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DIODES AND THYRISTORS FOR ELECTRONIC EQUIPMENT

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I. INTRODUCTION

Rapid advancement has been made in all areas of electronics in recent years, from complicated high-performance computers, automatic-control systems, and measuring instruments to mass-produced, lower cost radios, television sets, etc. Whether directly or indirectly, almost all industrial equipment can be linked to advancement made in electronics.

Much of this progress, especially that whthin the last ten years, is largely due to development of semiconductor technology. The many advantageous features of semiconductor elements—their compactness, light weight, high reliability and performance, suitability to mass production, etc.—have caused drastic changes in their applications in electronics.

Fuji Electric experience with semiconductors began twenty years ago with the production of cuprous oxide rectifiers. In 1954, Fuji Electric, under licensed agreement with Siemens of West Germany, imported selenium rectifier engineering and production know-how; selenium-rectifier engineering was highly developed in West Germany at that time. Fuji Electric then produced selenium rectifiers for industrial electrical-power applications.

After much concentrated research and development effort, Fuji Electric succeeded in manufacturing power diodes in 1957, with rated peak reverse voltage 1000 v and rated fowerd current 200 amp, and in manufacturing of thyristors in 1961, which have rated peak reverse and forward voltage 600 v and rated forward current 150 amp.

While producing large-power elements, Fuji Electric also produced medium-and small-power elements for electronic equipment.

Today, Fuji Electric manufactures a large variety of semiconductor elements which have many features and wide usage. Several million semiconductor elements are produced monthly.

II. SELENIUM RECTIFIERS

Selenium rectifiers have many features, for example, highly suitable construction for mass production, resistance to surge current and voltage, and high reliability and are especially advantageous in small-current high-voltage applications. Thus, the demand

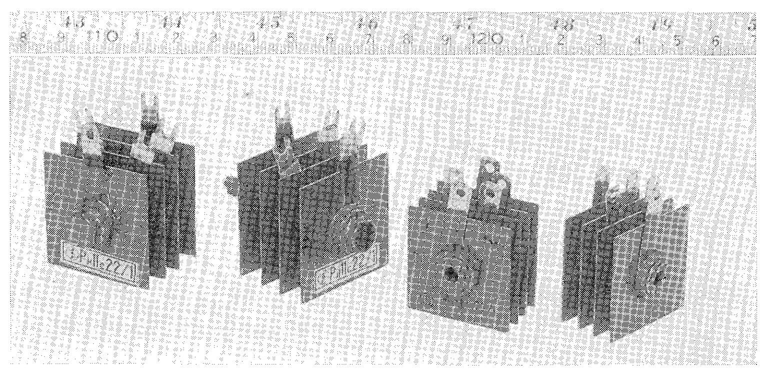


Fig. 1 Standard type selenium rectifiers for transistor television receiver

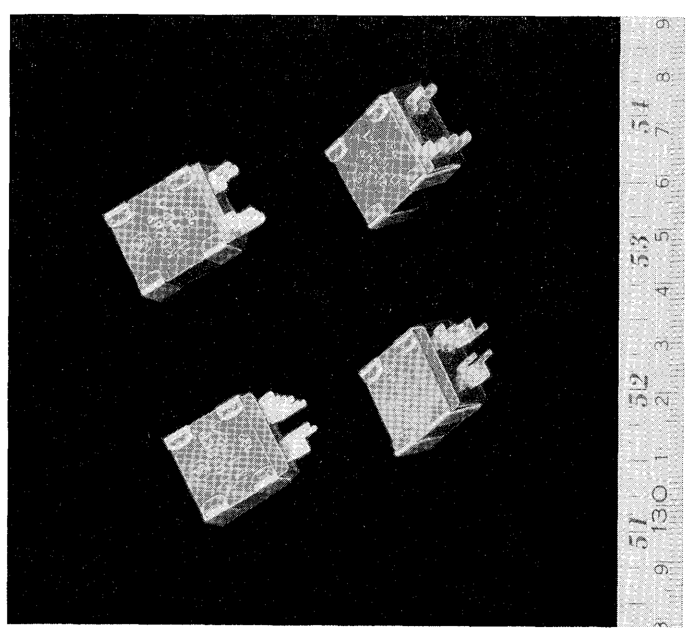


Fig. 2 Flat type selenium rectifiers for convergence circuit

selenium rectifiers has produced a constantly increasing trend in production.

1. Standard-Type Selenium Rectifiers

These selenium rectifier elements have a rated ac input voltage of 25 to 30 v_{eff} and 50 ma/cm^2 to 600 ma/cm^2 (depending on cooling conditions) of output current. By series and parallel connection, rectifier systems with ac inputs of 25 to 1000 v_{eff} and dc outputs of 0.1 to several thousand amperes can be obtained. For electronic applications, elements with dc outputs of 10 to 30 v and 0.5 to 3 amperes are manufactured in large quantity.

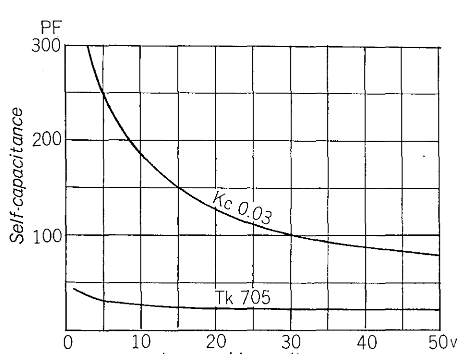
2. Flat-Type Selenium Rectifiers

The construction of these rectifier elements results in excellent heat-conduction characteristics. Therefore, they have extremely small dimensions, and are constructed in such a manner that they can easily be mounted on a chassis or printed circuit board in electronic applications. The dc output range of these elements is from 10∼600 v and 50 ma to 5 amperes, resulting in their wide use in power supply circuits of compact transistor-television sets, transistor-radio sets, and tape recorders.

Table 1 **Ratings and Characteristics of Flat-Type Selenium Rectifiers for Convergence Circuits**

Model	Kc 0.8 cp 11/1+12/1	Kc 1.3 cp 11/1+12/1	Kc 2dp 11/1+12/1
Number of Arms	3	3	3
Peak Inverse Voltage (v peak)	50	50	50
Rated Forward Current (ma mean)	80	115	180
Inverse Leakage ※ Current at 25°C (ma mean)	<0.8	<1.3	<2.0
Forward Voltage Drop at 25°C (v)	<0.88 (forward current 80 ma)	<0.88 (forward current 130 ma)	<0.88 (forward current 200 ma)
Permissible Continuous Selenium Rectifier Cell Temperature (°C)	85	85	85

Note: ※: Inverse leakage current at half-wave sinusoidal inverse voltage of 50 v peak



Kc 0.03: Ordinary selenium rectifier cell
Rectifying area: 0.5 sq mm
Tk 705: Local contact selenium rectifier cell
Rectifying area: 0.5 sq mm

Fig. 3 Self-capacitance of selenium rectifeer cell

Selenium rectifiers are well suited for high-frequency circuit application since they are free from the carrier storage effects found in single crystal semiconductor elements. The only limitation for frequency range is the self-capacitance of the selenium rectifier itself. Under favorable circuit conditions, these rectifiers can be used up to several tens of kilocycles for example, as flat type rectifiers in convergence circuits in color television sets which have standard specifications shown in *Table 1.*

3. Molded-Type Selenium Rectifiers

Selenium rectifiers possess inherent resistance to varying atmospheric conditions, and, can be used unsealed after simple moisture proofing. However, for protection against the effects of adverse atmospheric conditions when used for such applications as given below, rectifier elements are sealed in epoxy resin molds.

1) For use in atmospheres containing chemicals which adversely effect selenium such as mercury vapor, hydrogen sulfide, ammonia gas, etc.

2) In outdoor use or use corresponding to outdoor use (such as in outdoor cubicles) where atmospheric conditions are such that moisture may condense on metallic surfaces. If flat-type selenium rectifiers are used under such conditions, moisture within the rectifier case may lead to corrosion of the rectifier plates. In such case selenium rectifiers must be sealed.

Molded selenium rectifiers are also advantageous from the viewpoint of mechanical strength, of stacks and leads especially for miniature construction. Therefore, where small capacity is concerned, molded selenium rectifiers are used most frequently, next to flat-type rectifiers.

Considerable difficulty arose when selenium rectifiers were used in high-frequency applications, due to the self-capacitance of selenium rectifier plates. The methods to reduce this self-capacitance up until now has been to reduce the surface area of plates to form thin film of paint between selenium and cathode alloys. Neither method proved successful, since reduction in selenium rectifier surface area imposed punching press process limitations and since spraying with paint is disadvantageous from the viewpoint of uniform characteristics as large differences between individual rectifiers exist.

The construction of recently developed local-contact selenium rectifier cells is shown in *Fig. 4.*

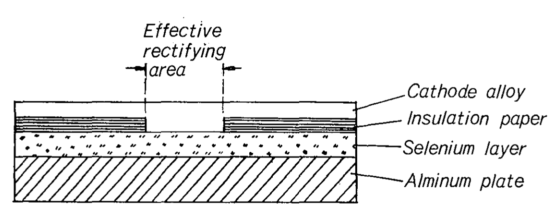


Fig. 4 Construction of local contact selenium rectifier cell

Table 2 **Ratings and Characteristics of Selenium Rectifier for Phase Discriminator**

Model	Tk 705 12/1
Number of Arms	2
Peak Inverse Voltage (v peak)	50
Rated Forward Current (ma mean)	1
Inverse Leakage Current at 25°C (μa)	<2 (inverse voltage 20 v)
Forward Voltag Drop at 25°C (v)	<1 (forward current 200μa)
Self Capacitance (pF)	<35 (inverse bias voltage 20 v) <40 (inverse bias voltage 10 v)
Permissible Continuous Selenium Rectifier Cell Temperature (°C)	85

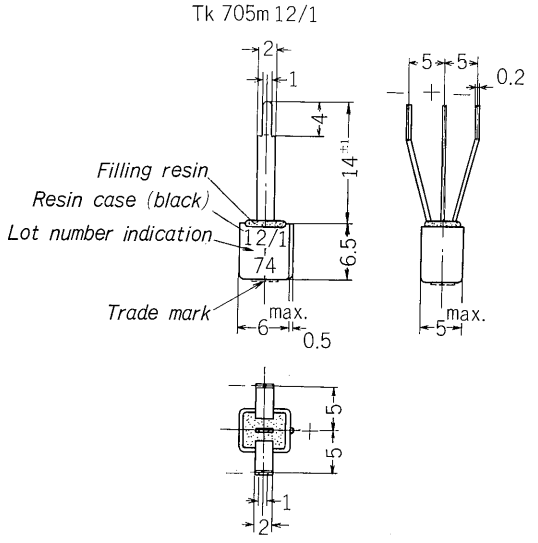


Fig. 5 Molded-type selenium rectifier for phase discriminator

Porous insulating paper with holes approximately 0.8 mm in diameter is bonded on the selenium layer, which is vacuum evaporated onto an aluminum plate. A cathode alloy is then sprayed onto the insulating paper, and a thermal treatment and forming process applied. Three millimeter × three milimeter cells, centered on each hole, are pressed out. Selenium rectifier cells thus obtained have uniform self-capacitance characteristics, forward-direction voltage drops, and allowable reverse voltages. Since self-capacitance and its dependence on voltage are both small, no pronounced variation characteristics result within ranges where reverse bias voltage is small. Selenium rectifier cells of this type are used as AFC circuit elements in television sets, and, compared with germanium diodes hitherto used for such purposes, inverse characteristics of these selenium rectifiers are least affected by temperature. This is an important reason as to why selenium rectifiers are gradually replacing germanium diodes in this application.

4. High-Voltage Selenium Rectifiers

Selenium rectifier elements may be connected in series without voltage dividers. Since these elements are flat, they can easily be laminated. Therefore, although voltage per single element is small, selenium elements are ideally suited for small-current high-voltage rectifier applications. Construction of HS-type high-voltage rectifiers, developed for electronic applications, is shown in *Fig. 6*.

To reduce overall length of laminated rectifier elements, an aluminum plate 100 microns thick is used as a base plate, making the overall thickness including the selenium layer and cathode alloy layer approximately 220 microns. Ratings and characteristics of HS-type high voltage selenium rectifiers are shown in *Table 3*. Although the peak inverse voltage within the permissible temperature range of the selenium rectifier element is assured, in application, it is desired that the design center of peak working voltage is approximately 70% of peak inverse voltage, considering line voltage variation and surge voltage.

Selenium rectifier inverse-voltage characteristics differ according to the wave form and frequency of voltage: flat dc inverse voltage or ac voltage, which has a forward bias period in each cycle. For dc voltage, permissible inverse voltage is reduced to approximately 60～70% of that for 50 cps half-wave

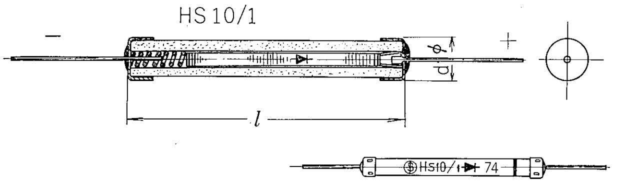


Fig. 6 Construction of HS-type high-voltage selenium rectifier

Table 3 **Ratings and Characteristics of HS-Type High-Voltage Selenium Rectifier**

Model	Peak Inverse Voltage (v)	Rated Forward Current (ma mean)	Inverse Leakage Current (μa mean)	Forward Voltage Drop at 25°C 1.5 ma (v)	Dimensions (see Fig. 6) *l*	d
HS1.5/1	1 500	1.0	<30	< 23	15	4
HS 3/1	3 000	1.0	<30	< 57	21	5.5
HS 5/1	5 000	1.0	<30	< 94	36	5.5
HS 6/1	6 000	1.0	<30	<113	37	6.0
HS 7/1	7 000	1.0	<30	<132	41	6.0
HS 8/1	8 000	1.0	<30	<150	45	6.0
HS 9/1	9 000	1.0	<30	<169	49	6.0
HS 10/1	10,000	1.0	<30	<188	53	6.0
HS 15/1	15,000	1.0	<30	<282	80	7.7
HS 20/1	20,000	1.0	<30	<375	100	7.7
HS 25/1	25,000	1.0	<30	<470	120	7.7
HS 30/1	30,000	1.0	<30	<565	140	7.7

inverse voltage. As the frequency of ac voltage increases, a slight increase in permissible inverse voltage occurs. Taking these facts into consideration, reverse characteristics of high voltage selenium rectifiers are tested in the circuit shown in *Fig. 7*.

As the number of selenium rectifier elements is increased in rectification of high frequency ac voltage unbalanced distribution of inverse voltage occurs and abnormally large voltages may be applied to rectifier elements near the ac terminals, resulting in damage to the elements. The cause of this is as follows: Denoted by C_s (stray capacitance of the selenium rectifier), by C_r (self-capacitance), and by R_r (resistance in the reverse direction), a distributed constant circuit is formed [see *Fig. 8* (*a*)]. For higher frequencies, R_r is negligible and distribution of inverse voltage is determined by C_r and C_s. Since C_r is larger than C_s, the effects of C_s are negligible, provided the number of elements connected in series is small. If a large number of elements are series-connected, however, parallel C_s increases and the effect is not negligible. Considering the inverse voltage component of the ac voltage, a lumped constant circuit will be analyzed and elements will be classified into two groups: dc side rectifier element group and ac side rectifier element group.

Since C_l is sufficiently large as compared with C_R and C_s (assuming the impedance to be zero), the circuit shown in *Fig. 8* (*a*) can be simplified to that shown in *Fig. 8* (*b*). In this circuit, if C_R is not negligible as compared with C_s, voltage applied to the elements in the ac side rectifier group increases.

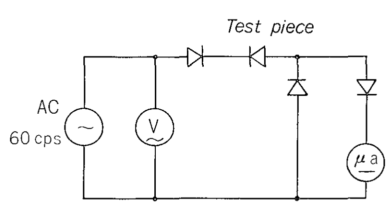


Fig. 7 Test circuit for inverse characteristic of high-voltage selenium rectifier

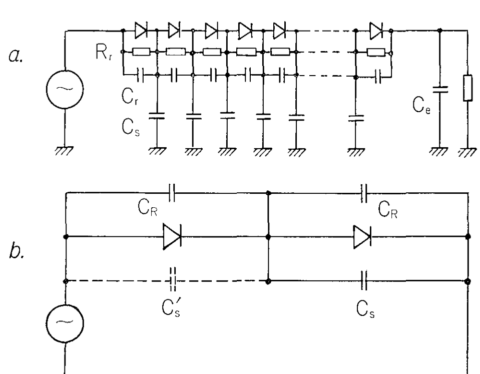


Fig. 8 Equivalent circuit of high-voltage selenium rectifier

By connecting compensating capacitor C_s' as shown by the broken line, compensation can be made. The effect of C_s' can be attained by connecting the shield electrode to the ac terminals. For example, the problem of inverse voltage distribution can be solved with construction such as that shown in *Fig. 9*.

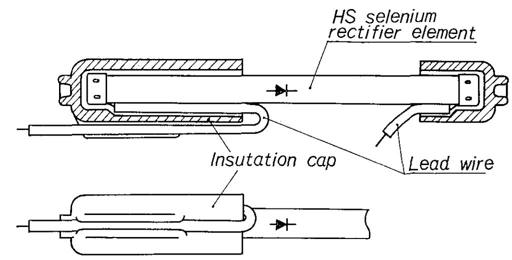


Fig. 9 Construction of high-voltage selenium rectifier with shield electrode

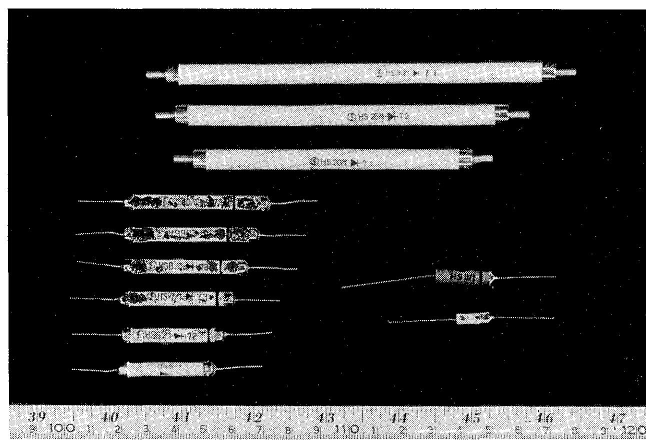


Fig. 10 HS-type high voltage selenium rectifier

III. SILICON DIODES

1. Lead-Type Silicon Diodes

Ratings and characteristics for standardized lead-type silicon power rectifiers are shown in *Table 4*. These silicon-power rectifiers are used in large quantity for a variety of applications. Of vital importance is their reliability, since they are major power-supply components in electric and electronic equipment applications. An example of the failure-rate curve is shown in *Fig. 12*. During the initial failure period, failure occurred due to unstable characteristics of the rectifier element, the result of faulty manufacture. Rectifier-element reliability depends on the degree of quality control during production and the testing process and the degree to which screening for unstable elements is made. Major failures are deterioration of PN-junction surfaces and deterioration of bonding between silicon pellets and bases.

Failures in the chance failure period are such that (although not definitely attributable to the rectifier element itself) rectifier stability is insufficient, or

Table 4 Ratings and Characteristics of Lead-Type Silicon Power Rectifier

Model	FR05	FR1	DS1	DS2
Peak Inverse Voltage (v peak)	140~1200	140~1200	140~1200	140~1200
Rated Ac Input Voltage (v eff)	75~450	75~450	75~450	75~450
Rated Mean Forward Current (amp mean)	0.375	0.5	1.0	1.4
Permissible Half-wave Surge Current (amp peak)	30	40	60	90
Allowable Continuous Temperature of Junction (°C)	−40~120	−40~120	−40~140	−40~140
Weight (g)	0.4	0.7	3.5	3.5
Dimensions	Fig. 11 (a)	Fig. 11 (b)	Fig .11 (c)	Fig. 11 (c)

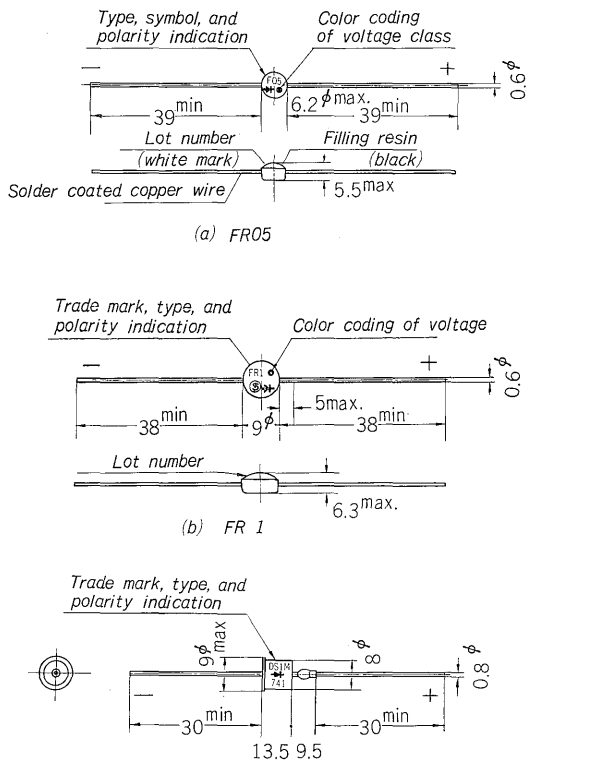


Fig. 11 Lead-type silicon power rectifier

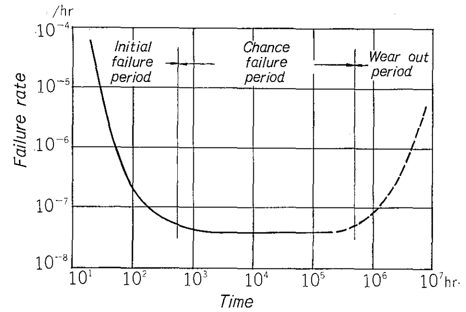


Fig. 12 Procedure of failure rate

rectifiers have inferior overcurrent characteristics, overvoltage characteristics, or high-temperature characteristics. When used under unfavorable conditions, failure becomes apparent. Failures of this type can be attributed to selection of material, design or construction, manufacturing process, conditions of inspection and test, or condition of use. Major causes of failure are those in the initial period and external causes, such as overcurrent and overvoltage.

Failures in the wear out period are due to natural aging of rectifier elements correctly manufactured. These failures or the service life of the rectifier element depends on material from which the element is made and construction. The most probable cause is thermal fatigue in bonded portions between silicon pellets and bases. The service life of low-power silicon rectifiers is extremely long, and, since the area of the silicon pellets is small, thermal fatigue rarely occurs. Their exact service life, however, is not known.

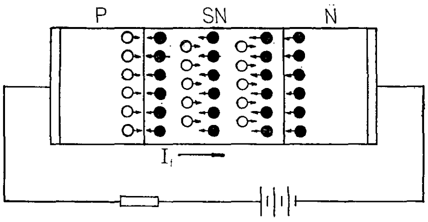
FR05 and FRI are molded resin types. DS1 and DS2 have hermetically sealed construction. In both types, full consideration has been given to design, construction, and selection of materials, and both types have durable construction and sufficient air tightness. PN-junction surfaces of silicon pellets are etched, cleaned through an ultrasonic washing process, and silicon-resin treated for high-voltage resistance and stability. Bonding of electrodes can be securely made since the element is made in such a manner that the alloy layer is prepared with the contact metal on the surface of the silicon pellet before the contact metal is soldered to the base. Where performance characteristics are concerned, the peak permissible inverse voltage and peak permissible surge current have sufficient allowances in respect to working inverse voltage and forward current.

Tests on forward, reverse, overcurrent, and thermal resistance characteristics are made on all individual rectifier elements. Automatic test instruments are employed. Moreover, screening for initial failure is made by a temperature cycle test. Thus, probability of failure during the initial period is as low as 10^{-7}/hr and that during the chance failure period 10^{-8}/hr.

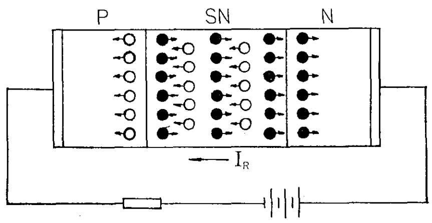
Elements are designed in a manner suitable for mass production, and automatic equipment and testing instruments are employed throughout the production and inspection process, resulting in advantages of economy.

2. High-Speed Silicon Diodes

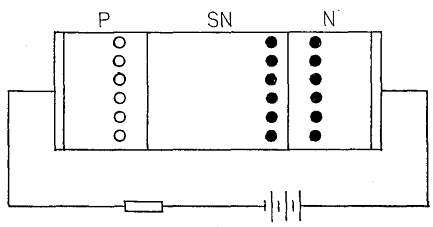
When the silicon diode is conducting, the PN-junction and surrounding areas are filled with positive holes and electrons, and a large forward current flows as shown in *Fig. 13* (*a*). In the inverse blocking state, a carrierless layer (depletion layer) is produced around the PN junction, presenting a high-insulation effect and blocking inverse voltage, as shown in *Fig. 13* (*c*). During the changeover from the conducting state to the blocking state, carriers flow from the PN junction as shown in *Fig. 13* (*b*). Since inverse



(a) Forward conducting state



(b) Transient state (toward conduction to inverse blocking)



(c) Inverse blocking state

Fig. 13 **Inverse recovery phenomena of single crystal semiconductor diode**

Table 5 **Ratings and Characteristics of High-Speed Silicon Diode**

Model	DG1	FT1	FU1
Peak Inverse Voltage (v)	140~600	140~1000	140~600
Rated Mean Forward Current (amp)	1.0	0.2	0.05
Forward Voltage Drop at 25 °C (v)	0.9 (at 2 amp)	1.5 (at 1 amp)	2.5 (at 0.5 amp)
Inverse Leakage Current at 25 °C (μa)	10 (at P.I.V)	10 (at P.I.V.)	10 at P.I.V.
Inverse Recovery Time at 25°C (μs)	4	3	0.3
Application	TV horizontal oscillating damper	TV pulse rectification	TV pulse rectification
Dimensions	Fig. 11 (c)	Fig. 11 (b)	Fig, 11 (b)

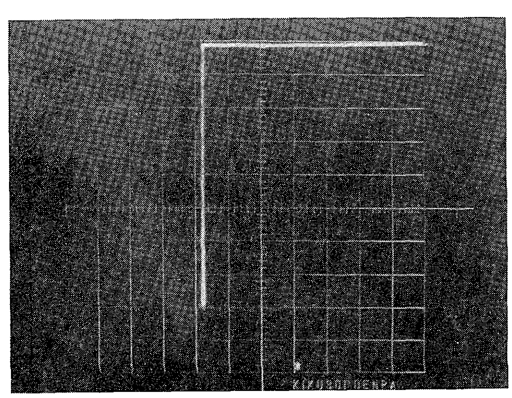
voltage is applied during this state and a large inverse current flows, the blocking effect is lost and large inverse loss is produced. In the process of changeover from the inverse blocking state to the forward conducting state, a period exists, in which the depletion layer extincts and the PN-junction and surrounding area are filled with carriers. In this period, the voltage drop of PN-junction is large and forward-current flow is extremely small.

These transiential periods are called inverse-recovery period and forward-recovery period, respectively. In general, these periods are in the order of several microseconds to approximately 20 microseconds, although they may depend on temperature, forward current, inverse voltage, inverse current, and forward voltage. These periods are short, however, so short that they present no problem whatsoever in rectification of commercial ac-line voltage. Nevertheless, for frequencies higher than several kilocycles (especially in high-frequency pulse-signal rectification in television sets and for damper diodes in horizontal oscillator circuits) such problems as excessive temperature rise and deterioration of rectifying efficiency are encountered. Silicon rectifiers for such applications must be designed in a manner unlike those used for low frequency power rectification. The PN-junction is designed so that the development and extinction periods of the depletion layer are minimized, and impurities are diffused into the silicon single-crystal so that recombination of carriers is accelerated. Ratings and characteristics of high-speed silicon diodes for electronic applications are shown in *Fig. 5*.

3. High-Voltage Silicon Stacks

Much advancement has been made in silicon diodes in recent years, especially in inverse-voltage characteristics, and silicon diodes with permissible inverse voltages up to approximately 3000 volts are economically available. Rectifier elements must be connected in series, however, when larger voltages are required. In the method of connection used up until now, voltage dividers consisting of capacitors and resistors were used for uniform distribution of reverse voltage. This method was particularly disadvantageous because cost and the space that voltage dividers consumed were respectively larger than cost and space for the rectifier elements themselves.

Avalanche diodes have inverse-voltage characteristics as shown in *Fig. 14*, and are not damaged even when substantially large current flow is present in the breakdown region, provided permissible loss is not exceeded. This is a very advantageous feature when using diodes connected in series or in applications where voltage dividers are not used. There is



Axis X : 200 v/div Axis Y : 1 ma/div

Fig. 14 **Inverse characteristic of avalanche diode**

***Table 6* Ratings and Characteristics of High-Voltage Silicon Rectifier Stack**

Model	Peak Inverse Voltage (v)	Rated Peak Working Voltage (v)	Forward Voltage Drop at 25°C 1.5 amp (v)	Rated Average Forward Current (ma)	Inverse Leakage Current at 25°C (μa peak)	Half-Cycle Surge Current (amp peak)	Construction
CFA 4/650	4 000	2 400	4	650	10	25	Fig. 15 (a)
CFA 5/500	5 000	3 000	5	500	10	25	Fig. 15 (a)
CFA 6/450	6 000	3 600	6	450	10	25	Fig. 15 (a)
CFA 7/400	7 000	4 200	7	400	10	25	Fig. 15 (a)
CFA 8/400	8 000	4 800	8	400	10	25	Fig. 15 (a)
BFA 6/900	6 000	3 600	6	900	10	25	Fig. 15 (b)
BFA 7/800	7 000	4 200	7	800	10	25	Fig. 15 (b)
BFA 8/700	8 000	4 800	8	700	10	25	Fig. 15 (b)
BFA 9/650	9 000	5 400	9	650	10	25	Fig. 15 (b)
BFA 10/600	10,000	6 000	10	600	10	25	Fig. 15 (b)
BFA 11/600	11,000	6 600	11	600	10	25	Fig. 15 (b)
BFA 12/550	12,000	7 200	12	550	10	25	Fig. 15 (b)
BFA 13/550	13,000	7 800	13	550	10	25	Fig. 15 (b)
BFA 14/500	14,000	8 400	14	500	10	25	Fig. 15 (b)
BFA 15/500	15,000	9 000	15	500	10	25	Fig. 15 (b)

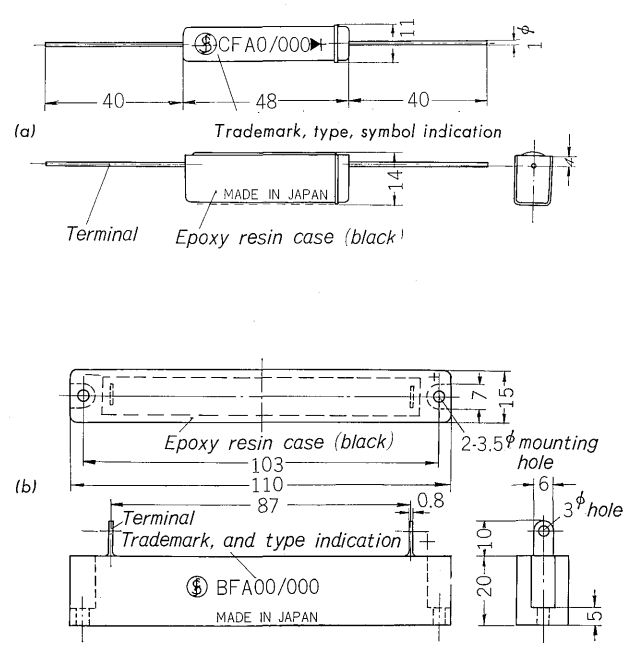


***Fig. 15* High-voltage silicon rectifier stack**

only one drawback, however; that is, the reverse loss or the product of multiplication between avalanche voltage (of each diode, during changeover from the forward conducting state to the reverse cut-off state and during normal inverse-voltage blocking) and inverse current must not exceed the permissible loss.

Although large current flows in the transient state, it flows only for a short time, for example 10 microseconds. Therefore, large loss is permissible and inverse current in the normal state can be made sufficiently small by providing ample allowance between avalanche breakdown voltage of the overall stack and peak value of line voltage. Thus, no substantially large loss is produced. Ratings and characteristics of high-voltage silicon diode stacks are shown in *Table 6*. These diode rectifiers are used in electronic ranges, high-freqaency welders, induction furnaces, high-voltage supply circuitry in transmitters, and in horizontal damper circuitry in television sets.

IV. THYRISTORS

Improvements in the production technique and an increase in demand have resulted in cost reductions which have in turn resulted in greater demand and use of thyristors, not only in expensive electronic applications (where they are used in small quantity, including also control instrument, communication, and electronic computer applications) but in economical, household appliance and automotive applications as well (where they are used in large quantity).

In our thyristors GTD 02, so-called compression bonding techniques are used instead of customary soft soldering. In this technique the copper base and silicon pellet are forced together by spring with an interposed thin silver plate. As described previously, two major factors largely affecting semiconductor element reliability are deterioration of PN junction surfaces and deterioration of bonding between base and element. For several years, Fuji Electric has used the compression bonding technique for large-power silicon rectifiers. The technique has proven to be very effective in improving reliability, primarily because it eliminates surface etching (after base bonding) which can result in adhesion of metallic ions around the PN junction surface, makes unnecessary the use of soldering flux after the PN junction has been formed, and does away with exposing the silicon pellet to temperatures exceeding the permissible limit.

Table 7 **Ratings and Characteristics of Thyristor GTD 02**

Model	GTD 02-01	GTD 02-03	GTD 02-06	GTD 02-09
Peak Inverse Voltage (v)	100	300	600	900
Peak Forward Voltage (v)	100	300	600	900
Rated Average Forward Current (amp)	5			
Forward/Inverse Leakage Current (ma peak)	≤ 2			
Forward Voltage Drop (v)	≤ 1.6 (25°C 15 amp)			
Holding Current (ma)	$\leq$ 120 (25°C)			
Permissible overcurrent (one cycle) (amp peak)	140 (under rated load conditions)			
$I^2 \cdot t$ Limit Value ($A^2 \cdot S$)	70 (under rated load conditions)			
Gate Trigger Current (ma)	≤ 60 (25°C)	≤ 75 (−10°C)		
Gate Trigger Voltage (v)	≥ 0.2 (125°C)	≤ 3.0 (−10°C)		
Permissible Gate Loss (w)	0.5			
Permissible Peak Gate Current (amp)	2			
Permissible Gate Inverse Voltage (v)	2			

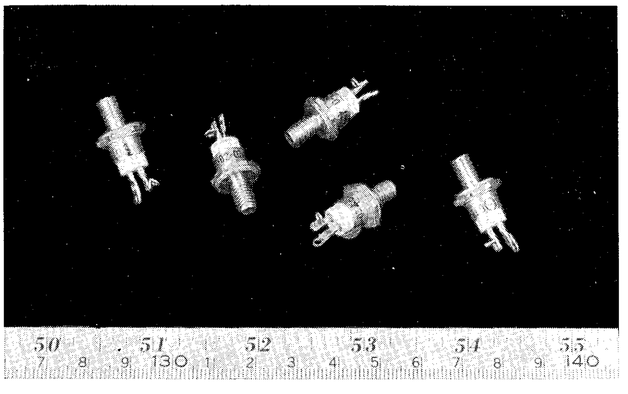


Fig. 16 Thyristor GTD 02

Since the pellet is separately etched, cleaned, surface-processed, and then mechanically pressed to establish contact, excellent PN-junction surfaces are easily obtained. This method also reduces initial-period failures, as it eliminates non-uniformity of thermal-resistance between silicon pellet and base, and, as might be expected, it solves the problem of thermal fatigue of soft solder due to differences in thermal-expansion coefficient between the copper base and molybdenum base plate.

As compared with the diode, the thyristor is basically a switching element. The compression bonding system is emplyed for GTD 02, as it is used under more frequent temperature-cycle conditions and as silicon pellets are comparatively large in respect to capacity (since a gate electrode is incorporated).

Other features of GTD 02 is its resistance to high voltage (up to 900 volts) and its large forward current capacity (as large as 5 amperes) even though it is compact in size. Thus, these thyristors are widely used. They have successfully passed switching applications in electronic computers, electric tools, speed control in sewing machines, voltage regulators in stereo radio receiver sets, and color television sets, contactless switching in automobile ignition circuitry, temperature control in heaters, and lighting control systems.

V. SUMMARY

An outline of semiconductors manufactured by Fuji Electric over the past several years for electronic equipment applications has been given in the foregoing paragraphs. Factors regarded above all others in the development of these semiconductor elements were production costs and operational reliability. It is, of course, desirable that semiconductor elements for electronic applications be compact and light, with good performance characteristics. However excellent semiconductor elements may be in these features, they are not ready for use commercially unless they also meet required levels in cost and reliability. The reason for this is clearly seen when considering the large number of circuit elements in electronic equipment, when considering the fact that laymen as well as persons with electric and electronic engineering backgrounds use this equipment for various applications, and lastly when considering that low cost is an indispensable requirement for greater demand. On the other hand, there is an inherent belief relative to electronic devices that, once made available commercially, huge demands and mass production result as a matter of course.

Some precious and semi-precious materials (single-crystal silicon, gold, and molybdenum) go into the making of semiconductors. However, the necessary quantity of these materials is relatively small, and represents only a small fraction of the total production cost of semiconductor elements. The larger and more important factors to be considered are processing costs and yield rate. The production cost itself is largely reduced when elements are mass-produced through rationalization and automation.

Advancements in semiconductor techniques are still being made. Studies to improve elements currently available, studies to develop new-type elements, and studies to improve production techniques and lead to the uniform mass-production of elements are being relentlessly pursued. In the future, semiconductors are expected to play an even greater role in electronics than they play today.