ with a correlation coefficient of 0.985. These data are adequate for the measurement of carrier density and carrier density uniformity but additional data will be added during the program from each new substrate lot which is received. These data are shown in Figure 4.

An evaporator for aluminum is in operation for the preparation of the evaluation Schottky barrier diodes to measure the epitaxial layer carrier density profile uniformity. The mask design which has been selected is a square array of 20 mil diameter Schottky diodes with the square dimension of 1 inch. The array contains 25 Schottky diodes on 0.250 inch centers. This type of array will provide more useful uniformity data than the cross arrangement and will accommodate various sizes and shapes of the epitaxial layer structure.

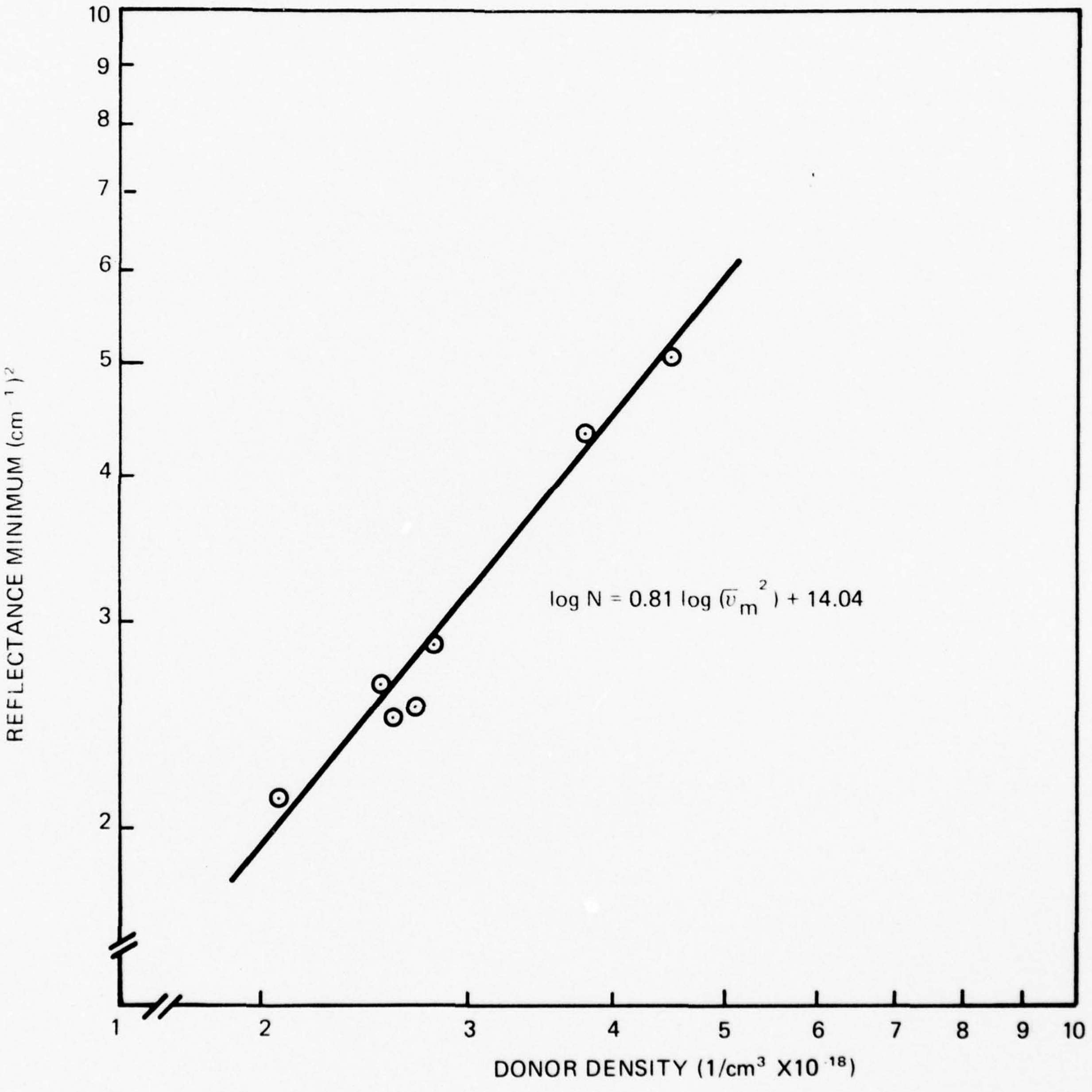


FIGURE 4 SQUARE OF REFLECTANCE MINIMUM VERSUS DONOR DENSITY FOR Si-DOPED GaAs

The doping system of the existing reactor failed due to component failure. It was therefore necessary to immediately build a new doping system which utilized some but not all of the components for the new doping system. This system utilizes only 3 mass flow controllers instead of the 4 shown in Figure 2.

Typical results for low-high-low epitaxial GaAs are shown in Figures 5, 6, 7, and 8 for material using this interim system. Since these data are not extensive, no interpretation will be attempted at this time. These structures were prepared without buffer layers.

The primary purpose of these runs was the evaluation of the doping system for the peak growth. As a result, only minor attention was paid to the drift carrier region except to insure that it was doped to the approximate level required for an LHL epitaxial crystal. As a result of this lack of attention and the absence of a buffer layer, the interface region is not adequate and for these runs indicates a small inversion layer.

The peak heights were targeted for 2 X 17 donors/cm^3 with a target location of 0.35 μm from the surface. The results of these runs are tabulated in Table II. These results are not definitive but are definitely encouraging. The performance of this doping system is superior to the 3 mass flow controller system previously in use especially with respect to peak location.

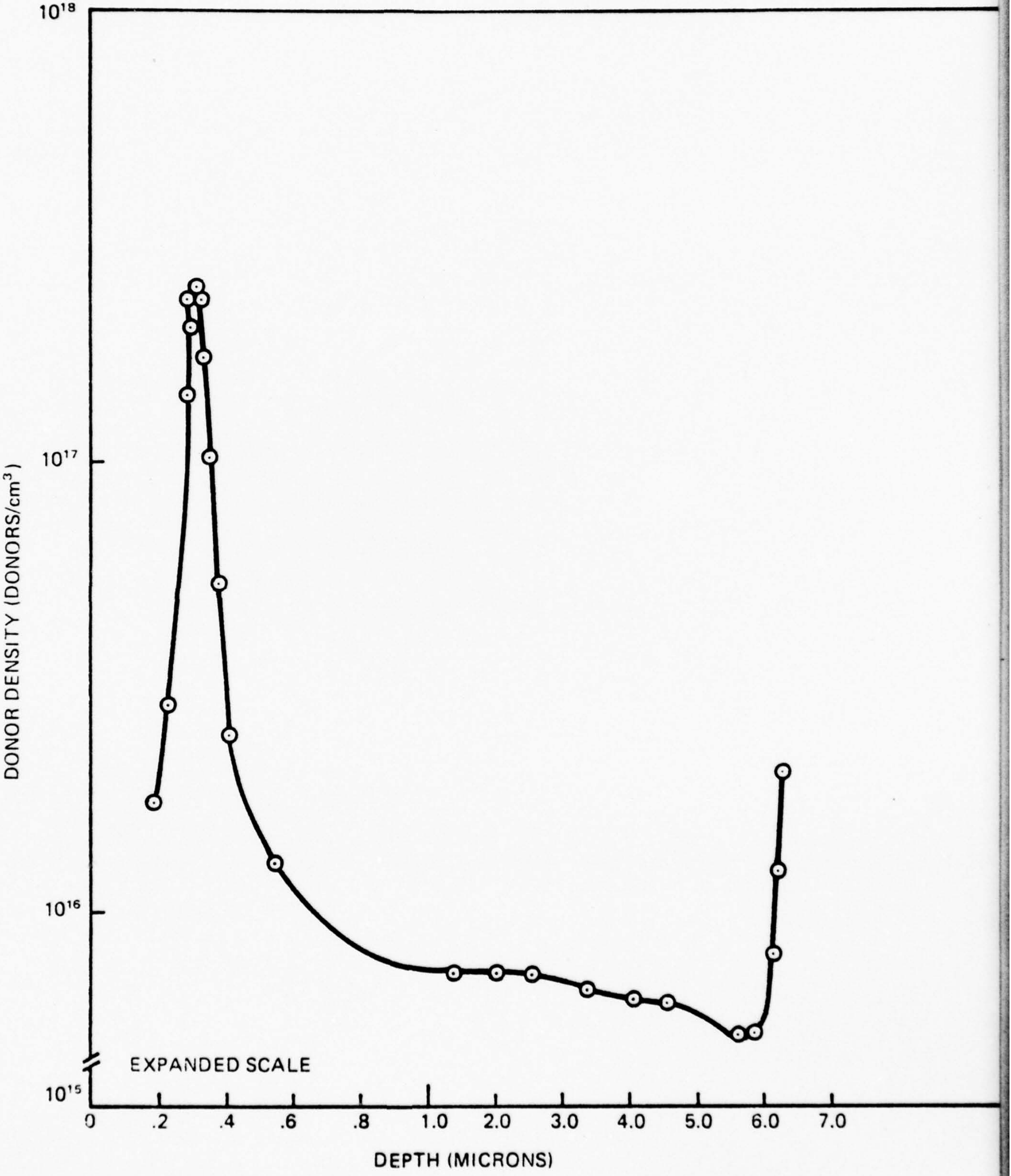


FIGURE 5 COMPOSITE CARRIER DENSITY PROFILE – CRYSTAL 4729

D-15567

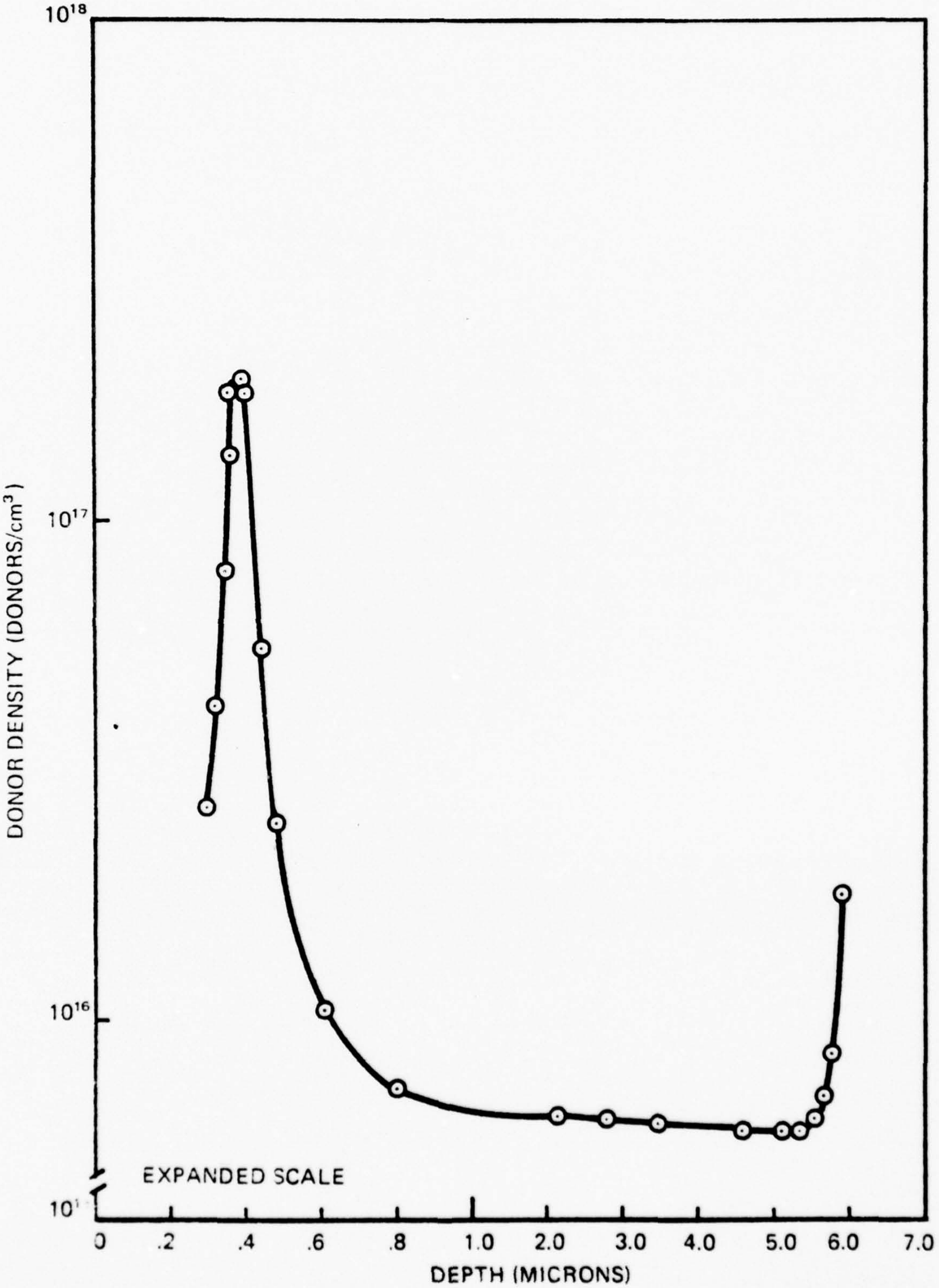


FIGURE 6 COMPOSITE CARRIER DENSITY PROFILE – CRYSTAL 4730

D-15564

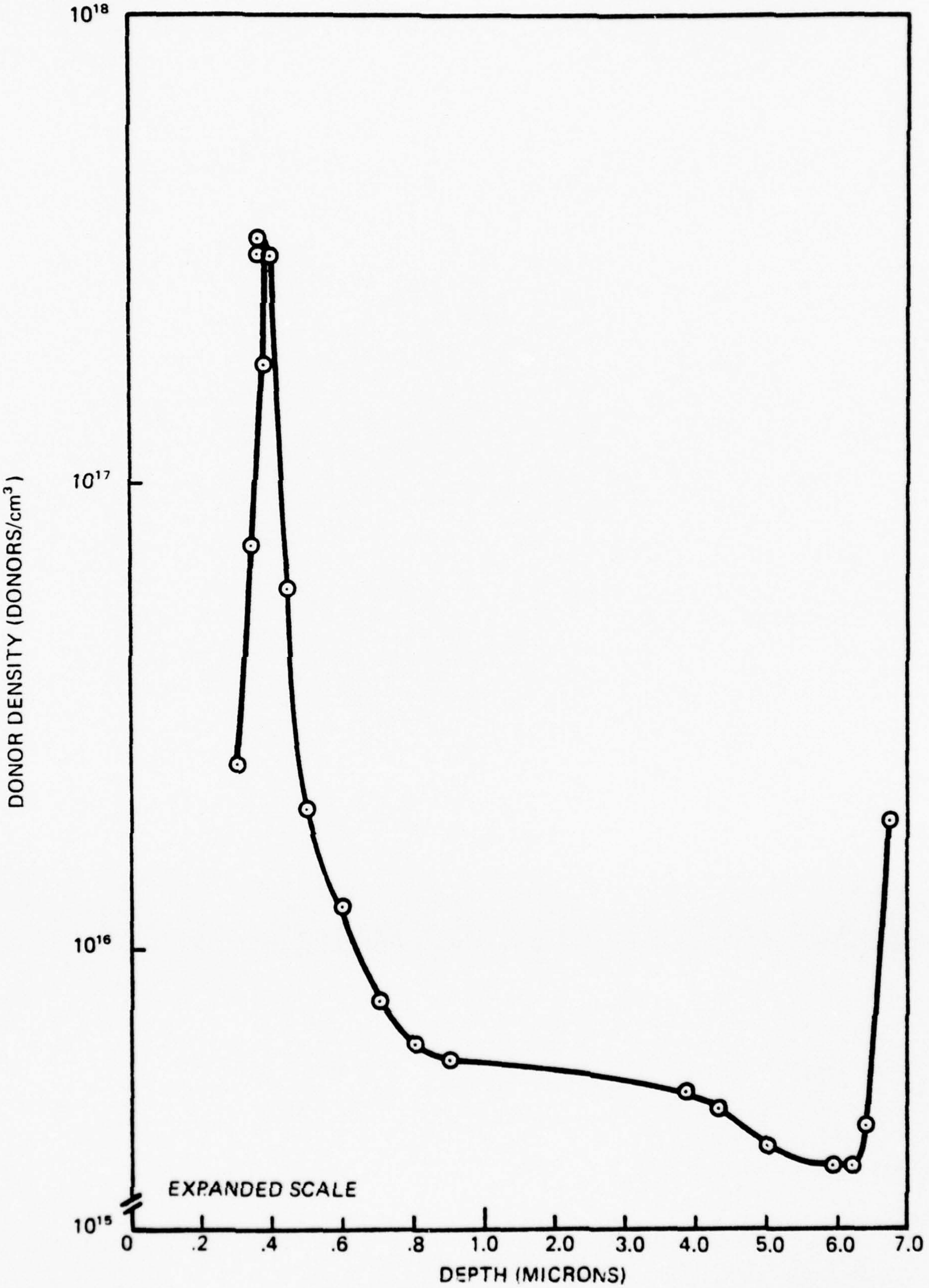


FIGURE 7 COMPOSITE CARRIER DENSITY PROFILE – CRYSTAL 4732

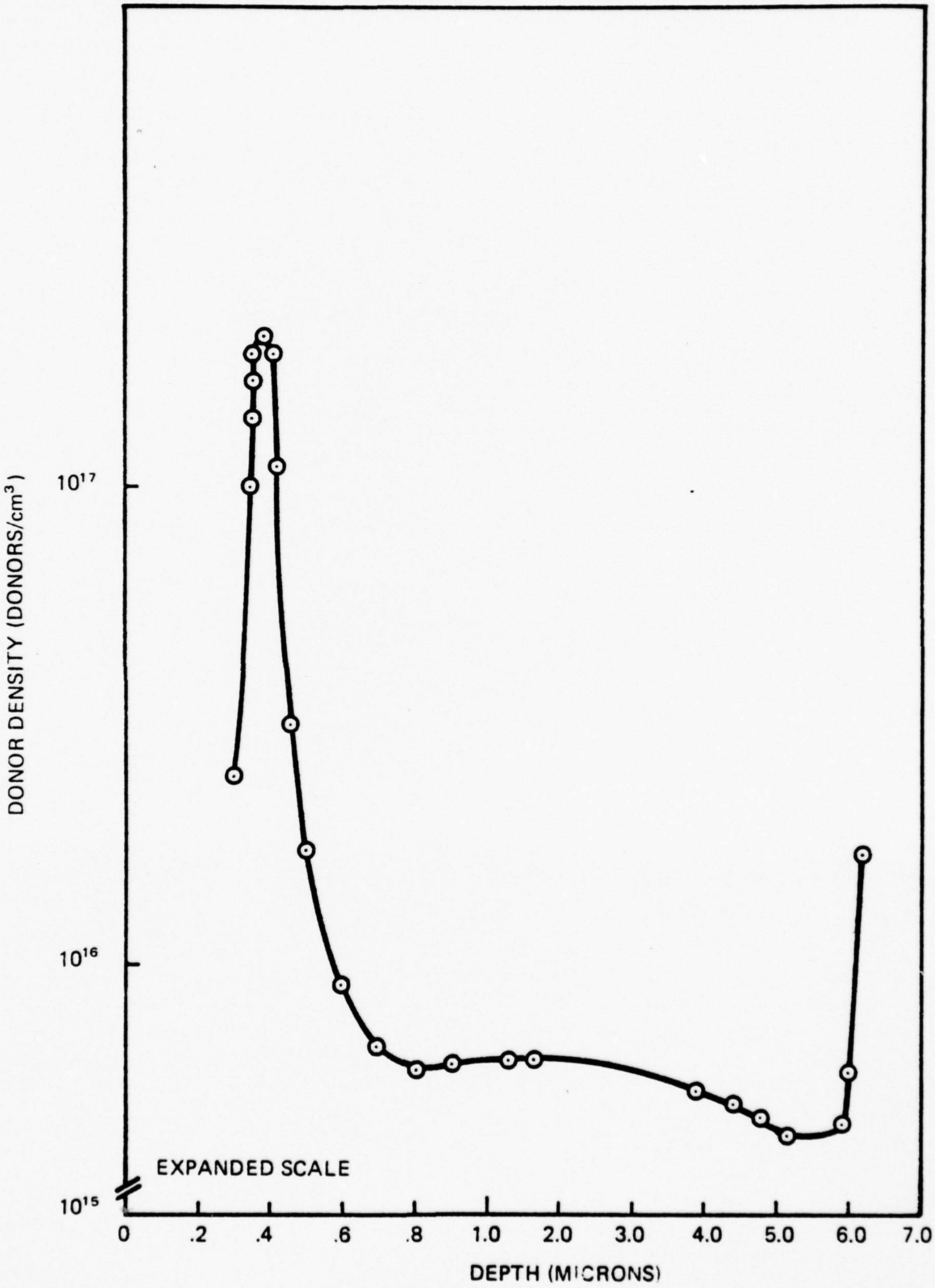


FIGURE 8 COMPOSITE CARRIER DENSITY PROFILE – CRYSTAL 4733

D-15561

Crystal	Peak Height (donors/cm^3)	Peak Location (μm from surface)
4729	2.4 X 10^{17}	0.36
4730	1.9 X 10^{17}	0.39
4731	3.3 X 10^{17}	0.39
4732	2.0 X 10^{17}	0.39

TABLE II

PEAK HEIGHTS AND PEAK LOCATION FOR LHL CRYSTALS

V. PROGRAM FOR THE NEXT QUARTER

The system which is presently in existence will be used to provide the material required for the first engineering sample. This system will continue to be operated for additional experimental data until the remainder of the components have been received. The system will then be shut down and rebuilt into its final configuration.

The computer control system is expected to be shipped in its entirety by the end of May. Work will begin during this quarter on getting the computer system interfaced with the reactor although this work will not be completed until the third quarter of this program.

VI. IDENTIFICATION OF PERSONNEL

NAME	TITLE	HOURS
Dr. Robert E. Walline	GaAs Department Manager	156
Dr. John Heaton	IMPATT Product Line Manager	159
James E. Holtz	Materials Engineer	278
Carl N. Foose	Engineering Assistant	112

REFERENCES

1. Black, J.T., Lanning, E., and Perkowitz, S., Infrared Physics 10, 125 (1970).

ELECTRONICS COMMAND
TECHNICAL REQUIREMENTS

SCS-481
23 December 1974

HIGH EFFICIENCY, HIGH-POWER GALLIUM ARSENIDE READ-TYPE IMPATT DIODES

1. SCOPE

1.1 Scope. - This specification covers the detailed requirements for high efficiency, high power Gallium Arsenide Read-Type IMPATT Diodes.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on the date of invitation for bids or request for proposal, form a part of the specification to the extent specified herein.

SPECIFICATIONS

MILITARY

MIL-S-19500	Semiconductor Devices, General Specification for.

STANDARDS

MILITARY

MIL-STD-750	Test Methods for Semiconductor Devices
MIL-STD-1311	Test Methods for Electron Tubes

(Copies of specification, standards, drawings and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the Contracting Officer).

3. REQUIREMENTS

3.1 Detail requirements. - The individual item requirements shall be in accordance with MIL-S-19500, and as specified herein. In the event of any conflict, the requirements of this specification shall govern.

3.2 Abbreviations and symbols. - The abbreviations and symbols used herein are defined in MIL-S-19500 and as follows:

Q_{ext} = external quality factor of diode oscillator

3.3 Design and construction and physical dimensions. - The diodes shall be made by epitaxial growth of Read-type profiles. The diode shall consist of a single mesa, single chip mounted in a ceramic-to-metal microwave package. The package shall be gold plated and hermetically sealed. The package shall provide means for readily heat sinking the diode. A schematic of a suitable package is shown in Figure 1.

3.3.1 Operating position. - The diode shall be capable of proper operation in any position.

3.4 Performance characteristics. - The diode performance characteristics, while operating as oscillators, shall be as specified in Tables I and II and as listed below. The performance characteristics shall apply over the specified ambient operating temperature range unless otherwise specified.

3.4.1 Process conditioning. - All units shall be process conditioned before they are subjected to the tests and examinations defined in Tables I and II (see 4.5.4).

3.5 Serial number. - The manufacturer shall assign a serial number to each device furnished to this specification. This serial number shall be sequential and non-repeating.

3.6 Interchangeability. - All parts having the same manufacturer's part number shall be directly and completely interchangeable with each other with respect to installation and performance within the requirements of this specification.

3.7 Storage life (non-operating). - Following storage at an ambient temperature of 200°C ± 3°C for 1000 hours minimum, all diodes shall meet the requirements of oscillator frequency, oscillator output power and oscillator efficiency as defined in Table III (see 4.6.5).

3.8 Operating life. - All diodes which have operated for 1000 hours minimum per the requirements of Table III shall have a power output of no less than 75 percent of the initial power output (see 4.6.6).

3.9 Mechanical tuning. - The RF output power shall not decrease below specified value in Table III. The frequency and power shall vary smoothly with no steps or jumps (see 4.6.3).

3.10 External Q. - The external quality factor, Q_{ext}, of the diode oscillator shall not be more than 200 (see 4.6.4).

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. - The contractor is responsible for the performance of all inspections specified herein. The contractor may utilize his own facilities or any commercial laboratory acceptable to the Government. Inspection records of the examinations and tests shall be kept complete and available to the Government as specified in the contract. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure that supplies and services conform to prescribed requirements.

4.2 Classification of inspection. - Inspection shall be classified as follows:

(a) First article inspection (does not include preparation for delivery) (see 4.4).

(b) Quality conformance inspection (see 4.5).

4.3 Test plan. - The contractor prepared Government-approved test plan shall contain:

(a) Time schedule and sequence of examinations and tests.

(b) A description of the method of test and procedures.

(c) Programs of any automatic tests including flow charts and block diagrams.

(d) Identification and brief description of each inspection instrument and date of most recent calibration.

4.4 First article inspection. - First article testing shall consist of the tests specified in Tables I and II. For the tests of Table I and the end point measurements of Table II, the diodes shall be operating as oscillators in the test cavity. The number of units to be subjected to each test shall be as stated in the contract. No failures will be permitted.

4.5 Quality conformance inspection. - This inspection shall be performed on samples selected from the pilot production as specified in the contract and shall consist of Group A and B inspections.

4.5.1 Group A inspection. - Group A inspection shall consist of the examinations and tests specified in Table I. The diodes shall be operating as oscillators in the test cavity.

4.5.2 Group B inspection. - Group B inspection shall consist of the examinations and tests specified in Table II.

4.5.3 Group C inspection. - Group C inspections are not applicable to this specification.

4.5.4 Process conditioning. - All diodes will be stored, non-operating, under the following conditions:

(a) Junction temperature: 225°C max
200°C min

(b) Storage time: 168 hrs. min

4.5.5 Test cavity. - Two suitable microwave test cavities, one for each frequency band, shall be used to test the performance of the diodes.

4.6 Methods of examination and test. - Methods of examination and test shall be as specified in Tables I and II and as follows:

4.6.1 AM noise. - An AM noise measurement system as shown schematically in Figure 2 shall be used to determine the AM noise to signal ratio. The AM noise spectrum shall be measured continuously from 10 KHz to 100 KHz from the carrier as a minimum and recorded by an x-y recorder. Noise measurements shall be performed while diode oscillator is meeting the operating requirements in Table III.

4.6.2 FM noise. - An FM noise measurement system as shown schematically in Figure 2 shall be used to determine FM noise deviation. The FM noise spectrum shall be measured continuously from 10 KHz to 100 KHz from the carrier as a minimum and recorded by an x-y recorder. Noise measurement shall be performed while the diode oscillator is meeting the operating requirements in Table III.

4.6.3 Mechanical tuning. - The oscillator unit will be mechanically tuned over the required frequency range of ± 250 MHz from operating frequency.

4.6.4 External Q. - The external quality factor, Q_{ext}, of the diode oscillator shall be determined by standard injection locking techniques. A small locking signal shall be injected into the diode oscillator for measurement of locking bandwidth as a function of injected power.

4.6.5 Storage life (non-operating). - The diodes shall be stored at an ambient temperature of 200°C ± 3°C for 1000 hours minimum. These diodes shall be selected randomly from diodes which have undergone process conditioning and have successfully passed all Group A inspections. Upon completion of storage, the diodes shall be subjected to the following tests described in Table I: Oscillator frequency, oscillator output power and efficiency.

4.6.6 Operating life. - The diodes shall be tested under operating conditions in accordance with Table III for 1000 hours minimum. Power output shall be monitored continuously. The diodes subjected to the operating life test shall be selected randomly from diodes which have undergone process conditioning and have successfully passed all Group A inspections. The number of failures as a function of time shall be recorded. The test shall be conducted in an ambient temperature of 25 ± 3°C and the cavity temperature shall not exceed 75°C during this test.

4.6.7 Efficiency (RF-DC). - The RF to DC power efficiency of diodes operating as oscillators shall be determined by measuring the DC input power and using standard methematical formulations.

$$\text{Power Efficiency (RF-DC)} = \frac{\text{Power output (RF)}}{\text{Power in (DC)}} \times 100$$

4.6.8 RF output power. - RF output power of diodes operating as oscillators shall be measured at operating frequency in accordance with method 4250, MIL-STD-1311 using a calibrated thermistor and power meter.

4.6.9 Oscillator frequency. - Frequency of diodes operating as oscillators shall be determined with a calibrated spectrum analyzer and verified with a calibrated frequency meter.

4.6.10 DC bias voltage. - DC bias voltage of diodes operating as oscillators shall be measured in accordance with method 4016, MIL-STD-750.

4.6.11 DC bias current. - DC bias current of diodes operating as oscillators shall be measured in accordance with method 4016, MIL-STD-750.

4.6.12 Nuclear radiation exposure. - Devices will be exposed to the neutron level specified below over a time period not to exceed five (5) minutes. This exposure will be conducted with the devices in a non-operating, non-biased condition and at a temperature not to exceed 40°C. Devices shall not experience temperatures in excess of 40°C prior to evaluation testing. Evaluation will be conducted in such a manner that no device will be operated for more than two (2) minutes prior to completion of the sub-group tests. These precautions are necessary to reduce the effects of high temperature annealing of the radiation induced damage.

10^{13} n/cm^2, 1 MeV equivalent (Si)

10^4 rads (Si) gamma

4.6.13 Junction temperature. - The junction temperature shall be determined as follows: The breakdown voltage of the diode shall be measured at 40°C intervals between 20°C and 200°C in accordance with method 4021 of MIL-STD-750. The breakdown voltage shall be that voltage corresponding to a reverse current of 1 mA. The diode shall then be biased under pulsed conditions in a lossy circuit to suppress oscillations thus making input power equivalent to dissipated power. Pulse width shall be sufficient (about 1 msec) for the diode to reach thermal equilibrium. The diode shall then be pulsed down to a current of 1 mA and breakdown voltage shall be measured. The pulse-down duration shall be short (several microseconds) to prevent cooling of the diode. From this data thermal resistance of the diode shall be determined. The junction temperature of a diode under operating conditions shall be determined from its power input, power output and thermal resistance.

5. PREPARATION FOR DELIVERY

5.1 Preparation for delivery. - Packaging and marking shall be in accordance with the contract.

6. NOTES - None.

TABLE I - GROUP A INSPECTION

$T_A = 25 \pm 3^{\circ}C$ unless otherwise specified

Test	Method	Symbol	Min	Max	Units
Subgroup 1					
Oscillator Frequency	4.6.9	f_o			
Diode Type 1			9	11	GHz
Diode Type 2			14	16	GHz
Oscillator output power	4.6.8	P_o			
Diode Type 1			3.5		W-CW
Diode Type 2			2.5		W-CW
Oscillator efficiency (RF-DC)	4.6.7	η	20		%
Junction Temp	4.6.13	T_j		200	°C
Subgroup 2					
Mechanical tuning	4.6.3	Δf_{mech}	± 250		MHz
Subgroup 3					
AM Noise	4.6.1	$(N/S)_{AM}$		-115	dB
FM Noise	4.6.2	Δf_{rms}		50	Hz
Subgroup 4					
DC Bias voltage	4.6.10	V_o		70	v
DC Bias current	4.6.11	I_o		500	ma
Subgroup 5					
External Q	4.6.4	Q_{ext}		200	

TABLE II GROUP B INSPECTION

Test	MIL-STD-750 Method	Details	Min	Max	Units
Subgroup 1					
Shock	2016	Non-operating; 500G, t = 1.0 msec, X_1, Y_1, and Z_1 orientation			
Vibration, Variable Freq.	2056	Non-operating; 20G, 50 to 2000 Hz.			
Constant acceleration	2006	Non-operating; 20,000G min, X_1, Y_1 and Z_1 orientation			
Hermeticity	1071	Test Condition H- Traces Gas Fine Leak (Helium)			
End point measurements; Table I, Subgroup 1					
Subgroup 2					
Nuclear radiation exposure	4.6.12				
End point measurements: Table I, Subgroup 1					
Subgroup 3					
Storage life (non-operating)	4.6.5				
Subgroup 4					
Operating life	4.6.6				

TABLE III OPERATING REQUIREMENTS

Ambient Temperature Range: -40°C to 65°C

Diode Type 1

Oscillator frequency	10.0 GHz ± 1.0 GHz
Oscillator output power	3.5 W-CW, min.
Oscillator efficiency (RF-DC)	20% min
Junction Temperature	200°C max

Diode Type 2

Oscillator frequency	15.0 GHz ± 1.0 GHz
Oscillator output power	2.5 W-CW, min
Oscillator efficiency (RF-DC)	20% min
Junction Temperature	200°C max

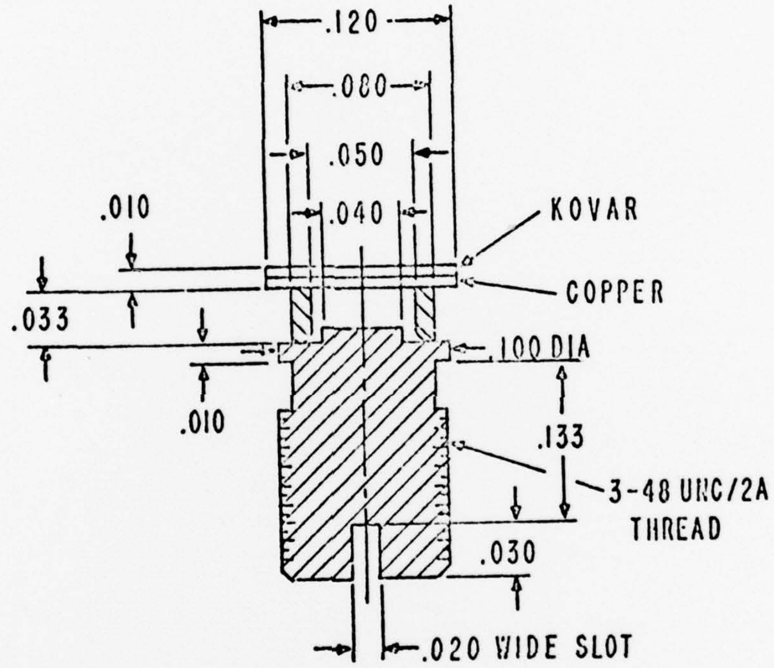


FIGURE 1

CERAMIC-TO-METAL MICROWAVE DIODE PACKAGE

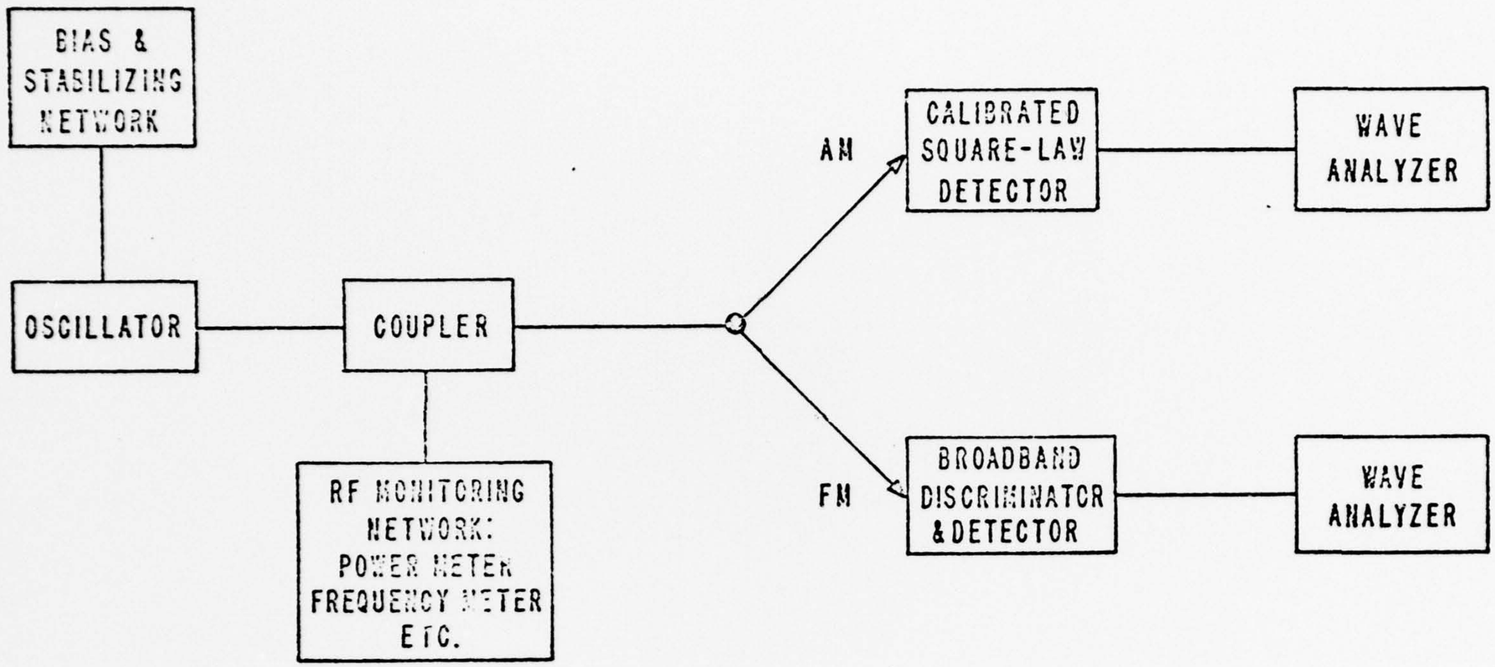


FIGURE 2

AM & FM NOISE MEASUREMENT SYSTEM (SCHEMATIC)

DISTRIBUTION LIST

CY

Commander 1
Rome Air Development Center
Griffiss Air Force Base
ATTN: (EMERR) Mr. L. Gubbins
Rome, New York 13440

Commander 1
Air Force Materials Laboratory
ATTN: MATE (Ms. E. Torrance)
Electronic Branch
Wright-Patterson Air Force Base
Dayton, Ohio 45433

Advisory Group on 2
Electron Devices
201 Varick Street, 9th Floor
New York, New York 10014

Commander 2
US Army Electronics Command
ATTN: DRSEL-PP-I-PI-1
Fort Monmouth, NJ 07703

NASA Scientific & 2
Tech Information Facility
PO Box 8757
Baltimore/Washington Int'l Airport
Maryland 21240

Commander 2
US Naval Air Development Center
ATTN: Library
Johnsville, Warminster, PA 18974

CY

Commander 1
Rome Air Development Center
Griffiss Air Force Base
ATTN: (EMERR) Mr. Regis C. Hilow
Rome, New York 13440

AFAL (AVTA) 1
Electronic Technology Division
ATTN: Mr. Robert D. Larson, Chief
Advanced Electronics Devices Branch
Wright-Patterson Air Force Base
Dayton, Ohio 45433

National Aeronautics & 1
Space Administration
George C. Marshall Space Flight
Center
ATTN: R-QUAL-FP
(Mr. Leon C. Hamiter)
Huntsville, Alabama 35812

NSSA-Manned Space Craft Center 1
Reliability and Flight Safety Division
ATTN: Library
Houston, Texas

Commander 2
US Army Material Development and
Readiness Command
ATTN: DRCRD-RS-PE-E, DRCRE-D
5001 Eisenhower Avenue
Alexandria, Virginia 22333

Chief 1
Naval Ship Systems Command
Department of the Navy
ATTN: Code 681A2b, Mr. L. Gumina
Room 3329
Washington, DC

DISTRIBUTION LIST

\# CY

Commander 1
Naval Electronics Laboratory
Center
ATTN: Library
San Diego, CA 92152

Commander 1
US Naval Research Laboratory
ATTN: G. Abraham 5205
Washington, DC 20390

Commander 1
Air Research & Development Command
ATTN: RDTCT
Andrews Air Force Base
Washington, DC

Avantek 1
ATTN: Mr. Thielan
3001 Copper Road
Santa Clara, CA 95051

American Electronics Laboratory 1
Richardson Road
Colmar, PA

Centralab Semiconductor 1
4501 North Arden Drive
El Nonte, CA 91734

Commander 1
US Army Research Office
ATTN: DRXRO-IP
PO Box 12211
Research Triangle Park
North Carolina 27709

\#CY

Commander 1
Department of the NAVY, ELEX 05143A
ATTN: A. H. Young
Electronics System Command
Washington, DC 20360

Commander 1
Defense Electronics Supply Center
Directorate of Engineering &
Standardization
ATTN: (DESC-ECS) Mr. N. A. Hauck
Dayton, Ohio 45401

Amelco Semiconductor 1
PO Box 1030
Mountain View, CA 94042

AIL 1
ATTN: Mr. Lou Ciaciulli
Commack Road
Deer Park, LI., New York

Alpha Industries, Inc. 1
20 Sylvan Road
Woburn, MA 01801

Rockwell International 1
Collins Radio Group
ATTN: Dr. Cheng Wen
MS 406-246
Dallas, Texas 75207

Fairchild Semiconductor Division 1
Fairchild Camera & Instrument Corp
ATTN: Mr. Robert Skurko
313 Fairchild Drive
Mountain View, CA 94040

DISTRIBUTION LIST

	# CY		#CY
Sanders Associates, Inc. ATTN: Microwave Department 95 Canal Street Nashua, NH 03060	1	Texas Instruments Semiconductor Components Div. ATTN: Semiconductor Library PO Box 5012 Dallas, Texas	1
Western Electric ATTN: Mr. R. Moore Marion & Vine Street Laureldale, PA	1	Varian Associates Solid State West ATTN: F. E. Rosztoczy 611 Hansen Way Palo Alto, CA 94303	1
Hughes Aircraft Corporation ATTN: Dr. Bruce Crammer 3100 West Lomita Boulevard Torrance, CA 90509	1	Texas Instruments PO Box 5936, MS 105 Dallas, Texas 75222 ATTN: Central Research Labs.	1
Commander US Army Missile Command Redstone Scientific Info. Center ATTN: Chief, Document Section Redstone Arsenal, AL 35809	1	General Motors Corporation Delco Radio Division ATTN: Box 1104 Kokomo, IN 46901	1
General Instrument Corp. Semiconductor Products Group 600 West John Street Hicksville, Long Island, NY 11802	1	Honeywell, Incorporated Semiconductor Products 2747 Fourth Avenue Minneapolis, MN 55408	1
Micro-Electronics Laboratory Hughes Aircraft Company 500 Superior Avenue Newport Beach, CA 92663	1	IBM Components Division ATTN: Mr. Al Kran East Fishkill, Rt. 52 Hopewell Junction, NY 12533	1
KSC Semiconductor Corp. ATTN: Mr. S. Cudletz, President KSC Way (Katrina Road) Chelmsford, MA 01824	1	Arthur D. Little Acorn Park ATTN: Dr. H. Rudenberg 15/206 Cambridge, MA 02140	1

DISTRIBUTION LIST

Address	# CY
Commander Defense Documentation Center ATTN: DDC-TCA Cameron Station, Building 5 Alexandria, VA 22314	12
Director Electronic Components Laboratory ATTN: DRSEL-TL-1J Fort Monmouth, NJ 07703	1
Commander Harry Diamond Laboratories ATTN: Mr. Horst Gerlach (DRXDO-RAA) Connecticut & VanNess St. N.W. Washington, DC 20438	1
Director Electronic Components Laboratory ATTN: DRSEL-TL-1J (Wadergin) Fort Monmouth, NJ 07703	4
Office of Defense Research & Engineering Communications and Electronics Room 3D1037 Washington, DC 20330	1
Motorola, Inc. ATTN: Mr. J. LaRue 5005 East McDowell Road Phoenix, AZ 85008	1
General Electric Co. No. Concourse Bldg. Syracuse, NY 13212	1
Director US Army Production Equipment Agency ATTN: (Mr. C. McBurney) Rock Island Arsenal Rock Island, IL 61201	1
Commander US Army Materiel Development & Readiness Command ATTN: DRCPM-NXE-D (Dr. McClung) Nike X Project Office Redstone Arsenal, Alabama 35809	1
Commander US Army Missile Command ATTN: DRSMI-IEVL (Mr. Buckelew) Building 4500 Redstone Arsenal, Alabama 35809	1
MSI Electronics Inc. 32-34 57th Street Woodwise, NY 11377	1
Northrop Corporation Laboratories ATTN: Library 320-61 3401 West Broadway Hawthorne, CA 90250	1

DISTRIBUTION LIST

\# CY

Raytheon Company 1
Semiconductor Operation
ATTN: Mr. S. Weisner
350 Ellis Street
Mountain View, CA 94040

Sprague Electric Company 1
ATTN: Mr. W. C. Donelan
87 Marshall Street
North Adams, MA 01247

US Army Missile Command 1
ATTN: DRSMI-RGP
(Mr. Victor Ruwe)
Redstone Arsenal, AL 35805

Department of Defense 1
Deputy for Science & Technology
Ofc Assist Sec Army (R&D)
Washington, DC 20310

\# CY

Dr. Robert H. Rediker 1
Massachusetts Institute of Technology
Building 13-3050
Cambridge, MA 02139

Raytheon Company 1
ATTN: Dr. S. F. Paik
130 Second Avenue
Waltham, MA 02154

Bell Laboratories 1
Whippany Road
ATTN: M. A. Rello, Library
Whippany, NJ 07981