# SEMICONDUCTOR DEVICE RELIABILITY

## 1. Introduction

It has only been somewhat over 30 years since semiconductor devices such as rectifier diodes, thyristors, and transistors gained widespread acceptance for use in industrial machinery and consumer appliances, but during that period the reliability standards for these devices have made rapid advances.

In equipment where high reliability is a must, failure rate of the semiconductor devices must range from 10 to 100 FIT (1 FIT $=10^{-9}$/ hours). Of course, to achieve such reliability in the equipment itself, not only must each individual device be reliable, but it is also extremely important to match the specific characteristics of the device with its application within the piece of equipment. In fact, information obtained in field studies show that for semiconductor devices manufactured using identical procedures, failure rates in the field can vary by a factor of 10 depending simply on how the device was used.

The following information covers device reliability with regards to how a device is used. An introductory discussion is also presented on quality-control procedures, and some examples of reliability testing data are given.

## 2. Basic Concepts of Semiconductor Device Reliability

The failure rate of devices used in an average piece of equipment can be expressed by using the bathtub curve shown in Fig. 1, line(a). Taken from the standpoint of time, device failures can be classified as an early failure, random failure and wearout failure period. Two points must be considered regarding the service life of a device; early and random failures rate, and life time before wearout. But the failures rate of semiconductors, is illustrated by line (b) in the graph, where failure rate is shown to gradually diminish as a factor of time. In other words, a notable feature of semiconductor devices is that the longer a particular device has been used, the more stable it will be. Viewed from a different perspective, even though random failure rate has been reduced to virtual stability, the failure distribution pattern shows early failures to still be prevalent. As shown by Fig. 2 where failure rate versus time is given for an actual device, the highest failure rate occurs immediately after manufacture, but the process of againg and debugging gradually lowers this failure rate.

The next step is with the user, who assembles, adjusts, and takes the device aging. Failure rates continue to decline during this period also. Generally, the rate for major defect during this period drops to less than 0.1%, and if this rate is exceeded by a substantial margin, one must look for a fault in the circuit design, assembly procedure, or the device itself. Unless the problem is found and corrected, frequent field failures will be the likely result. In most cases, the field failure rate can be correlated to major defect during this period, so this is an important aspect of device reliability.

Upon transferring the equipment to field service, the stress level is reduced further, with a corresponding drop in failure rates. Failure rates normally range from several FIT to several hundred FIT during this period.

Another typical characteristic of semiconductor devices is their long service lives. Generally the devices can be expected to far outlast the equipment that they are installed in.

As noted by the failure rate curve in Fig. 2, after the semiconductor device has been in service for several thousand hours, failure rate shows a slight tendency to further decrease, and parameter m on the

Weibull distribution scale is usually 0.3 to0.6. Presently, devices contained in hermetically-sealed metal packages have not yet reached the wearout phase while in practical use, but the probable cause for eventual failure will be corrosion of the package pins or similar environmental causes.

The normal procedure for evaluating device reliability is to use various means to accelerate testing, or to life test over a relatively short period ranging from 200 to 1000 hours. The first of these methods is intended mainly to check for device wearout failure mode, while the second method is used to detect sudden and catastrophic failures occurring in the early and random failure period of the distribution curve.

After a piece of equipment has been assembled and adjusted, or has been placed in field service, failed devices that are returned to the factory are analyzed to determine the cause of failure. This procedure is intended to determine whether the problem lies with the device itself, or the manner in which it was used. For devices that prove good, the usual reason given for returning it is unsuitability from the standpoint of rating or characteristics, or that it does not work properly in combination with other devices. However, in most cases these have been a mistake in judgement on the part of the user. In analyzing failed devices where usage conditions were suspected to be the cause, the problem in nearly all cases was determined to be due to electrical stress such as caused by surge current or voltage, or by exceeding di/dt of maximum rating specifications. In very few cases was the cause determined to be due to mechanical stress, such as excessive vibrations or shock.

Well in analyzing the most common type of failure, which was found to be with the device itself with High power thyristors, the problem was determined to be either defective surface treatment of the silicon, or a defect in the structure of the device. The first cause was a defect in
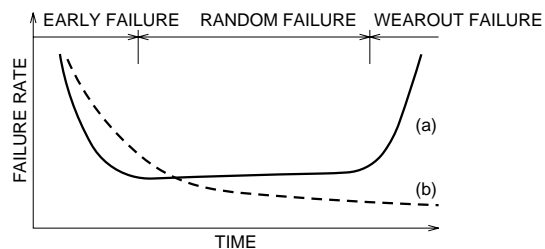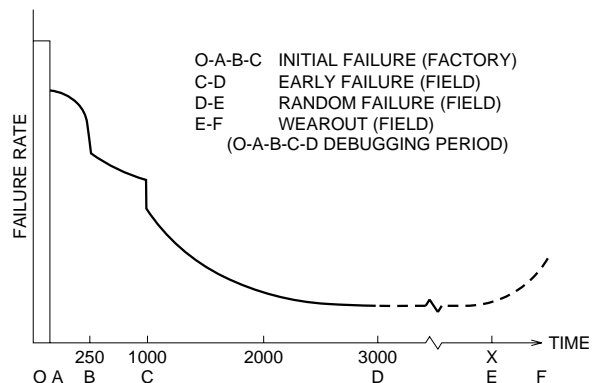


**Fig. 1 Failure Rate Versus Time**

O-A-B-C INITIAL FAILURE (FACTORY)
C-D EARLY FAILURE (FIELD)
D-E RANDOM FAILURE (FIELD)
E-F WEAROUT (FIELD)
(O-A-B-C-D DEBUGGING PERIOD)



**Fig. 2 Semiconductor Device Failure Rate Versus Time**

the manufacturing process that left ion impurities in the vicinity of the silicon junction, degrading device performance. The second type of fault was determined to be defective parts or materials or their joint parts of the device.

The largest area of application for large power thyristors and diodes is in the control of industrial machinery. Consequently, the parts and materials, and the manufacturing process must be under a rigorous quality-control program to eliminate these types of defects at the source. This must be backed up by an effective debugging program in order to assure optimum device yield.

In the device failure rate curve shown in Fig. 2, it is apparent that equipment reliability can be increased by extending the flat middle section of the curve to the left, and lowering early failure rates. On the other hand, greater margins must be designed by the user. For example, diodes and thyristors should be operated at 50 ~ 80% of their maximum voltage ratings, and junction temperatures should not exceed 70 ~ 80% of maximum rating. It is also important to remember that a device must be in working harmony with other components in the circuit for maximum reliability standards can be assured.

When designing a piece of equipment for reliable service, device selection must be considered from a standpoint of performance, reliability, and economy. Since it is not easy to achieve high performance/reliability and economy at the same time, a balance must be struck on the side of practical value. In other words, device selection should be based on the user's expectations for the machine he is designing.

## 3. Mitsubishi's Quality-Assurance Program

One of the basic goals of Mitsubishi Electric is to offer our customers quality products. As a consequence, product quality, price, timely delivery, and service are equally important aspects deserving an equal amount of attention. Still, product quality must stand above all others from a standpoint of customer confidence.

Quality standards in the semiconductor industry are extremely high; production of wafers is a carefully controlled, precision process, and assembly processes are done under microscopes to assure that there are no sacrifices made in technology, or in quality. The following subsections outline the quality-assurance programs Mitsubishi Electric uses in its mass-production.

### 3-1. The Path to a mass-production device

From research prototype, through mass-production, a serial type tests are run at each stage to assure performance and reliability of the ultimate product. At the same time, the design drawings are also closely checked. The path from the research stage to mass-production is shown in the flow chart of Fig. 3. The subsections that follow briefly describe the reliability tests used to check for device reliability.

### 3-2. Environmental controls

The semiconductor industry as a whole recognizes the affect environmental factors have on product quality, and rigorous standards have been established regarding the control of dust, humidity, and temperature in manufacturing facilities. The same level of standards are also used for the various gases, and the water used in the manufacturing process.

### 3-3. Periodic inspection and maintenance of manufacturing equipment and instrumentation

The various equipment and measuring instruments used in semiconductor production are an extremely important element of the total process. It is therefore imperative that a periodic program be implemented to inspect and adjust these components so that optimum precision standards are maintained, and to forestall any interruptions in the production process.

### 3-4. Quality-control of materials purchases

Materials are subjected to rigorous acceptance tests using equipment such as spectrometers, helium leak detectors, etc. Before placing full orders, thorough sample testing is done, and all problem areas are worked out before making an official decision.Quality-control procedures at the supplier's plant are also considered in any procurement decision.

### 3-5. Control of the manufacturing process

Various measures have been taken to control the elements that have a decisive influence on the quality of the product. Measuring instruments are used to monitor water purity, atmospheric conditions, furnace temperatures, gas flow, and other factors. Check-sheet inspections are made, and recorders keep automatic records. These records are carefully correlated with the records kept on matters such as diffusion depth and surface density to establish proper working conditions.

### 3-6. In-process and final inspections

The goals of the in-process and final inspections are twofold: the first is to assure product quality from the standpoint of outer appearance, dimensions, structural integrity, and mechanical and electrical characteristics. The second is to feed this information back upline to improve quality, and to reduce variations in future batches.

In-process inspections are intended to check the wafer and assembly processes, and serve two purposes; one being a self-imposed check on the production process, the other for use as a quality-control tool. As its name implies, the self-imposed check is used by production personnel to correct deficiencies they clearly recognize, and emphasis is placed on points that are difficult to detect in completed devices. After the device is completed, it is subjected to the final inspection and the quality-assurance inspection.

The final inspection is run on all devices, and consists of testing electrical characteristics and outer appearance.

Quality-assurance personnel assume the role of the end user, and inspect samples for correct electrical characteristics, outer appearance, and reliability before devices are packed in storage. The flow chart for the quality-assurance program covered in the above is noted in Fig. 3.

### 3-7. Quality information

Various kinds of quality information such as inspection results and customer-supplied information are compiled mainly by the quality assurance division. They are quickly fed back to related divisions including the production division for maintenance and improvement of quality. In addition, we employ computer-based, streamlined, and effective quality control systems in order to modernize the information management.

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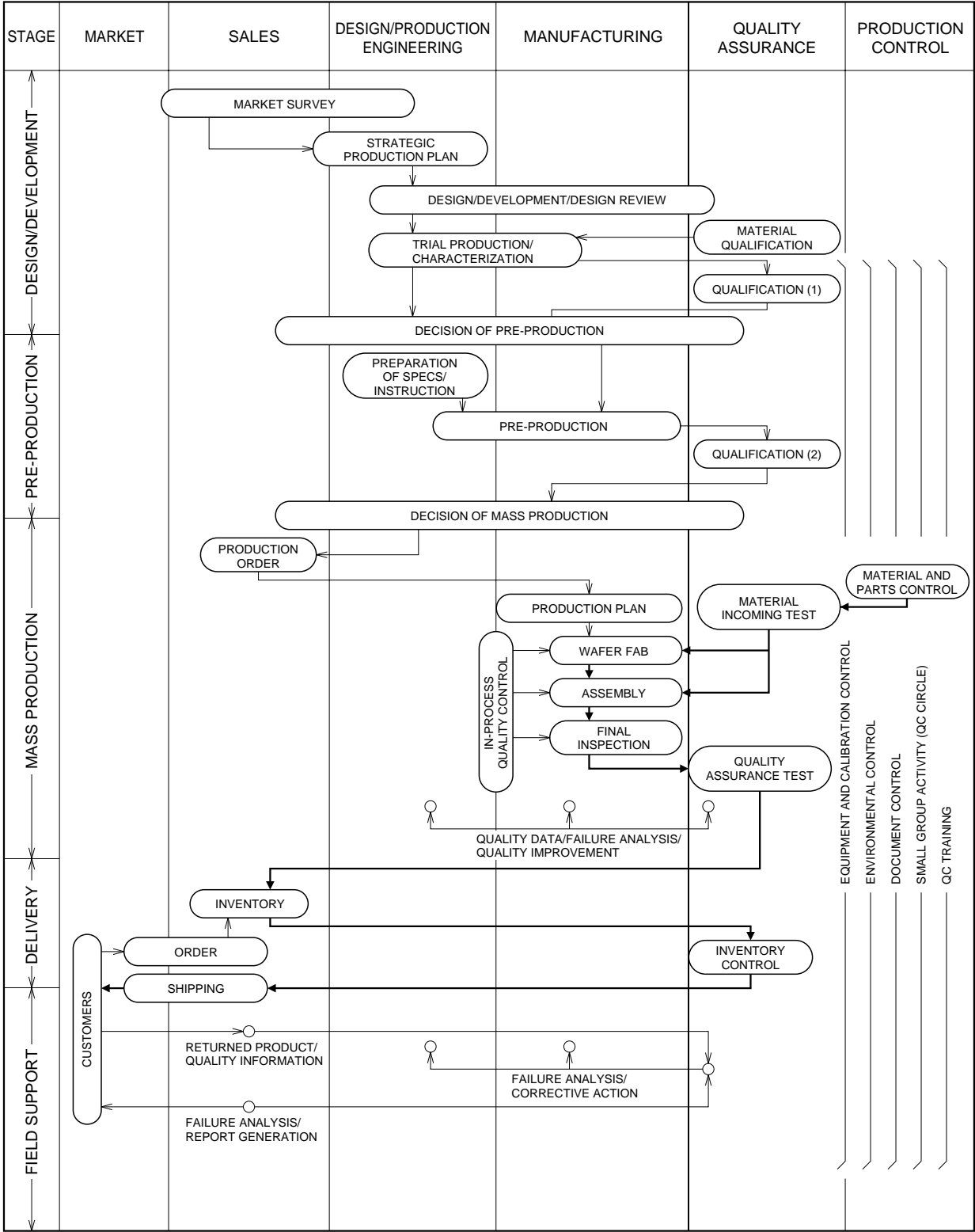**Fig. 3 Flow Chart of Quality Assurance Program**

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## 4. Reliability Testing
## 4-1. Reliability Testing Procedures

High reliability standards are assured with Mitsubishi semiconductor devices through the rigorous quality-control inspections which the devices are subjected to in the design and manufacturing stages, and through the quality-assurance inspections run on each production lot. Numerous reliability tests have been implemented in order to maintain this standard of reliability.

This section provides an overview of the reliability testing of thyristor devices. Test parameters are shown in Table 1, and as noted, conform to the procedures specified by the Japan Industrial Standards (JIS) handbook.

## 4-2. Result of reliability test of High power GTO thyristor

The procuct illustrated here is the Mitsubishi High Power GTO Thyristor FG4000BX, a flat type gate turn-off device that uses repetitive controllable on-state corrent of 3000A. This device is widely used in traction application.

Table 2 lists the results of the reliability tests performed on this device to date, and Fig. 5 illustrates the various characteristics versus time graphs constructed from intermittent operation load test results. Failure criterion information is noted in Table 3.
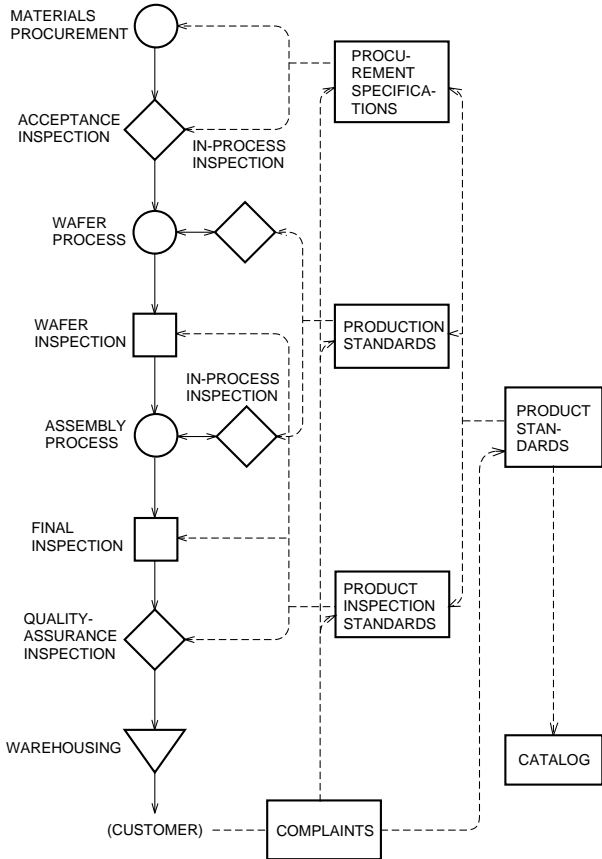


**Fig. 4 Semiconductor Device Quality-Assurance Flowchart**

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## Table 1  Mitsubishi Semiconductor Device Reliability Testing
### (Example given for high power thyristor.)

| Test parameter | | Test method | | Test conditions | | Notes |
|---|---|---|---|---|---|---|
| Environmental test | Thermal shock | JIS C 7021* | A – 3 | 100°C, 15 minutes; 0°C, 15 minutes; five cycles | | |
| | Temperature cycling | JIS C 7021* | A – 4 | Tstg (max), 30 minutes; Tstg (min), 30 minutes; five cycles | | Time determined by weight of device |
| | Sealing | JIS C 7021* | A – 6 | Method I | Small leak test using helium gas | Using He gas |
| | | | | Method III | Bubble testing for gross leaks | Using fluorocarbon |
| | Mechanical shock | JIS C 7021* | A – 7 | 100 ~ 500G, three times in each direction | | |
| | Vibration | JIS C 7021* | A – 10 | 10 ~ 55Hz, 1.5mm, two hours each in the X, Y, and Z axis | | |
| | Robustness of termination | JIS C 7021* | A – 11 | Mathod I | Pull, and specified load, 30 seconds | |
| Endurance test | High temperature storage | JIS C 7021* | B – 10 | $T_a = T_{stg (max)}$, 1000 hours | | |
| | Low temperature storage | JIS C 7021* | B – 12 | $T_a = T_{stg (min)}$, 500 hours | | |
| | Intermittent current flow | JIS C 7021* | B – 18 | $I_T = I_{T(AV)}max$, $T_j$ = less than 50°C ~ $T_j$ (max), 5000 cycles | | |
| | High temperature voltage application | JIS C 7021* | B – 20 | $T_j \le T_{j (max)}$, $V_{AK} = V_{DRM}$, $V_{RRM}$ or 80%, 1000 hours | | |

*: Environmental and resistance testin conforms to standards specified in JIS C 7021 for discrete semiconductor devices.

## Table 2  FG 4000BX-90DA Reliability test results

| Test parameter | | Test method | | Test conditions | | No of samples | No of failures |
|---|---|---|---|---|---|---|---|
| Environmental test | Thermal shock | JIS C 7021 | A – 3 | 100°C, 15 minutes; 0°C, 15 minutes; 30 cycles | | 10 | 0 |
| | Temperature cycling | JIS C 7021 | A – 4 | −40°C ~ 25°C ~ 150°C, 50 cycles | | 10 | 0 |
| | Sealing | JIS C 7021 | A – 6 | Method I | Helium leak test (over $1 \times 10^{-8}$ cc/sec) | 40 | 0 |
| | | | | Method II | Bubble test using fluorocarbon | 40 | 0 |
| | Mechanical shock | JIS C 7021 | A – 7 | 500G, 3-times in the X, Y, and Z axis. | | 10 | 0 |
| | Vibration | JIS C 7021 | A – 10 | 10 ~ 55Hz, 1.5mm, two hours each in the X, Y, and Z axis | | 10 | 0 |
| | Robustness of termination | JIS C 7021 | A – 11 | Mathod I | Pulling load, 45N, 30 seconds (applied to cathode and gate lead) | 10 | 0 |
| Endurance test | High temperature storage | JIS C 7021 | B – 10 | $T_a$ = 150°C, 1000 hours | | 10 | 0 |
| | Low temperature storage | JIS C 7021 | B – 12 | $T_a$ = −40°C, 1000 hours | | 10 | 0 |
| | Intermittent current flow | JIS C 7021 | B – 18 | $I_{T(AV)}$ = 1000 A, $T_j$ = 40°C ~ 125°C, 20000 cycles | | 10 | 0 |
| | High temperature voltage application | JIS C 7021 | B – 20 | $T_j$ = 125°C, $V_D$ = 3600V (DC)(anode-cathode), $V_{GK}$ = −2V, 1000 hours | | 10 | 0 |
| | | | | $T_j$ = 125°C, $V_{GK}$ = −19V (gate-cathode), 1000 hours | | 10 | 0 |

## Table 3  FG 4000BX-90DA Failure criterion

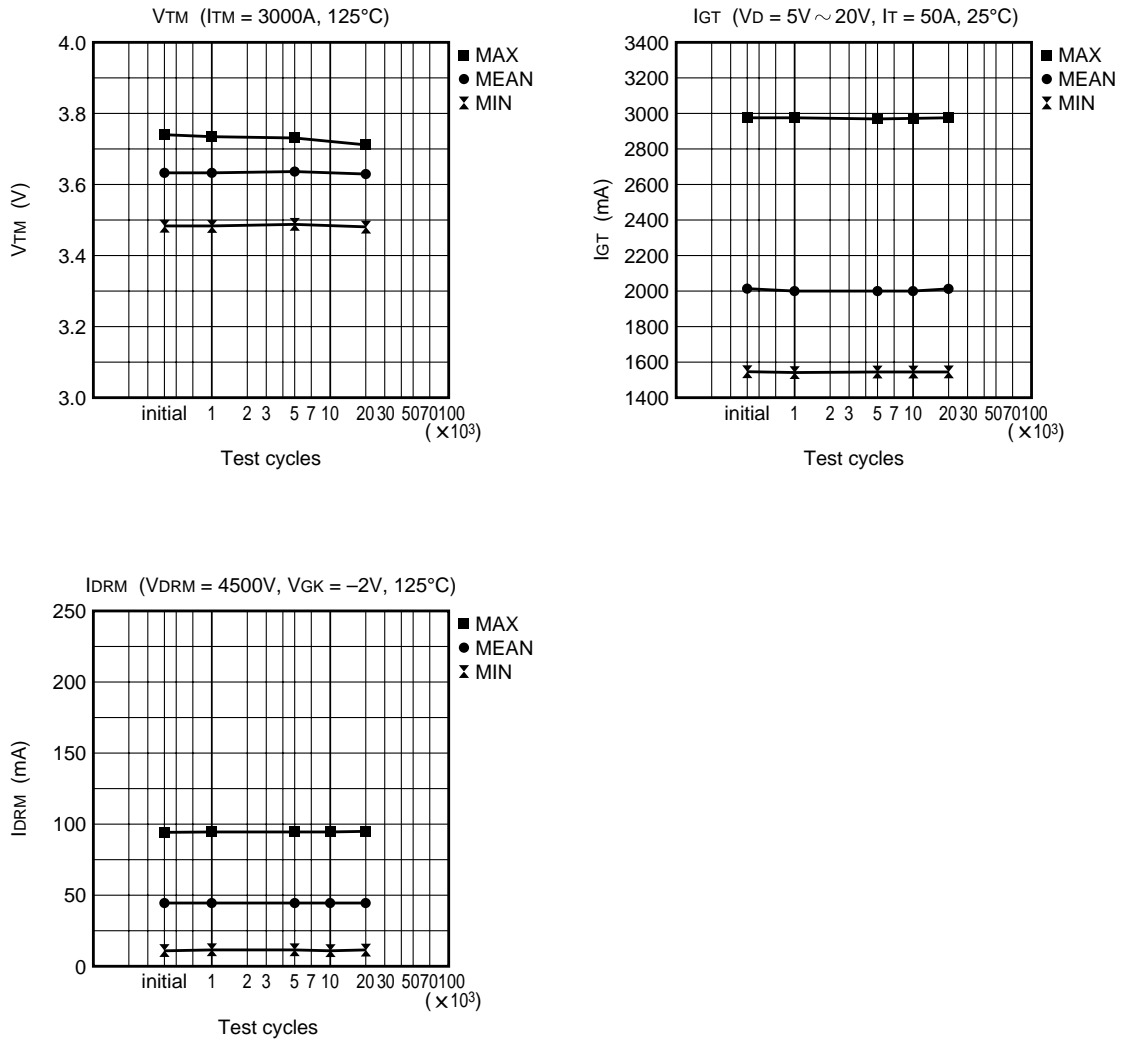| Test parameter | Test conditions | U. S. L | Failure criterion | | Unit |
|---|---|---|---|---|---|
| | | | Lower limit | Upper limit | |
| $V_{TM}$ | $T_j$ = 125°C, $I_{TM}$ = 3000A, $I_G$ = 3A | 3.8 | — | U. S. L × 1.1 | V |
| $I_{GT}$ | DC METHOD : $V_D$ = 24V, $R_L$ = 0.1Ω, $T_j$ = 25°C | 3200 | — | U. S. L × 1.1 | mA |
| $V_{GT}$ | | 1.5 | — | U. S. L × 1.1 | V |
| $I_{RG}$ | $T_j$ = 125°C, $V_{RG}$ = 19V | 100 | — | U. S. L × 1.1 | mA |
| $I_{DRM}$ | $T_j$ = 125°C, $V_{DRM}$ = 4500V, $V_{GK}$ = −2V | 150 | — | U. S. L × 1.1 | mA |

U. S. L : upper specification limit

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**Fig. 5 FG 4000BX Typical changes as a factor of time in intermittent current flow.**

## 5. Failure Analysis

Failure analysis is one of the sources of information used in maintaining, and making improvements in standards of quality and reliability. Failure analysis procedures are performed on failed devices at all stages of their life cycle, ranging from the development state to failure while in use.

Failure analysis procedures are generally divided into area of external inspections, electrical testing, internal inspections, and chip analysis. The flow chart for these procedures is shown in Fig. 6, while Table 4 lists the nature of the tests.

The results of the various reliability and failure analysis tests reveal the failure mode and mechanism, and this information is fed back to the process technology and manufacturing personnel so that they can take the appropriate measures to improve the final product.

## 6. Derating and Reliability Projections

The degree of reliability for a semiconductor device varies considerably depending on usage and environmental conditions. Design standards, the method of manufacture, and quality-control procedures also play a role in establishing the intrinsic reliability for semiconductors. Correlating device derating with reliability is also not an easy task. However, in this section some methods will be introduced for projecting the reliability of diodes, and thyristors.

The methods for projecting reliability of devices meeting U.S. Military standards are described in MIL-HDBK-217F.

Since this handbook covers acceptance standars for parts used by the U.S. Military, it also contains much good reference matter for the average user. The information presented here has been taken form the portions of that manual that cover discrete semiconductor diodes and thyristers.
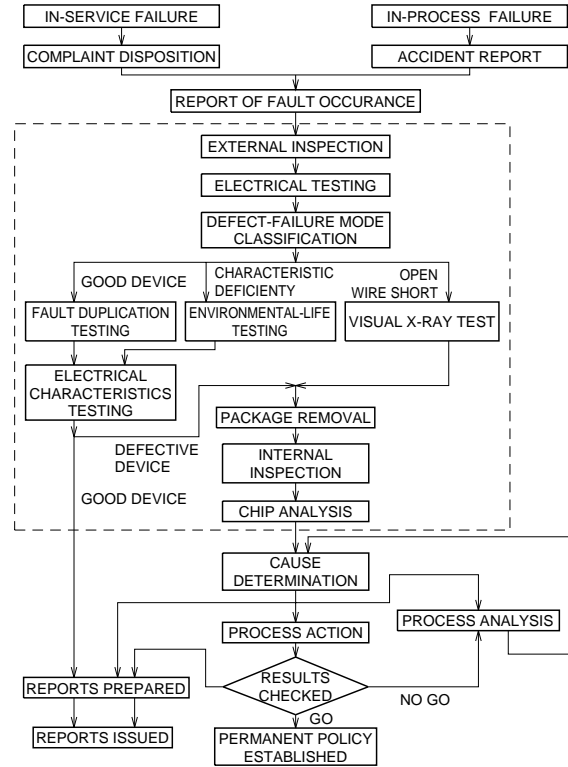


**Fig. 6 Fault analysis procedure**

## Table 4 Fault analysis inspections and equipment used

| Category | Inspection items | Equipment |
|---|---|---|
| External inspection | ○ Condition of leads, plating, soldering, and welds.<br>○ Marking<br>○ Packaging defect<br>○ Solderability<br>○ Hermetic seal | Stereoscopic microscope<br>Metallurgy microscope<br><br>Leak detector |
| Electrical characteristics testing | ○ Static electrical characteristics, voltage and temperature margins, checking for broken bond wire, wire bond shorts, and degradation through operational testing<br>○ Internal wiring | Oscilloscope<br>Curve tracer<br>Characteristics tester<br>X-ray equipment |
| Internal inspection | ○ Device removed from package and chip surface observed for defects<br>○ Electrical characteristic check using microprobe<br>○ Check for hot sopts and other abnormalities | Metallurgy microscope<br>microprobe<br>Scanning electron microscope<br>X-ray microanalyzer<br>Infrared microscanner<br>Spectrum analyzer |
| Chip analysis | ○ Analysis techniques used to supplement chip surface observation in internal inspection<br>○ Cross-section of chip observed for analyzing oxide film, diffusion and metallizing | |

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According to MIL-HDBK-217F, model $\lambda_P$ for projected failure rate in discrete semiconductor device on derating is calculated according to the following equation based on Reliability Prediction of Electronic Equipment.

$$\lambda_P = \lambda_b \, (\pi_E \times \pi_Q \times \pi_A \times \pi_S \times \pi_R \times \pi_C \times \pi_T)$$

Where:

| | | |
|---|---|---|
| $\lambda_b$ : Basic failure rate | $\pi_{S2}$ : | Voltage stress factor |
| $\pi_E$ : Environmental factor | $\pi_R$ : | Rating factor |
| $\pi_Q$ : Quality factor | $\pi_C$ : | Construction factor |
| $\pi_A$ : Circuit factor | $\pi_T$ : | Temperature factor |

Basic failure rate $\lambda_b$ is determined by power dissipation or current stress ratio S, and operating temperature T. In other words, this value depends on the amount of derating, and applies in principle to all devices. Expected device reliability under actual usage conditions can be projected by multiplying $\lambda_b$ by the factors that define design and manufacturing parameters ($\pi_C$, $\pi_Q$, $\pi_R$), environmental conditions under which the device will be used ($\pi_E$) and circuit conditions ($\pi_A$, $\pi_S$). Of the factors used to modify $\lambda_b$, $\pi_E$ and $\pi_Q$ are common factors used in the $\lambda_P$ calculation for all device types, but other factors can be omitted or used depending on the device. For example, in common diodes and transistors, all factors are used as illustrated in the basic equation, but in the equation for thyristor ($\lambda_P = \lambda_b \times \pi_E \times \pi_Q \times \pi_R \times \pi_T \times \pi_S$), serve as modifiers.

Tables 4 through 11 are excerpts taken from MILHDBK-217F, and list $\lambda_b$ and the various modifying factors for diodes and thyristors.

## Table 5-1 MIL-S-19500 Rectifier diode basic failure rate

$\lambda_b$ **(failure/$10^6$ hours)**

### Basic failure rate model $\lambda_b$

| Diode type/application | $\lambda_b$ |
|---|---|
| General analog | .0038 |
| Switching | .0010 |
| Power rectifier, Fast recovery | .069 |
| Power rectifier, Schottky-barrier | .0030 |
|    Power diode | |
| High voltage Rectifier | .005/JUNCTION |
|    Transient | .0013 |
|    Suppresser/varistor | |
| Current regulator | .0034 |
| Current regulator | .0020 |
|    (avalanche and Zener) | |

## Table 5-2 MIL-S-19500 Rectifier diode basic failure rate

$\lambda_b$ **(failure/$10^6$ hours)**

### Basic failure rate model $\lambda_b$

| Device type | $\lambda_b$ |
|---|---|
| All type | .0022 |

Failure rate $\lambda_P$ in the actual application is calculated as follow, using basic failure rate $\lambda_b$ and various other factors.

Example:

(Proposition)

A JAN-class silicon rectifier diode is provided with the maximum rated current 1.0A (ambient temperature 30°C, Ts = 30°C) $T_{jmax}$ = 150°C.

Obtain the estimated failure rate $\lambda_P$ when the device is used in the rectifier operation with a current of 0.5A and at 40% of the rated voltage on the ground (fixed) under the ambient temperature (Tj = 100°C).

(Calculation)

We obtain

$\lambda_P$ = 0.0010/$10^6$ hours from Table 5-1,

$\pi_E$ = 6.0 when on the ground (fixed) from Table 6,

$\pi_Q$ = 2.4 when JAN-class device is used from Table 7,

$\pi_E$ = 8.0 when Tj = 100°C from Table 8,

$\pi_S$ = 0.11 at 40% of the rated voltage from Table 9,

$\pi_S$ = 0.11 when the diode is metallurgically bonded from Table 11.

Using the above values, $\lambda_P$ is calculated as follows:

$$\lambda_b = 0.0010 \, (8.0 \times 0.11 \times 1.0 \times 2.4 \times 6.0)$$
$$= 0.0126/10^6 \text{ hours} = 12.6\text{FIT}$$

## Table 6 Environmental factor (diode, thyristor)

| Environment | Symbol | Diode | Thyristor |
|---|---|---|---|
| Ground (Environment Good) | $G_B$ | 1.0 | 1.0 |
| Ground (Environment Fixed) | $G_F$ | 6.0 | 6.0 |
| Ground (Portable) | $G_M$ | 9.0 | 9.0 |
| Nautical (Covered Vessels) | $N_S$ | 9.0 | 9.0 |
| Nautical (Uncoverd Vessels) | $N_U$ | 19 | 19 |
| Aircraft (Conveyance Craft Inhabited Areas) | $A_{IC}$ | 13 | 13 |
| Aircraft (Fighter Inhabited Areas) | $A_{IF}$ | 29 | 29 |
| Aircraft (Conveyance Craft Uninhabited Areas) | $A_{UC}$ | 20 | 20 |
| Aircraft (Fighter Uninhabited Areas) | $A_{UF}$ | 43 | 43 |
| Aircraft (Rotary Wing) | $A_{RW}$ | 24 | 24 |
| Space (In Flight) | $S_F$ | .50 | .50 |
| Missile (In Flight) | $M_F$ | 14 | 14 |
| Missile (During Launch) | $M_L$ | 32 | 32 |
| Missile (During Launch) | $C_L$ | 320 | 320 |

## Table 7 Quality factor $\pi_Q$ (diode, thyristor)

| Quality | Diode | Thyristor |
|---|---|---|
| JANTXV | 0.7 | 0.7 |
| JANTX | 1.0 | 1.0 |
| JAN | 2.4 | 2.4 |
| Lower | 5.5 | 5.5 |
| Prastic | 8.0 | 8.0 |

## Table 8-1 Temperature factor $\pi T$ (diode)

General analog, switching, fast recovery, power rectifier, transient suppresser

| TJ(°C) | $\pi T$ | TJ(°C) | $\pi T$ |
|---|---|---|---|
| 25 | 1.0 | 105 | 9.0 |
| 30 | 1.2 | 110 | 10 |
| 35 | 1.4 | 115 | 11 |
| 40 | 1.6 | 120 | 12 |
| 45 | 1.9 | 125 | 14 |
| 50 | 2.2 | 130 | 15 |
| 55 | 2.6 | 135 | 16 |
| 60 | 3.0 | 140 | 18 |
| 65 | 3.4 | 145 | 20 |
| 70 | 3.9 | 150 | 21 |
| 75 | 4.4 | 155 | 23 |
| 80 | 5.0 | 160 | 25 |
| 85 | 5.7 | 165 | 28 |
| 90 | 6.4 | 170 | 30 |
| 95 | 7.2 | 175 | 32 |
| 100 | 8.0 | | |

$$\pi T = \exp\left[ -3091\left(\frac{1}{TJ+273} - \frac{1}{298}\right)\right]$$

TJ = Junction temperature

## Table 8-3 Temperature factor $\pi T$ (thyristor)

| TJ(°C) | $\pi T$ | TJ(°C) | $\pi T$ |
|---|---|---|---|
| 25 | 1.0 | 105 | 8.9 |
| 30 | 1.2 | 110 | 9.9 |
| 35 | 1.4 | 115 | 11 |
| 40 | 1.6 | 120 | 12 |
| 45 | 1.9 | 125 | 13 |
| 50 | 2.2 | 130 | 15 |
| 55 | 2.6 | 135 | 16 |
| 60 | 3.0 | 140 | 18 |
| 65 | 3.4 | 145 | 19 |
| 70 | 3.9 | 150 | 21 |
| 75 | 4.4 | 155 | 23 |
| 80 | 5.0 | 160 | 25 |
| 85 | 5.7 | 165 | 27 |
| 90 | 6.4 | 170 | 30 |
| 95 | 7.2 | 175 | 32 |
| 100 | 8.0 | | |

$$\pi T = \exp\left[ -3082\left(\frac{1}{TJ+273} - \frac{1}{298}\right)\right]$$

TJ = Junction temperature

## Table 8-2 Temperature factor $\pi T$ (diode)

Voltage regulator, reference and current regulator

| TJ(°C) | $\pi T$ | TJ(°C) | $\pi T$ |
|---|---|---|---|
| 25 | 1.0 | 105 | 3.9 |
| 30 | 1.1 | 110 | 4.2 |
| 35 | 1.2 | 115 | 4.5 |
| 40 | 1.4 | 120 | 4.8 |
| 45 | 1.5 | 125 | 5.1 |
| 50 | 1.6 | 130 | 5.4 |
| 55 | 1.8 | 135 | 5.7 |
| 60 | 2.0 | 140 | 6.0 |
| 65 | 2.1 | 145 | 6.4 |
| 70 | 2.3 | 150 | 6.7 |
| 75 | 2.5 | 155 | 7.1 |
| 80 | 2.7 | 160 | 7.5 |
| 85 | 3.0 | 165 | 7.9 |
| 90 | 3.2 | 170 | 8.3 |
| 95 | 3.4 | 175 | 8.7 |
| 100 | 3.7 | | |

$$\pi T = \exp\left[ -1925\left(\frac{1}{TJ+273} - \frac{1}{298}\right)\right]$$

TJ = Junction temperature

### Table 9-1 Voltage stress factor $\pi$S (diode)

| S | $\pi$S |
|---|---|
| Transient, suppresser. voltage regulator, reference, current regulator | 1.0 |
| The other<br>Vs ≤ 0.30<br>0.3 < Vs ≤ 0.40<br>0.4 < Vs ≤ 0.50<br>0.5 < Vs ≤ 0.60<br>0.6 < Vs ≤ 0.70<br>0.7 < Vs ≤ 0.80<br>0.8 < Vs ≤ 0.90<br>0.9 < Vs ≤ 1.0 | <br>0.054<br>0.11<br>0.19<br>0.29<br>0.42<br>0.58<br>0.77<br>1.0 |
| Transient, suppresser, voltage regulator, reference or the other except current regulator<br>$\pi$S = 0.054   (Vs ≤ 0.3)<br>$\pi$S = Vs$^{2.43}$   (0.3 < Vs ≤ 1)<br>Vs = Voltage stressrate = $\dfrac{\text{Applied voltage}}{\text{Rated voltage}}$<br><br>Voltage is reverse voltage of diode | |

### Table 9-2 Voltage stress factor $\pi$S (thyristor)

| Vs (Applied blocking voltage/ Rated blocking voltage | $\pi$S |
|---|---|
| Vs ≤ 0.30<br>0.3 < Vs ≤ 0.4<br>0.4 < Vs ≤ 0.5<br>0.5 < Vs ≤ 0.6<br>0.6 < Vs ≤ 0.7<br>0.7 < Vs ≤ 0.8<br>0.8 < Vs ≤ 0.9<br>0.9 < Vs ≤ 1.0 | 0.10<br>0.18<br>0.27<br>0.38<br>0.51<br>0.65<br>0.82<br>1.0 |
| $\pi$S = 0.10   (Vs ≤ 0.3)<br>$\pi$S = (Vs)$^{1.9}$   (Vs > 0.3) | |

### Table 10 Reted Voltage factor $\pi$R (thyristor)

| Ifrms (Amp) | $\pi$R |
|---|---|
| 0.05 | 0.30 |
| 0.10 | 0.40 |
| 0.50 | 0.76 |
| 1.0 | 1.0 |
| 5.0 | 1.9 |
| 10 | 2.5 |
| 20 | 3.3 |
| 30 | 3.9 |
| 40 | 4.4 |
| 50 | 4.8 |
| 60 | 5.1 |
| 70 | 5.5 |
| 80 | 5.8 |
| 90 | 6.0 |
| 100 | 6.3 |
| 110 | 6.6 |
| 120 | 6.8 |
| 130 | 7.0 |
| 140 | 7.2 |
| 150 | 7.4 |
| 160 | 7.6 |
| 170 | 7.8 |
| 175 | 7.9 |
| $\pi$R = (Ifrms)$^{0.10}$<br>Ifrms = RMS forward rated current | |

### Table 11 Construction factor $\pi$C (diode)

| | $\pi$C |
|---|---|
| Metallurically bonded | 1.0 |
| Non-metallurically bonded (Spring contact load) | 2.0 |

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## 7. CONCLUSION

The above is a simple introduction to general ideas about reliability, reliability tests, and derating and forcasting of reliability of high power semiconductor, which are semiconductor devices for electric power. As explained above, it is vital for higher reliability in practical use of semiconductor devices to understand their features and select those which are suitable for equipment and sets. Is is also important to design semiconductor devices with some allowance to improve reliability, fully taking their derating into consideration in relation to operating and environmental conditions.

Other essential things to do is to "debug" equipment and sets, and to analyze data obtained in fabrication process and actual operation to feed them back to design and fabrication stages. To improve the reliability by design of high power semiconductor require considerations on many issues as described above. Utilize the semiconductor devices successfully with the utmost care with comprehensive understanding of their quality, reliability, and economy.

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