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RADIO CORPORATION OF AMERICA

INTERIM DEVELOPMENT REPORT

FOR

RESEARCH AND DEVELOPMENT ON
HIGH CURRENT TUNNEL DIODES

This Report Covers the Period
1/1/63 to 3/31/63

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RADIO CORPORATION OF AMERICA
SEMICONDUCTOR AND MATERIALS DIVISION
SOMERVILLE, NEW JERSEY

NAVY DEPARTMENT BUREAU OF SHIPS ELECTRONICS DIVISIONS

CONTRACT: NOBSR-87540 PROJECT SERIAL NO.: SR-0080301 9350

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ABSTRACT

Gallium arsenide tunnel diodes with peak currents of up to 860 amperes and efficiencies greater than 60 per cent have been fabricated. Process improvements have reduced pellet cracking and allow current densities of as low as 100 amperes to be used while still maintaining good I_P/I_V ratios. These improvements will greatly reduce contacting problems.

The counterdopant dot alloying process has been found to provide very thin effective base wafer thicknesses, further reducing contacting problems, and allowing relatively thick wafers to be used.

It appears that the dependence of the I_P/I_V ratio on current density is more pronounced for germanium than for gallium arsenide. Current densities of about 3,000 amp/cm^2 are required for germanium, if an I_P/I_V ratio of 10/1 is to be obtained. This high current density places restrictions on the contact and base wafer thickness.

Packages for 100 - ampere and 300 - ampere tunnel diodes have been fabricated and are available.

The theoretical limit of efficiency for gallium arsenide tunnel diodes is about 70 per cent, while the practical limit for germanium tunnel diodes is about 60 per cent.

PART I

I. PURPOSE

The objective of the program is to investigate analytically and experimentally, the techniques required to fabricate high current tunnel diodes. Specifically, the proposed program will be to develop efficient tunnel diodes with peak currents of 100 amperes, 300 amperes or higher.

II. GENERAL FACTUAL DATA

A. Tunnel Diode Design

In the interim development report covering the period 10/1/62 to 12/31/62 the following equations giving diode efficiency and junction temperature rise were derived.

$$\eta_o = \frac{(1 - I_V/I_P)}{(1 + I_V/I_P)} \left\{ \frac{(V_V' - V_P') - (1 - I_V/I_P)(\rho_{CBH} + \rho_{CJW} + \rho\, t)\, J}{V_V' - V_P' + (1 + I_V/I_P)(\rho_{CBH} + \rho_{EJW} + \rho\, t)\, J} \right\} \tag{1}$$

$$\Delta T = \frac{1}{2K} \left\{ (V_P' + I_V/I_P\, V_V') + \left[1 + (I_V/I_P)^2\right] (\rho_{CBH} + \rho_{CJW} + \rho\, t) \right\} Jt \tag{2}$$

To maximize diode efficiency and minimize junction temperature rise for a given material, it is necessary for;

1) I_P/I_V to be large
2) J to be small
3) t to be small
4) ρ_{CBH} and ρ_{CJW} to be small

It is very easy to make J small by using materials with low doping densities. However, I_P/I_V must be maintained at a sufficiently large value at the low current densities.

Figure 1 shows the variations of I_P/I_V with current density for both gallium arsenide and germanium. Notice, that to obtain reasonable values of I_P/I_V with germanium (say 10 to 1) current densities as high as 3000 amp/cm^2 must be used, while with gallium arsenide, ratios of greater than 10/1 are obtained at current densities as low as 100 amp/cm^2. The high current density required to achieve reasonable I_P/I_V ratio's in germanium places considerable emphasis on reducing the base wafer thickness, t, and the contact resistance. For gallium arsenide, however, these requirements

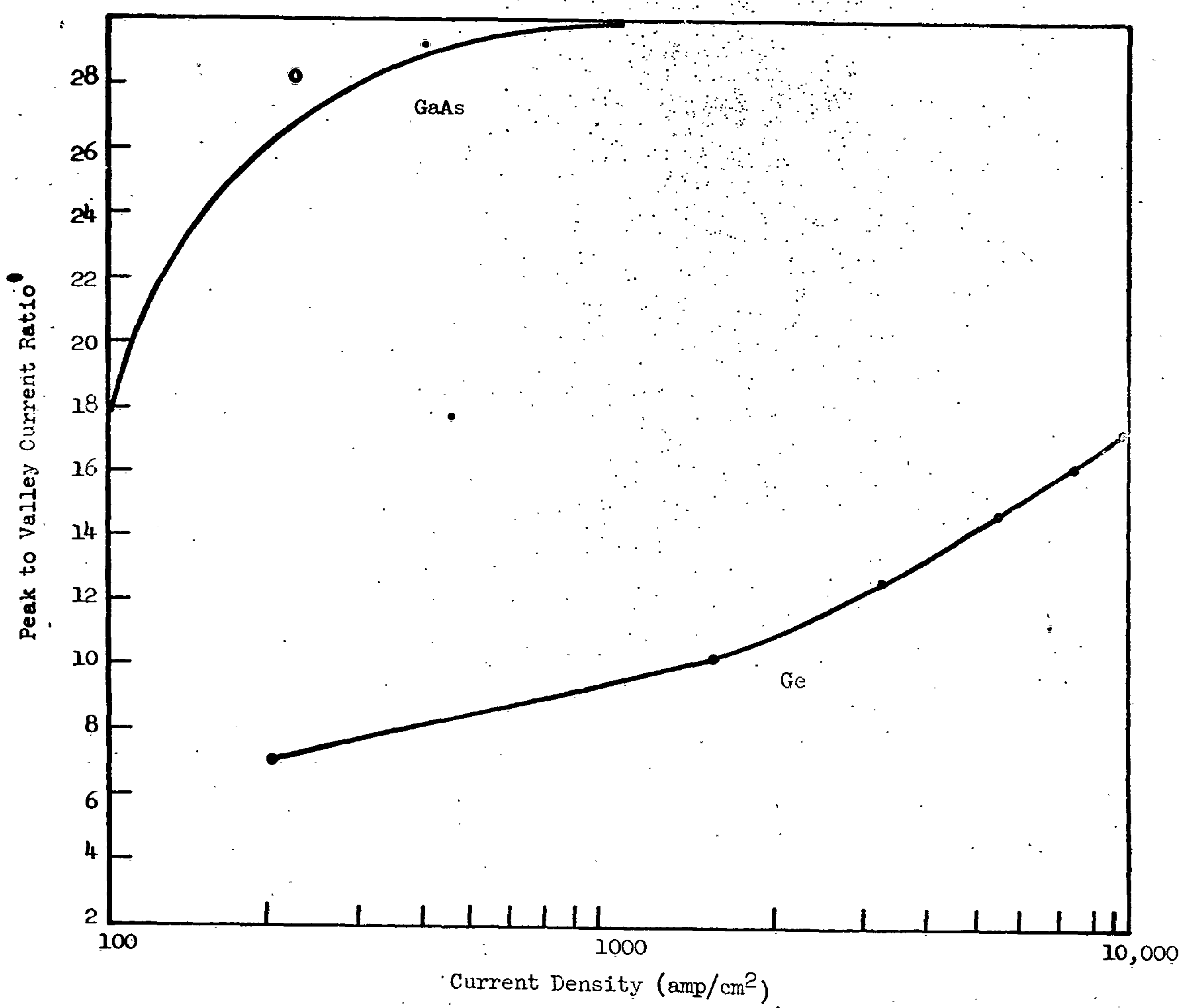


FIGURE 1 VARIATION OF PEAK TO VALLEY CURRENT RATIO OF Ge AND GaAs WITH CURRENT DENSITY

are much less stringent.

A further consideration is that with gallium arsenide, very thin effective thicknesses may be obtained. By careful selection of the alloying cycle and initial base wafer thickness, it is possible to form the p-n junction very close to the bottom of the wafer, since the counter-dopant dot alloys into the wafer. This provides effective base wafer thickness of less than one mil, and with careful control, may be made as small as 0.1 mil. These effects, coupled with the use of very low current densities, enable high efficiencies to be easily obtained.

In the case of germanium, however, the use of the solution regrowth process does not, in general, provide this reduction in base wafer thickness. Although, in this process part of the surface of the germanium is dissolved, the amount of dissolution is small, and the n-type layer is regrown on the surface. The amount of germanium dissolved may be increased considerably, but this would result in a very thin wafer, with consequent handling problems. Thus, the alloying process has the advantage in providing thin effective base thickness from relatively thick (6-8 mil) base wafers.

From the data presented in Section III, C, it appears that the upper limit of efficiency for gallium arsenide is 70 per cent, and that a practical upper limit for germanium is about 60 per cent.

B. Man Hours Spent During the Past Quarter

R. Minton	Engineer	51	Hours
P. Gardner	Engineer	132	Hours
A. Roswell	Engineer	16	Hours
E. Braniecki	Technician	159	Hours
P. Britt	Technician	37	Hours
E. Strouse	Technician	124-1/2	Hours
A. Herd	Technician	50	Hours

III. DETAILED FACTUAL DATA

A. Packaging

During this period, the new caps and packages described in the previous report were made available. These packages are now being used to fabricate devices.

Figure 2 shows the design of the modified cap for the DO-8 header, to be used for the 100-ampere peak current diodes, and Figure 3 shows the package to be used for the 300-ampere peak current diodes.

A pair of 100-ampere peak current gallium arsenide tunnel diodes, mounted on transistor type heat sinks, with a thermal resistance rating of 2 °C/Watt, were operated in a push-pull inverter circuit. After one hour of operation, the diode case temperature had increased by about 10°C, indicating adequate thermal design.

B. Germanium Tunnel Diodes

As reported in the last quarterly report, a series of low current diodes had been fabricated using a new solution regrowth melt which gave I_P/I_V ratios of 10/1 at low substrate carrier concentration. Higher current units were fabricated to further test the result from the new melt. Table I lists the typical electrical parameters obtained for 10- and 20-ampere peak current units.

TABLE I

ELECTRICAL CHARACTERISTICS OF 10-AND 20-AMPERE GERMANIUM TUNNEL DIODES
MELT NO. 3

I_P(amp)	I_V(amp)	V_P(mv)	V_V(mv)	η_o(%)
10	0.9	90	340	49
20	2.0	90	340	47.5

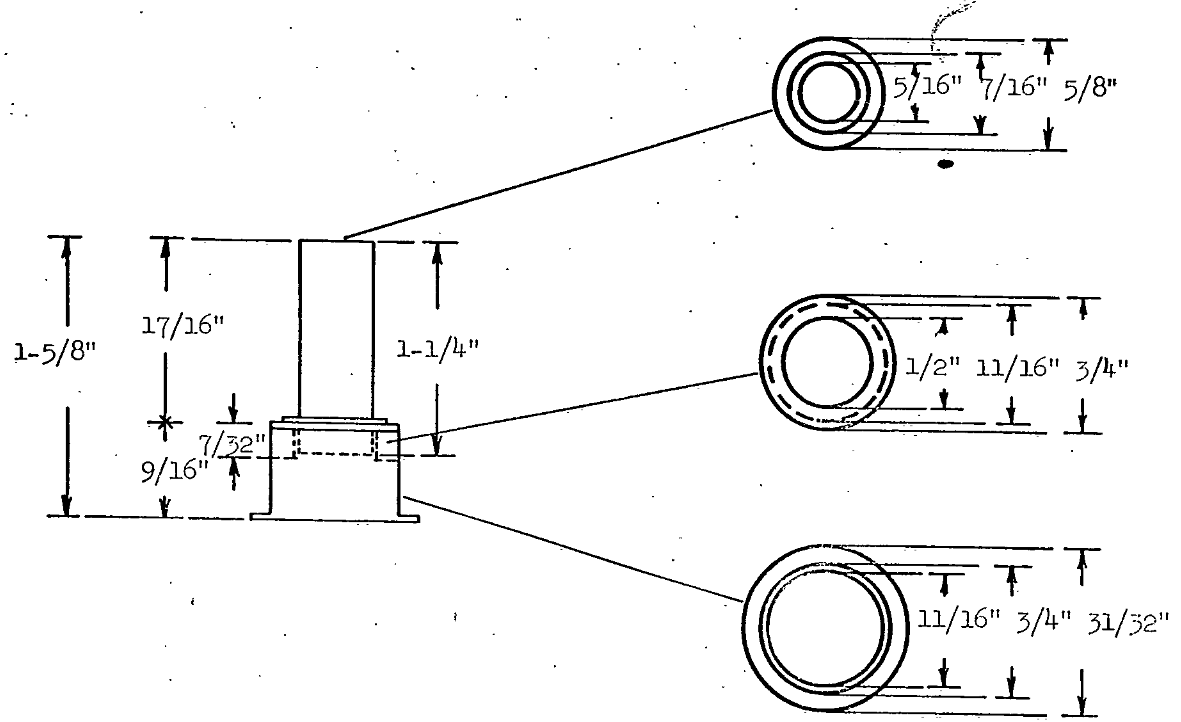


FIGURE 2 MODIFIED CAP FOR DO-8 100 -AMPERE TUNNEL DIODE PACKAGE

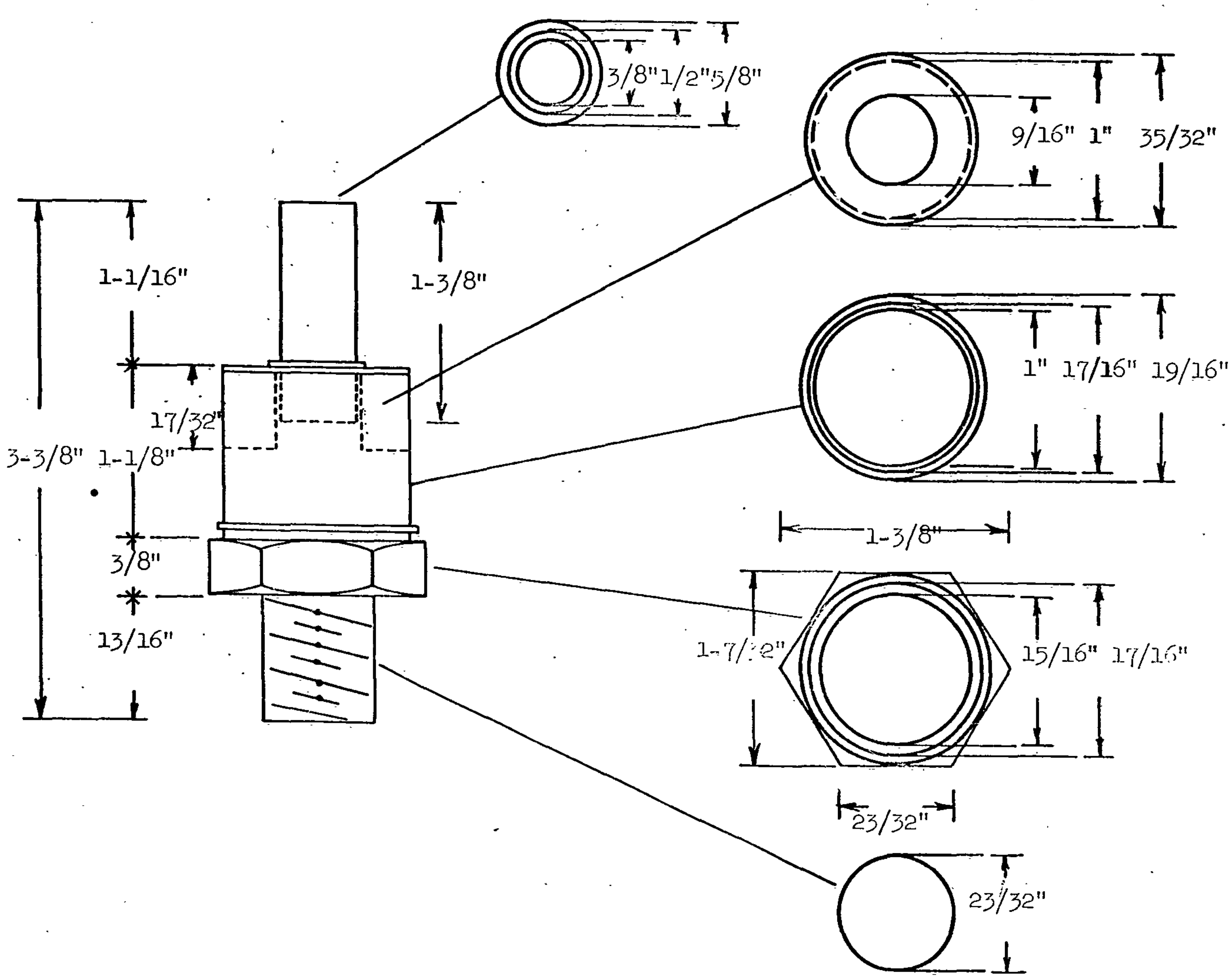


FIGURE 3 300-AMPERE TUNNEL DIODE PACKAGE

The high peak voltages were due to the use of a 7-mil thick wafer, and the somewhat higher current densities for a given substrate carrier concentration produced by the new melt. Again using 7-mil thick wafers, similar results were obtained from the normal melt with higher substrate carrier concentrations.

All successful attempts to produce diodes with good I_P/I_V ratios, at low substrate carrier concentrations, have produced higher current densities, by increasing the n-type doping. It appears that it will be extremely difficult to obtain a relationship between the I_P/I_V ratio and current density which differs significantly from the results presented in Figure 1.

During this period, the solution regrowth process produced wafers with very thin regrown layers, poor I_P/I_V ratios, and low current densities. Investigation showed that the problems were associated with the use of a new melt which was made up to replace the original depleted melt. Further investigation showed that one of the materials used in making the melt was contaminated with zinc, which is a p-type dopant. This counterdoping apparently reduced the n-type carrier concentration, leading to the low current density and poor I_P/I_V ratios. Also, the germanium crush in the new melt was larger than that previously used, and did not go into solution during the subsequent regrowth process. This reduced the regrowth, resulting in the thin n-type layers. To solve this problem, a new melt was made from uncontaminated materials and the original germanium crush size. Test wafers from this melt gave normal results.

As discussed in Section II-A, it is possible to achieve small effective base wafer thicknesses by alloying a counterdopant dot into the base wafer material. This allows the use of relatively thick wafers, which considerably reduces handling problems. This technique was tried, using p-type base wafers and alloying an arsenic doped tin dot into the wafer. Although this is a standard technique for making milliampere tunnel diodes, the high current diodes fabricated by this process have shown poor I_P/I_V ratios, and consequently poor efficiency. However, further attempts will be made in this direction.

Work has also continued on improving the contacts on germanium tunnel diodes. It has been found that an indium-gallium-zinc alloy provides an excellent low resistance contact on p-type germanium. This contact will be evaluated on wafers regrown using the new melt.

C. Gallium Arsenide Tunnel Diodes

It has been found that gallium arsenide tunnel diodes can be fabricated with current densities as low as 100 amp/cm^2 while still maintaining very good I_P/I_V ratios, and that very thin effective base wafer thickness may be achieved by a suitable selection of alloying conditions and base wafer thickness.

These results have considerably reduced the contacting problems, and allow high efficiency diodes to be easily fabricated. Table II lists the parameters of some typical diodes fabricated under these conditions.

TABLE II

ELECTRICAL PARAMETERS OF GaAs TUNNEL DIODES

I_P (amp)	I_V (amp)	V_P (mv)	V_V (mv)	η_o (%)
25	1.0	116	700	65.8
22.8	0.9	114	690	66.2
29	1.1	116	690	66.0
19.6	1.2	108	680	63.8
19.4	1.3	104	650	63.2
100	4.0	100	660	67.0
102	5.0	121	640	61.3
270	12.0	126	620	60.5
310	12.0	110	660	65.0
860	48.0	110	620	62.0

The results shown in Table I indicate that gallium arsenide tunnel diodes may be fabricated with efficiencies greater than 60 per cent at current levels of 900 amperes.

It was noticed that there was some cracking of the base wafer during the fabrication processes. Investigation showed that the majority of the cracking occurred during the mounting process, with some occurring at the alloying step. It was also noticed that wafers with high lineage were more susceptible to cracks at both process points. By rejecting wafers with high lineage, and by avoiding rapid temperature variations, the cracking problem was reduced considerably.

Further, the wafers are now highly polished, which shows up many wafer faults which might not have otherwise been noticed. Although laborious, this polishing step also improves the alloying process, giving more uniform alloying and providing more consistant results.

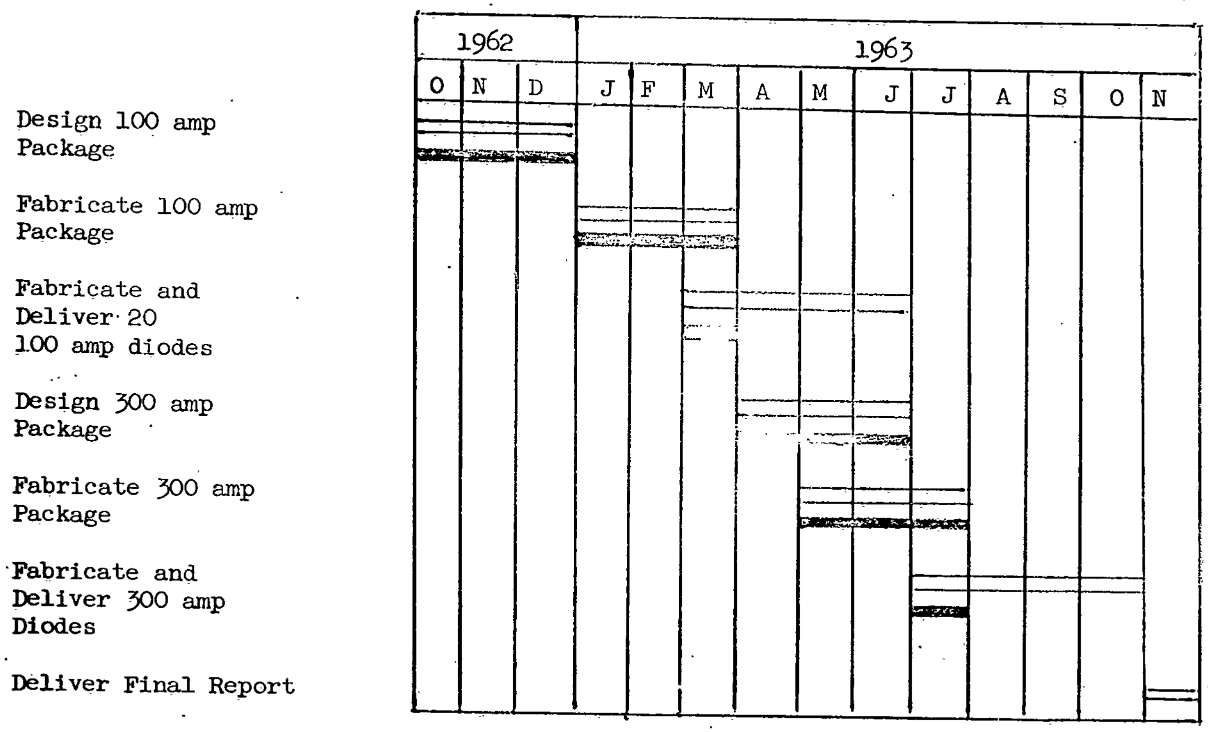
D. Project Performance Schedule

RCA SEMICONDUCTOR AND MATERIALS DIVISION
PROJECT PERFORMANCE AND SCHEDULE

Project No. SR-0080301 Task No. 9350

Contract No. NOBSR-87540

Report Date: April 30, 1963
Period Covered: 1/1/63 to 3/31/63



LEGEND: Schedule of Projected Operation

Work Performed

IV. CONCLUSIONS

Gallium arsenide tunnel diodes with peak currents of up to 860 amperes at efficiencies greater than 60 per cent have been fabricated, indicating a reproducible process and confirming the design equations derived in the previous report.

The dependence of the I_P/I_V ratio on current density is much more pronounced in the case of germanium than for gallium arsenide, and shows that gallium arsenide diodes may be fabricated with good I_P/I_V ratios using current densities 30 times lower than that of germanium.

The alloying process has been found to provide thin effective base wafer thickness from relatively thick wafers, thereby, providing an advantage over the solution regrowth process. However, as yet equivalent efficiencies have not been obtained with this process for germanium, due to poor I_P/I_V ratios.

Packages for 100- and 300- ampere peak current tunnel diodes have been fabricated and are available.

PART II

I. PROGRAM FOR NEXT QUARTER

The work during the next quarter will be directed toward:

1) Fabricating 100-ampere gallium arsenide tunnel diodes with high efficiencies for delivery to the Navy.

2) Fabricating 100-ampere germanium tunnel diodes with high efficiencies for delivery to the Navy.

3) Further increasing the efficiency of germanium tunnel diodes.