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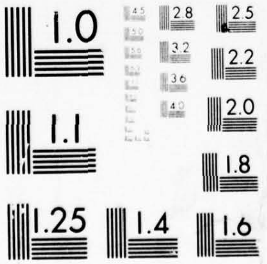

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(9) ~~4TH~~ QUARTERLY ~~REPORT~~ . no. 4, 1 Oct-31 Dec 77,

By

(10) **~~DR.~~ R. E. WALLINE [redacted] J. L. HEATON**

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

FOURTH QUARTERLY REPORT

01 October 1977 to 31 December 1977

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FOR

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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.

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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

The success of the computer controlled epitaxial GaAs system in the preparation of low-high-low (L-H-L) epitaxial GaAs capable of producing 20% DC - RF conversion efficiency has permitted the program to address the reproducibility of the epitaxial GaAs system and the uniformity parameters of the epitaxial GaAs crystals. These requirements, reproducibility and uniformity, are necessary to insure high manufacturing yields of the high power, high efficiency GaAs IMPATT diodes.

During this period, the second engineering samples were delivered. These diodes meet all of the requirements of the X-band diode specified in SCS-481. These diodes had output powers from 4.0 - 4.5 watts at frequencies from 10.4 to 11.2 GHz. The DC to RF conversion efficiency was 21.0 to 23.7%. Junction temperature for these diodes was a maximum of 175°C for a 25°C case temperature.

III EPITAXIAL GaAs CRYSTAL GROWTH

The computer controlled epitaxial GaAs reactor was completed during the last quarter and was demonstrated by preparing epitaxial low-high-low GaAs which was utilized to prepare IMPATT diodes with efficiencies greater than 20% at X-band. It was, therefore, decided to investigate the flexibility of the epitaxial system, the reproducibility of the system and the uniformity of the epitaxial GaAs prepared.

In order to successfully prepare epitaxial GaAs for use in low-high-low Read IMPATT diodes, it is necessary to control the:

1) Drift layer thickness
2) Drift layer doping density
3) Doping peak doping density or height
4) Doping peak width
5) Doping peak position relative to the epitaxial crystal surface

A series of epitaxial runs was made with the material parameters targeted for Ku-band devices at the start of the series and for C-band devices at the end of the series. This series was selected to investigate the performance of the epitaxial system with drift doping changes and different growth times in order to determine the reproducibility of the system under circumstances in which it must be utilized to manufacture high efficiency IMPATT diodes at various frequencies.

This type of reproducibility avoids fortuitous reproducibility data which can be obtained on a single type of material. If the system loses control of the growth process at some time after the epitaxial growth is initiated, the growth of C-band material, which is thicker than the X-band material, will determine if this problem exists. The growth of less heavily doped drift regions (C-band) and more heavily doped drift regions (Ku-band) allow the verification of the reproducibility of the intentional doping system and lack of contamination of the Ga source leading to a fixed doping density.

This series has been utilized to demonstrate the reproducibility of the growth rate and the resultant reproducibility of the drift layer thickness. The growth rate is determined by dividing the average thickness of the epitaxial layer by the growth time. The average thickness is determined by averaging the five thickness measurements which are made on each epitaxial wafer using the infrared (IR) reflectance technique.

The reproducibility of the growth rate should be better than ± 10% in order to manufacture high efficiency IMPATT diodes. This variation would result in a ± 10% variation in the drift thickness which is acceptable for the manufacture of these devices.

The data for the growth rate for six epitaxial crystal runs made with the same $AsCl_3$ concentration are shown in Table I. The first four of these runs were targeted for Ku-band IMPATT diodes and the latter two were targeted for C-band devices. The growth rate is reproducible to ± 7% which is better than the ± 10% required.

It is important to verify the use of the average thickness to determine the growth rate. The use of the average thickness depends on the epitaxial layers having uniform thickness across the wafer so that the average thickness is not distorted by non-uniformities.

The epitaxial layer thickness uniformity for these six crystals is shown in Table II. The maximum deviation is the percentage deviation of the thickest and thinnest of the five measurements from the average thickness.

CRYSTAL	GROWTH RATE (μm/min)
4838-1	0.16
4839-1	0.15
4840-1	0.16
4841-1	0.15
4844-1	0.14
4845-1	0.14

NOTE: Average of 6 (six) Runs = 0.15 ± 6.7%

TABLE I GROWTH RATE REPRODUCIBILITY

CRYSTAL	AVG THICKNESS	MAX DEVIATION + %	 - %
4838-1	4.4	9.1	6.8
4839-1	4.1	4.9	2.4
4840-1	4.4	4.5	4.5
4841-1	4.2	2.4	2.4
4844-1	7.4	1.4	0
4845-1	7.2	2.8	4.2

TABLE II EPITAXIAL LAYER THICKNESS UNIFORMITY

All of these epitaxial layers have thickness uniformities better than ± 10% and for five of the six, the uniformity is better than ± 5%. All of these epitaxial crystals had areas in excess of one square inch with the nominal area being about 1.4 square inches.

The drift carrier density reproducibility was determined for the four Ku-band runs. The drift carrier density was evaluated by measuring the carrier density profiles on step-etched samples using evaporated Schottky barrier diodes. The use of step-etched samples introduces error in the Schottky diode evaporation by preventing the samples from lying flat against the metal evaporation mask. This factor introduces additional uncertainty in the area of the Schottky barrier diode. Since the square of the area is utilized in the measurement, the uncertainty of the measurement could be significantly larger than the ± 10% accuracy normally considered for the carrier density profile measurement.

The data which were obtained are shown in Table III. The average for this series, excluding the first run, is 9.6 e 15 donors/cm^3 +15% -17%. These data were not as reproducible as was expected.

This lack of reproducibility may be related to the measurement process which was previously mentioned. There is some indication, however, that the epitaxial system does not always respond to the first run after a change is made but requires an additional run. It was felt that this lack of reproducibility was related to inadequate cleaning between epitaxial runs. The cleaning time was lengthened and an additional series was prepared for X-band IMPATT diodes at lower doping densities. These data are shown in Table IV. The average drift carrier density is 5.0 e 15 donors/cm^3 ± 8% which is the variation expected from the measurement technique. It may be concluded that the computer controlled epitaxial GaAs system will reproduce the drift carrier density to better than ± 10%.

CRYSTAL	$n_{DRIFT} \times 10^{-15}$	FREQUENCY
4838-1	6.5	Ku
4839-1	11.0	Ku
4840-1	9.9	Ku
4841-1	8.0	Ku

NOTE: Average of 3 Ku-Band Runs = 9.6 + 15% - 17%

TABLE III DRIFT CARRIER DENSITY REPRODUCIBILITY FOR Ku-BAND L-H-L STRUCTURES

CRYSTAL	$n_{DRIFT} \times 10^{-15}$	FREQUENCY
4864-1	5.0	X
4865-1	5.0	X
4866-1	4.6	X
4867-1	5.4	X

NOTE: Average of 4 X-Band Runs = 5.0 ± 8%

TABLE IV DRIFT CARRIER DENSITY REPRODUCIBILITY FOR X - BAND L-H-L STRUCTURES

The reproducibility of the growth of the doping peak is characterized by the reproducibility of the doping peak height (n_p), doping peak position (X_p), and the doping peak shape normally characterized by the width at 1/2 the peak height (δ). Reproducibility data for the peak is shown in Table V for six epitaxial L-H-L runs. For five of the six runs, two measurements were performed on the peak height and peak position from widely separated portions of the epitaxial layer, at least one inch apart. These data were obtained to provide preliminary uniformity data on the peak parameters for an epitaxial wafer.

From these data, it is apparent that the reproducibility of the peak height is +15% -21%, the peak position is ± 15%, and the peak width is ± 9%. These data may be interpreted as excellent reproducibility of the doping peak.

The variation in the peak doping density may be related to slightly different growth processes which may occur using different substrates. These slight differences would be magnified by the non-equilibrium doping conditions which are required to form the doping peak.

In order to more clearly show the reproducibility of the peak shape, the doping peaks obtained from five epitaxial runs are replotted from the carrier density profiles in Figure 1. The peak position is normalized to the center of the doping peak so that the reproducibility of the peak shape can be illustrated. No curves have been drawn since the excellent reproducibility of the doping peak shape is apparent from the doping points and the inclusion of curves would unnecessarily complicate the figure.

The uniformity of the doping peak across the surface of the epitaxial GaAs L-H-L crystal is also extremely important in the manufacture of high efficiency, high power IMPATT diodes at high manufacturing yields. In order to establish this uniformity, an array, 25 x 25, of Schottky barrier diodes

CRYSTAL	n_p ($\times 10^{-17}$)		X_p (μm)		δ (nm)	FREQUENCY
4838-1	4.6 4.6	4.6	0.21 0.22	0.22	40	Ku
4839-1	5.3 5.0	5.2	0.25 0.26	0.26	44	Ku
4840-1	5.4	5.4	0.30	0.30	47	Ku
4841-1	3.7 3.6	3.7	0.24 0.28	0.26	48	Ku
4844-1	4.9 5.6	5.3	0.28 0.25	0.27	42	C
4845-1	4.1 3.7	3.9	0.21 0.28	0.25	42	C

NOTE: Average:

n_p = 4.7 + 15% - 21%

X_p = 0.26 + 15% - 15%

δ = 44 + 9% - 9%

TABLE V PEAK REPRODUCIBILITY

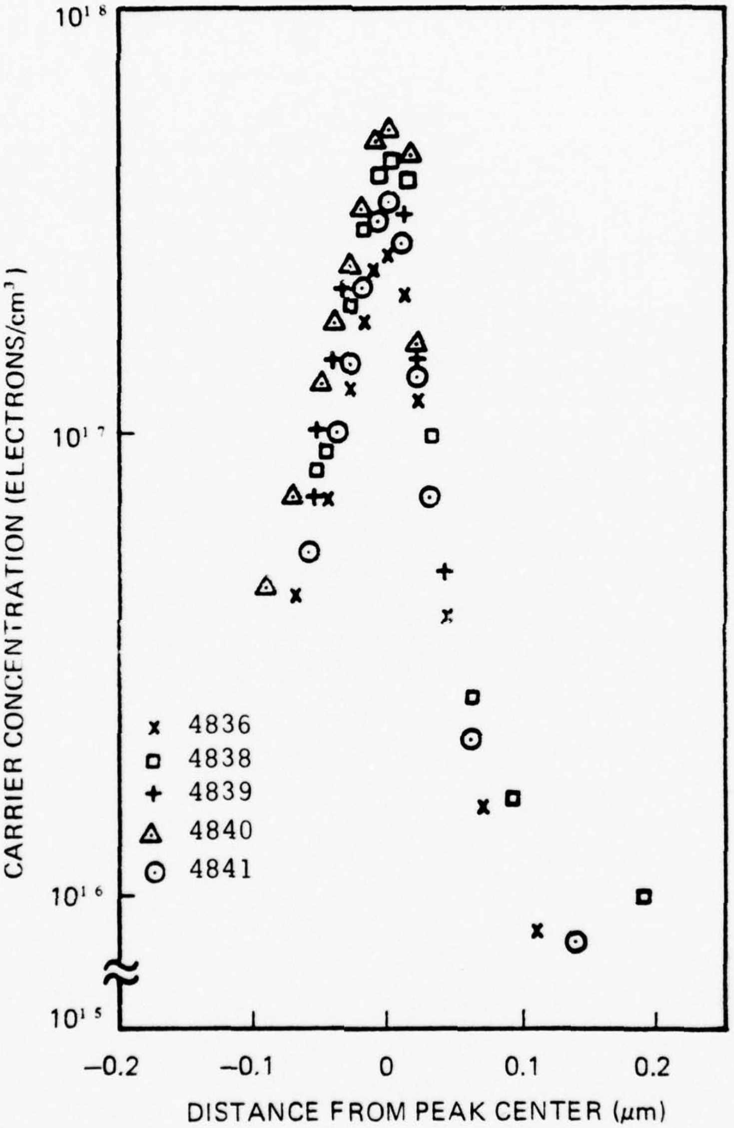

FIGURE 1 REPRODUCIBILITY OF PEAK SHAPE IN LHL CRYSTALS

was evaporated on the surface of crystal 4844-1. These diodes formed an array of one inch by one inch or one square inch of the crystal surface. The carrier density profile for 35 (thirty-five) of these diodes was measured and the peak height, peak position and peak width were determined. These data are listed in Table VI, and a summary of the data is shown in Table VII.

The total variation of the measurements are:

Peak Height = 5.15×10^{17} donors/cm^3 ± 7%
Peak Position = 0.285 μm ± 7%
Peak Width = 42.5 nm ± 11%

If the precision of the technique is estimated to be 5 - 6%, the total number of measurements within this deviation is:

Peak Height = 33 of 35 or 94%
Peak Position = 32 of 35 or 91%
Peak Width = 33 of 35 or 94%

These data indicate that the computer controlled epitaxial GaAs reactor is capable of both reproducible and uniform doping peak growth.

Sufficient information is now available to initially predict the yields which will be obtainable in the production of epitaxial L-H-L GaAs crystals. The critical parameters which are required and their reproducibility are

1) Drift Thickness ± 10%
2) Drift Carrier Density ± 10%
3) Doping Peak Height ± 15%
4) Doping Peak Width ± 10%
5) Doping Peak Position ± 10%

The buffer layer parameters are not critical provided a minimum thickness and carrier concentration are obtained.

SCHOTTKY ROW	POSITION COLUMN	PEAK HEIGHT (n x 10^{-17})	PEAK POSITION (μm)	WIDTH (nm)
1	1	5.2	0.300	42
	5	5.4	0.290	40
	10	5.3	0.285	38
	15	5.4	0.287	45
	20	5.3	0.300	45
	25	5.4	0.290	41
5	1	5.1	0.285	42
	5	5.1	0.283	43
	10	5.0	0.283	45
	15	5.2	0.287	45
	20	4.9	0.305	41
	25	5.2	0.295	43
10	1	5.2	0.280	42
	5	5.1	0.275	43
	10	5.0	0.267	41
	15	5.0	0.278	42
	20	4.8	0.295	42
	25	5.1	0.290	47
15	1	5.2	0.273	42
	5	5.4	0.270	41
	10	5.2	0.268	45
	15	5.1	0.280	45
	20	5.1	0.288	42
	25	5.0	0.290	43
20	1	5.0	0.275	42
	5	5.2	0.280	40
	10	5.5	0.272	40
	15	5.2	0.282	45
	20	5.1	0.290	44
	25	4.9	0.293	45
25	1	4.9	0.273	43
	5	5.2	0.280	45
	10	5.2	0.280	44
	15	5.2	0.275	43
	20	4.9	0.280	40

TABLE VI UNIFORMITY OF PEAK HEIGHT, PEAK POSITION, PEAK WIDTH FOR L-H-L CRYSTAL 4844

Parameter	Range	Average	Deviation	No. of Schottky's Within Deviation
Peak Height	$4.8 - 5.5 \times 10^{17}$	5.15×10^{17}	± 5%	33
Peak Position	0.267 - 0.305 μ	0.285 μ	± 5%	32
Peak Width	38 - 47 nm	42.5 nm	± 6%	33

AREA PROFILED: 1 Square Inch

NUMBER OF SCHOTTKY'S USED: 35

TABLE VII SUMMARY OF UNIFORMITY DATA -- L-H-L CRYSTAL 4844

The yield for each step is given in Table VIII. These yields result in an overall yield of the 56% for the epitaxial low-high-low GaAs structure. The computer controlled epitaxial GaAs reactor will thus exceed the yield requirements of this contract.

The uniformity information indicates that the epitaxial crystals prepared will have in excess of the 80% usable area required. This required uniformity is obtained over more than one square inch or 6.5 cm^2, far in excess of the 3 cm^2 area required.

BUFFER LAYER	Thickness	100%
	Carrier Concentration	100%
ACTIVE LAYER	Drift Thickness	90%
	Drift Carrier Concentration	90%
	Peak Height	83%
	Peak Width	100%
	Peak Position	83%
OVERALL YIELD		56%

TABLE VIII PROJECTED YIELD FOR n/n+/n/n+/n+ L-H-L GaAs STRUCTURES

IV IMPATT DIODE RESULTS

The required device to be utilized for this program is an X-band IMPATT diode with the following specifications:

Frequency (F_o) = 9.0 GHz min, 11.0 GHz max
Output Power (P_o) = 3.5 watts CW minimum
Efficiency (η) = 20% minimum
Temperature Rise (ΔT) = 175°C maximum
Operating Voltage (V_{op}) = 70 volts maximum
Operating Current (I_{op}) = 500 mA maximum

The second engineering samples have been provided and exceeded all of these specifications. The device results for these diodes are listed in Table IX. As can be observed, the output power ranged from 4.0 to 4.5 watts and operated in the upper portion of the required frequency change 10.4 - 11.0 GHz. Efficiencies ranged from a low of 21.0% to a high of 23.7%. Of particular importance are the thermal resistance and the junction temperature rise above case temperature. The thermal resistance values are low, 8.0 - 10.1°C/W, leading to junction temperature rise of 121 to 150°C. These diodes also met the noise specification of SCS-481.

The computer controlled epitaxial reactor has also been utilized to prepare IMPATT diode material in Ku-band and C-band in order to investigate its versability. The epitaxial crystal is evaluated as thermocompression bonded (TCB) diodes, referred to as the evaluation portion, and subsequently as plated heat sink (PHS) diodes, referred to as the process portion. Data for Ku-band diodes are shown in Table X, and C-band diodes in Table XI.

DIODE	V_B (V)	C_{T0} (pF)	P_o (Watts)	V_{op} (V)	I_{op} (mA)	F_o (GHz)	η (%)	θ ($^oC/W$)	ΔT (^oC)
1	25.8	25.6	4.0	42.4	445	10.6	21.2	10.0	148
2	23.8	26.3	4.4	43.2	461	10.5	22.1	9.3	144
3	21.4	24.3	4.2	41.0	449	11.0	22.8	9.2	131
4	23.7	25.4	4.5	42.9	453	10.5	23.2	9.8	146
5	23.3	26.7	4.3	43.3	464	11.0	21.4	9.5	150
6	26.4	22.5	4.3	43.8	415	11.2	23.7	9.7	135
7	24.1	26.0	4.5	44.1	445	10.6	22.9	9.4	142
8	26.3	22.7	4.4	44.3	435	11.0	22.8	10.1	150
9	22.1	22.3	4.0	41.2	464	10.4	21.0	8.0	121
10	26.5	22.4	4.3	43.7	416	11.0	23.7	9.2	128
MEASUREMENTS REQUIRED :									
Minimum	--	--	3.5	--	--	9.0	20	--	--
Maximum	--	--	--	70	500	11.0	--	--	175

TABLE IX RESULTS FOR PHS DIODES - CRYSTAL 4819-1

EVALUATION PORTION							
DIODE	V_B	C_{T0}	P_o	V_{op}	I_{op}	F_o	η
4	32.5	12.2	3.20	46.8	338	11.7	20.2
5	32.6	14.3	3.65	47.6	370	11.4	20.7
PROCESS PORTION							
DIODE	V_B	C_{T0}	P_o	V_{op}	I_{op}	F_o	η
1	19.5	11.6	3.5	36.8	427	12.7	22.3
2	21.0	10.0	3.0	37.4	341	14.1	23.1
6	21.8	12.0	3.3	36.9	430	12.5	20.8

TABLE X DEVICE RESULTS FOR L-H-L CRYSTAL 4826-1

EVALUATION PORTION

DIODE	V_B (V)	C_{to} (pF)	P_o (watts)	V_{op} (V)	I_{op} (mA)	F_o (GHz)	n (%)
2	34.2	13.0	3.2	57.6	273	8.8	20.3
3	29.0	11.3	3.0	60.7	257	7.5	19.2
4	35.8	11.1	3.0	62.0	239	7.5	20.0
PROCESS PORTION #1							
1	48.7	18.2	5.2	69.7	293	7.3	25.5
2	44.0	21.7	5.4	68.4	364	7.1	21.7
3	51.2	19.2	5.2	70.1	310	7.1	23.9
PROCESS PORTION #2							
1	37.9	16.9	5.0	63.8	324	7.5	24.2
2	38.0	16.8	4.2	65.1	337	7.2	19.1
3	37.6	17.7	4.8	65.1	334	7.2	22.1

TABLE XI DEVICE RESULTS FOR L-H-L CRYSTAL 4842-1

The process portions are tailored to obtain maximum diode performance by sputter etching some of the surface away to attempt to precisely locate the doping peak relative to the surface. This etching has a marked effect on the breakdown voltage and also affects the operating voltage. It is this processing step which results in the changes seen in the breakdown voltage and operating voltage. As more experience is obtained with the epitaxial system, it should be possible to eliminate or at least minimize this process and its subsequent effect.

The material parameters for the crystals used in Tables IX, X, and XI are shown in Table XII.

CRYSTAL	THICKNESS (μm)	DRIFT DOPING DENSITY $(n \times 10^{-15})$	PEAK HEIGHT $(n \times 10^{-17})$	PEAK POSITION (μm)	PEAK WIDTH (nm)
4819-1	5.4	5.8	4.8	0.35	48
4826-1	4.7	10.0	5.8	0.26	35
4842-1	6.3	5.2	3.2	0.33	44

TABLE XII MATERIAL PARAMETERS FOR THE X, Ku AND C BAND CRYSTALS

V PROGRAM FOR THE NEXT QUARTER

The epitaxial system will be operated to provide the required epitaxial GaAs for the third engineering samples. Additional data will be obtained on the reproducibility of the epitaxial system and uniformity of the epitaxial crystals.

Doping density curves as a function of dopant concentration and $AsCl_3$ mole fraction will be started in order to provide the doping curves required in order for the computer program to calculate the appropriate doping conditions for the required drift doping density. The initial attempt will be made to process the copius data generated by the computer control system into more useful formats.

VI IDENTIFICATION OF PERSONNEL

NAME	TITLE	HOURS
Dr. Robert E. Walline	GaAs Department Manager	96
Dr. John L. Heaton	IMPATT Product Line Manager	67
Mr. James E. Holtz	Materials Engineer	444
Mr. Carl N. Foose	Engineering Assistant	80

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 $200^{\circ}C \pm 3^{\circ}C$ 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 $25 \pm 3^{\circ}C$ and the cavity temperature shall not exceed $75^{\circ}C$ 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 mathematical 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

$T_A = 25 \pm 3^oC$ unless otherwise specified

Test	Method	Symbol	Min	Max	Units
Subgroup 1					
Oscillator Frequency	4.6.9	fo			
Diode Type 1			9	11	GHz
Diode Type 2			14	16	GHz
Oscillator output power	4.6.8	Po			
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

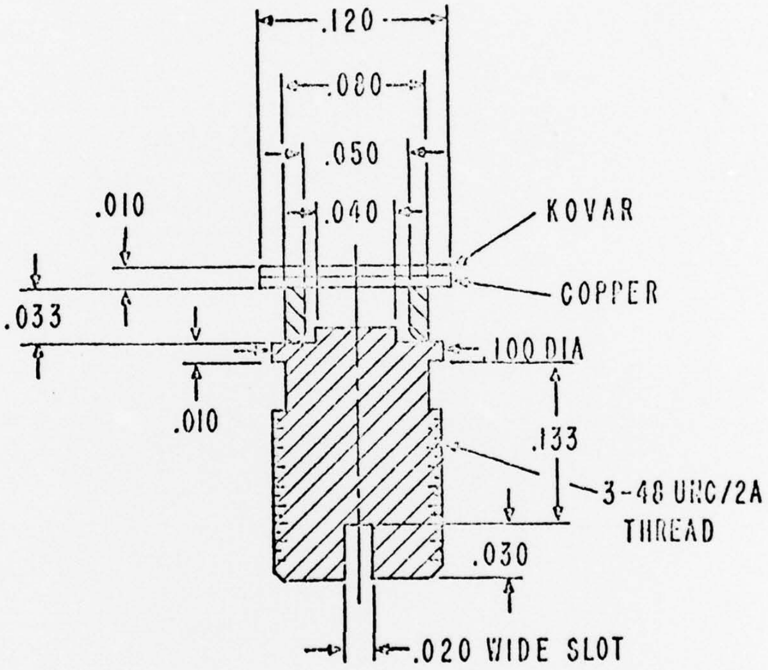

FIGURE 1

CERAMIC-TO-METAL MICROWAVE DIODE PACKAGE

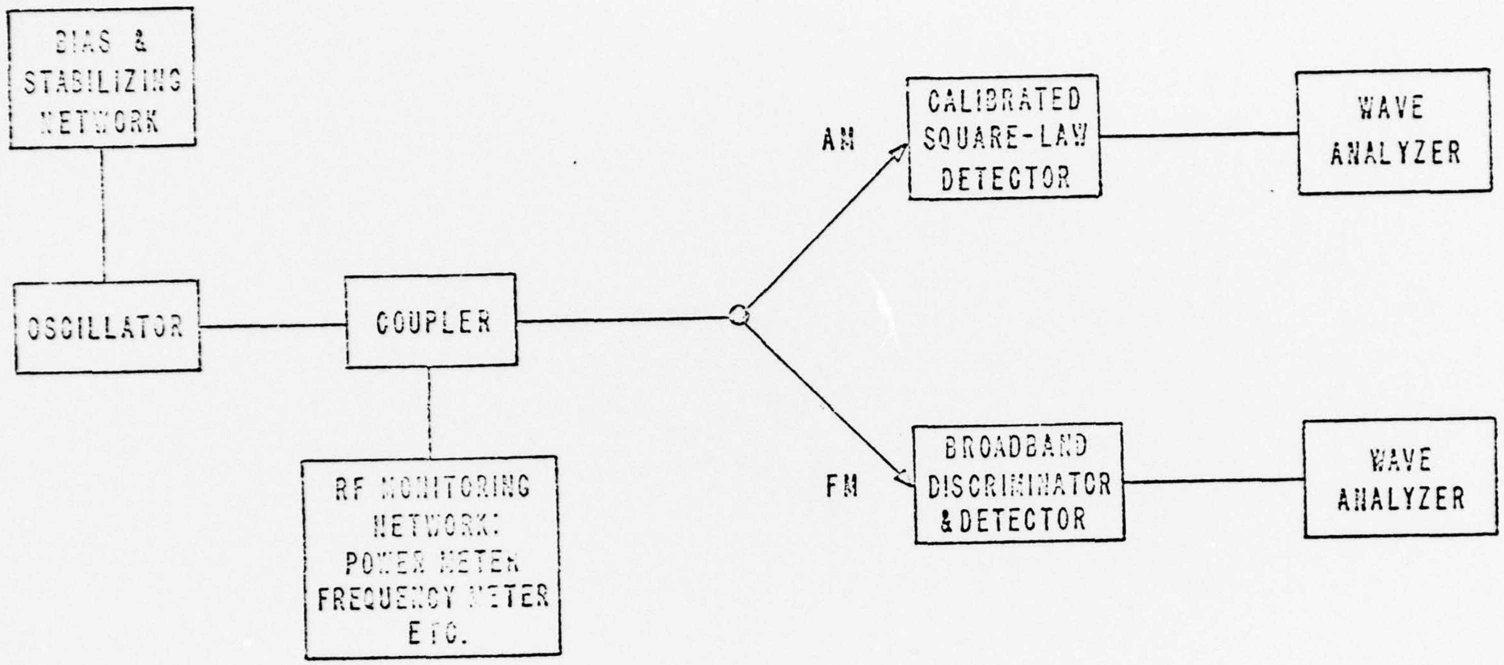

FIGURE 2

AM & FM NOISE MEASUREMENT SYSTEM (SCHEMATIC)

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