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1000 Locust Street, Philadelphia 3, Pennsylvania

SECOND QUARTERLY PROGRESS REPORT

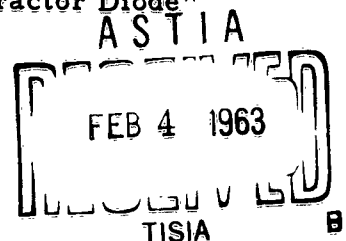
"Production Engineering Measure for Gallium Arsenide Varactor Diode"

September 1, 1962 - November 30, 1962

Contract No. DA-36-039-SC-86736

Order No. 19058-PP-62-81-81

Industrial Preparedness Activity
U. S. ARMY ELECTRONICS MATERIEL AGENCY
Philadelphia 3, Pennsylvania



"Production Engineering Measure (PEM) in accordance with Step I
of Signal Corps Industrial Preparedness Procurement Requirements
No. 15, dated 1 Oct. 1958, for Gallium Arsenide Varactor Diode
per Specification SCS-128, dated 2 March 1962 and Modification #1, 2 May 1962"

SECOND QUARTERLY PROGRESS REPORT
September 1, 1962 - November 30, 1962

Submitted to:

Industrial Preparedness Activity
PEM and Facilities Procurement Branch
U. S. ARMY ELECTRONICS MATERIEL AGENCY
225 South Eighteenth Street
Philadelphia 3, Pennsylvania

Contract No. DA-36-039-SC-86736
Order No. 19058-PP-62-81-81

SYLVANIA SEMICONDUCTOR DIVISION
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Contracts

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ABSTRACT

Studies to obtain the processes necessary for the high volume production of gallium arsenide varactor diodes are described in this report. These investigations include the areas of diffusion, contacting, mesa formation and packaging. Capacitance measurements on new package designs are tabulated.

PURPOSE

The purpose of the work being carried out under this contract is to establish the producibility, in accordance with Steps I and II of Signal Corps Industrial Preparedness Procurement Requirements (SCIPPR) No. 15 dated 1 October 1958, of Gallium Arsenide Varactor Diode per Specification SCS-128, dated 2 March 1962 and amendment No. 1 dated 2 May 1962. Fulfillment of the stated purpose is being accomplished by the completion of the major steps as follows:

1. Engineering work necessary to establish capability to manufacture the subject varactor diode on a pilot line basis. This includes the development of production processes, materials design, and test procedures suitable for fabrication of the diode in accordance with the requirements of specification SCS - 128 (See Appendix A) on a volume basis.
2. Manufacture and submission of samples for evaluation and approval according to established schedules as follows:

375 Engineering samples

100 Preproduction samples

3. Design, development, procurement and/or fabrication of production type equipment necessary to manufacture and test units meeting the above mentioned specification at the rate of 200 per day on a single eight (8) hour shift basis.
4. A production type run of 1000 units for the purpose of demonstrating the capability of the pilot line processes and equipment to manufacture at the specified rate of 200 units per eight (8) hour day in accordance with the applicable device specifications.
5. Submission of monthly, quarterly and final reports.
6. Preparation of a report in accordance with Step II of SCIPPR No. 15 dated 1 October 1958, outlining steps required to establish production of units meeting the applicable specification at the rate of 2000 units per eight (8) hour day.

1.0 Narrative and Data

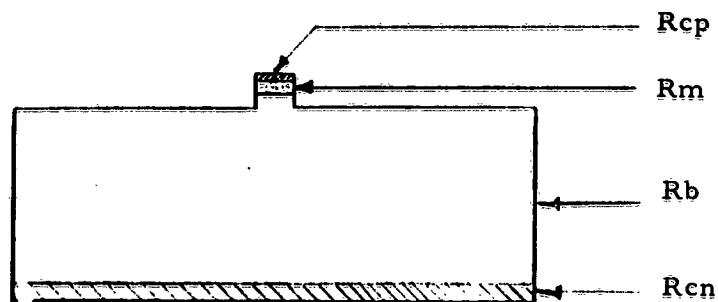
1.1 Diffusion

Elemental zinc diffusion has proved to be quite uncontrollable because the surface concentration is always extremely high while the diffusion profile is always of the abrupt type ($n \approx 1/2$). Reducing the quantity of diffusant in order to lower the surface concentration is not feasible, since the present weight of the zinc charge is down to 0.5 mg.

This problem has been solved by the use of a solution of zinc in gallium and depends on the percentage of zinc in the source solution. The diffusion profile is predictable and follows a normal error function distribution. With it we obtain a cube law capacitance versus voltage dependence. However as the percentage of zinc is increased, the elemental zinc case is approached and a square law capacitance versus voltage dependence is obtained. See figure (1).

This diffusion is performed as described in Quarterly Report #1, with the addition of a small boat in the ampoule to hold the diffusant.

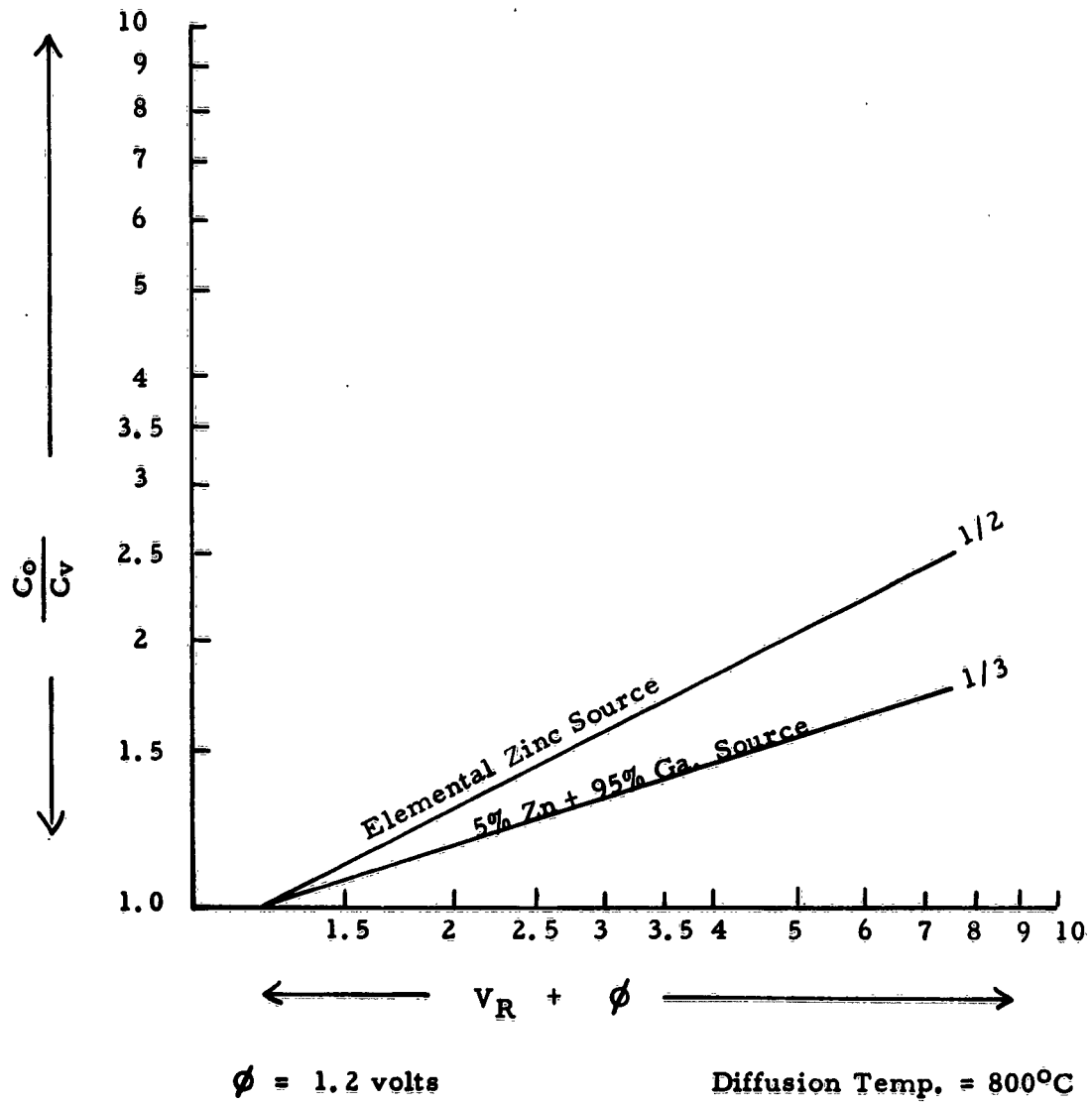
One of the major problems encountered in the production of high Q varactors is the magnitude of the series resistance in the diode. The total series resistance can be separated into four major parts, R_{cp} , R_m , R_b and R_{cn} .



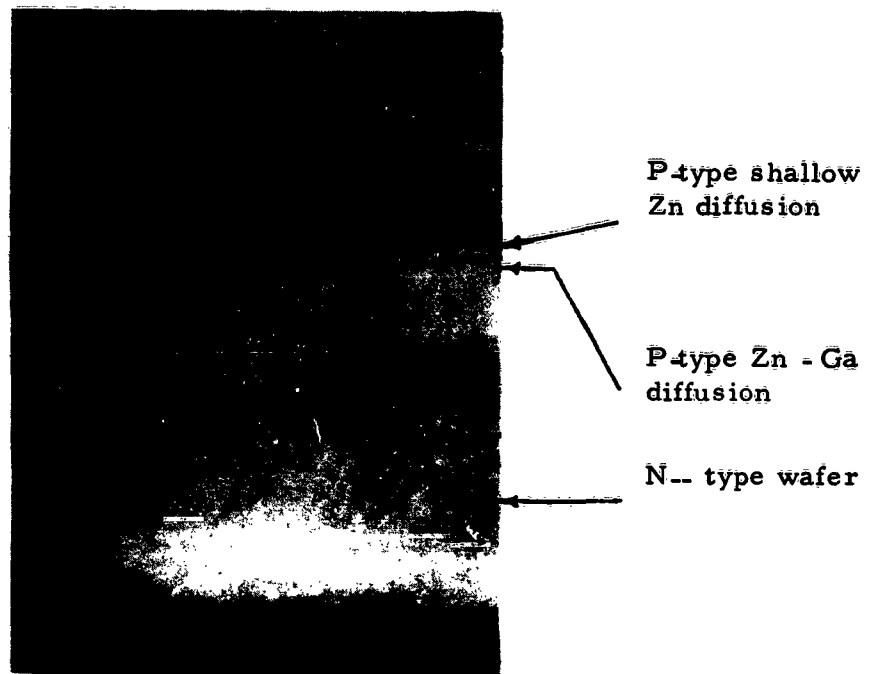
R_{cp} is the resistance encountered in making contact to the small P-type area mesa. R_m is the resistance in the neck of the mesa which consists of the bulk N and diffused P-type region. In this case, the resistance of the diffused (P) region is small compared to the narrow N region. R_b is the spreading resistance in the bulk N type region and the resistance of the N type contact to the base is denoted by R_{cn} .

In dealing with extremely small diameter ($d < .001''$) mesas, the magnitude of the R_{cp} becomes the dominant resistance. A large amount of effort has been concentrated in this area in order to obtain the lowest possible resistance. At present a second diffusion into the wafer has helped to reduce R_{cp} significantly. A shallow elemental zinc diffusion is superimposed on the zinc gallium diffusion. The result is illustrated in Figure (2). With this approach, the elemental zinc diffusion creates a highly doped region which is almost metallic and allows a low resistance contact to be made.

FIGURE 1



**CAPACITANCE VERSUS VOLTAGE DEPENDENCE FOR
ELEMENTAL ZINC AND ZINC-GALLIUM DIFFUSION SOURCES**



CROSS SECTION OF A DOUBLE DIFFUSED P REGION
WHICH IS USED TO REDUCE CONTACT RESISTANCE

FIGURE 2

1.2 Ohmic Contacts

Two problems have been encountered with the Au - Zn P-type contact. The adherence of the contact to the mesa needs improvement for volume production. After mesa etching, some contacts peel off while others can be scraped off easily.

The second problem involves decreasing the series resistance further. The present approach to the reduction of series resistance was discussed under "Diffusion".

Au - Ag - Ge is being investigated and compared with Au-Zn as a P-type contact. This contact is quite tenacious and does not scrape off without pulling mesa material with it. The series resistance of this contact seems to be equivalent to that of the Au - Zn contact which is approximately one (1) ohm.

1.3 Mesa Formation

Mesa areas are being defined by wax evaporation through 1 X 2 mil masks. This process requires further improvement in order to produce more uniform mesas in high volume production. Shadowing problems are encountered during the evaporation of the wax and some wax comes off during etching. The latter problem appears to be due to the heat generated during etching, which melts and loosens the wax around the periphery of the mesa.

A promising approach that is under investigation to improve the uniformity of the mesa areas is Kodak Photo Resist. Photo resist is a coating material used in photo-mechanical reproduction. It serves as an acid-resisting material for etching techniques and is tenacious when placed on properly prepared surfaces. The K. P. R. is flowed onto the wafer which is rotated at a constant speed to produce the desired layer thickness. The K.P. R. layer is then entirely exposed except for those areas which are masked. Various plates can be made up to produce any desired mesa areas. The entire wafer is then placed in a developer which dissolves the K. P. R. in the exposed areas. The remaining K.P.R. is baked to harden it before etching.

The K.P. R. coating will stand a higher temperature than wax, thus eliminating melting during etching. In addition, the exposure process used in K.P. R. processing does not seem to result in shadowing as does the wax evaporation process. The K. P. R. technique will be explored further and compared to the wax evaporation procedure in order to decide on the best production process.

1.4 Packages

Investigations have continued on reducing package capacitance while limiting the minimum self-resonant frequency of the diode to 10 KMC. Many different package designs have been evaluated with respect to package capacitance. The results of these experiments are tabulated in Table (1). The most promising design to date is number 9 of Table 1 which has a package capacitance of .109 uuf. It is illustrated in Figure 3. The advantage of this configuration is that the contact wire is kept reasonably short while the package capacitance is significantly reduced. The capacitance is minimized by reducing the pedestal diameter and decreasing the diameter of the ceramic wall. In table (1) it can be seen that the ceramic wall thickness is quite significant in the package capacitance, while the dielectric constant of the ceramic is not as important a factor. Consequently, it is felt that the use of BeO (dielectric constant = 6) will not greatly reduce C_p in this particular design and thus alumina (dielectric constant = 9) will probably be used as the ceramic wall. More tests will be made to determine the magnitude of the capacitance differences using alumina and BeO.

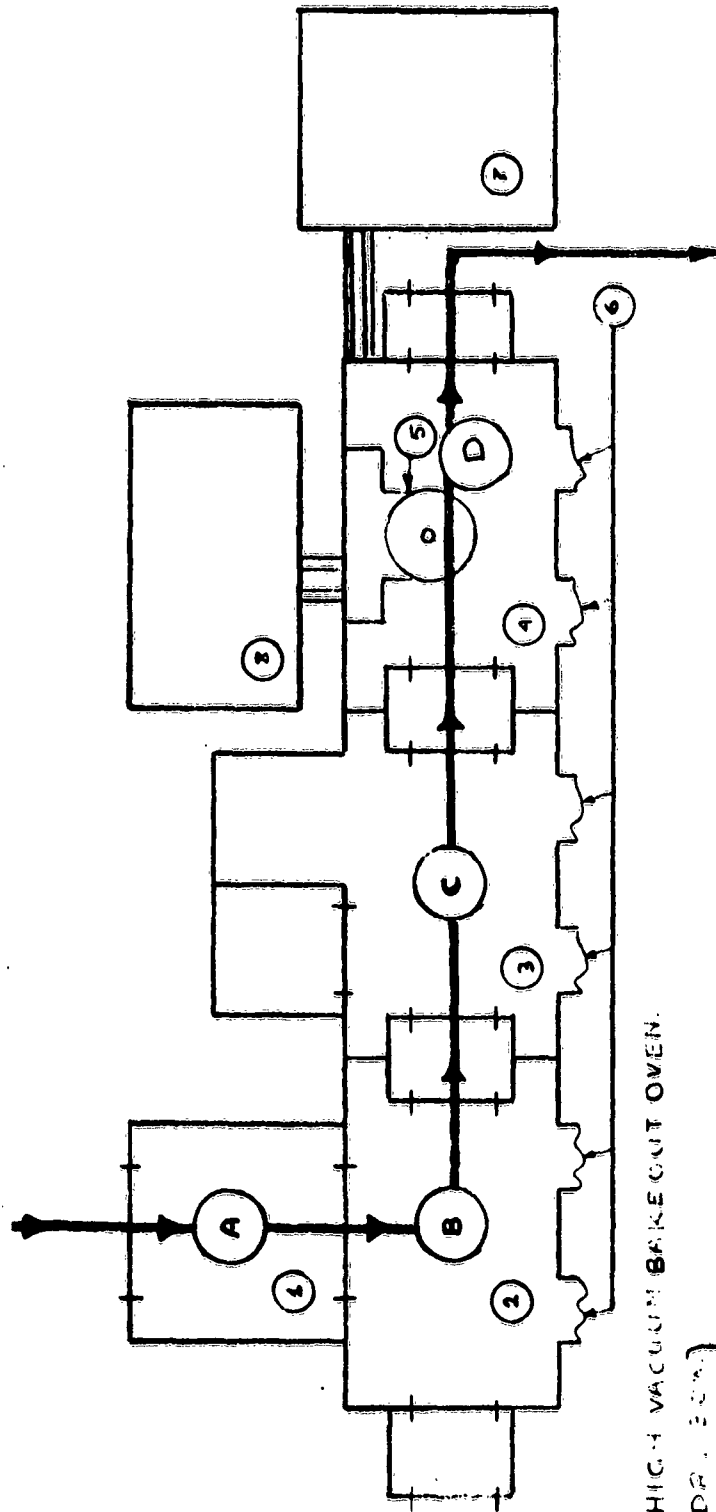
The equipment necessary for diode encapsulation in a controlled atmosphere is now operational. Prior to the final weld, the diodes are baked in a 200°C ambient which is evacuated to a pressure of 10^{-6} mm of mercury. From the bakeout, the units are moved directly into a -90°F dew point environment (see Figure (4) in which they are welded without any exposure to the outside atmosphere. The hermeticity of these welds has been helium leak checked to 10^{-9} mm successfully.

Equipment for measuring inductance in conjunction with self-resonant frequency is in the process of being set up. Measurements will be tabulated and presented in the next quarterly.

BY g.k. DATE
 CHKD. BY DATE

SUBJECT ENVIRONMENTAL CONTROLLED
 PACKAGING AREA FOR
 PACKAGING GA. A. VARIATORS.

SHEET NO. OF
 JOB NO.



1. HIGH VACUUM BAKE OUT OVEN.
 2. DRY BOX (STAINLESS STEEL)
 3. DRY BOX (STAINLESS STEEL)
 4. DRY BOX
 5. WELDING HEAD.
 6. POTS WITH FULL SLEEVE RUBBER CLOYS.
 7. MOLECULAR DRYER.
 8. POWER SUPPLY FOR WELDER.
- A. UNITS UNDER HIGH VACUUM BAKE OUT.
 B. UNITS COOL AT MINUS 90 DEGREE POINT.
 C. PRE-HEAT AREA.
 D. FINAL TOP CAP WELD.

Figure 4

BY g.k. DATE
 CHKD. BY DATE

SUBJECT G. A. VARIATION
PACKAGE

SHEET NO. OF
 JOB NO.

AVERAGE PACKAGE (Cp) VS. MATERIAL AND DIMENSIONS OF PACKAGE

No.	NUMBER OF SAMPLES	CERAMIC HEIGHT H	CERAMIC THICKNESS Y	HEIGHT OF PED. X	DIAM. OF PED. Z	CERAMIC MATERIAL	AVG. Cp IN MM.
1	10	.030	.015	.012	.040	ALUMINA	.328
2	5	.060	.015	.012	.040	ALUMINA	.147
3	5	.060	.015	.042	.040	ALUMINA	.193
4	4	.060	.018	.000	.040	BeO	.146
5	4	.060	.010	.000	.040	BeO	.108
6	3	.060	.018	.052	.020	BeO	.162
7	5	.060	.018	.042	.020	BeO	.155
8	3	.060	.018	.032	.020	BeO	.146
9	4	.060	.010	.032	.020	BeO	.109

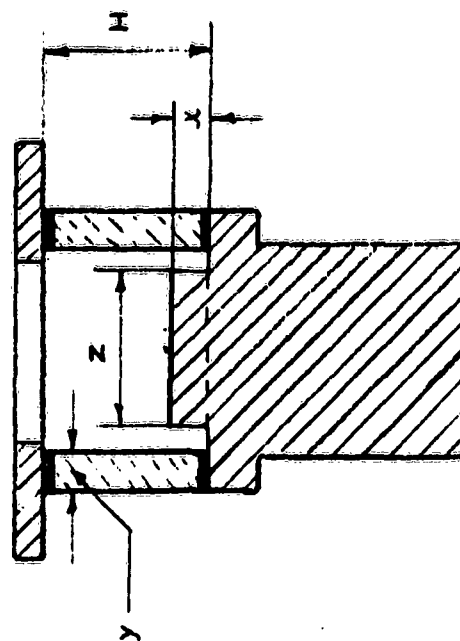


Table (1)
 - 10 -

1.5 Engineering Samples

Seventy-five engineering test samples were sent to the U.S. Army Electronic Research and Development Laboratory in Fort Monmouth, New Jersey according to schedule on November 30, 1962. These diodes were all fabricated from one wafer during one complete run. The varactors were hermetically sealed in a controlled environment with a dew point of -90°F . The median breakdown voltage was 15 volts, while the total capacitance ranged between 0.37 and 2.80 uuf. The cutoff frequency of these units varied between 28 KMC and 157 KMC.

The wafer used for this pilot run had a resistivity of .0035 ohms/cm, and a mobility of $2800\text{ cm}^2/\text{volt sec}$. It was diffused twice according to the procedure described earlier in this report.

The P-type contact consisted of an evaporated 1% Zn - 99% Au layer was alloyed at 500°C . The N-type contact was Au-Sn, which was evaporated and alloyed in forming gas. The latter procedure is described more fully in Quarterly Report #1. The mesas were masked by wax evaporation and etched in 18 HF + 1 HNO_3 until the desired junction capacitance values were reached. The dice were header mounted with 99% Au - 1% Sb preforms and an 0.7 mil Au wire was attached to the mesa by thermal compressing bonding.

The frequency cutoff measurements were made utilizing the matching method (references 1, 2) in which the ratio of $\frac{X_c}{R_s}$ is measured at a frequency where X_c and R are of the same order of magnitude. From the ratio of $\frac{X_c}{R_s} = Q$, and the measuring frequency, F_m , which is 9.375 KMC, the cutoff frequency is determined. The requirements for this type of measurement are an impedance measuring system and a holder for the varactors with appropriate tuners. The holder for the varactor is a

- modified HP detector mount HPX 485B with an E-H tuner between holder

and transmission line where impedance measurements are made. The diode impedance $Z_d = R_s - j X_c$ is transformed to a match in the uniform transmission line, at some bias $V_{bias} = V$. A change in bias voltage produces a corresponding change in the diode reactance X_c since C is a function of voltage; the series resistance remains essentially constant, at least for small changes in bias.

The measurement of total diode capacitance was made using a Boonton Electronic Capacitance Bridge, Model 75A-58. The test signal is 1 Mc with an amplitude of approximately 20 mv. D. C. bias is obtained from an Epsco precision voltage source model VRS611.

2.0 Conclusions

During the past quarter, 75 engineering sample diodes were manufactured and sent to the United States Army Electronic Research and Development Laboratories for evaluation.

Investigations have continued in order to evolve the procedures necessary for the high volume production of gallium arsenide varactors.

Capacitance measurements have been carried out on many new package designs. Several packages have evolved which will meet the 0.15 capacitance specification of SCS-128.

3.0 Program For Next Interval

1. Fabricate 75 engineering samples for delivery on January 31, 1963.
2. Continue studies in order to evolve a varactor package which will meet the SCS-128 specifications.
3. Continue the investigation of P-type contacts in order to find the optimum contact for high volume production.
4. Continue refining the diffusion process so as to make it more production oriented.

Note: A planning and scheduling chart breaking down the major tasks into five divisions is shown in Figure 5.

FIGURE 5

**SEMICONDUCTOR DIVISION, SYLVANIA ELECTRIC PRODUCTS INC.
PROJECT PERFORMANCE AND PLANNING SCHEDULE**

Contract No. DA-36-039-SC-86736
Order No. 19058-PP-62-81-81

% Completion Information
as of November 30, 1962

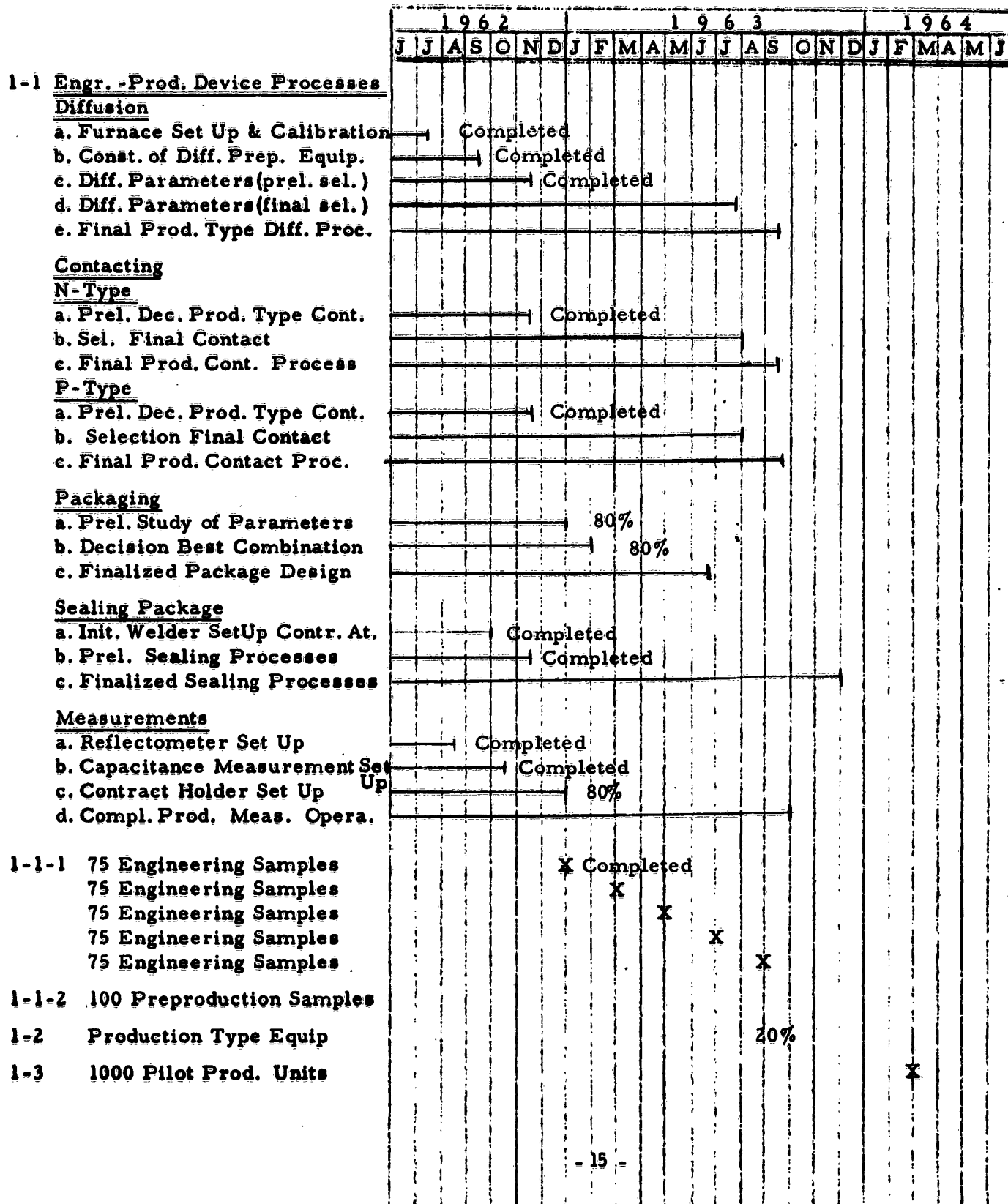


FIGURE 5 Cont'd.

**SEMICONDUCTOR DIVISION, SYLVANIA ELECTRIC PRODUCTS INC.
PROJECT PERFORMANCE AND PLANNING SCHEDULE**

		1 9 6 2					1 9 6 3					1 9 6 4														
		J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
1-4 Reports																										
1-4-1 Monthly																										
1-4-2 1 st Quarterly Report (draft)																										
	Distribution																									
2 nd Quarterly Report (draft)																										
	Distribution																									
3 rd Quarterly Report (draft)																										
	Distribution																									
4 th Quarterly Report (draft)																										
	Distribution																									
5 th Quarterly Report (draft)																										
	Distribution																									
6 th Quar terly Report(draft)																										
	Distribution																									
7 th Quarterly Report (draft)																										
	Distribution																									
1-4-3 Final Report - Step I (draft)																										
	Distribution																									
1-4-4 Bills of Material & Parts																										
2 General Report-Step II(draft)																										
	Distribution																									

4.0 Identification of Technical Personnel

Mr. G. Kokk joined the Semiconductor Division of Sylvania in 1957. Since that time Mr. Kokk has progressed from a Class A machinist to a Senior technician. He has acquired considerable experience in semiconductor technology through working in the germanium mesa transistor development area for the past three years. Recently Mr. Kokk was transferred to the Microwave Department where he is contributing to the gallium arsenide production engineering measure contract.

4.1 Man Hours of Work Performed

<u>Engineers</u>	<u>Second Quarter</u>	<u>6 Month Cumulative Total</u>
T. Baker	424	792
G. Bowne	69	117
G. Ching	81	86
F. Tausch	48	200
H. Ramsey	15	15
 <u>Technicians</u>		
W. Hyde	18	18
E. Juleff	232	408
D. Johnson	188	324
E. Penny	--	116
A. Marmiani	488	632
G. Kokk	384	384
F. Skalkos	72	72
R. Greene	1.5	1.5
 <u>Operators</u>		
Grade 5 Operators	47	81
TOTAL HOURS	2067.5	3246.5

4.2 Visits

15 October 1962 - Mr. George Hall, USAERDA visited Woburn to discuss contract progress. Pilot line set up was inspected and present production processes reviewed. He talked with Dr. Tausch regarding the epitaxial gallium arsenide material and examined the epitaxial and crystal growing furnaces.

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