Technical Documentation (Diodes)

ShinDengen

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1． Diodes

1-1. Diode types

<u>**General rectifying diodes**</u>

General rectifying diode is a high-voltage P-N junction element.

Our die structure stands out for its heat and humidity resistance, using our own chemically and physically stable glass passivation.

<u>**Bridge diodes**</u>

Bridge diode is well suited to rectification in commercial power supplies. We offer a variety of high I_{FSM}, low noise, and low V_F products.

We also offer bridge diodes composed of Schottky barrier diode dies, fast recovery diode dies, and other high speed diode dies for secondary rectification and other applications.

<u>**Schottky barrier diodes（SBD）**</u>

Schottky barrier diode uses a barrier that is formed with a metal-semiconductor junction.

Compared to the one using a P-N junction, the forward rise voltage is lower and the switching speed is extremely high, making it the most suitable rectifier for high speed low V_F diodes.

<u>**Fast recovery diodes（FRD）**</u>

Fast recovery diode is also a P-N junction element with better reverse recovery characteristics.

It controls carrier life time to increase speed.

1-2. Characteristic terminology list

1-2-1. Product configuration

Table.1 Product configuration

Type		Terminology explanation
Single diode		General term for diodes composed of 1 die per 1 product
Twin diode		General term for diodes composed of 2 dies per 1 product These are further classified into center tap, doubler, and array types.
	Center tap	These have 2 dies which are connected in parallel via internal wiring and are available in "cathode common" types where all cathodes are connected to a single terminal and "anode common" types where all anodes are connected to a single terminal.
	Doubler	These have 2 dies connected in series via internal wiring
	Array	These have 2 dies which are each wired independently Each individual product is composed of 2 sets of cathodes and anode terminals
Bridge diode		General term for diodes composed of multiple dies per 1 product where a bridge circuit is formed by internal wiring Available in SIP (Single In-line Package), DIP (Dual In-line Package), SQIP (Square In-line Package), SMD (Surface Mounting Device), etc. package types

1-2-2. Absolute maximum ratings（Values which must not be exceeded even momentarily）

Table. 2 Absolute maximum ratings

Item	Symbol	Description
Storage temperature	Tstg	Storage ambient temperature that must not be exceeded during device non-operation
Junction temperature	Tj	Junction temperature that must not be exceeded during device is powered
Repetitive peak reverse voltage	V_{RRM}	Maximum value of AC voltage that can be applied to the device
Non-repetitive peak reverse voltage	V_{RSM}	Maximum value of single surge reverse voltage that can be applied to the device ⚠ Caution Please carefully refer to the actual surge condition
Repetitive peak surge reverse voltage	V_{RRSM}	Maximum value of surge reverse voltage that can be continuously applied to the device ⚠ Caution Please carefully refer to the actual surge condition
Average forward current	I_F(AV)	Average value of maximum output current average value obtained by sinusoidal rectification of 50 Hz with resistive load ⚠ Caution I_F(AV) itself is unchangeable in either 50Hz or 60Hz condition Please have the derating with actual operating temperature to use the device safely
Surge forward current	I_{FSM}	The maximum allowable current value that can be applied without repetition in 1 cycle of 50Hz (pulse width 10ms) sine wave ⚠ Caution If necessary, multiply the value by approx. 1.09 to change it for the condition used at 60Hz (pulse width 8.3ms) Please have the derating with actual operating temperature to use the device safely
	I_{FSM1}	The maximum allowable current value that can be applied without repetition in sine wave at the pulse width 1 ms ⚠ Caution Derating with actual usage temperature required
Current squared time	I^2t	Value to calculate the maximum allowable non-repetitive current at the pulse width 1 ms to 10 ms ⚠ Caution Derating with actual usage temperature required
Dielectric strength	Vdis	Dielectric withstand voltage value between terminal - case and fin when applying the effective value of AC voltage
Mounting torque	TOR	The maximum value of the tightening torque of the screw when mounting the product on the heatsink

1-2-3. Electrical and thermal characteristics

Table. 3 Electrical and thermal characteristics

Item	Symbol	Description
Forward voltage	V_F	The value of the voltage drop that occurs when forward current flows under specified conditions
Reverse current	I_R	Current value flowing when reverse voltage is applied under specified conditions
Reverse recovery time	trr	Under the specified conditions, the voltage is applied in the forward direction, the current flows, the time until the current disappears after changing in the reverse direction
Total capacitance	Ct	Capacity value under specified conditions
Thermal resistance	Rth(j-x)	Value which represents the heat conduction rate in the steady state or the temperature difference which occurs per 1W between junction and x under regulation conditions Rth(j-a): Steady state thermal resistance between junction and ambient Rth(j-c): Steady state thermal resistance between junction and case Rth(j-l): Steady state thermal resistance between junction and lead

1-2-4. Additional notes

In accordance with JEITA ED-4511B, since FY2017, our company has changed some of the previously used characteristic symbols.

Please refer to the following table when reading.

New notation	Old notation	Notes
Junction temperature Tj	Operating Junction Temperature Tj	Basically the same ED-4511B uses "estimated junction temperature", however our company calls this "junction temperature"
Repetitive peak reverse voltage V_{RRM}	Peak reverse voltage V_{RM}	Applies to AC voltage application Expressed as V_R(DC) when guaranteeing direct voltage application
Average forward current I_F(AV)	Average Rectified Forward Current Io	Same
Total capacitance Ct	Junction Capacitance Cj	Basically same
Thermal resistance Rth(j-x)	Thermal resistance θjx	Same Excess thermal impedance is expressed as Zth(j-x)

1-3. Electrical characteristics

Ideal characteristics for rectifying diodes would be no forward voltage drop (V_F=0V) and complete blockage (I_R=0A) of current even when reverse voltage is applied.

However, actual diode current-voltage characteristics are that when current flows in the forward direction, voltage drop V_F occurs, and when voltage is applied in the reverse direction, reverse current IR flows, as shown in Fig.1. This V_F and I_R (as well as the later-described trr) cause power dissipation to occur, which is a cause of increased temperatures.

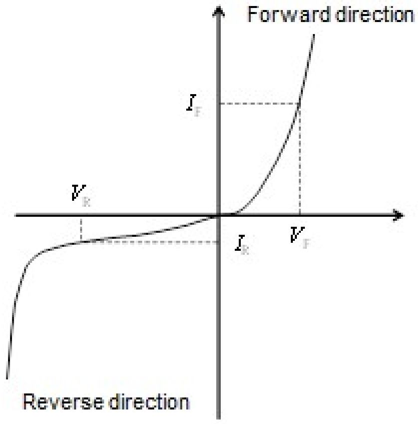

Fig.1 Diode current-voltage characteristics

Table. 4 Schottky barrier diode rating table (example)

Item	Symbol	Conditions	Ratings	Unit
Storage temperature	Tstg		-55 to 150	℃
Junction temperature	Tj		-55 to 150	℃
Repetitive peak reverse voltage	V_{RRM}		60	V
Repetitive peak surge reverse voltage	V_{RRSM}	Pulse width 0.5ms, duty1/40	65	V
Average forward current	I_F(AV)	50Hz sine wave, Resistance Load, With heatsink, Per diode I_F(AV)/2, Tc=118℃	20	A
Surge forward current	I_{FSM}	50Hz sine wave, Non-repetitive 1cycle peak value, Tj=25℃	230	A
Dielectric strength	Vdis	Terminals to case, AC 1 minute	2.0	kV
Mounting torque	TOR	(Recommended torque：0.3N・m)	0.5	N・m
Forward voltage	V_F	I_F = 10A, Pulse measurement, Per diode	0.63 max.	V
Reverse current	I_R	V_R=V_{RRM}, Pulse measurement, Per diode	8.0 max.	mA
Total capacitance	Ct	f=1MHz, V_R=10V, Per diode	370 typ.	pF
Thermal resistance	Rth(j-c)	Junction to case	1.8 max.	℃/W

1-3-1. Forward voltage characteristics V_F

Forward voltage characteristics (example) are shown in Fig.2. This is shown in a single logarithmic chart with the forward current IF as the vertical axis and the forward voltage VF as the horizontal axis. Diode forward voltage characteristics have the following features.

- There is voltage drop even if the current is extremely low.
- The temperature coefficient will be negative in diodes made of silicon (The higher the temperature, the lower the V_F)
- The temperature coefficient will be positive in silicon carbide schottky barrier diodes (SiC-SBD).
  (The higher the temperature, the higher the V_F)

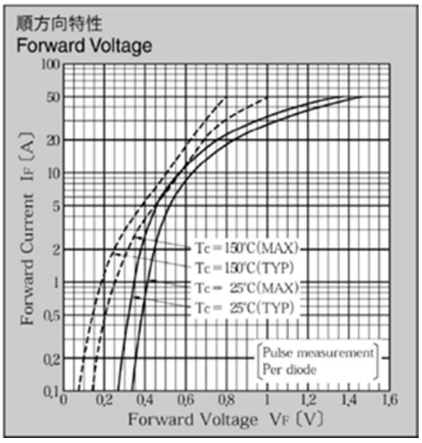

Fig.2 Forward voltage characteristics

Before using, verify the approximate voltage drop value for the current to be applied from the forward voltage characteristics chart, and use it for design reference. (Ex. Flow of 10A at 25°C: Max. 0.64V)

Also take the following points into consideration for use.

- When measuring V_F, carry out measurement using Kelvin connection (4 terminal method)
- Diodes have characteristic variation
- Contact our sales staff for information on micro current range V_F and temperatures not in the characteristics chart.

As shown in Fig.3, the V_F-I_F curve can resemble (approximate) a straight line connecting the two points of the average value of forward current per 1 die I_F(AV) and the peak value I_P.

There is almost no error in the ranges outside the micro current and high current ranges even if the curve approximates at the two points of average forward current I_F(AV) and I_P (=3×I_F(AV)) in the rating table.

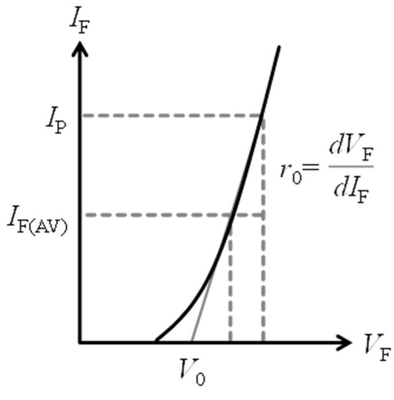

Fig.3 V_F-I_F curve

This approximate linearity can be expressed in a formula as

$V_F = Vo + ro \times I_F$

if Fig.3's I_F=0 point V_F is set as Vo and the straight line slope inverse dV_F/dI_F is set as ro.

Contact our sales staff if Vo and ro parameters are required.

1-3-2. Forward power dissipation characteristics P_F

An example forward power dissipation curve is shown in Fig.4

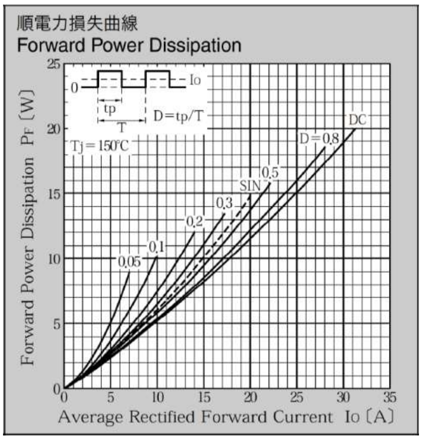

Fig.4 Forward power dissipation curve

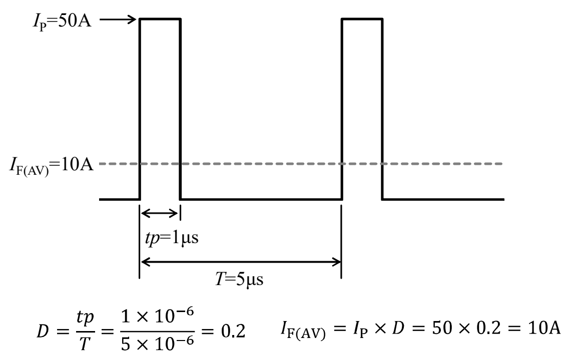

Fig.5 Duty

If the applied current waveform is a square wave as shown in Fig.5, Duty D will be 0.2 and the average forward current I_F(AV) is calculated as 10A.

The forward power dissipation P_F in this case will be 7.5W if the forward power dissipation is read from the I_F(AV)=10A point on the D=0.2 line in Fig.4. D represents the interval while diode forward current is applied.

1-3-3. Reverse current characteristics I_R

Compared to standard P-N junction diodes, SBD have high reverse current I_R so dissipation cannot be ignored. On the other hand, non-SBD has low I_R, so dissipation can be mostly ignored.

An example of reverse current characteristics is shown in Fig.6. This is shown in a single logarithmic chart with the reverse current I_R as the vertical axis and the reverse voltage V_R as the horizontal axis.

A feature of reverse current characteristics is a positive temperature coefficient (the higher the temperature, the higher the I_R). Characteristic values for typical temperatures are shown in the graph.

Contact our sales staff for information on temperatures and characteristics not shown in the graph, as well as for information on General rectifying diode and FRD I_R characteristics for reference.

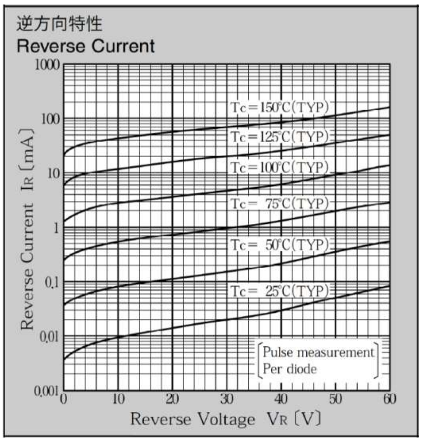

Fig.6 Reverse current characteristics

Caution Effects of ambient temperature

For SBD, the ambient temperature increases reverse power dissipation, and thermal runaway can damage the elements depending on the amount of dissipated heat. (Refer to "1-9. Thermal runaway" for details)

Give sufficient consideration to element usage conditions and heat dissipation conditions before use.

1-3-4. Reverse power dissipation P_R

Reverse power dissipation P_R is dissipation which occurs as a result of reverse current IR, and as with reverse current characteristics, information is only provided for SBD.

An example reverse power dissipation curve is shown in Fig.7. This is shown in a graph with the reverse power dissipation P_R as the vertical axis and the reverse voltage V_R as the horizontal axis. Conditions are shown in the waveform on the top left of the graph. D represents the interval (Duty) while diode reverse current is not applied.

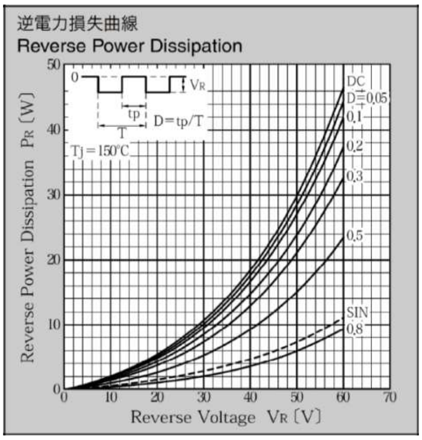

Fig.7 Reverse power dissipation curve

1-3-5. Switching characteristics

1) Reverse recovery time trr

P-N junctions have limited operation frequencies as a result of the cumulative effects of minority carriers. The reverse recovery time trr is used as an indicator which expresses the limitations of the operation frequency. A trr measurement circuit model and measurement methods are shown in Fig.8.

a) Set E1, E2, R1, and R2 on the measurement circuit and measure the measurement condition forward current I_F and reverse current I_R.

b) Turn SW1 ON to have forward current I_F flow from E1.

c) Turn SW2 ON, and apply reverse voltage from E2 to decrease forward current I_F. Then, after the reverse current I_R flows, current will almost completely stop flowing. The waveform for this condition is shown in Fig. 9.

d) The period from when the current decreases from the current zero point to I_{R2} passing reverse recovery current peak value I_{R1} is called the reverse recovery time trr.

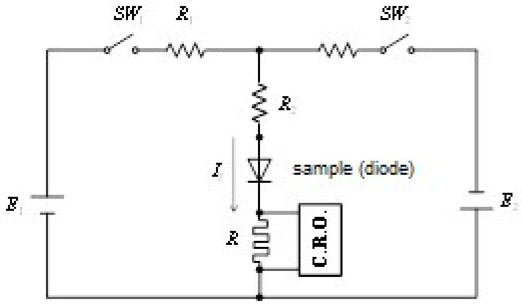

Fig.8 trr measurement circuit

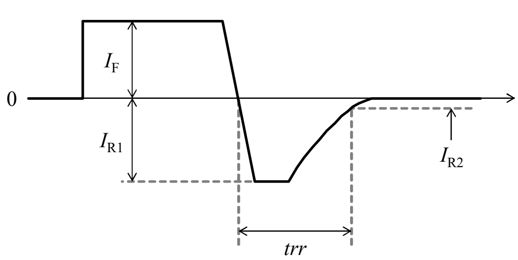

Fig.9 Recovery current waveform

2) Total capacitance Ct

General rectifying diodes and FRD operate using minority carriers, so there is trr.

On the other hand, SBD operate using majority carriers, so in theory there should be no trr, however operation similar to trr has been observed depending on the capacitance of the junctions.

Total capacitance Ct serves as an indicator of operation frequency in place of SBD trr.

1-3-6. Switching loss P_S

As noted earlier, the cumulative effect of minority carriers during diode forward bias creates a period during which reverse voltage cannot be blocked and reverse current flows momentarily during turn off. The power dissipation which occurs during the diode reverse recovery time trr in Fig.10 is switching loss.

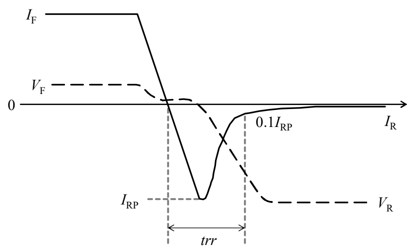

Fig.10 Switching waveform

Switching loss P_S is generally calculated as:

$$P_S = \frac{1}{6} V_R \times I_{RP} \times \mathrm{trr} \times \mathrm{f}$$

If the operation frequency is high, switching loss will also be higher, and it will no longer be possible to ignore the ratio of switching loss to total diode dissipation. As such, you should find the switching loss P_S after verifying the actual operation waveform.

1-4. Derating curve

The derating curve is defined as the limit for junction temperature Tj, which is the absolute maximum rating from various temperatures (case, lead, ambient) and average forward current I_F(AV).

We have prepared characteristics charts which prescribe sine wave input for use of General rectifying diodes for power source primary rectification, and Duty for use of SBD and FRD in secondary rectification. These charts use standard diodes as an example to illustrate determination methods for actual uses.

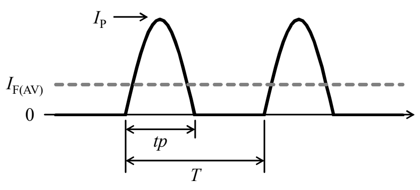

Fig.11 Sine wave current waveform example

First find the average forward current I_F(AV) from the actual measurement value of peak current IP which flows to the diode.

Example: I_P=1A, tp=10ms, T=20ms:

$$I_F(\mathrm{AV}) = \frac{2\mathrm{tp}}{\pi\mathrm{T}} \times I_P = \frac{2 \times 10 \times 10^{-3}}{3.14 \times 20 \times 10^{-3}} \times 1 = 0.32\mathrm{A}$$

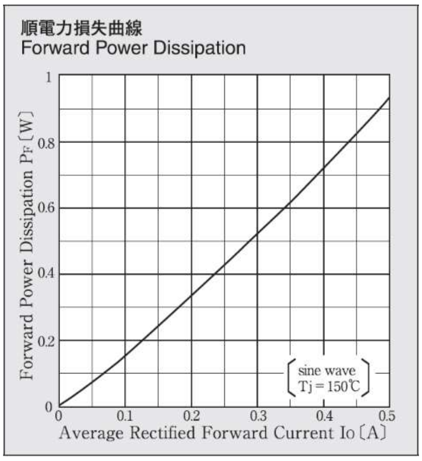

Fig.12 Forward power dissipation curve

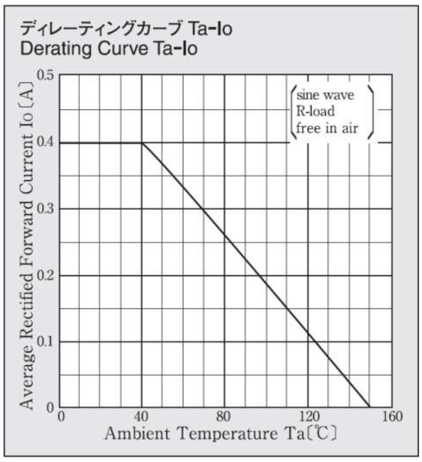

Fig.13 Derating curve

The forward power dissipation curve (Fig.12) is then used to find the forward power dissipation P_F from the I_F(AV) value found above.

From the characteristics chart, the forward power dissipation P_F when I_F(AV)=0.32A can be read as approximately 0.55W. Now, the found forward power dissipation is multiplied by the thermal impedance, and the actual temperature is added to find the Tj value.

If this value is equal to or below the Tj found in the absolute maximum ratings of the product specifications, it can be used.

In addition, according to the found I_F(AV) value (0.32A) and derating curve (Fig.13), the ambient temperature can be deduced to be approximately 65°C or less, so if the value is equal to or lower than that, it can also be inferred that it is equal to or lower than Tjmax.

1-5. Junction temperature estimation

1-5-1. Thermal impedance

All of the power dissipation which occurs during diode operation is converted to heat which increases the junction temperature Tj. It is necessary to check that the designed heat dissipation system (heat dissipation fins, etc.) maintains the junction temperature at or below the Tjmax stipulated in the rating table, and if Tjmax is exceeded, the heat dissipation fins and ambient temperature conditions must be revised so that they are equal to or lower than the rated temperature.

The junction temperature of diode dies sealed in mold resin, etc., cannot be directly measured, so the junction temperature must be estimated from external temperature. The thermal resistance Rth is used for this estimation, and indicates the degree of impedance of heat conduction vs. the diode power consumption (power dissipation). The conduction routes of heat from the junction to the ambient area (open air) can be illustrated by an electrical equivalent circuit like that shown in Fig.14. The locations of the temperatures and thermal impedance which appear in the rating tables and characteristics charts are indicated by the subscript notations.

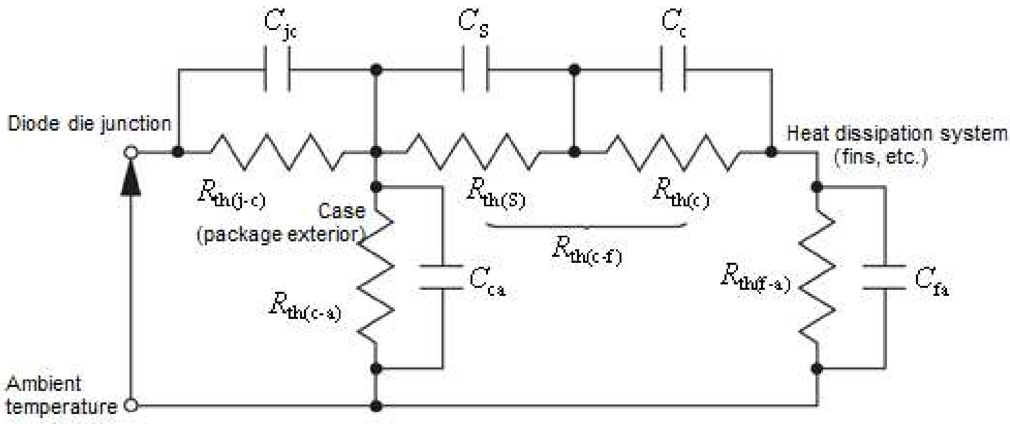

Fig.14 Thermal impedance equivalent circuit

Each of the subscript notations indicates the following locations.

Rth(j-c) : Thermal resistance of junction - case

Rth(c-f) : Thermal resistance between case - heat dissipation fin

Rth(f-a) : Thermal resistance of heat dissipation fin – ambient temperature

Rth(c-a) : Thermal resistance of case – ambient temperature

Rth(S) : Thermal resistance of insulating plate

Rth(c) : Thermal resistance of case

Cjc : Thermal capacitance between junction - case

Cfa : Thermal capacitance heat dissipation fin – to ambient temperature

Cca : Thermal capacitance between case- ambient temperature

Cs : Thermal capacitance of insulating plate

Cc : thermal capacitance of case

Tj is the diode junction temperature, and Rth(j-c) is the thermal resistance between the junction and case.

The forward dissipation and reverse dissipation can be found from the actual voltage and current applied to the diode. The value of both dissipations added together is the diode total dissipation. The value of the total dissipation multiplied by thermal resistance Rth(j-□) will be the temperature difference between the diode junction and the applicable location (position).

1-5-2. Method for calculating power dissipation

For General rectifying diodes and FRD, the reverse current I_R dissipation is sufficiently low, so only the forward power dissipation is calculated. However, for SBD, I_R is high, so the total of both forward power dissipation and reverse power dissipation is calculated.

1) Method for calculating power dissipation when sine wave current is applied to a bridge diode

The power dissipation when current like that shown in Fig.15 is applied to a bridge diode can be found as follows.

If peak current IP and Average forward current I_F(AV) are used in Fig.15:

I_P=1.57A（measured value）

$$I_F(\mathrm{AV}) = \frac{2\mathrm{tp}}{\pi \mathrm{T}} \times I_P \times 2 = \frac{2 \times 10 \times 10^{-3}}{3.14 \times 20 \times 10^{-3}} \times 1.57 \times 2 = 1.0\mathrm{A}$$

If the forward power dissipation P_F at this time is read from the forward power dissipation curve (Fig.16), the P_F will be approximately 1.6W.

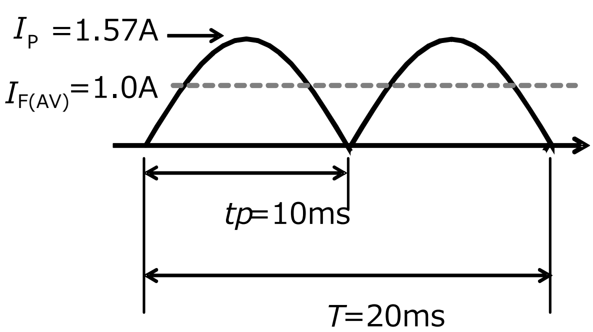

Fig.15 Sine wave current waveform(example)

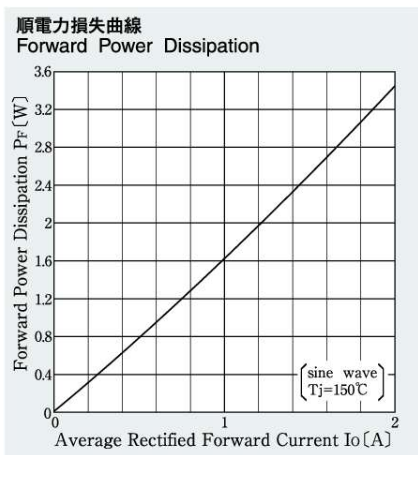

Fig.16 Forward power dissipation curve

2) Method for calculating power dissipation when triangular wave current is applied to a single FRD

Assuming a triangular wave current waveform is applied to an FRD as shown in Fig.17. If using a peak current I_P=10A triangular wave with a Duty (=1μ/5μ)=0.2, the average forward current I_F(AV) will be the average×Duty between tp, so:

I_F(AV)=10÷2×0.2=1.0A

If the forward power dissipation P_F at this time is read from the Forward power dissipation curve (Fig.18), the P_F will be approximately 1W at Duty=0.2 and I_F(AV)=1A.

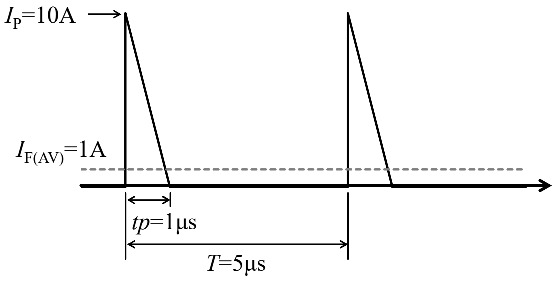

Fig.17 Triangular wave current waveform (example)

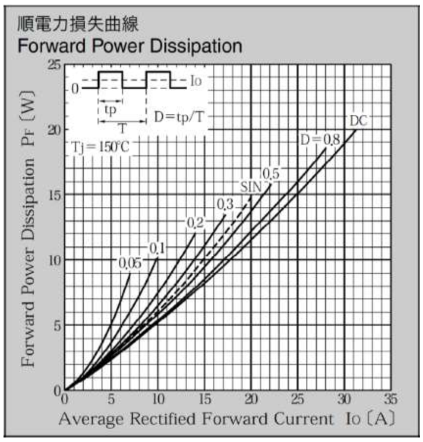

Fig.18 Forward power dissipation curve

3) Method for calculating power dissipation when trapezoidal wave current is applied to a center tap (2 elements) SBD

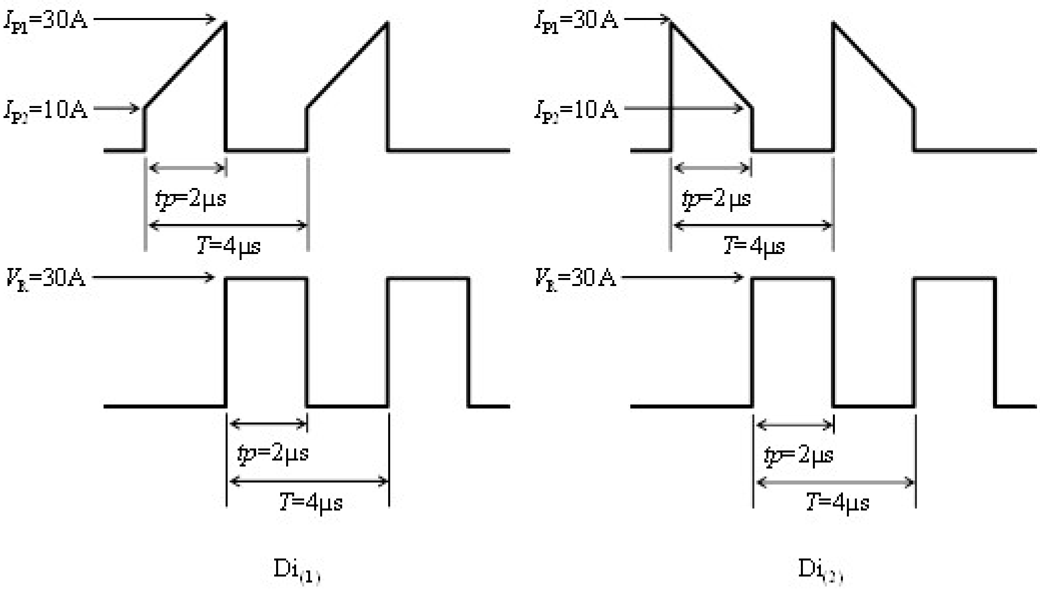

Fig.19 Trapezoidal wave current/voltage waveform (example)

Assuming a trapezoidal wave current waveform is applied to a center tap SBD as shown in Fig.19. In this case:

Duty(＝2μ/4μ)＝0.5

In addition, the average forward current $I_F(AV)$ can be calculated as follows.

$Di_{(1)}$:　$I_F(AV)(1)=(I_P1+I_P2)\div2\times D=(30+10)\div2\times0.5=10A$

$Di_{(2)}$:　(in the same manner) $I_F(AV)(2)=10A$

P_F is read from the forward power dissipation curve in Fig.20 based on these conditions.

$P_F(1)=6W$,　$P_F(2)=6W$

In addition, reverse power dissipation P_R is read from the reverse power dissipation curve in Fig.21. And because V_R=30V is applied to both Di(1) and Di(2):

$P_R(1)=5W$,　$P_R(2)=5W$

From the above, the total power dissipation P of both forward and reverse current will be:

$P=P_F(1)+P_F(2)+P_R(1)+P_R(2)=(6+6)+(5+5)=22W$

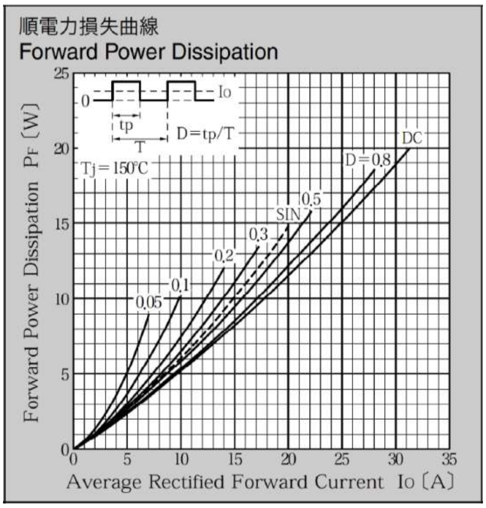

Fig.20 Forward power dissipation curve

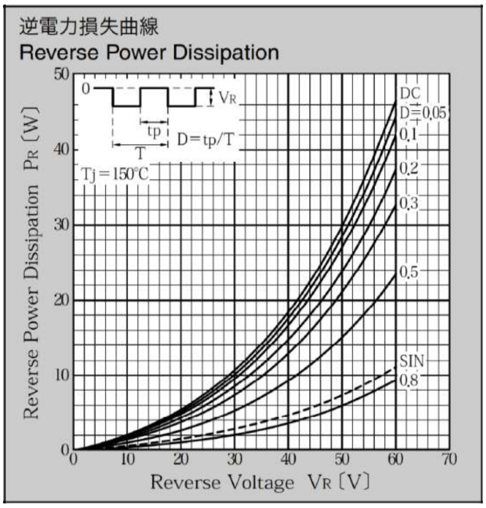

Fig.21 Reverse power dissipation curve

1-5-3.　Junction temperature Tj estimation method

1)　Method for estimating Tj in printed circuit board without heat dissipation fin (1)

The junction temperature Tj during steady operation can be found with the following formula using the thermal resistance between the junction and lead Rth(j-l).

Tj=P×Rth(j-l)+T(l-a)+Ta(ope)

This is a calculation carried out based on the example in 1-5-2 Method for calculating power dissipation 1).

a) Find the average forward current $I_F(AV)$ power dissipation P from the forward power dissipation curve in the characteristics chart.

（Assuming P＝0.8W）

b) Use the rating table electrical characteristics values for thermal resistance between the junction and lead Rth(j-l)

（Assuming Rth(j-l)＝10℃/W）

c) Find the lead – ambient temperature increase Tl-a using actual measurements.

T(l-a)=Tl-Ta

Tl : lead temperature (Refer to Fig.22, depends on package type)

Ta : Ambient temperature (locations which are not directly affected by generation of heat)

（Assuming Ta＝25℃, Tl＝80℃）

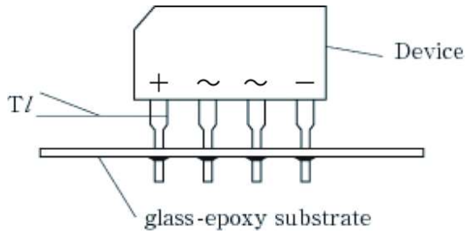

Fig.22 lead temperature measurement locations (example)

d) Ambient temperature Ta(ope) depends on design.

（Assuming Ta(ope)＝50℃）

Calculating using the above conditions results in:

Tj=P×Rth(j-l)+T(l-a)+Ta(ope)=0.8×10+(80-25)+50=113℃

From the above, the Tj estimated value will be 113°C.

2) Method for estimating Tj in printed circuit board without heat dissipation fin(2)

The junction temperature Tj during steady operation can be found with the following formula using the thermal resistance between the junction and ambient area Rth(j-a).

Tj=P×Rth(j-a)+Ta(ope)

This is a calculation carried out based on the example in 1-5-2 Method for calculating power dissipation 2).

a) Find the average forward current $I_F(AV)$ power dissipation P from the forward power dissipation curve in the characteristics chart.

（Assuming P=0.85W）

b) Use the rating table electrical characteristics values for thermal resistance between the junction and ambient temperature Rth(j-a).

(Assuming Rth(j-a) = 110℃/W)

c) Ambient temperature Ta(ope) depends on design

(Assuming Ta(ope) = 45℃)

Calculating using the above conditions result in:

Tj=P×Rth(j-a)+Ta(ope)=0.85×110+45=138.5℃

From the above, the Tj estimated value will be 138.5℃

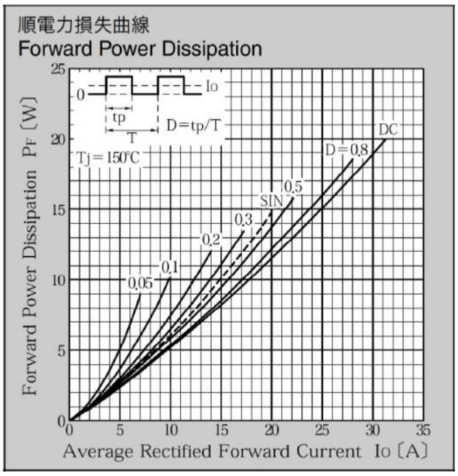

Fig.23 forward power dissipation curve

3) Method for estimating Tj in printed circuit board with heat dissipation fin

The junction temperature Tj when using fin can be found with the following formula using the thermal resistance between the junction and case Rth(j-c)

Tj=P×Rth(j-c)+T(c-a)+Ta(ope)

This is a calculation carried out based on the example in 1-5-2 Method for calculating power dissipation 3).

a) Find power dissipation P from the power dissipation curve in the characteristics chart.

(Assuming P = 14.5W)

b) Use the rating table electrical characteristics values for thermal resistance between the junction and case Rth(j-c)

(Assuming Rth(j-c) = 2℃/W)

c) Find the case temperature – ambient temperature increase T(c-a) using actual measurements.

(For example, if Tc=80℃, Ta=25℃ : T(c-a)=Tc-Ta=80-25=55℃)

d) Ambient temperature Ta(ope) depends on design.

(Assuming Ta=(ope)=45℃)

Calculating using the above conditions results in:

Tj=P×Rth(j-c)+T(c-a)+Ta(ope)=14.5×2+55+45=129℃

From the above, the Tj estimated value will be 129℃

1-6. Surge forward current characteristics

In commonly used capacitor input type power supply circuits, there is a high inrush current when the power supply is turned on. This is because a large charge current flows through the diode when the input side switch is turned ON because the rectifier later stage smoothing capacitor is not charged. Check that this inrush current is equal to or lower than the diode surge forward current capability, and if current higher than the capability flows, it will be necessary to implement countermeasures.

1-6-1. Surge forward current I_{FSM}

Surge forward current I_{FSM} is the non-repetitive maximum allowable forward current value in 1 cycle sine wave at 50Hz and cannot be applied to repeated operations such as restart before temperature returns to designated conditions. In addition, if I_{FSM} is applied for 2 cycles or more, the capability will decrease, so check the surge forward current capability characteristics chart. The non-repetitive maximum allowable forward current value which occurs in a pulse width 1ms sine wave (θ=180°) is defined as I_{FSM1}.

For repetitive operations, the current peak value per 1 repetition must satisfy the ratings according on the number of repetitions.

1-6-2. Current squared time I^2t

This is the standard for the I_{FSM} noted in the rating table when a 50Hz sine wave is input. However, in an actual circuit, the applied voltage, power supply impedance, etc., will cause the inrush current peak value and pulse width tp to change individually, and most pulse widths will be shorter than 10ms.

When calculating the non-repetitive allowable forward current value at a pulse width of 1ms≦ tp<10ms, use the current squared time I^2t, and if

$$I^2t \geqq \int_0^{tp} I^2 dt$$

is satisfied, it can be judged as allowable.

Ex. If a sine wave is applied at Tj=25°C as in Fig. 24, the applied current waveform will be the sine wave for peak current I_P=180 A, however current squared time I^2t will be regulated as a square wave.

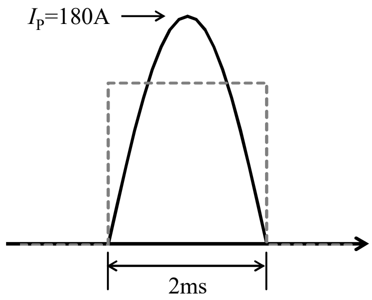

Fig.24 Sine wave (example)

1) Convert from a sine wave to a square wave

$180 \div \sqrt{2} = 127.3A$

2) Calculate I^2t

$I^2t = 127.3 \times 127.3 \times 0.002 = 32.4A^2s$

From the above, there will be no problems with use at Tj=25℃ if a diode for which I^2t is $32.4A^2s$ or higher is selected.

1-6-3. Inrush current at high temperature

In the rating table only Tj=25°C is guaranteed, however it can be determined if usage is possible when current is applied at high temperatures through derating of the current squared time I2t rating value from the Fig.25 surge forward current derating characteristics chart.

Ex. If a sine wave is applied at Tj=100℃ as in Fig.24, use the value calculated at Tj=25℃ for 2) to read the derating.

If the derating at Tj=100℃ from Fig.25 is read, the value will be 70%, so if the rated calue is set to $60A^2s$:

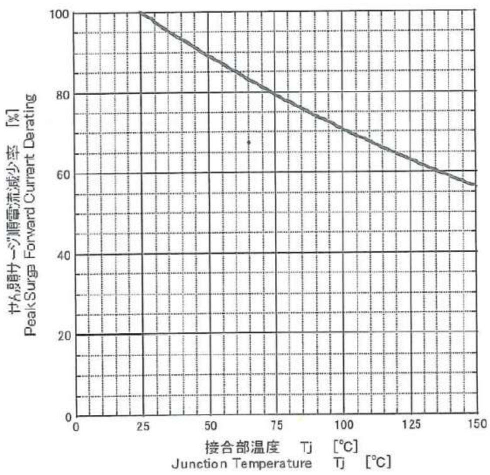

Fig.25 Surge forward current derating

$I^2t = 60 \times 70\% = 42A^2s$ (Tj=100℃)

From the above, there will be no problems with use because the Fig.24 current waveform will be equal to or less than $I^2t < 42A^2s$.

1-7. Surge reverse voltage characteristics

Because reverse current I_R rapidly increases in diode, which could cause damage to the element, application of reverse voltage which exceeds repetitive peak reverse voltage V_{RRM} is not allowed.

However, usage is possible even if V_{RRM} is exceeded if the following items are satisfied.

- Repetitive peak surge reverse voltage V_{RRSM}
- Repetitive peak surge reverse power P_{RRSM}

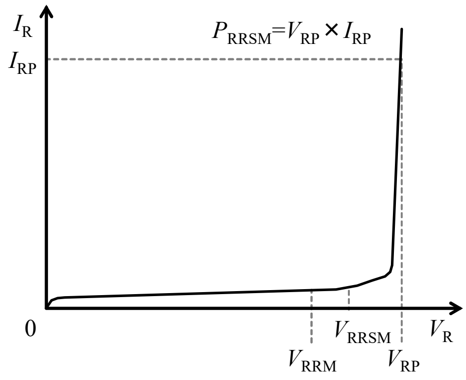

Fig.26 V_{RRSM}, P_{RRSM} definition

These are mainly used for spike voltage which exceeds V_{RRM}.

1-7-1. Non-repetitive peak reverse voltage V_{RSM}

Within the allowable range that the non-repetitive peak reverse voltage V_{RSM} does not exceed breakdown voltage (I_R does not rapidly increase), the usable maximum voltage is regulated with pulse width Duty conditions applied.

1-7-2. Repetitive peak surge reverse voltage V_{RRSM}

Within the allowable range that the repetitive peak surge reverse voltage V_{RRSM} does not exceed breakdown voltage (I_R does not rapidly increase), the usable maximum voltage is regulated with pulse width Duty conditions applied.

1-7-3. Repetitive peak surge reverse power P_{RRSM}

If overloaded beyond the nominal V_{RRSM} whether repetitive peak surge reverse power P_{RRSM} can be applied for voltage which exceeds V_{RRSM}.

P_{RRSM} is expressed as the product of reverse maximum voltage V_{RP} and the peak reverse current I_{RP} at the time. If junction temperature Tj and pulse width tp are derated and satisfy the conditions, use is possible.

1-8. Diode parallel and series connection

1-8-1. Diode parallel connection

When using diodes in parallel connection as shown in Fig.27, it will be necessary to take into consideration that there will be variance in the forward voltage V_F even among the same products, and eventually there would be unbalanced current flows to each diode in parallel.

When using a combination of $V_F$max characteristics and $V_F$min characteristics diode as shown in Fig.28, the $V_F$min characteristic diode will have a higher current load than the $V_F$max characteristics diode. In addition, there will also be possibly the current will not be flowing in a balanced way, if the temperature environments for the 2 diodes differ. As such, when using diodes connected in parallel, it is necessary to mount the diodes so that no differences in temperature occur, including considering these issues when setting margins, etc.

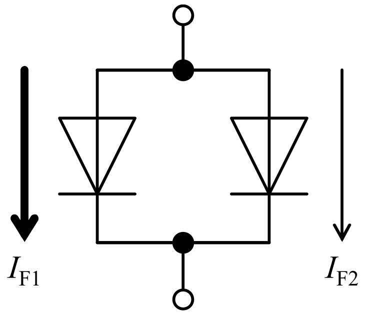

Fig.27 Diode parallel connection

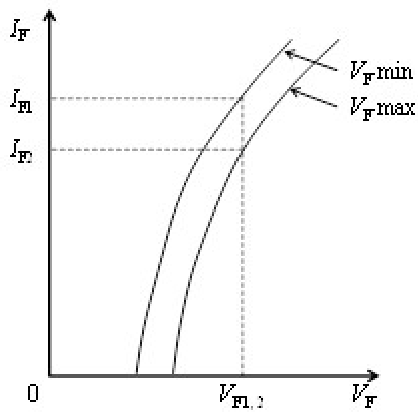

Fig.28 Forward voltage characteristics variance

1-8-2. Diode series connection

When using diodes in series connection as shown in Fig.29, total capacitance and reverse current variance may cause differences in the reverse voltage V_R applied to each diode.

Equal distribution of voltage can be achieved by connecting balance resistance to each diode in parallel through direct current, however, during diode turn off in high frequency operation, trr variance can be expected to momentarily destroy the resistance dividing balance.

As such, use of diodes in series connection is not recommended for high frequency operation.

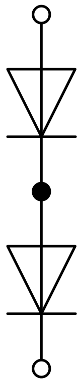

Fig.29 Diode series connection

1-9. Thermal runaway

Diode temperature increases can result from element self-heating causes, such as forward power dissipation P_F, reverse power dissipation P_R, as well as from secondary affected by (external factor like) ambient temperature. Besides, we should note that diode has a feature that temperature increases also cause the element reverse current I_R to increase. If the element heat dissipation is lower than its heat generation, it will result in even greater temperature increases, so:

Temperature increase → **Reverse current increase** → **Reverse power dissipation increase** → **Temperature increase**

will repeatedly occur, and the continued increase of element temperature will eventually damage the element. This phenomenon is called thermal runaway.

Fig.30 shows the relationship between diode junction temperature and dissipation. A property of diodes is that when the junction temperature increases, the forward voltage V_F decreases, so the forward power dissipation P_F also decreases. On the contrary, another property is that reverse current I_R increases, so reverse power dissipation P_R also increases. The sum of P_F and P_R is the diode total dissipation P_{total}. If certain temperatures are exceeded, the PR will rapidly increase, so in terms of P_{total}, the impact of P_R increase is greater than that of

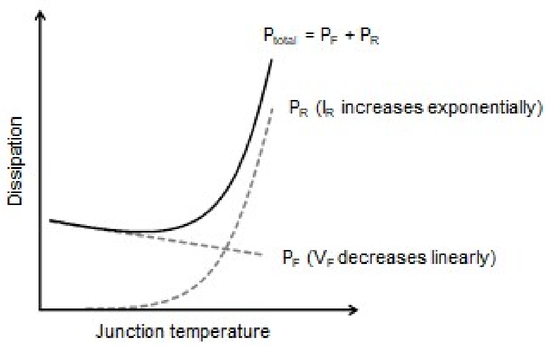

Fig.30 Relationship between diode junction temperature and dissipation

P_F decrease.

The P_{total} slope will become sharper, and once the slope exceeds a certain range, thermal runaway will occur. Until what point the slope is allowable depends on the heat dissipation (thermal resistance).

Compared to General rectifying diodes and FRD, SBD, which have higher I_R, have an increased risk of thermal runaway, so always thoroughly verify the element usage conditions and heat dissipation conditions before use.