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6,000 V HIGH VOLTAGE RECTIFIER DIODES

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I. INTRODUCTION

The large capacity high voltage diodes manufactured previously by Fuji Electric were the 3,000 V 800 A disk-type KSPO3 and the 4,000 V 300 A stud-type SINO3-40 rectifier diodes.

After the further investigations of the blocking capability, a 6,000 V 700 A diode has been developed, and the manufacturing techniques have been established. Exceptional progress has also been made in recent years in improving the blocking voltage of power rectifier diodes and thyristors, and Fuji Electric has succeeded in raising the blocking voltage by the use of design techniques and fabrication techniques such as manufacturing methods and surface treatments based on new ideas. This diode possesses the same excellent characteristics as other Fuji Electric power diodes and is suitable for application to high voltage power sources in chemical plants, rolling stock and railway substations.

This article presents the construction and characteristics of this diode and describes the problems encountered during the development.

II. CONSTRUCTION AND CHARACTERISTICS OF DIODES

1. Construction

These diodes employ the pressure contact disk-type, which is believed to be most appropriate for large capacity devices. *Fig. 1* and *2* show the outer view and external dimensions of these diodes respectively. As can be seen from the figure, the ceramic part of the case is arranged in a double fold and

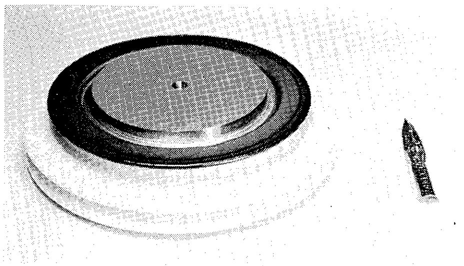


Fig. 1 Outer view of 6,000 V rectifier diode

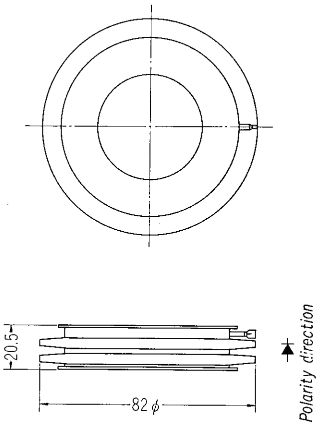


Fig. 2 Size of 6,000 V rectifier diode

the VDE standards are considered to be satisfied.

The disk type construction has already proven itself in other rectifier diodes and thyristors. Careful consideration has been given to the treatment and quality of contact materials of the case were studied in respect to their influence on the heat cycle, thermal resistance and forward voltage drop. The manufacturing procedures were established so that the flatness and parallelism of the contact parts is kept under good condition.

2. Characteristics

Fig. 3 and *4* show the forward and reverse charac-

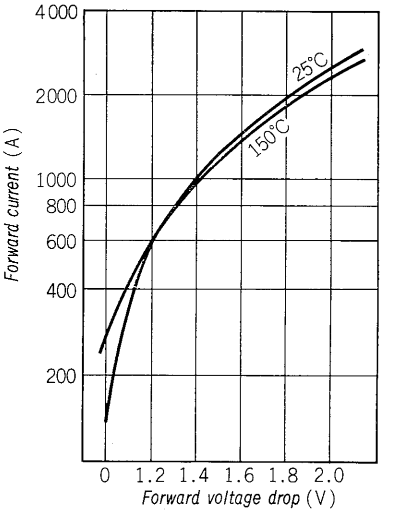


Fig. 3 Forward characteristics

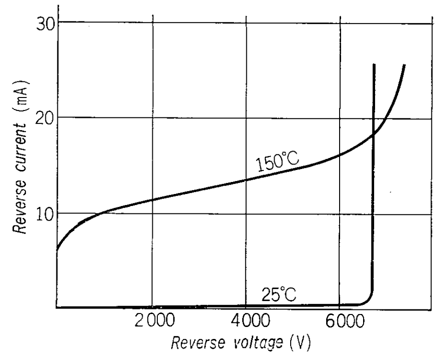


Fig. 4 Reverse characteristics

Table 1 **Ratings and characteristics**

Item	Symbol	
Repetitive peak reverse voltage	V_{R0}	6,000 V
Non repetitive peak reverse voltage	V_{Rt}	6,600 V
Forward voltage drop	V_F	≦1.9 V T=25°C 2,200 A
Average forward current	I_F	700 A
Peak reverse blocking current	I_{R0}	≦5 mA (25°C) ≦50 mA (150°C)
Peak one cycle surge forward current	I_S	10,000 A (60 Hz 1 cycle)
Maximum allowable operating frequency		≦2,000 Hz
Operating temperature	T_i	−40∼+150°C
Effective thermal resistance (junction to sink)	R_{th}	≦0.04 deg/W
Storage temperature	T_{stg}	−40∼+150°C
Mounting force required		1,000±100 kg

teristics of the diode respectively. The reverse characteristics show the so called avalanche characteristics and avalanche voltage at 150°C is higher than that at room temperature. *Table 1* lists the ratings and characteristics of this diode.

3. Reliability

The results of the equivalent load test, the temperature storage test and the voltage life test, all of which are important in determing the reliability of the reverse characteristics, were excellent and no changes in leakage current were observed. Variations in leakage current, forward voltage drop and thermal resistance were extremely small in life tests such as long intermittent load test and heat cycle tests (12,000 times).

All tests were carried out with ordinary methods. For example, the heat cycle test was carried out by means of the standard circuit (JES 178) as shown in *Fig. 5*. After sinusoidal half-wave current with an average value equal to the average forward current has flown in the element until the rated temperature is reached, the current is interrupted and the case temperature is reduced to a value of 50°C or less. This constitutes one cycle of the test.

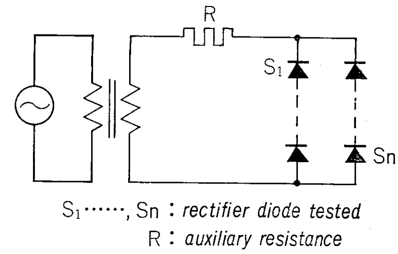


Fig. 5 Heat cycle test circuit

III. PLOBLEMS IN RAISING THE BLOCKING VOLTAGE

All of the elements used in the KSPO3[1], KSNO3 and SINO3 diodes are the diffusion-alloy type but this diode, our newly developed one, is the all diffusion type which has enable to control the surface shape and surface treatment very easily. That is, all of the junctions which consists p^+nn^+ structure were formed with diffusion process. Generally speaking, resistivity of the *n* layer must be large and the *n* layer must be wide in order to achieve high blocking voltage[2]. However, when the width of the *n* layer is increased, the forward voltage drop increases and for this reason the silicon thickness must be as thin as possible.

When designing the diode, essential factors were the selection of resistivity of silicon as well as the silicon thickness. When developing a large capacity and high voltage diode, there are several problems which must be solved, and the major ones are as follows:

(1) Improvement of surface break down voltage.
(2) Improvement of diffusion techniques.

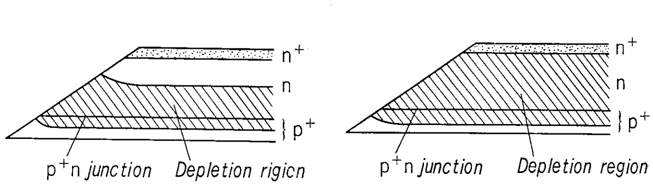
The following are the main problems concerned with the breakdown voltage and their countermeasures.

1. Improvement of surface breakdown voltage

The surface of semiconductor is very sensitive to the surrounding atmosphere and surface treatment. The breakdown voltage is often decided by the surface breakdown and the surface effect is one of the main factors for instability. When the electric field in the surface becomes greater, the current is increased considerably due to ionization multiprication and breakdown occures[3]. Therefore, improvements in the surface breakdown voltage are related to decreasing the surface field.

1) Junction construction and peak surface field

In diodes with comparatively low voltage, the depletion region in the *n* layer is not very wide and does not reach the n^+ region as is shown in *Fig. 6* (*a*).



(a) When n layer is wider than depletion region (b) When n layer is narrower than depletion region

Fig. 6 Expansion of depletion region

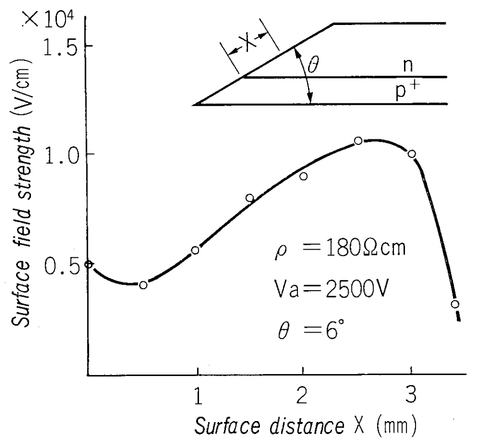


Fig. 7 **Examples of measured surface field distribution**

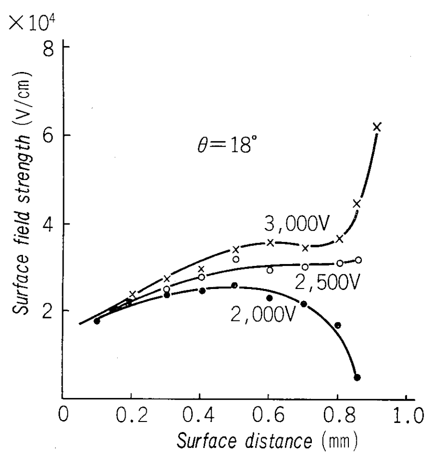


Fig. 8 **Relations between surface field distribution and applied voltage**

In such cases, there is not generally the peak field in the surface field distribution. *Fig. 7* shows a typical example of a measured field distribution when 2,500 V is applied. The surface field increases gradually from the p^+n junction in the *n* layer.

Fig. 8 shows another example where the *n* layer is narrow. The surface field distribution was measured for different applied voltages. When 2,000 V was applied, the depletion region did not reach the n^+ region and there was no peak in the distribution, i.e. the results were like those in *Fig. 7*. However, when the applied voltage was increased to 3,000 V, the depletion region was extended to the n^+ region and this expansion is limited there, and the peak field occurs at the nn^+ surface.

In high voltage diodes, the depletion region expands easily because of the high resistivity of the base region(5). Whereas, in order to get sufficiently low forward voltage drop, the *n* base width must be limited to a certain value. Therefore, the depletion region can expand to cover whole *n* layer as is shown in *Fig. 6* (*b*). In such cases, if there is a weak point in the nn^+ section due to imcomplete treatment since the field will be emphasized at such points, surface breakdown will occure and it will limit the blocking voltage. Thus, the width of the

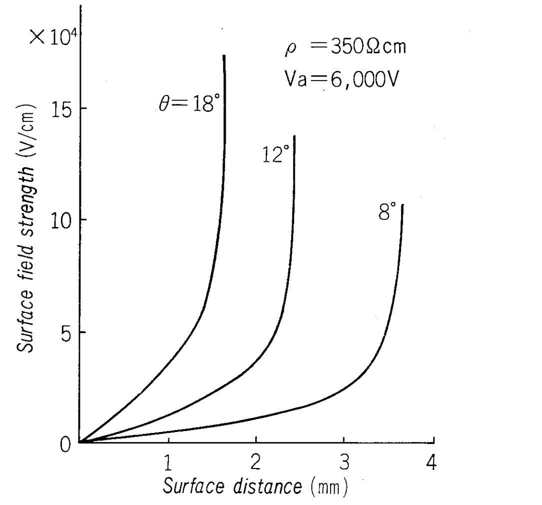


Fig. 9 **Bevel angle dependence of surface field distribution**

n layer has considerable influence on the distribution of surface field.

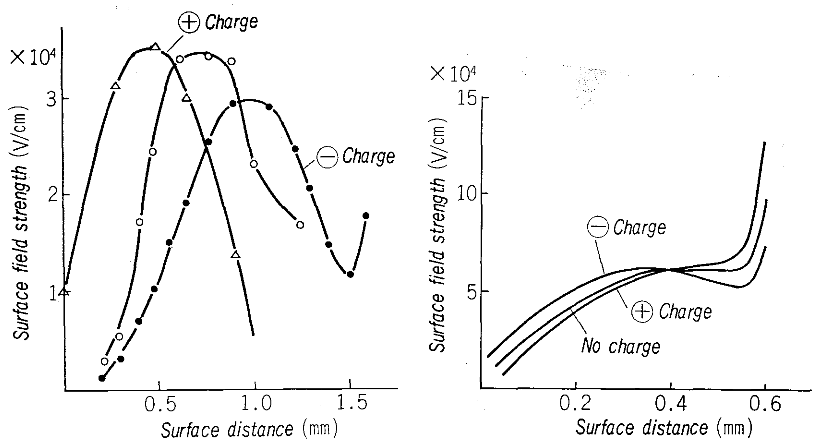
Another important factor is the surface shape since the electric field distribution can change in accordance with it. For example, the influence of the bevel angle θ on the field distribution (calcutated values) is as shown in *Fig. 9*(4) for an applied voltage of 6,000 V. The smaller the angle θ, the longer the distance along the surface. By making bevel angle small, the surface field can be made sufficiently low even at the peak in the nn^+ section.

2) Reduction of the peak surface field

In order to improve the surface breakdown of high voltage diodes, it is necessary to decrease the peak field in the nn^+ section also completely eliminate the causes of local current increases in the silicon surface such as defect and the adherence of foreign matter.

In the diffusion-alloy type, since the nn^+ junction is made by alloy, the position of the nn^+ junction is fixed and can not be altered freely. However, when the junction is made by diffusion, the position and the shape of the nn^+ junction surface can be changed by lapping and etching without difficulty. Thus, the surface field distribution can be controlled. Surface treatment such as etching is easier with the diffusion type, and even when there are defects, there can be eliminated fairly easily. The peak surface field can be decreased by considering such things as the silicon thickness, surface shape etc. was described in 1), but the electric field can also be changed by means of surface treatment. In etching or surface protecting treatment "negative" or "positive" charge is applied electrically to the silicon surface and this surface charge influences the distribution of the surface field.

Fig. 10 (*a*) and (*b*) show examples of the influence of surface charge when the depletion region does not reach the nn^+ region and when it does reach the region respectively. *Fig. 10* (*a*) shows actually measured results, while *Fig. 10* (*b*) shows calculated



(a) When depletion region does not reach the nn⁺ region

(b) When depletion region reaches the nn⁺ region

Fig. 10 **Surface charge dependence of electric field distribution**

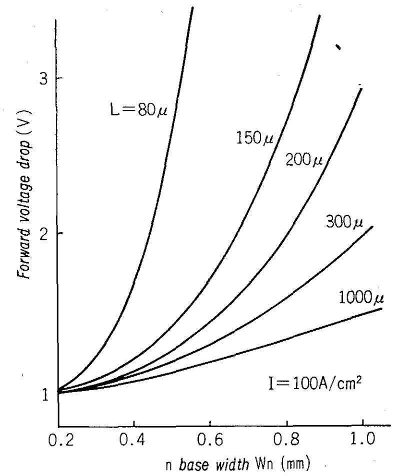


Fig. 11 **Forward voltage drop V_F vs. n base with W_h with various values of minority carrier diffusion length L**

results. Other investigations have confirmed the agreement between the calculated and measured results[(4)].

It can be seen from these examples that when the charge is "negative", the depletion region near the surface tends to expand in the direction of the n^+ region and when the charge is "positive", it seems to contract rather than expand. In elements with high blocking voltages, the peak field appears when the depletion region expands to the n^+ region. When the surface is treated with "positive" charge, the peak field in the nn^+ section can be reduced.

These diodes are of the all diffusion type for the above-mentioned reasons. The surface shape of the nn^+ section and the treatment are easy to control and a special junction-coating resin has been developed especially for the high voltage diode so that even when the depletion region can expand to the n^+ region, there are still improvements in reliability over long periods of operation.

2. Improvements in diffusion techniques

Diffusion techniques have a considerable influence on the breakdown voltage and forward voltage drop. Since one of the conditions required for diffusion is that the junction plane is flat, there is not any problems in this respects.

Another major problem is related to the forward voltage drop. In order to keep this forward voltage drop low, the minority carrier diffusion length L, which is easily shortened in the diffusion process, must be kept long. *Fig. 11* shows the relation between the forward voltage drop V_F and the n base width W with this diffusion length L as parameter. As has been described, it is necessary in high voltage diodes to make W as small as possible in order to keep V_F small but it is also evident that the diffusion length L must be long.

The diffusion techniques developed by Fuji Electric are based on the wide experience gained with various types of previous devices. With these methods, the minority carrier diffusion length can be kept long so that the forward voltage drop will be small even when the silicon is thick.

IV. CONCLUSION

This article has introduced the construction and characteristics of 6,000 V rectifier diodes and also described some of the problems encountered in raising the blocking voltage. The current capacities and the blocking voltage of power devices are even increasing. One of the major points in respect to an increase in the current capacity is the ability to obtain a silicon single crystal with a large diameter.

It can be said that the present stage of the blocking voltage is sufficient from the viewpoints of requirements and economy, but it will be widened by technical advances and new applications and these will require the invention of semiconductor devices with still more functions. Techniques developed for high voltage devices are already being applied in the manufacturing processes, and the stability and yield of elements are improved. There are many proposals for improvement concerning the surface treatment, diffusion techniques and device construction. Research into these points is now in progress.

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