
Evaluation of Dynamic and Static Electrical Characteristics for the DY8 & YI8 process Gallium diodes in comparison to the DI8 process Boron diodes

by

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Abstract:

A Rectifier is an electrical device, comprising one or more semiconductor devices arranged for converting alternating current to direct current by blocking the negative or positive portion of the waveform. An Irving-based semiconductor company that sponsored the research manufactures 15A rms to 25A rms rectifiers with voltages rated from 200V to 1000V. These rectifiers are packaged in electrically-isolated TO-220 package and fabricated with a process called the DI8-Process. After years of research the company decided to fabricate rectifier chips with Gallium as p-type material to be added to silicon instead of the traditionally used Boron in their rectifiers. They created two different types of rectifiers with slight manufacturing differences using Gallium as the base referred to as DY8 & YI8 processes.

The purpose of this study was to evaluate dynamic and static electrical characteristics of rectifier chips fabricated with (a) DY8 process and (b) YI8 process and compare them with the existing DI8 process rectifiers. These new rectifiers were tested to compare their performance to meet or exceed requirements of lower forward voltages, leakage currents, reverse recovery time, and greater sustainability at higher temperatures compared to diodes manufactured using boron as base (DI8 process diodes) for similar input variables.

Keywords: semiconductor, characteristics, Gallium diodes, Boron diodes, statistical analysis

Introduction

The Department of Engineering Technology at the University of North Texas' College of Engineering is ABET accredited and offers undergraduate and graduate programs in Engineering Technology. One of our graduate options is an M.S.E.T/MBA dual degree option, wherein a student gets a graduate degree in either electronics or mechanical engineering technology with a MBA from the business school. The duration is typically 3 – 3.5 years for this option. This paper presents an industry sponsored project undertaken by a graduate student for her dual degree option.

The project was sponsored by an Irving-based semiconductor company. The company is one of the leading manufacturers of network protection semiconductor devices, in the nation. As we are aware, a rectifier is an electrical device, comprising one or more semiconductor devices (such as

diodes) arranged for converting alternating current (AC) to direct current (DC) by blocking the negative or positive portion of the waveform [1]. A diode is a p-n junction formed by judicious introduction of dopants or impurities in intrinsically pure semiconductor material [2, 3]. This is accomplished using a series of complex procedures that are beyond the scope of this paper. When only one diode is used to rectify AC, the difference between the term diode and rectifier is merely one of usage. Almost all rectifiers comprise a number of diodes in a specific arrangement for more efficiently converting AC to DC than is possible with just a single diode.

The sponsoring company manufactures 15A rms to 25A rms rectifiers with voltages rated from 200V to 1000V [company data sheets]. These rectifiers are packaged in an electrically-isolated TO-220 package and may be used in common anode or common cathode circuits using only one part type, thereby simplifying stock requirements. These rectifiers are fabricated with an Anti-Base process, called the DI8-Process.

Purpose of the Study

After years of research, the R&D group at the company decided to fabricate rectifier chips using Gallium as p-type material to be added to silicon (n-type) instead of the traditionally used Boron in their rectifiers. Gallium is a costlier element than boron, but the aim was to research and explore if similar results can be obtained for similar input specifications with a much smaller die in comparison to boron based diodes. The rectifiers manufactured using Gallium as the base is referred to as DY8 and YI8 Anti-Base processes. The process names DY8, YI8, or DI8 do not conform to any general industry standards, rather, a nomenclature that the company uses to distinguish between its various test processes.

The purpose of this study was to evaluate dynamic and static electrical characteristics of rectifier chips fabricated with DY8 Anti-Base process and YI8 Anti-Base processes and compare them with the existing DI8 process rectifiers.

Research Questions

The research questions addressed in this study are stated below for hypotheses testing. Do diodes fabricated using the DY8 process meet or exceed the requirements of lower forward voltages and leakage currents compared to diodes fabricated using the DI8 process for similar input variables?

Null Hypothesis:

Anti-base Gallium diodes DY8 do not meet or exceed requirements in comparison to Boron based diodes.

Alternative Hypothesis:

Anti-base Gallium diodes DY8 do meet or exceed requirements in comparison to Boron based diodes.

Do diodes fabricated using the YI8 process meet or exceed the requirements of lower forward voltages and leakage currents compared to diodes fabricated using the DI8 process?

Null Hypothesis:

Anti-base Gallium diodes Y18 do not meet or exceed requirements in comparison to Boron based diodes.

Alternative Hypothesis:

Anti-base Gallium diodes Y18 do meet or exceed requirements in comparison to Boron based diodes.

In order to answer the research questions with some clarity, we need to understand the rectifier fabrication process and its various entities.

Background: Rectifier Fabrication Process

Rectifiers fabricated at the company, follow generic processes [1], which can be categorized as follows:

- i. Silicon wafer (substrate) preparation.* The starting material for crystal growth is highly purified (99.99999) polycrystalline silicon. The Czochralski crystal growth process is the most often used for producing crystal silicon ingots. The polycrystalline silicon together with an appropriate amount of dopant is put in a quartz crucible and is then placed in a furnace. The material is heated to a temperature in excess of 1420 °C. The ingot is then sliced using a stainless steel blade with industrial diamonds embedded into the inner diameter cutting edge. This produces circular wafers or slices with a very rough surface due to surface polishing. A number of polishing steps are required to produce a flat surface on these wafers. These silicon wafers will contain several hundred rectangular chips, each one containing a complete integrated circuit. After all the fabrication processes are complete, these wafers are sawed into 100 to 8000 rectangular chips having side of 10 to 1 mm.
- ii. Epitaxial Growth:* Epitaxy is described as arranging atoms in single crystal fashion upon a single crystal substrate, so that the resulting layer is an extension of the substrate crystal structure. The basic chemical reaction used for the epitaxial growth of pure silicon is the hydrogen reduction of silicon tetrachloride. The process is carried out in a reaction chamber consisting of a long cylindrical quartz tube encircled by a RF induction coil. The silicon wafers are placed on a rectangular graphite rod called a boat. This boat is then placed in the reaction chamber where the graphite is heated inductively to a temperature 1200 °C. The various gases required for the growth of desired Epitaxial layers are introduced into the system through a control console.
- iii. Oxidation:* Silicon dioxide (SiO₂) has the property of preventing the diffusion of almost all impurities through it. It serves two very important purposes. SiO₂ is an extremely hard protective coating and is unaffected by almost all reagents except hydrofluoric acid. Thus it stands against any contamination. Silicon wafers are stacked up in a quartz boat and then inserted into a quartz furnace tube. The Si-wafers

- are raised to a high temperature in the range of 950 to 1150 °C and at the same time, exposed to a gas containing O₂. This oxidation process is called thermal oxidation because high temperature is used to grow the oxide layer. The thickness of the film is governed by time, temperature and the moisture content. The thickness of the oxide layer is usually in the order of 0.02 to 2 μm.
- iv. *Photolithography*: Photolithography involves two processes, namely: making of a photographic mask and photo etching. The making of a photographic mask involves the preparation of the initial art work and secondly its reduction. The initial artwork or layout of an IC is normally done at a scale several hundred times larger than the final dimensions of the finished monolithic circuit. The initial layout is then decomposed into several mask layers, each corresponding to a process step in the fabrication schedule. Photo-etching is used for the removal of SiO₂ from desired regions so that impurities can be diffused. The etching process used is a dry-etching process called plasma etching. A major advantage of the dry etching process is that it is possible to achieve smaller line openings (< 1 μm) compared to wet process.
- v. *Diffusion*: Another important process in the fabrication of monolithic ICs is the diffusion of impurities in the silicon chip. This uses a high temperature furnace having a flat profile over a useful length (about 20" length). A quartz boat containing about 20 cleaned wafers is pushed into the hot zone with temperature maintained at about a 1000 °C. Impurities to be diffused are rarely used in their elemental forms. Normally, compounds such as Boron oxide or Boron chloride are used for Boron. A carrier gas, such as dry oxygen or nitrogen is normally used for sweeping the impurity to the high temperature zone. The depth of diffusion depends upon the time of diffusion which normally extends to 2 hours. The diffusion of impurities takes place both laterally as well as vertically.
- vi. *Ion Implantation*: Ion implantation is the other technique used to introduce impurities into a silicon wafer. In this process, silicon wafers are placed in a vacuum chamber and are scanned by a beam of high-energy dopant ions (boron for p-type and phosphorous for n-type). These ions are accelerated by energies between 20 kV to 250 kV. As the ions strike the silicon wafers, they penetrate some small distance into the wafer. The depth of penetration of any particular type of ion increases with increasing accelerating voltage. Ion implantation technique has two important advantages. It is performed at low temperatures. Therefore, previously diffused regions have a lesser tendency for lateral spreading. In diffusion process, temperature has to be controlled over a large area inside the oven, whereas in ion implantation technique, accelerating potential and the beam current are electrically controlled from outside.
- vii. *Isolation Technique*: Since a number of components are fabricated on the same IC chip, it becomes necessary to provide electrical isolation between different components and interconnections. One of the commonly used techniques is the *p-n Junction Isolation*. In this isolation technique, p+ type impurities are selectively diffused into the n-type epitaxial layer so as to reach p-type substrate. This produces islands surrounded by p-type moats. If the p-type substrate material is held at the

- most negative potential in the circuit, the diodes will be reverse biased providing electric isolation between these islands. The concentration of the acceptor atoms in the region between isolated islands is usually kept much higher (p+) than the p-type substrate. This prevents the depletion of the reverse biased diode from penetrating more into p+ region and possibly connecting the isolation islands. There is, however, one undesirable by-product of this isolation process. It is the presence of a transition capacitance at the isolating p-n junctions, resulting in an inevitable capacitor coupling between the components and the substrate. These parasitic capacitances limit the performance of the circuit at high frequencies. But being economical, this technique is commonly used.
- viii. *Metallization:* The purpose of this process is to produce a thin metal film layer that will serve to make interconnections of the various components on the chip. Aluminum is used for metallization as it offers several advantages: It is relatively a good conductor; it is easy to deposit aluminum films using vacuum deposition. Aluminum makes good mechanical bonds with silicon and also forms low resistance, no-rectifying (i.e. ohmic) contact with p-type silicon and the heavily doped n-type silicon. After the thin metallization is done, the film is patterned to produce the required interconnections and bonding pad configuration. This is done by photolithographic process and aluminum is etched away from unwanted places by using etchants like phosphoric acid ($H_3 PO_4$).
- ix. *Assembly processing and packaging:* Each of the wafer processed contains several hundred chips, each being a complete circuit. These chips are separated and individually packed using a method called scribing and cleaving used for separation makes use of a diamond tipped tool to cut the lines into the surface of the wafer along the rectangular grid separating the individual chips. Thus the wafer is fractured along the scribe lines and the individual chips are physically separated. Each chip is then mounted on a ceramic wafer and attached to a suitable package [1].

The main differences during the manufacturing of DI8 rectifiers and DY8 & YI8 rectifiers are the fabrication stages of Epitaxial Growth, Oxidation, and Diffusion. The *Epitaxial Growth* process of fabrication for the DI8 rectifiers has Boron diffused on both sides of the wafer, whereas DY8 & YI8 rectifiers have Gallium diffused on the wafer. Both the Boron and Gallium-based (Ga-based) diodes start with N-Type silicon as the base wafer. *Oxidation process* of Boron-based (B-based) rectifiers involves diffusion of boron for 6-hours @ 1275 ° C, and then a Gallium deposition for 18 hours @ 1200 ° C. On the other-hand, Gallium-based rectifiers require that gallium is both diffused and deposited simultaneously after the oxidation process.

Procedure

Over the course of this study, experiments were conducted on the Ga-based rectifiers to test if they pass all requirements and then compare their performance to B-based rectifiers. No tests were conducted on B-based diodes, as data was already available for these. All experiments were conducted using standard procedures followed by the company. Since the company already manufactures and sells boron based diodes, tests run on gallium based diodes were actual comparisons for the same input specifications and similar die sizes.

Experiments Conducted:

1) Parametric Evaluation (V_F and I_R): When a small voltage is applied to the diode in the forward direction, current flows easily. Because the diode has a certain amount of resistance, the voltage will drop slightly as current flows through the diode. A typical diode causes a voltage drop of about 0.6 to 1V (V_F) (In the case of silicon diode, almost 0.6V). This voltage drop needs to be taken into consideration in a circuit which uses many diodes in series. Also, the amount of current passing through the diodes must be considered. When voltage is applied in the reverse direction through a diode, the diode will have great resistance to current flow. Different diodes have different characteristics when reverse-biased. The current that will flow through a diode biased in the reverse direction will vary from several mA to just μA , which is very small. The limiting voltages and currents permissible must be considered on a case by case basis. For example, when using diodes for rectification, part of the time they will be required to withstand a reverse voltage. If the diodes are not chosen carefully, they will break down [4]. Since a particular current-rating will not be known for these devices, the V_F will be measured at several current levels between 5A and 50A in order to determine the V_F vs. I_R characteristic. Single Half-Cycle Surge Capability (IFSM) is defined as the maximum forward single cycle AC surge current allowed for a specific duration. These devices have a high electrical surge capability to help protect against transient faults and high off-state impedance, rendering them virtually transparent during normal system operation [5]. Five samples from each group were surged in 25A increments (starting - 100A, this value was chosen after reviewing previous work and data sheets) until failure. After testing, surge resolution and sample-size were studied and if considered insufficient, an additional 5 samples from each group were to be surged in 10A increments (starting - 150A).

2) Reverse-Recovery Time (t_{rr}): Ideally, a diode shows the following characteristics: (a) a perfect conductor when it is forward biased, (b) a perfect insulator when reverse biased; and (c) the transition from conductor to insulator is instantaneous upon a forward bias/reverse bias switch. Practical diodes don't display these ideal characteristics. At the switch time, the current reverses and stays at a constant level for a period of time called the storage time, t_s [6]. During this time, the diode acts essentially as a short circuit. Then the current decreases to the reverse leakage current value. This latter time is called the transition time. The sum of the storage and transition times is the reverse recovery time. The reason for this behavior is that, when p-n junction is forward biased, a large number of electrons are injected into the p-material and a large number of holes are injected into the n-material of the p-n junction. When the diode is then reverse-biased, these stored minority carriers must return to the opposite material. The time it takes for the electrons to move from the p-material back to the n-material and the holes to move from the n-material to the p-material is the storage time, and is determined by the geometry of the p-n junction. Once the migration is complete, electrons diffuse to, and recombine at the cathode until there are no more of the original stored carriers left. This time is the transition time, and is determined by the geometry and doping levels of p- and n-materials [4]. Five samples from each group were evaluated using the following test conditions [7]: $I_{FM} = 25A$ (1ms sinusoidal pulse); $di/dt = -0.065A/s$; $V_{RM} = 12V$.

3) Average Power Dissipation (PD): This is the value of gate power, which may be dissipated between the gate and main terminal 1 (or cathode) average over a full cycle. It could be defined as the dispersion of the heat generated from a film circuit when a current flows through it [8].

The measurements of forward voltages and currents collected would assist in generating 60Hz average power dissipation curves for each of the chip process.

4) High-Temperature AC blocking: In this test, the air surrounding a test specimen is raised or lowered to pre-determined levels. The purpose is to observe the effect of the temperature extremes on the equipment, which may be operational. Temperature extremes and rapid temperature transitions are also used to purposely induce failures to determine weak points or latent defects. The Device Under Test (DUT) is immersed into a portable oven and a temperature sensor inserted into an opening, as shown in Figure 1. The DUT is also interfaced with a curve tracer such that when the temperature inside the portable oven increases to the desired value while the device is still in the oven, it is tested for failures. Forty devices from each 150Y18 and 150DY8 were subjected to AC blocking with the following conditions: V_{RM} (peak) = 800 VAC and temperature, $T = 125^\circ \text{C}$. After tests were completed, data containing readings and fluctuations were automatically transferred to the computer every hour for easy monitoring. Heat sinks were attached to each device in order to prevent power generated by the current-leakage from further raising the junction temperature.



Figure 1: The DUT interfaced with a curve tracer for performance evaluation.

Results:

Parametric Evaluation (V_F and I_R): The primary static parameter requiring evaluation is forward voltage V_F . Since a particular current-rating was not known for these devices, the V_F was measured at several current levels between 4 A and 50 A in order to determine the V_F vs I_F characteristic. The company publishes values of forward voltages in their catalog to meet industry standards for the particular current levels mentioned above. Five samples of each chip size were selected randomly and forward voltages measured by varying current levels. The average of the voltages was also calculated to assist in generating the V_F vs I_F characteristic graph. The averages from all the chip sizes were organized to enable the generation of the characteristic graph. The graph is shown in Figure 2. All 50 pieces from each sample were evaluated once again for forward voltages at varying current levels from 250 mA to 50 A. These evaluations were conducted to compare performances of all samples on a percentile basis. The minimum, 25th, 50th, 75th and the maximum values for samples pertaining to each current were extracted from the data. This data was used to create graphs highlighting the performance of both

boron and gallium based diodes. The forward voltage distributions were measured for three dimensions of the anti-base rectifiers – 0.125", 0.135" and 0.150". The data was then compared to that from existing DI8 devices. Figure 3 is a representative graph that indicates the V_F range for the DI8 devices. Since the DI8 devices were taken from sample inventory, they may not represent the entire voltage range of V_F that is characteristic of the current products. In general, devices with the YI8 chips were found to possess lower V_F than the DY8, and thus stand out to be better performers. When a reverse voltage is applied to a PN junction, the holes in the p-region are attracted to the anode terminal and electrons in the n-region are attracted to the cathode terminal creating a region where there is little current. This depletion region is essentially devoid of carriers and behaves as a dielectric. The depletion region increases as reverse voltage across it increases; also, since capacitance varies inversely as dielectric thickness, the junction capacitance will decrease as the voltage across the PN junction increases. Thus, by varying the reverse voltage across a PN junction, the capacitance of the junction can be varied. The relationship between capacitance and reverse voltage is non-linear. The voltage-capacitance curves for all samples used, followed the expected trend. In the reverse direction, there is a small leakage current (I_R) up until the reverse breakdown voltage is reached. This leakage is undesirable, obviously the lower the better and is specified at a voltage less than breakdown. Reverse leakage current was measured for all sample devices and compared as shown in Figure 4. I_R was also characterized with respect to temperature, up to 125 °C; starting from 25 °C. Data was collected for 5 devices from each category of DY8 and YI8 as indicated in Figure 5. It was found that devices with the DY8 chips possessed higher leakage current than the YI8. The current-leakage relationship for all devices followed the expected trend of increasing with higher temperatures.

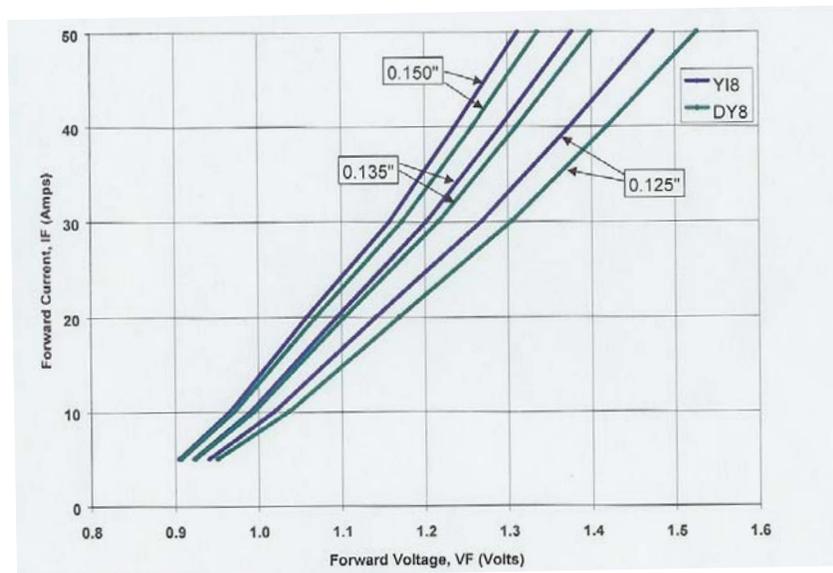


Figure 2: Forward current vs forward voltage characteristic for rectifiers.

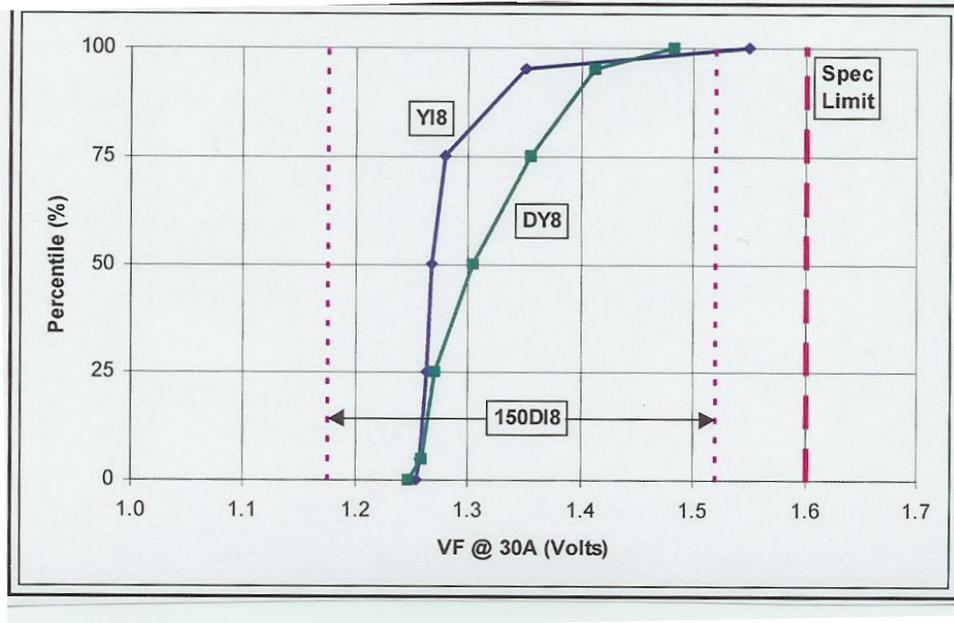


Figure 3: Forward voltage range for DI8 devices.

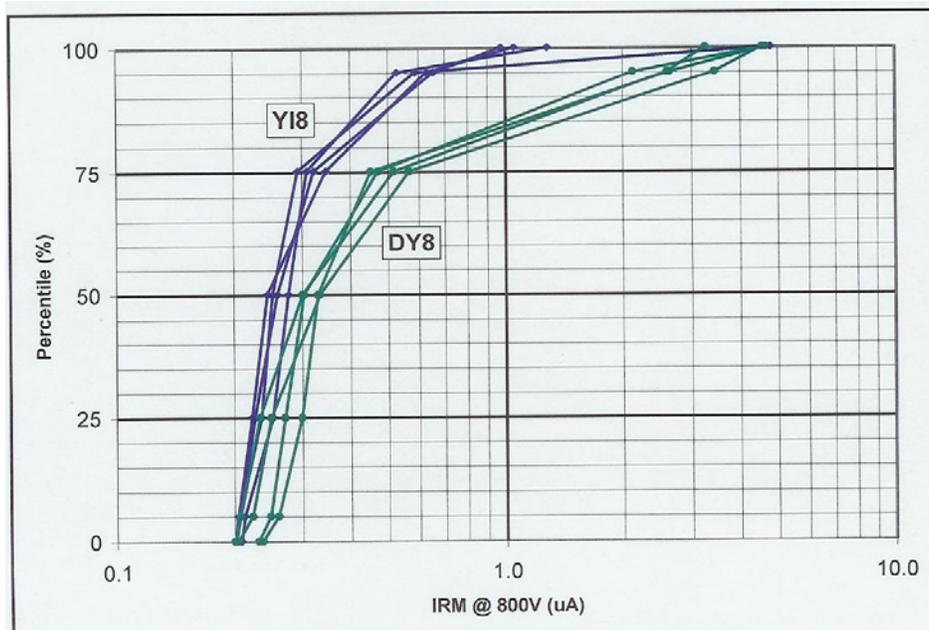


Figure 4: Reverse leakage current for all devices.

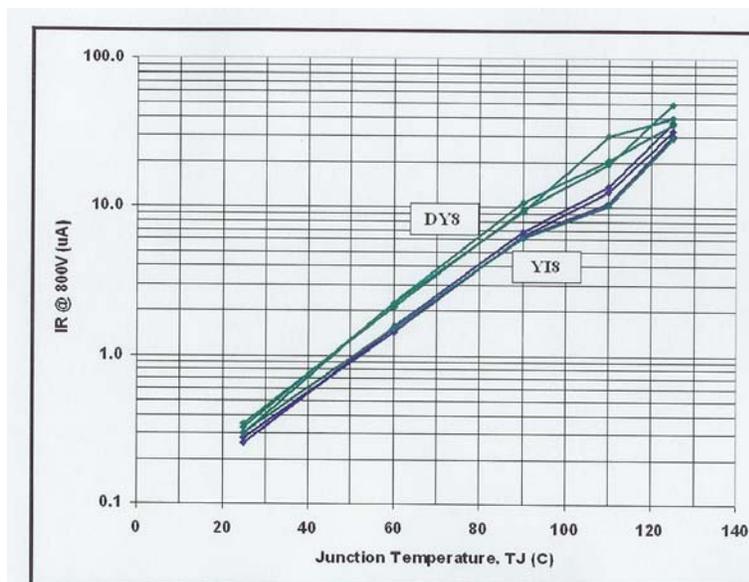


Figure 5: Reverse current variation with junction temperature for samples under consideration.

Single Half-Cycle Surge Current (I_{FSM}): Five samples from each group were surged in 25 A increments (starting at 100 A) until failure. However, after testing, the surge resolution and sample size were deemed insufficient. Hence, an additional 5 samples from each group were surged in 10 A increments (starting at 150 A). Data from both tests were combined to produce the I_{FSM} vs chip-size graph shown in Figure 6. The graph shows a plot of median peak surge current at which each group failed, as well as the minimum, peak surge current. The solid blue line denotes median peak surge-current failure and the dashed blue line denotes the lowest peak surge current where the first failure occurred.

Reverse recovery time (t_{rr}): Theoretically, a diode's transition from conductor to insulator when reverse biased is instantaneous. Reality is different, in that it takes a certain amount of reverse recovery time to switch states. In order to study this aspect, five samples from each group were evaluated using the following test conditions: $I_{FM} = 25$ A (1 ms sinusoidal pulse); $(di/dt) = -0.65$ A/s; $V_{RM} = 12.5$ V. Figure 7 shows the results of the mean reverse-recovery times of all the samples. The reverse recovery time for p-n junction diodes are of the order of microseconds for general purpose rectifier diodes [6]. The Boron based diodes DI8 actually stood out as better in this aspect, when compared to the Gallium diodes for the same die size. Since the difference in the reverse recovery time values was no greater than 2-4 us, the performance was considered to be acceptable.

Average Power Dissipation (PD): When current flows in a component, the component tends to heat up. This process is called power dissipation, measured in watts. Power is the amount of current times the voltage level at any given point. Using the measured values of forward voltages and currents, power dissipation values were tabulated and 60Hz average power dissipation curves for each of the chip process were generated as shown in Figure 8. It was found that,

power increased linearly with increasing forward current. The trend of the samples followed expectations.

High Temperature AC blocking: High temperature AC blocking tests were conducted only on the bigger die-size chips, 150DY8 and the 150YI8. This being the last experiment, 84 of the supposed 100 diodes (16/100 had failed during the other experiments) from both samples was subjected to 125°C of high temperatures. High-temperature testing was carried out in a blocking rack and heat sinks were attached to each device to prevent power generated by the current-leakage from further raising the junction temperature. After the desired temperature was reached, the blocking rack was programmed to test the samples for failure, and results were automatically transferred to a computer. A single compartment of a blocking rack can hold up to 126 devices for testing. The test was stopped after 504 hours. During the course of the tests, current-leakage of all devices did not show any extreme increases. However, after the test, the room-temperature current-leakage of two 150DY8 devices was found to exceed to 10μA (internal) specification.

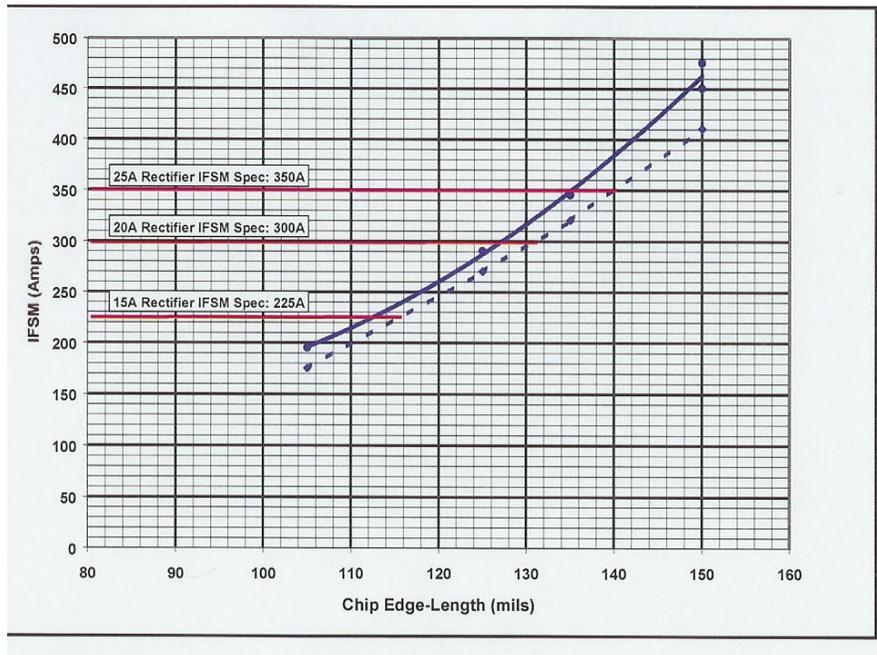


Figure 6: Variation of single half cycle surge current with respect to chip size.

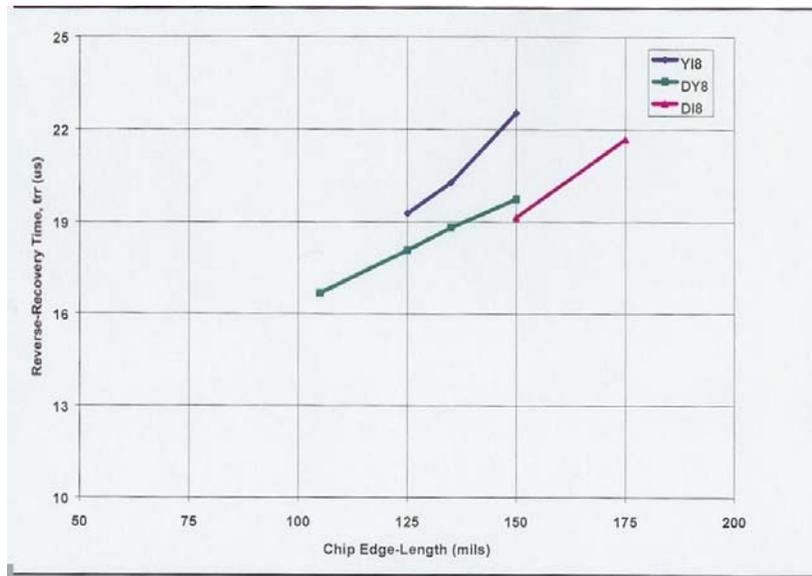


Figure 7: Reverse recovery time for all samples with respect to chip size.

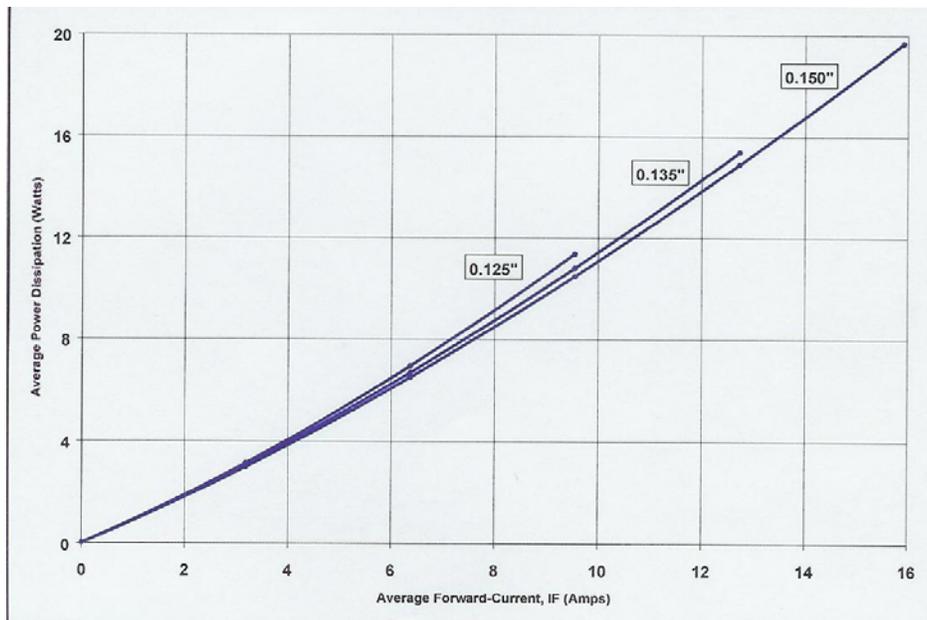


Figure 8: Average power dissipation for 3 various dimensions of rectifiers with respect to average forward current.

Statistical Analysis:

Multiple Linear Regression

Statistical analysis was conducted using data from the above numerical analysis to investigate relationships among the variables. The process of finding a mathematical model (an equation) that best fits the data is part of a statistical technique known as Regression Analysis [9]. Probabilistic models that include more than one independent variable are called multiple regression models. A multiple linear regression model is of the form

$$\hat{y} = b_0 + b_1 x_1 + b_2 x_2 + \dots + b_k x_k$$

where b_0 = the estimated y -intercept, b_j = the regression coefficient of x_j , $j = 1, 2, \dots, k$; x_j = the j th independent variable; $j = 1, 2, \dots, k$, and \hat{y} = the estimated value of the dependent variable [10].

Multiple Linear regression analysis was used to find the similarities in performance among the various Boron die-sizes versus smaller Gallium die-sized diodes. The DY8 Gallium diodes were not tested using multiple linear regressions as they had failed the High Temperature AC blocking test. Tables were formatted for the analysis posed current as the independent variable and voltage as the dependent variable. The materials used were interchanged between Boron and Gallium as needed in the analysis. To check for an interaction between the current passed through the diode and the material of the die, another column was added, namely “Current Material Interaction” and later using the *Regression* tool in MS Excel, the estimated regression equation for various die-sizes was obtained. A snap-shot of the actual table used to run the regression is shown in Table 1. We can obtain the estimated regression equation for the data as,

$$\hat{y} = 0.83 - 0.0015\text{Material} + 0.0098\text{Current} + 0.0023 \text{Current Material Interaction}$$

For the materials used – boron and gallium, respectively, the models reduced to:

$$\hat{y} = 0.83 + 0.0098\text{Current} \quad \text{Boron}$$

$$\hat{y} = 0.828 + 0.0121\text{Current} \quad \text{Gallium}$$

From the output obtained, we concluded that the model provides an excellent fit to the data, as evidenced by the regression coefficient, R , which is 0.914. From the ANOVA table we noted that the model is significant, with a significance of 1.5869E-270, which is the probability of getting these results if all of the coefficients of the independent variables are really zero. Also, all of the p -values for the individual coefficients are very small, indicating that we may reject the hypotheses that individual coefficients are equal to zero. The test statistic used to test our hypothesis is an F statistic, which is the ratio of the explained variability divided by the model degrees of freedom to the unexplained variability divided by the error degrees of freedom. Thus, the larger the proportion of the total variability accounted by the model, the larger the F statistic.

For determining when the ratio becomes large enough to confidently rejecting the null hypothesis and conclude that the model is useful, we compare the calculated F statistic to a tabulated F value with k degrees of freedom in the numerator, and $[n - (k + 1)]$ degrees of freedom in the denominator. The rejection region would be that the calculated F value should be greater than the tabulated value of F , where F is based on k numerator and $[n - (k + 1)]$ denominator degrees of freedom. In this case, $[n = 511, k = 3, n - (k + 1) = 508, \alpha = .05]$, we will reject H_0 if, $F > F_{0.05}$, where $F_{0.05} = 2.60$.

From Table 1, we found the value of the F-statistic to be 1806, which is much higher than the table value of 2.60. Thus we can reject the null hypothesis at a 95% confidence level and propose that the 125YI8 is a replacement of the 150DY8 @ 15A.

Similarly performing multiple linear regressions on the remaining die-sizes we studied the output from the regression model for comparing the 135YI8 and the 150DY8 @ 20A. We obtained the estimated regression equation for the data of 135YI8 and 150DY8 @ 20A as,

$$\hat{y} = 0.82 + 0.0095\text{Material} + 0.011\text{Current} - 0.0013 \text{ Current Material Interaction}$$

As in the previous case, for the materials used, the model reduced to:

$$\hat{y} = 0.82 + 0.011\text{Current} \quad \text{Boron}$$

$$\hat{y} = 0.8295 + 0.0097\text{Current} \quad \text{Gallium}$$

In this case, we obtained a regression coefficient of 0.866. From the ANOVA table (Table 2) we noted that the model is significant, with a significance of 5.9229E-210, which is the probability of getting these results if all of the coefficients of the independent variables are really zero. Also, all of the p -values for the individual coefficients are very small, indicating that we may reject the hypotheses that individual coefficients are equal to zero.

Testing our hypothesis with the F statistic, in this case, $[n = 511, k = 3, n - (k + 1) = 508, \alpha = .05]$, we will reject H_0 if, $F > F_{0.05}$, where $F_{0.05} = 2.60$.

From Table 2, we noticed that the value of the F-statistic is 1042, which is much higher than the table value of 2.60. Thus we can reject the null hypothesis at a 95% confidence level and propose that the 135YI8 is a replacement of the 150DY8 @ 20A.

Finally performing a linear regression for the 150YI8 versus the 175DY8, we obtained the estimated regression equation for the data as,

$$\hat{y} = 0.82 + 0.0095\text{Material} + 0.011\text{Current} - 0.0013 \text{ Current Material Interaction}$$

For Boron and Gallium, the model reduced to:

$$\hat{y} = 0.81 + 0.006\text{Current} \quad \text{Boron}$$

$$\hat{y} = 0.8181 + 0.0089\text{Current} \quad \text{Gallium}$$

The model provides an excellent fit to the data, as evidenced by R , which is 0.911. From the ANOVA table (Table 3) we noted that the model is significant, with a significance of 3.9301E-266, which is the probability of getting these results if all of the coefficients of the independent variables are really zero. Also, all of the p -values for the individual coefficients are very small, indicating that we may reject the hypotheses that individual coefficients are equal to zero.

Testing our hypothesis with the F statistic, in this case, $[n = 511, k = 3, n - (k + 1) = 508, \alpha = .05]$, we will reject H_0 if, $F > F_{0.05}$, where $F_{0.05} = 2.60$.

From Table 3, we noticed that the value of the F -statistic is 1792.6, which is much higher than the table value of 2.60. Thus we can reject the null hypothesis at the 95% confidence interval and propose that the 150YI8 is a replacement of the 175DY8.

Table 1:
Regression
125YI8 vs
@ 15A

Regression Statistics	
Multiple R	0.956195525
R Square	0.914309882
Adjusted R Square	0.913603838
Standard Error	0.059798401
Observations	512

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	19.38230992	6.460769972	1806.779406	1.5869E-270
Residual	508	1.816531191	0.003575849		
Total	511	21.19884111			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0.830044968	0.009689755	85.66212137	4.0926E-304	0.811008042	0.849082	0.811008	0.849082
Material	-0.001511264	0.010333129	-0.146254222	0.883778721	-0.02181219	0.01879	-0.02181	0.01879
Current	0.009834806	0.00046278	21.25158627	3.51986E-72	0.008925608	0.010744	0.008926	0.010744
Current-Material Interaction	0.00232812	0.000493969	4.713086545	3.15497E-06	0.001357646	0.003299	0.001358	0.003299

ANOVA-
table for
150DY8

Table 2: ANOVA-Regression table for the 135YI8 vs the 150DY8 @ 20A.

Regression Statistics	
Multiple R	0.838941096
R Square	0.666651324
Adjusted R Square	0.655919628
Standard Error	0.063372726
Observations	485

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	12.55467707	4.184892357	1042.028312	5.9229E-210
Residual	481	1.931745232	0.004016102		
Total	484	14.4864223			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0.816478499	0.01026894	79.5095223	7.4395E-279	0.796300976	0.836656	0.796301	0.836656
Material	0.009508369	0.010992855	0.864959004	0.38749246	-0.012091581	0.031108	-0.01209	0.031108
Current	0.011010274	0.000490442	22.44971695	6.93191E-77	0.010046801	0.011974	0.010047	0.011974
Current-Material Interaction	-0.001343557	0.000525535	-2.5565531	0.010877516	-0.002376184	-0.00031	-0.00238	-0.00031

Table 3: ANOVA-Regression table for 150YI8 versus the 175DY8.

Regression Statistics	
Multiple R	0.95437265
R Square	0.91082715
Adjusted R Square	0.91030054
Standard Error	0.04836617
Observations	512

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	12.13809297	4.046031	1729.6	3.9301E-266
Residual	508	1.188357521	0.002339		
Total	511	13.32645049			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper
Intercept	0.81273312	0.007837272	103.701	0	0.797335662	0.828131	0.797336	0.82
Material	-0.0019771	0.008357646	-0.23666	0.81309	-0.018396927	0.014443	-0.0184	0.01
Current	0.006727	0.000374306	17.97195	2.91E-56	0.005991626	0.007462	0.005992	0.00
Current-Material Interaction	0.00298968	0.000399533	7.482944	3.22E-13	0.00220474	0.003775	0.002205	0.00

Conclusions:

Based primarily on the peak current-surge results and forward-voltage characteristics, smaller YI8 anti-base chips can replace the current DI8 chips to provide similar performance. These recommended die-sizes would also possess power characteristics comparable to the existing products. No solid conclusions can be drawn as to the reliability of the anti-base rectifiers because of the short duration of the high-temperature AC blocking test. However, it is likely that the 150DY8 rectifiers evaluated have a reliability problem since two of the 50 devices possessed a permanent change in current leakage that exceeded the 10µA (internal-company) specification. Also, since the 150YI8 showed no adverse change in current-leakage, it is a strong possibility that these devices would meet long term AC blocking testing. Adequate statistical analysis was conducted with one-on-one comparison of different specimen samples. It could be concluded from the analysis that we accept the Null Hypothesis that anti-base diodes DY8 do not meet or exceed requirements in comparison to boron diodes. At the same time, we can also draw a conclusion that anti-base diodes YI8 are much better performers than the diodes fabricated using the DI8 process for similar input variables. Further Reliability testing needs to be conducted before releasing products with these chips. Taking into account, the statistical analysis, on-state voltage, current-leakage, and the brief reliability testing, The YI8 rectifiers stand out as better performers over the DY8.

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