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FUJI HIGH POWER HIGH VOLTAGE RECTIFIER DIODES

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I. INTRODUCTION

In the field of high power silicon rectifier diodes, rectifier systems with diodes having current capacities of 200∼300 amp and reverse blocking voltages of 1200∼1400 v have been widely used up to the present for rolling stock, railway substations and chemical applications. However, because recent progress has lead to increase in the current capacity of unit cells, higher reliability and improved system construction methods, small, lightweight systems are now possible. In the past, Fuji Electric has manufactured a large number of power rectifier diodes including the 3000 v, 800/500 amp flat packaged rectifie rdiodes (KSPO3–30, KSNO3–30) and the 3000 v, 280 amp stud type (pressure contact) rectifier diode (SINO3–30) based on practical experience and new techniques. These diodes have already been used in actual systems. Since the diodes combine with our superior junction design, manufacturing techniques, and diode construction techniques, their high reliability and high performance has been verified by practical operation results. This article introduce the junction design, manufacturing techniques and diode construction techniques employed in these high power, high voltage rectifier diodes.

II. DIODE CONSTRUCTION

1. Diode Manufacturing Techniques

The manufacturing process of the diffused and alloyed type diode used in both the KSNO3, KSPO3 and SINO3 types is shown in *Table 1.*

Compared with the previous Si 250–3 diode, the high resistivity base region width W is larger. This was determined in consideration of the forward voltage drop. *Fig. 1* shows the relation between W (between p^+ and n^+ regions), a carrier diffusion length L of the zone and a the forward voltage drop v. As can be seen in the drawing, when $L \geqq 300\ \mu$, the forward voltage drop is nearly independent on L at the 300∼500 μ base widths commonly used in high voltage rectifiers above the 3000 v class. Considering this, L is maintained above 300 μ after diffusion by employing very strict process control. The resulting forward voltage drop unbalance is very small. Typical forward characteristics of the KSPO3, KSNO3 and SINO3 diodes are shown in *Fig. 2.* These diodes were designed so that a high avalanche

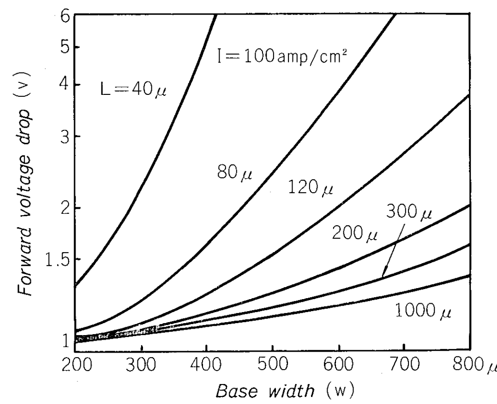


Fig. 1 **Relationship between base width and forward voltage drop**

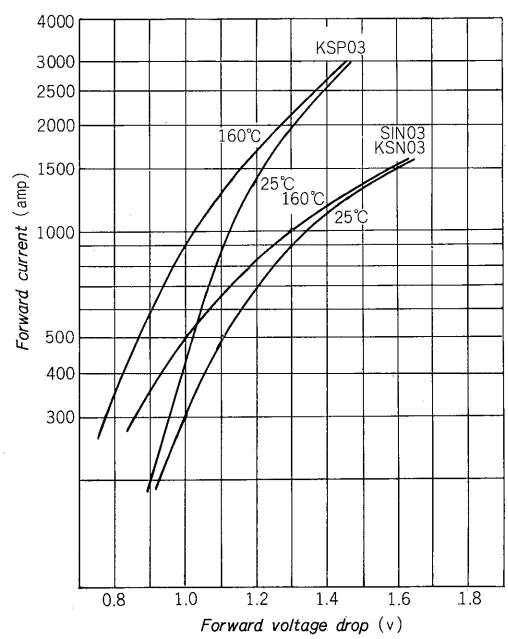


Fig. 2 **Forward characterristics**

Table 1 **Manufacturing process**

n type Si crystall slicing and lapping
↓
Ⅲ Impurity diffusion : pnp wafer
↓
Lapping : pn wafer
↓
Alloying, forming ohmic contact
↓
Surface Bevel lapping
↓
Etching, surface treatment
↓
Mounting
↓
Encapsulation

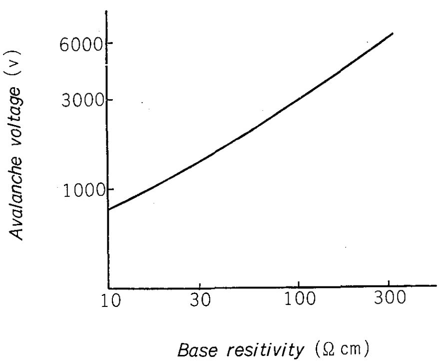


Fig. 3 **Relationship between base resistivity and avalanche voltage**

breakdown voltage appears at a narrow base widths and low resistivity is achieved by making the doping concentration gradient of the diffused junction very gradual. This is very important in achieving high yield, economic production of high voltage diodes in which the blocking and conducting characteristics are balanced. It is easy to manufacture not only 3000 v diodes with a long lifetime after diffusion but also higher voltage diodes for any requirements. The relationship between the avalanche breakdown voltage and the base resistivity at the Fuji Electric diffused junction diodes is shown in *Fig. 3*.

For the reverse characteristics of these diodes, it is necessary to consider the above-mentioned avalanche breakdown voltage and also the pn junction bulk and surface leakage current. The bulk leakage current is almost uniform throughout the junction and the smaller the rate of carrier generation G in the space charge layer, the less it becomes. Diffusion with the above-mentioned gradual doping concentration gradient allows for uniformity and it is easy to reproduce junctions with only slight influence due to the precipitation of impurities. In order to insure a long lifetime, G is kept small and the leakage current is also kept low up to the point where the avalanche breakdown voltage is reached as shown in *Fig. 4*. To achieve such reverse characteristics, it is naturally essential to carry out a more extensive investigation into the treatment of the junction surface. This investigation into addition agents for surface protection, methods of cleaning by etching, the shape of the surface etc. In the KSPO3 and other such diodes, bevel construction is adopted in order to

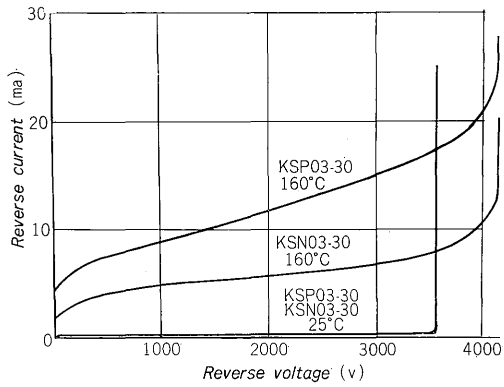


Fig. 4 **Reverse characteristics (KSPO3, KSNO3)**

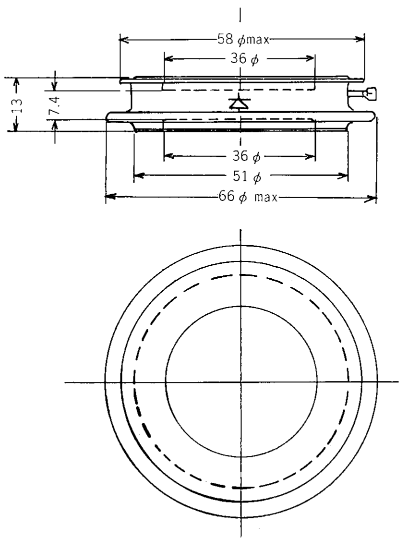
eliminate leakage current due to ionization multiplication in the surface by reducing the electric field density of the junction surface. For cleansing by etching, a special process is used in which the alloyed anode electrode metals are not adhered to the junction surface by rendering it in the etching solution. In this way contamination which is very closely connected with high voltage diode reliabilty is essentially eliminated in the manufacturing of these diodes. When operation is carried out at high voltages, discharge along the surface develops between the anode and cathode electrodes of the diode, the insulation functions of the surface protection material are lowered and deterioration results from the above-mentioned semiconductor junction surface phenomenon. Therefore a sufficient safety factor was provided by adopting the results of detailed voltage life tests carried out in respect to the above points over a long period.

2. Diode Construction

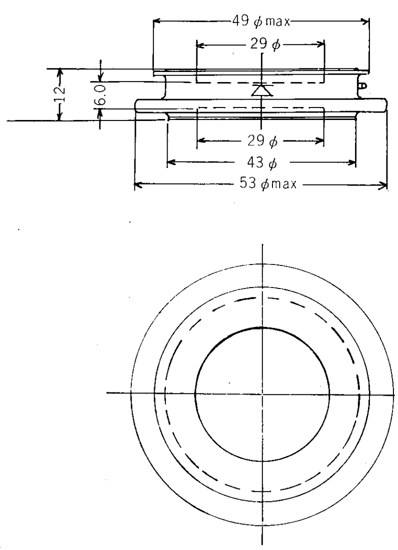
The construction and view of the KSPO3 and KSNO3 diodes are shown in *Fig. 5* and *6*, while those of the SINO3 diode are shown in *Figs. 7* and *8*. The KS type is of the flat-packaged construction and the SI type employs the pressure contact stud type construction. The flat packaged type is the most appropriate for large capacity and high power type diodes. As can be seen from the figure, the diode is extremely small. The SINO3 is of almost the same construction as the Fuji Electric Si 250–3 power diode but since it is a high power diode, it employs a ceramic piece with creases which lengthens the insulation length along the surface. These two types of diodes have the following features in addition to the above-mentioned element.

1) Large capacity because of the pressure contact type construction

If the diameter of the element used to increase the capacity of the single diode units is large, the thermal stress in the element can also become large. During large currents, a problem can arise in respect to the forward characteristics depending on whether the element contact parts are satisfactory or not,

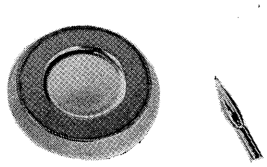


(a) KSPO 3



(b) KSNO 3

Fig. 5 **Outline view of rectifier diodes KSPO3, KSNO3**



(a) KSPO 3)

(b) KSNO 3)

Fig. 6 **Rectifier diodes KSPO3, KSNO3**

and also in respect to the cooling effect, i.e. the thermal resistance between the junction and case. These problems are completely eliminated in the pressure contact type construction and by keeping

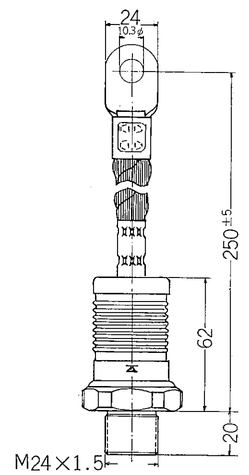


Fig. 7 **Outline view of rectifier diode SINO3**

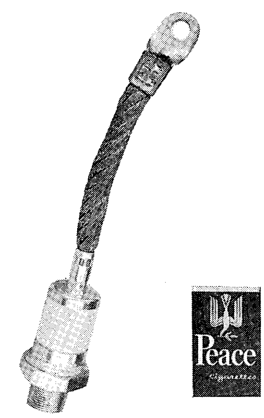


Fig. 8 **Stud-type rectifier diode**

deviation of the above mentioned element forward characteristics low. The characteristics and reliability are improved when the capacity is increased.

2) Decrease in internal thermal resistivity because of dual side dissipation constructon

In the KS type diodes, sufficient current burden capacity of the element is achieved with the flat packaged type construction without any restrictions on capacity due to diode assembly construction. In this respect, special consideration has also been given to the treatment of the contact part materials in order to make the most of the advantages arising from the pressure contact type construction. In this way, there is more freedom of choice in the type of cooling system and the rectifier construction and the equipment becomes easy to employ in various applications.

3) Insulation

As can be seen from the figure, the stud-type diode employs a ceramic piece with creases, while the flat packaged type diode uses a ceramic ring which extends around the surface and allows for more than sufficient insulation length along the diode surface. In the diode interior, the above mentioned element material with the specially treated surface and the internal construction materials and dimensions allow for ample safety.

4) Elimination of element surface contamination.

In high voltage diodes, the stability of the reverse characteristics can be affected especially by the operation and the atmosphere in the casing and the method of surface treatment used for the element.

In the pressure contact type diodes, the element is completely surface treated and encapsulated in an atomosphere with controlled purity without contamination of other materials by brazing etc. Therefore, since an element with surface protection treatment in a purified atmosphere is encapsulated without any futher factors which could cause deterioration of the characteristics, the reliability of the finished diode is extremely high.

III. DIODE CHARACTERISTICS

1) Ratings and characteristics

The ratings and characteristics of the 3000 v, 800 amp flat-packaged-type KSPO3–30, the 3000 v, 500 amp flatpackaged-type KSNO3–30, and the 3000 v, 280 amp stud-type rectifier diodes are shown in *Table 2*. The overload characteristics for those three diodes when overcurrent flows for a time previously specified according to the rated load conditions and no-load conditions are shown in *Figs. 9, 10* and *11*.

2) Reliability tests

(1) Voltage life test

The reverse characteristics stability of high voltage rectifier diodes is the most important thing which determines the diode reliability. One of the tests to confirm this stability is the voltage life test in which the specified reverse voltage is applied to the diode at high temperatures. This test is performed on a large number of diodes over a long period of time and no traces of diode deterioration in the from of leakage current increases or variations are found. The reverse

Table 2 Ratings and Characteristics of Rectifier Diodes KSPO3-30, KSNO3-30 and SINO3-30

	Terms		KSPO3-30	KSNO3-30	SINO3-30
1	Maximum Peak Reverse Voltage	V_{RO}	3000 v	3000 v	3000 v
2	Transient Peak Reverse Voltage	V_{Rt}	3300 v	3300 v	3300 v
3	Forward Voltage Drop	V_F	≦1.65 v 25°C, 2500 amp	≦1.8 v 25°C, 1500 amp	≦1.8 v 25°C, 1500 amp
4	Rated Average Forward Current (Single phase sinusoidal half-wave connection)	I_F	800 amp T_C=110°C	500 amp T_C=100°C	280 amp T_C=100°C
5	Reverse Current	I_{RO}	≦8ma (25°C) ≦50 ma (160°C)	≦5ma (25°C) ≦30 ma (160°C)	≦5ma (25°C) ≦30 ma (160°C)
6	Surge Current (60Hz)	I_S	12,500 amp (1 cycle)	7500 amp (1 cycle)	7500 amp (1 cycle)
7	I^2t Value	I^2t	700,000 amp²-S	230,000 amp²-S	230,000 amp²-S
8	Maximum Allowable Frequency		≦2000 Hz	≦2000 Hz	≦2000 Hz
9	Allowable Junction Temperature	T_j	−40~160°C	−40~160°C	−40~160°C
10	Thermal Resistance (betw. junction and base)	R_{th}	≦0.04°C/w	≦0.06°C/w	≦0.14°C/w
11	Weight of Element		ca 120 g	ca 80 g	ca 550 g
12	Screw		—	—	M24×1.5 E41
13	Tightening Torque or Pressure		1000±100 kg	550±50 kg	6 kg-m

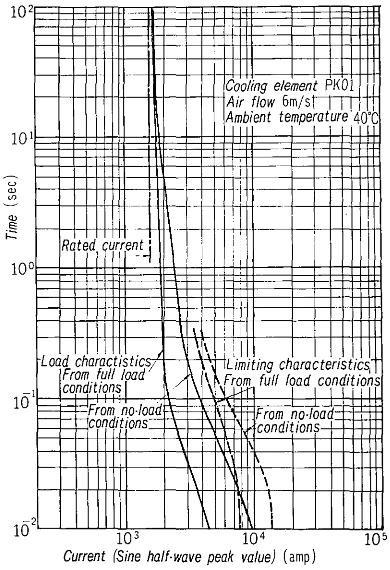


Fig. 9 Relationship between overcurrent and time (KSNO3)

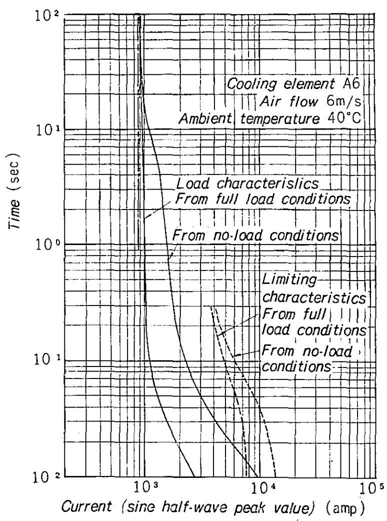


Fig. 10 Relationship between overcurrent and time (SINO3)

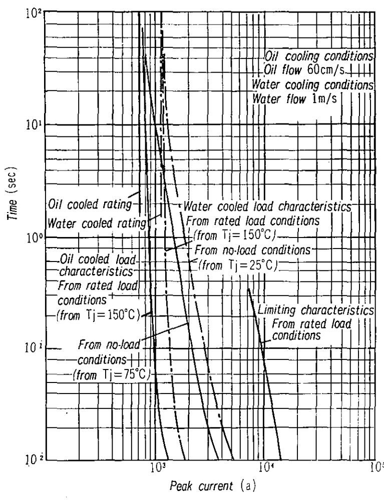


Fig. 11 Relationship between overcurrent and time (KSPO3)

characteristics can therefore be consisdered stable. The results of the voltage life test for the KSPO3 diode are given in *Fig. 12*.

(2) Temperature storage test

The diodes are stored for a long period at the maximum permissible junction temperature. The reverse characteristics are considered as good es-

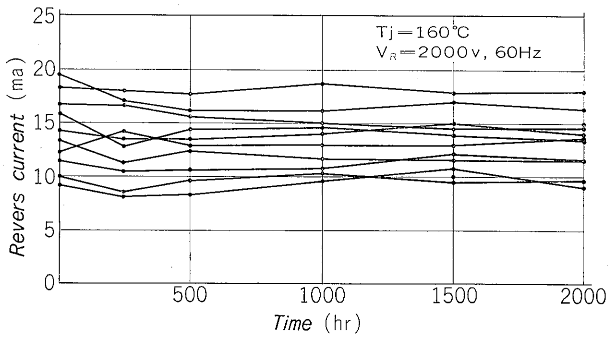


Fig. 12 Example of voltage life test

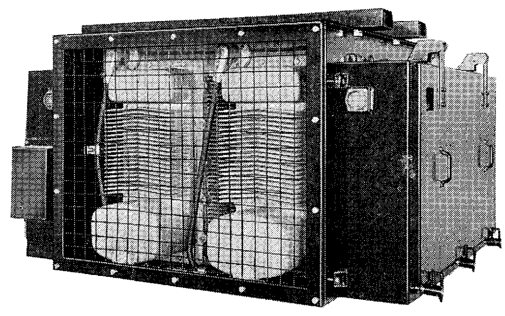


Fig. 15 Rectifier set of electric car

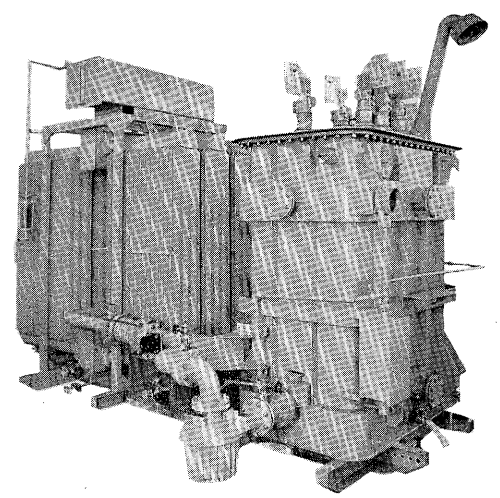


Fig. 13 Forced oil self-cooled silicon rectifier

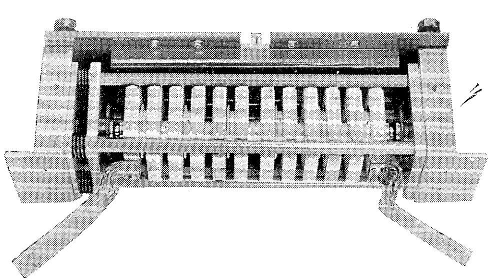


Fig. 14 Rectifier stack

pecially at high temperatures since there are no variations in the overall characteristics before and after storage.

(3) Equivalent load test

The diode is tested over a long period with an equivalent load test system which exhibits the actual load conditions and the equivalent effect by switching over other half cycle with low voltage high current source and a high voltage low current source. The results of this test show that there are no variations in any of the characteristics and excellent performance is obtained.

(4) Others

Besides the heat cycle test and the intermittent load test, mechanical vibration and shock tests were carried out, but no problems arose in respect to characteristics or construction.

The results of all of the above reliability test confirm that these high power high voltage rectifier diodes have a reliability greater than the previous power diodes. When these diodes are mass produced, all of the reliability tests are carried out by screening at the final stage of production. The Tests are carried out with the appropriate reliability test conditions for the specified times and high reliability is thus assured.

IV. RECTIFIERS EMPLOYING HIGH VOLTAGE RECTIFIER DIODES

The KSPO3–30 is employed in silicon recifier systems for railway dc substations. Forced oil self cooled systems with ratings of 1500 v, 3000 (3S4P6A) /4000 kw (3S6P6A) have been completed. (*Figs. 13* and *14*). Forced oil air cooled silicon rectifier systems with ratings of 1660 v, 980 amp (continuous), 1500 amp (8 min) are manufactured for rolling stock. This system employs 60 KSNO3–30 diodes in a single phase bridge (*Fig. 15*).

V. CONCLUSION

These high voltage high power rectifier diodes have been mass produced for some time, and up until now have shown excellent reliability in the field of power diodes. The diodes exhibit revolutionary new characteristics and construction because of improvements in the level of Fuji Electric's diode design and construction techniques combined with the pressure-contact and flat-packaged types of construction. Problems concerning large increases in the capacity of the diodes have been overcome by strict quality control in respect to the selection of component materials and careful selection of design and production. Since the diodes are used only in systems with feature compactness, light weight and easy maintenance, the reliability demanded of these diodes is extremely high. Fuji Electric has solved all these problems and is now manufacturing high voltage diodes with large capacities. The characteristics and actual applications of the KSPO3, KSNO3 and SINO3 diodes prove that they have reached the highest international levels.