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# DIODES AND SPECIAL SEMICONDUCTOR ELEMENTS FOR TV SETS PART 2: SILICON RECTIFIER DIODES AND ZENER DIODES

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## I. INTRODUCTION

This article will introduce silicon diodes for use in TV sets manufactured by Fuij Electric. Rectifier diodes include the normal type and the fast reverse type. Zener diodes include many types with Zener voltages from 6 v to 300 v.

Device construction, p–n junction characteristics, thermal impedance of the device and reliability will be described first. Then problem points in the application of the elements based on the experience gained from the large number of diodes which Fuji Electric has supplied to the market will be dealt with.

## II. CONTRUCTION OF SILICON DIODES

The p–n junction is produced by means of the diffusion process. The surface of the junction is cleaned by etching and ultrasonic washing and coated with silicon resin. The silicon pellet to which the electrode is attached is either hermetically sealed or resin molded. Fuji Electric employs the following 4 types of sealing methods.

1. The silicon pellet is placed in a resin case which is then filled with resin (FR05, FR1, FR2, FG2, FT05, FT1, FU1, FA1 and ZB1 series).
2. Transfer mold is used (SIBO1 series).
3. Hermetic seal in a metal case (DS–1, DS2, DG 1 and SID 26 series).
4. Glass tube seal (SIB03 series)

*Fig. 1* shows various types of diodes.

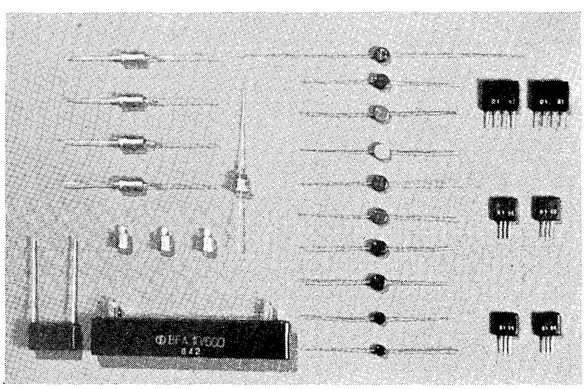

*Fig. 1* Silicon diodes for TV circuits

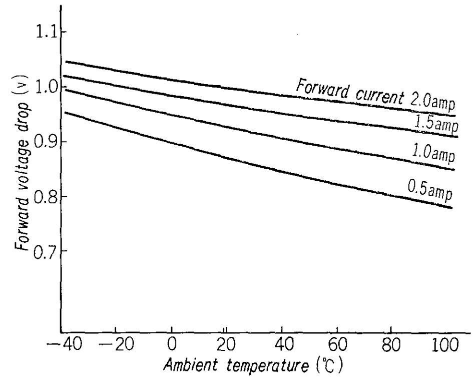


*Fig. 2* Temperature dependency of FR 05 and its forward characteristics

## III. CHARACTERISTICS OF SILICON DIODES

### 1. Forward Characteristics

In diodes for TV sets, the current density of the silicon pellet is below 1 amp/mm$^2$ and the forward voltage drop is over 0.4 v. In this region, the temperature dependency of the forward voltage drop and forward characteristics are as shown in *Fig. 2.* This figure shows data for the normal type FR05 diode. In high frequency diodes, however, the forward voltage drop is larger than this.

### 2. Reverse Characteristics

The reverse characteristics of silicon diodes are as shown in *Fig. 3.* These characteristics are divided into 2 parts: one where the reverse current is almost

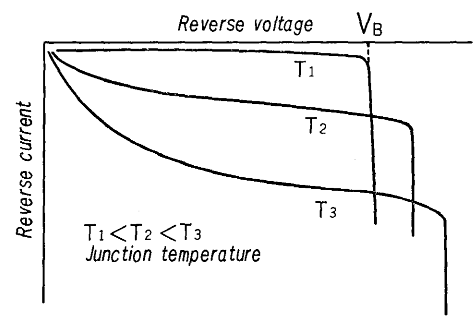


*Fig. 3* Typical reverse characteristics of diode

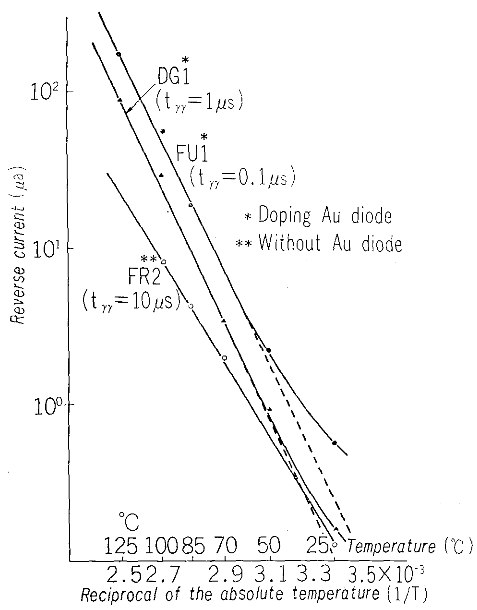


*Fig. 4* Temperature dependency of reverse current and $t_{rr}$ dependency

constant and one where the current increases sharply. In the first part, the reverse current is determined by the temperature and there is a linear relation between the logarithm of the reverse current and the reciprocal of the absolute temperature *T*. *Fig. 4* shows measured values for the normal diode FR 2 and the high frequency diodes DG 1 and FU 1. In the room temperature region, the graphs deviate from the straightline relation. The difference between the actual and the extended straight dotted line is the surface leakage current. This is especially conspicuous in the room temperature region.

The part where the current increases sharply arises due to the Zener and avalanche phenomena. The Zener phenomenon arises at the voltages below 6 v, while the avalanche phenomenon occurs at the voltages above 13 v. At the voltages in between 6 and 13 v, both phenomena occur at the same time. In the Zener phenomenon, the conjugate connection is separated by the field intensity in the silicon due to the reverse voltage. Free electrons and holes occur which cause sharp increases in the reverse current.

In the avalanche phenomenon, the reverse current carrier collides with the conjugate connection and multiplication of the carrier causes increases in the reverse current. The temperature coefficient of the Zener voltage is negative and that of the avalanche voltage is positive. Even in the so-called Zener diodes, the avalanche phenomenon due to voltage is used.

### 3. Reverse Recovery Time

The reverse recovery time is the time that elapses before the reverse blocking state appears when a voltage in the reverse direction is applied to a diode in the forward conduction state. During the reverse

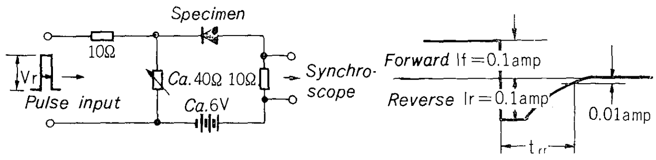


*Fig. 5* Measurement circuit for $t_{rr}$

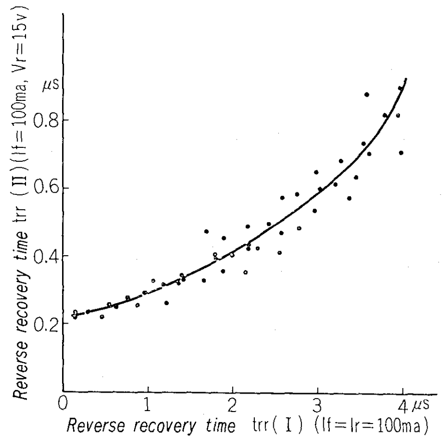


*Fig. 6* Reverse recovery time according to test methods

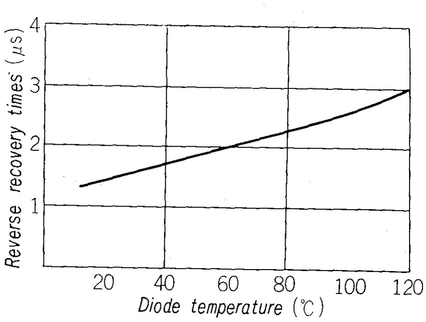


*Fig. 7* Temperature dependency of $t_{rr}$

recovery time, current flows in the reverse direction due to the carrier storage effect and there is no blocking capability in the reverse direction.

There are large differences in the reverse recovery time according to the conditions used for measurement as well as the temperature. *Fig. 5* shows the measuring circuit used by Fuji Electric and the waveform obtained. With this method, the reverse recovery time ($t_{rr}$) is measured when the forward current ($I_f$) and the reverse recovery current ($I_r$) are equal. *Fig. 6* shows a comparison of this measured value with the reverse recovery time when the forward recovery current is absorbed if the voltage applied in the reverse direction is a constant 15 v. The relation between the reverse recovery time and the temperature for the FU 1 type diode is shown in *Fig. 7*. Since the reverse recovery time varies according to the conditions, the actual reverse recovery time in actual circuit will vary from the catalog value.

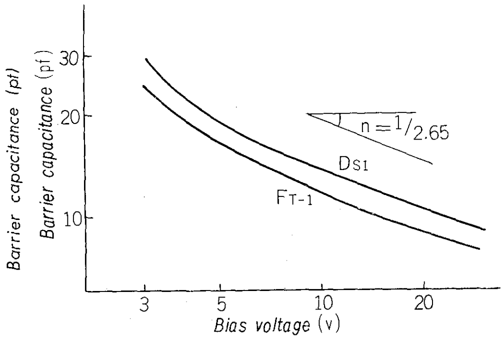


*Fig. 8* Barrier capacitance of DS 1 and FT 1

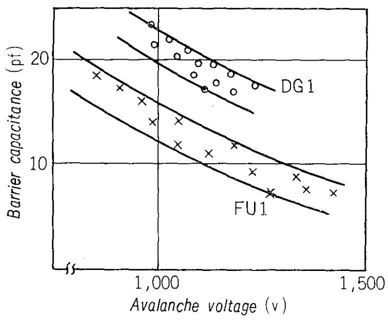


*Fig. 9* Barrier capacitance and avalanche voltage

## 4. Static Capacitance

In silicon diodes, the width of the space charge layer varies according to the reverse voltage and therefore there is a dependence between the static capacitance and the voltage.

The static capacity is also dependent on the avalanche voltage and the specific resistance of the silicon material. The results of measurements of the relation between the capacitance and the avalanche voltage are as shown in *Fig. 9*.

## 5. Thermal Resistance and Transient Thermal Impedance

When silicon diodes are employed, the diode loss and junction temperature influence the life of the diodes considerably. As shown in *Fig. 10,* diode loss develops in the silicon pellet, and the diode case temperature rises due to heat transfer to the case. The heat is dissipated from the case to the atmosphere.

If the ambient temperature is $T_A$, the junction temperature $T_j$ and the loss $Q$, the transient thermal impedance can be expressed as follows:

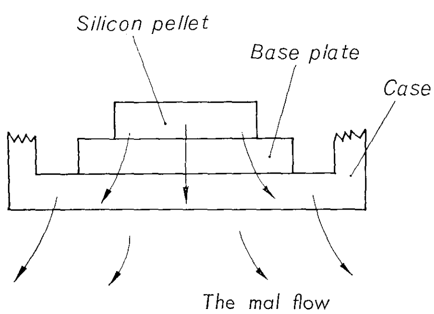


*Fig. 10* Thermal dissipation path

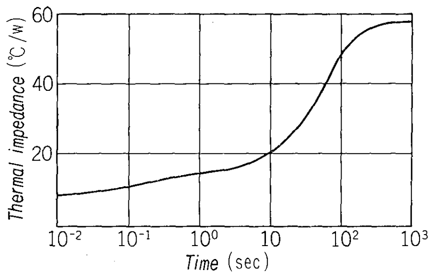


*Fig. 11* Transient thermal impedance of DS 1

$$Z_{th}\ (t)=\frac{T_j(t)-T_A}{Q}$$

The transient thermal impedance for the the DS 1 diode is shown in *Fig. 11.* At thermal equilibrium state, the thermal impedance is constant and is known as the thermal resistance.

$$R_{th}=\frac{T_j-T_A}{Q}$$

The thermal impedance is applied to determination of the relation between the duty cycle and the load current. At Fuji Electric, the thermal impedance is measured as a routine test for all diodes by measurements for 0.3 sec. on an automatic device. In this way, the quality of the soldering between the silicon pellet and the base plate can be determined. *Fig. 12* shows the circuit used for measuring thermal impedance. A current of 6 amp is applied to the diode for 0.3 seconds and the junction temperature rise is measured, using the temperature dependence of the forward characteristics for the junction temperature, comparing with the forward voltage value before and after the current was applied.

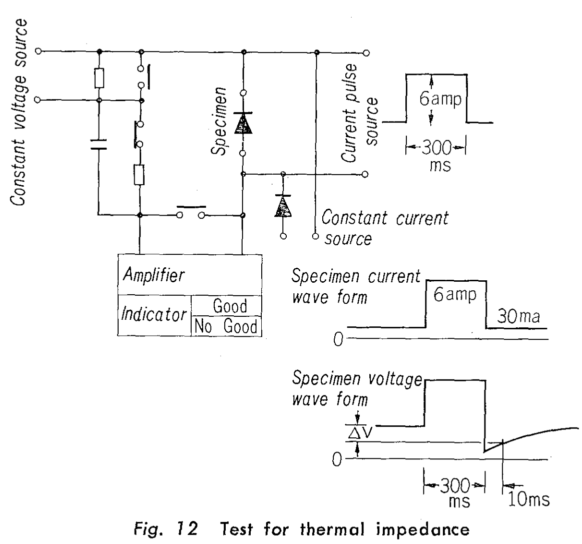


*Fig. 12* Test for thermal impedance

## 6. Temperature Rise

The temperature rise is determined from the thermal resintance discussed in section 5. However, care is necessary since thermal dissipation from the diode differs according to the method of mounting the

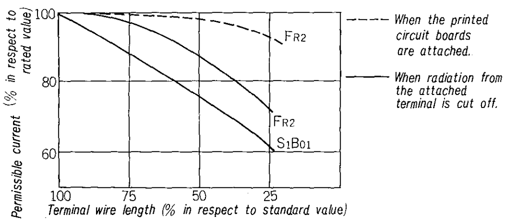


*Fig. 13* **Permissible current and terminal wire length**

diode in the equipment. In silicon diodes which make use of the wire lead for thermal dissipation, the permissible forward current varies according to lead length as shown in *Fig. 13*. Even when the lead is short, the heat dissipated to the body to which the lead is attached has little influence in respect to the magnitude of the current.

## IV. LIFE AND RELIABILITY OF SILICON DIODES

Although there is no substantial wear-out in silicon diodes like that in selenium rectifiers, occasional failure does occur at random when the diodes are in actual use. This random failure depends on voltage and current stress as well as temperature. However, when failure is allowed to occur under a severe artificial environment, this rate can not be used as data to estimate the failure rate under normal conditions. The accelerated test is effective in checking the uniformity of diode quality, but when artificial stress applied to the diode is magnified or the criterion for judging failure is severe, diodes which are able to be used are judged as defective. Therefore, in addition to the accelerated test, Fuji Electric uses a life test for many of its diodes. This latter test is conducted under environment and stress near to that found in practice. A description will be given here of Fuji's experience from the results of the boiling test and the reverse current deviation which appears in the reliability test.

1) Deviation of reverse current

The reliability of silicon diodes is almost entirely dependent on reverse blocking assurance. The reverse current serves as an index for this. Although no problem arises concerning the initial value of the reverse current, there is a problem with deviations in the reverse current during operation and this fluctuation cause a loss in blocking ability.

The various patterns of this reverse current deviation are shown in *Fig. 14* (*a*), (*b*), (*c*), (*d*) and (*e*). The relation between the various causes of this deviation and blocking failure will now be described. When the current flow as in (*a*), the reverse current increases and when the current is cut, the reverse current decreases. This is because a charge is emitted at the surface in the region of the p–n junction due to the recombination energy of the carrier. This charge appears as a surface leakage current and the avalanche phenomenon arises in certain parts of the surface. In this case, even if there is a in-

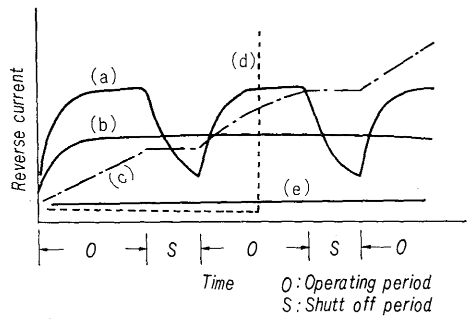


*Fig. 14* **Leakage current change during operation**

crease reverse current, if it is not excessive there is no danger of diode failure. In (*b*), there is ionization in the surface coating layer and this results is few danger of failure. The (*c*) curve shows the case of a substantial change in the surface coating layer which also leads to a greater probability of failure. And as (*d*), even when the reverse current is small or stable, there is a possibility of sudden failure, but this is due mainly to a microvoid spark discharge or an insulation puncture in the surface coating layer caused by a voltage spike etc. during the reliability test. Naturally, many of these causes can be present at the same time and the phenomena then become very complicated.

The ideal is a stable reverse current and a permanent blocking ability but in practice there will be some deviation in the reverse current. However, reverse current deviation is not necessarily linked with failure.

For this reason, Fuji Electric is naturally conducting physical and chemical research into surface phenomena and continuously improving surface treatment. However, to insure high diode reliability, a manufacturing lot test is conducted. For this test, there are three methods : the high temperature storage method, the forward current burden method and the reverse voltage burden method. Of these the reverse voltage burden method gives results which are near to those of the forward current and reverse voltrge burden method under practical application conditions. Therefore, this method is used as a lot. *Fig. 15* shows a comparison of the results obtained with the reverse voltage burden method and the forward current and reverse voltage burden method.

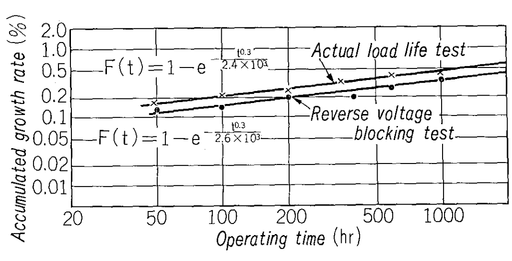


*Fig. 15* **Weibull chart of FR 1 M with leakage current over the limit**

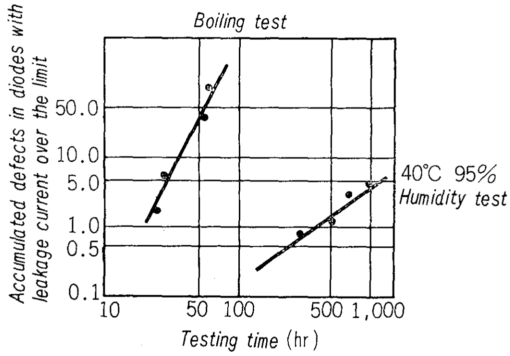


*Fig. 16* Failure in boiling test and humidity test

2) Moisture-proof characteristics and boiling test

Diodes with resin seals have moisture-proof characteristics. However, since it requires a long time to determine moisture proofing, a boiling test is used instead. Since it is sufficient just to check for any seal defects in hermetically sealed diodes, only the boiling test is required but in resin sealed diodes, it is not sufficient to consider only the accelerated test. It is also necessary to determine differences with a defective unit. *Fig. 16* is a Weibull chart showing typical results of the humidity test and the boiling test for a resin sealed silicon diode. The variance in slopes shows that there are differences in respect to defective units. Experience has shown that in practice a diode which shows bad results with the boiling test will not always have bad moistureproof characteristics.

At Fuji Electric the boiling test is often used in pratice and it has become a tentative criterion. However, it is necessary ultimately to store the diode in a highly humid atmosphere similar to that found in actual practice.

## V. RATINGS OF SILICON DIODES

The ratings of silicon diodes are given as values under defined conditions. The ratings for the diodes described in this article were determined after considering the following conditions.

### 1. Repetitive Peak Reverse Voltage

For Fuji Electric diodes, the avalanche point is taken at a reverse voltage slightly high in respect to the working voltage. Therefore, the surge voltage remains within the flat zone of the leakage current as shown in *Fig. 3*. The diode rating is for a repetitive peak voltage ($V_R$) of 1.5 times the working voltage ($V_w$). In this diode a transient peak voltage of 1.5 $V_R$ is permissible. The voltage in case of d-c blocking is set at $V_R/1.5$.

### 2. Mean forward Current

The rated value of the mean forward current is the avarage of a sine half wave of one cycle duration at an ambient temperature of 60°C. Therefore, when the pulse has a current duration of less than 180°, the current must be derated. Since the waveform in high frequency diodes especially often varies considerably from the sine wave, there can be large changes in the switching loss. This means that considerable care is essential in this respect. It is necessary to check the case temperature under practical conditions.

## VI. SILICON DIODES FOR USE IN TV RECEIVERS

Silicon diodes for use in TV circuits are as listed in *Table 1*.

### 1. Normal Diodes for d-c Power Supply

Connections used for d-c power supplies are the single phase bridge connection, single phase center tap connection, voltage doubler connection and single phase half wave connection. The following points must be considered when using these diodes.

1) Cooridination between diode and protective circuit (fuse) during short circuits on the output side.

2) Limiting of capacitor charging rush current during switch closing.

3) Noise due to carrier storage effect.

4) Surge voltage.

Capacitor charging rush current is limited by means

*Table 1* Silicon Diodes Used in TV Receiver

| Type | ※※ Seal | Rated Current (amp) | With-stand Voltage (v) | Application |
|---|---|---|---|---|
| FR 05 | M | 0.4 | 140～1000 | Power supply circuits Preheater circuits |
| FR 1 | M | 0.5 | 50～1000 | Clamp circuit Vertical distortion compensation power supply |
| FR 2 | M | 1.0 | 50～600 | Centering circuit |
| SIBO 1 | M | 1.0 | 50～200 | Demagnetizing circuit |
| SIBO 2 | M | ※ | 50～200 | ※ Center tap connection 1.5 amp |
| SIBO 3 | G | 1.0 | 300～1000 | |
| DS 1 | H | 1.0 | 50～1000 | Bridge connection 1.2 amp |
| DS 2 | H | 1.5 | 140～1000 | |
| FG 2 | M | 1.0 | 140～800 | Damper circuit |
| DG 1 | H | 1.0 | 140～1500 | Clamp circuit |
| SID 23 | H | 1.0 (3.0) | 1000～1500 | |
| FT 05 | M | 0.2 | 140～1000 | Focus circuit video power source |
| FT 1 | M | 0.2 | 140～600 | Brightness circuit Pulse clamp |
| FU 1 | M | 0.2 | 140～600 | Convergence circuit Color recovery circuit |
| ZB 1 | M | 750 mw | 6～300 | Stabilizor power supply Standard voltage circuit Clamp circuit |

※※ M: resin mold seal
H: hermetic seal
G: glass seal

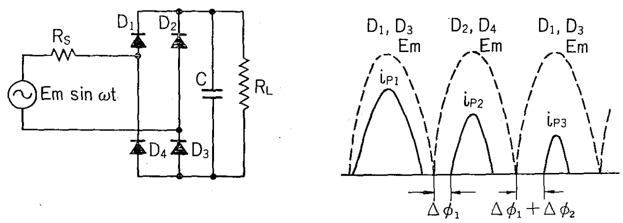


*Fig. 17* Bridge circuit and charging current

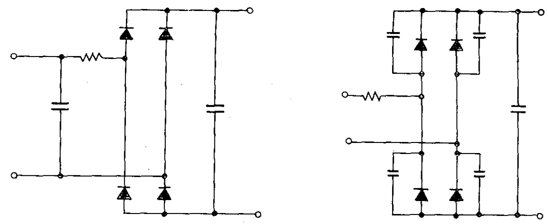

*Fig. 19* Bridge rectifier circuit

of impedance on the a-c side. When the single phase bridge connection as shown in *Fig. 17* is used, rush current whith charges the capacitor during switch closing is approximately as shown in following equation.

$$i_p = \frac{E_m}{R_s}(1-\sin\phi),$$

$$\Delta\phi/\text{cycle} = \frac{1}{\omega CR_s}\left\{2-(\pi-\phi)\tan\phi\right\}$$

$$\therefore i_{p1} = \frac{E_m}{R_s}, \qquad \Delta\phi_1 = \frac{2}{\omega CR_s}$$

$$i_{p2} = \frac{E_m}{R_s}(1-\sin\Delta\phi_1),$$

$$\Delta\phi_2 = \frac{1}{\omega CR_s}\left\{2-(\pi-\Delta\phi_1)\tan\Delta\phi_1\right\}$$

$$i_{p3} = \frac{E_m}{R_s}\left\{1-\sin(\Delta\phi_1+\Delta\phi_2)\right\} \qquad \Delta\phi_3 = \cdots$$

In order to keep the transient temperature rise due to this current within the permissible limit, it is necessary to select the resistance $R_s$ so that the impedance on the power source side is $E_m/(\sqrt{2}\,\text{A})$ (Ω) or over when $C \leq 200\,\mu$f. A is 44 for 1 amp element and 33 for small than 1 amp elements. When diodes $D_1$ and $D_4$ are considered at the moment forward conduction finishes as shown in *Fig. 18*, a reverse current determined by the power source impedance and the voltage $\left[E_0 - e_0 + L\left(\frac{di}{dt}\right)_{t=0}\right]$ flows in $D_1$ and $D_4$ since there in no reverse recovery condition. When a reverse blockage suddenly occurs at $t=t_2$, an induced voltage arises because of the $L$ on the power source side. It becomes necessary to keep this voltage within the element withstand voltage but since radiowave noise or power source noise generally influence the circuits more than the withstand voltage but since radiowave noise or power source noise generally influence the circuits more than the withstand voltage, a capacitor is inserted in the circuit as shown in *Fig. 19*.

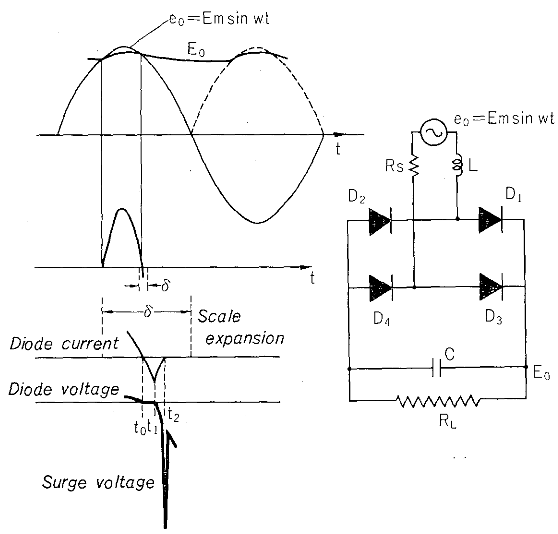


*Fig. 18* Induced voltage at reverse recovery

For protection during faults, a fuse coordinated with the overcurrent characteristic curve of the diode is usually employed.

Other surge voltages arise due to switching of parallel inductive loads, switching of d-c circuits or switching of $L$-type d-c filter circuits. Since these can influence the rectifier circuit no matter whether they are in the circuit itself or other circuits, a thorough study of these voltages is required.

## 2. High Speed Diodes

High speed diodes are used in damper circuits, focus circuits, video source circuits and pulse clamps, but their main use is in 15.57 kHz pulse circuits where they require short reverse recovery characteristics. The relation between the reverse recovery time and the rectifier power when a sine wave power source is rectified is as shown in *Fig. 20*,

In practice, there is though to be no problem when 2–3 μs diodes are used, but at Fuji Electric, two classes of fast recovery diodes, the 2–3 μs class and the 0.2–0.3 μs class, are manufactured. When these diodes are used, a reverse current appears as

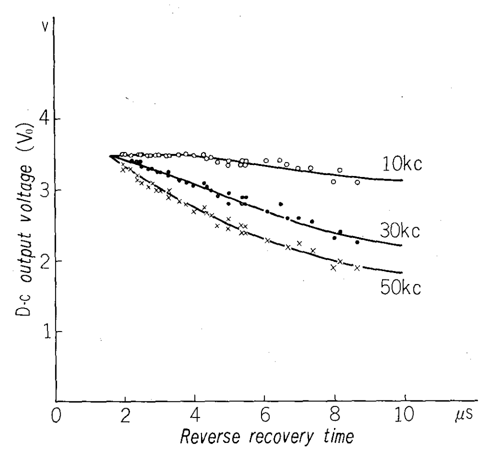


*Fig. 20* Reverse recovery time and rectifier efficiency

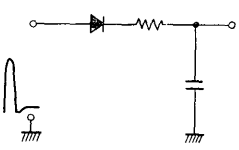

*Fig. 21* Booster rectifier circuit

dynamic noise within the reverse recovery time in addition to the rectification efficiency. Therefore, a resistor is generally inserted in the circuit as shown in *Fig. 21.*

In order to decrease the reverse recovery time in these diodes, gold is dopen in the elements and therefore in the reverse characteristics, the high temperature reverse current increases due to the heat release current. When temperature of 120°C in the 2–3 $\mu$s diodes or 100°C in the 0.2–0.3 $\mu$s diodes are exceeded, the increased reverse loss becomes a problem. Therefore, the permissible temperatures for these diodes must be determined with these points in mind.

1) Diodes for use in damper circuits

The types of silicon diodes for use in damper circuits are the FG 2, DG 1 and SID 23. The FG 2 and DG 1 types are intended mainly for transistor TV sets with B voltage of up to 50 v. The SID 23 type was developed for use with recent line operation and if the magnitude of the current as well as the radiation when attached to the chassis etc. are considered, these diodes can be used with devices up to 3 amp Since the forward current must also be established quickly in damper diodes, the forword recovery characteristics are controlled by a circuit as shown in *Fig. 22.* These forward recovery characteristics are also influenced by the specific resistance and life time of the silicon. The relation required with the barrier capacitance which is also influenced by the specific resistance is as shown in *Fig. 23.* The relation of this with the withstand voltage is as shown in *Fig. 9.* The larger the withstand voltage, the larger the $V_{FP}$ value.

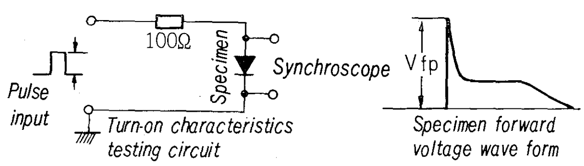


*Fig. 22* Foward recovery test circuit

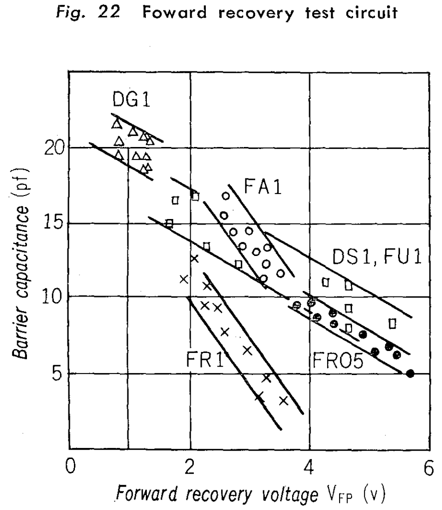


*Fig. 23* Barrier capacitance and forward recovery

Damper diodes require a short reverse recovery time. In addition, an oscillation is also induced for snap-off of the reverse recovery current and therefore Fuji Electric employs a suitable tail off for the reverse recovery.

Snap off characteristic induces a striped noise in the center of the pattern. After forward recovery, circuit oscillation appears separately and at this time, striped noise appears on the left side of the pattern. Since this phenomenon is due to the characteristics of the diodes and the circuit design, a suitable circuit design is necessary for the domping part.

2) Silicon diodes for booster circuits

FT 1 and FU 1 diodes are used mainly for rectifying the outputs of FBT medium and high voltage power sources, pulse clamps etc. The FT 1 is a 2–3 $\mu$s diode and the FU 1 is a 0.2–0.3 $\mu$s diode.

The FU 1 is not only used for rectification of FBT pulses but also recently it has been used as clamper in chromor circuits in MHz circuits.

At present, 1000–1500 v DG 1 diodes are being employed as protective clamps for horizontal output transistors of transistor TV sets using the line operation system.

The diodes used in these circuits can easily influence the spark inside the picture tube and therefore a spark gap must always be provided especially when the rectifier output is connected to the picture tube terminals. The use of a R–C buffer circuit as shown in *Fig. 24* is one method of stabilizing the silicon rectifier elements since it insures sufficient control of the spark voltage in the spark gap and gap time following characteristics.

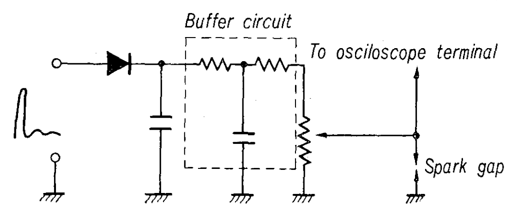


*Fig. 24* Protection method in booster circuit

## 3. Zener Diodes

The item of required characteristics of Zener diodes differ according to the circuit in which they are employed. The characteristics of Zener diodes are as follows:

1) Reverse leak current
2) Zener voltage
3) Temperature dependency of Zener voltage
4) Zener current and dynamic impedance

The dependence of each of these on the Zener voltage is shown in *Figs. 25～27.* Although these

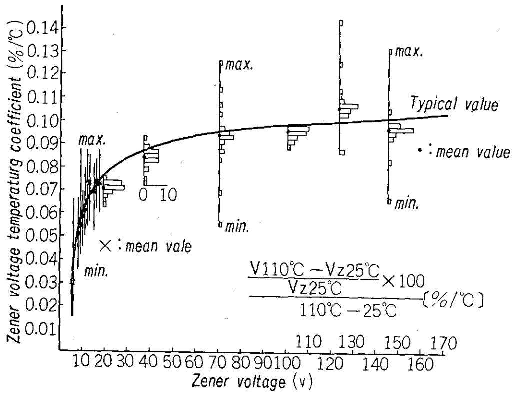


*Fig. 25* **Temperature coefficient of Zener diode**

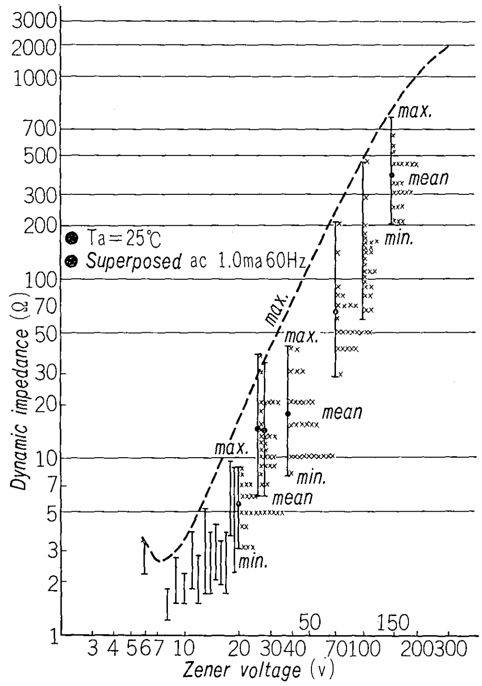


*Fig. 26* **Zener voltage and dynamic impedance**

are generally known as Zener diodes, as was previously described, avalanche characteristics are mainly used in practice and therefore the temperature coefficient is positive. Since the Zener phenomenon and the avalanche phenomenon are mixed in the 13 v region, temperature coefficient has a high dependence in respect to Zener voltage. Fuji Electric has completed Zener diodes of up to 300 v in keeping with the recent changes to high withstand voltages in transistors.

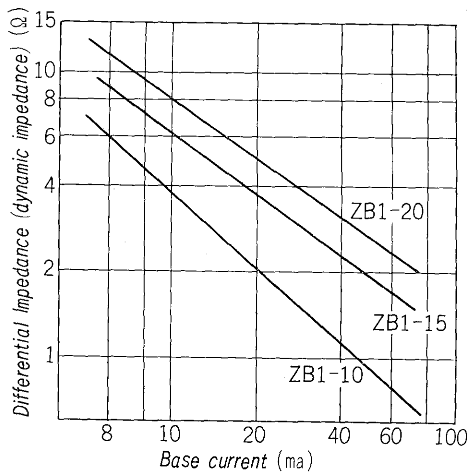


*Fig. 27* **Dynamic impedance and base current**

These diodes are all manufactured by the diffusion method. A special diffusion method is used in diodes of around 6 v and this method gives an extremely thin diffusion depth.

In the Zener diodes of around 6 v the condition of the space charge layer differs in the step junction made by the alloy mathod and the graduated junction made by the diffusion method. Therefore, the the saturated current at voltages below the Zener voltage also varies.

Since Fuji Zener diodes are manufactured by means of the diffusion method, the reverse leak current in Zener diodes of around 6 v is larger than that in diodes made by the alloy method. However, this is something that appears due to the manufacturing method and therefore has nothing to do with stability.

## VII. CONCLUSION

This article has given some of the problem points and characteristics not found in catalogs of silicon rectifier diodes used in TV sets. It is felt that the demand for these diodes will increase steadily in the future and therefore it is hoped that this article will be of some help in making more effective silicon diodes.

At Fuji Electric a systematic development is being carried out by comparing the features of selenium rectifier elements manufactured for use in TV sets. Attempts are being made to develop the most suitable products for use in the various circuits.