1. **Diodes**

1-1. **Diode types**

**General rectifying diodes**

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.

**Bridge diodes**

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.

**Schottky barrier diodes (SBD)**

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.

**Fast recovery diodes (FRD)**

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>
<thead>
<tr>
<th>Type</th>
<th>Terminology explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single diode</td>
<td>General term for diodes composed of 1 die per 1 product</td>
</tr>
<tr>
<td>Twin diode</td>
<td>General term for diodes composed of 2 dies per 1 product</td>
</tr>
<tr>
<td></td>
<td>These are further classified into center tap, doubler, and array types.</td>
</tr>
<tr>
<td>Center tap</td>
<td>These have 2 dies which are connected in parallel via internal wiring and are available in &quot;cathode common&quot; types where all cathodes are connected to a single terminal and &quot;anode common&quot; types where all anodes are connected to a single terminal.</td>
</tr>
<tr>
<td>Doubler</td>
<td>These have 2 dies connected in series via internal wiring</td>
</tr>
<tr>
<td>Array</td>
<td>These have 2 dies which are each wired independently</td>
</tr>
<tr>
<td></td>
<td>Each individual product is composed of 2 sets of cathodes and anode terminals</td>
</tr>
<tr>
<td>Bridge diode</td>
<td>General term for diodes composed of multiple dies per 1 product where a bridge circuit is formed by internal wiring</td>
</tr>
<tr>
<td></td>
<td>Available in SIP (Single In-line Package), DIP (Dual In-line Package), SQIP (Square In-line Package), SMD (Surface Mounting Device), etc. package types</td>
</tr>
</tbody>
</table>
### 1-2-2. Absolute maximum ratings (Values which must not be exceeded even momentarily)

#### Table. 2 Absolute maximum ratings

<table>
<thead>
<tr>
<th>Item</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage temperature</td>
<td>Tstg</td>
<td>Storage ambient temperature that must not be exceeded during device non-operation</td>
</tr>
<tr>
<td>Junction temperature</td>
<td>Tj</td>
<td>Junction temperature that must not be exceeded during device is powered</td>
</tr>
<tr>
<td>Repetitive peak reverse voltage</td>
<td>VRRM</td>
<td>Maximum value of AC voltage that can be applied to the device</td>
</tr>
</tbody>
</table>
| Non-repetitive peak reverse voltage | VRSR   | Maximum value of single surge reverse voltage that can be applied to the device
|                                    |        | Please carefully refer to the actual surge condition                                            |
| Repetitive peak surge reverse voltage| VRRS   | Maximum value of surge reverse voltage that can be continuously applied to the device        |
|                                    |        | Please carefully refer to the actual surge condition                                            |
| Average forward current             | IF(AV) | Average value of maximum output current average value obtained by sinusoidal rectification of 50 Hz with resistive load
|                                    |        | IF(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               | IFSM   | The maximum allowable current value that can be applied without repetition in 1 cycle of 50Hz (pulse width 10ms) sine wave
|                                    |        | 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           |
|                                    | IFSM1  | The maximum allowable current value that can be applied without repetition in sine wave at the pulse width 1 ms
|                                    |        | Derating with actual usage temperature required                                                |
| Current squared time                | IT2    | Value to calculate the maximum allowable non-repetitive current at the pulse width 1 ms to 10 ms
|                                    |        | 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

<table>
<thead>
<tr>
<th>Item</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward voltage</td>
<td>$V_F$</td>
<td>The value of the voltage drop that occurs when forward current flows under specified conditions</td>
</tr>
<tr>
<td>Reverse current</td>
<td>$I_R$</td>
<td>Current value flowing when reverse voltage is applied under specified conditions</td>
</tr>
<tr>
<td>Reverse recovery time</td>
<td>$t_{rr}$</td>
<td>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</td>
</tr>
<tr>
<td>Total capacitance</td>
<td>$C_t$</td>
<td>Capacity value under specified conditions</td>
</tr>
<tr>
<td>Thermal resistance</td>
<td>$R_{th(j-x)}$</td>
<td>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 $R_{th(j-a)}$: Steady state thermal resistance between junction and ambient $R_{th(j-c)}$: Steady state thermal resistance between junction and case $R_{th(j-l)}$: Steady state thermal resistance between junction and lead</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>New notation</th>
<th>Old notation</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junction temperature</td>
<td>Operating Junction Temperature $T_j$</td>
<td>Basically the same ED-4511B uses &quot;estimated junction temperature&quot;, however our company calls this &quot;junction temperature&quot;</td>
</tr>
<tr>
<td>Repetitive peak reverse voltage</td>
<td>Peak reverse voltage $V_{RM}$</td>
<td>Applies to AC voltage application Expressed as $V_R$(DC) when guaranteeing direct voltage application</td>
</tr>
<tr>
<td>Average forward current</td>
<td>Average Rectified Forward Current $I_{o}$</td>
<td>Same</td>
</tr>
<tr>
<td>Total capacitance</td>
<td>Junction Capacitance</td>
<td>Basically same</td>
</tr>
<tr>
<td>Thermal resistance</td>
<td>Thermal resistance</td>
<td>Same Excess thermal impedance is expressed as $Z_{th(j-x)}$</td>
</tr>
</tbody>
</table>
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 \(I_R\) flows, as shown in Fig.1. This \(V_F\) and \(I_R\) (as well as the later-described \(t_{rr}\)) cause power dissipation to occur, which is a cause of increased temperatures.

Table. 4  Schottky barrier diode rating table (example)

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

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 \( I_P (=3\times I_F(AV)) \) in the rating table.
This approximate linearity can be expressed in a formula as

\[ V_F = V_o + r_o \times I_F \]

if Fig.3’s \( I_F = 0 \) point \( V_F \) is set as \( V_o \) and the straight line slope inverse \( dV_F/dI_F \) is set as \( r_o \).

Contact our sales staff if \( V_o \) and \( r_o \) parameters are required.

1-3-2. Forward power dissipation characteristics \( P_F \)

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

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.

![Reverse current characteristics](image)

**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 I_R, 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.
1-3-5. Switching characteristics

1) Reverse recovery time $t_{rr}$

P-N junctions have limited operation frequencies as a result of the cumulative effects of minority carriers. The reverse recovery time $t_{rr}$ is used as an indicator which expresses the limitations of the operation frequency. A $t_{rr}$ 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 $t_{rr}$.

---

**Fig.7 Reverse power dissipation curve**

---

**Fig.8 trr measurement circuit**

**Fig.9 Recovery current waveform**
2) Total capacitance \( C_t \)

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 \( C_t \) 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.

Switching loss \( P_S \) is generally calculated as:

\[
P_S = \frac{1}{6} V_R \times I_{RP} \times trr \times f
\]

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 \( T_j \), 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.
First find the average forward current $I_{F}(AV)$ from the actual measurement value of peak current $I_P$ which flows to the diode.

Example: $I_P=1\,\text{A}$, $t_p=10\,\text{ms}$, $T=20\,\text{ms}$:

$$I_{F}(AV) = \frac{2t_p}{\pi T} \times I_P = \frac{2 \times 10 \times 10^{-3}}{3.14 \times 20 \times 10^{-3}} \times 1 = 0.32\,\text{A}$$

Fig. 11 Sine wave current waveform example

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 $I_{F}(AV)=0.32\,\text{A}$ 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 $T_j$ value.

If this value is equal to or below the $T_j$ 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 $T_{j\text{max}}$.

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 $T_j$. It is necessary to check that the designed heat dissipation system (heat dissipation fins, etc.) maintains the junction temperature at or below the $T_{j\text{max}}$. 

![Forward power dissipation curve](image1)

![Derating curve](image2)
stipulated in the rating table, and if $T_{jmax}$ 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 $R_{th}$ 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.

- $R_{th(j-c)}$: Thermal resistance of junction - case
- $C_{jc}$: Thermal capacitance between junction - case
- $R_{th(c-f)}$: Thermal resistance between case - heat dissipation fin
- $C_{fa}$: Thermal capacitance heat dissipation fin - to ambient temperature
- $R_{th(f-a)}$: Thermal resistance of heat dissipation fin - ambient temperature
- $C_{ca}$: Thermal capacitance between case- ambient temperature
- $R_{th(c-a)}$: Thermal resistance of case - ambient temperature
- $C_{s}$: Thermal capacitance of insulating plate
- $C_{c}$: thermal capacitance of case
- $R_{th(S)}$: Thermal resistance of insulating plate
- $R_{th(c)}$: Thermal resistance 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 IF(AV) are used in Fig.15:

\[ I_P = 1.57 \text{A} \] (measured value)

\[ I_F(AV) = \frac{2 \times 10 \times 10^{-3}}{3.14 \times 20 \times 10^{-3}} \times 1.57 = 0.5 \text{A} \]

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 0.8W.

---

**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 ($=1\mu s/5\mu s)=0.2$, the average forward current $I_F(AV)$ will be the average $\times$ Duty between $t_p$, so:

$$I_F(AV) = 10 \div 2 \times 0.2 = 1.0A$$

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)](image17)
![Fig.18 Forward power dissipation curve](image18)

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)](image19)
Assuming a trapezoidal wave current waveform is applied to a center tap SBD as shown in Fig.19. In this case:

\[
\text{Duty} = \frac{2\mu}{4\mu} = 0.5
\]

In addition, the average forward current \(I_F(\text{AV})\) can be calculated as follows.

\[
\begin{align*}
D_{(1)} & : \quad I_F(\text{AV})(1) = (I_{p1} + I_{p2}) ÷ 2 \times D = (30 + 10) ÷ 2 \times 0.5 = 10A \\
D_{(2)} & : \quad (\text{in the same manner}) \quad I_F(\text{AV})(2) = 10A
\end{align*}
\]

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

\[
P_F(1) = 6W, \quad P_F(2) = 6W
\]

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 \(D_{(1)}\) and \(D_{(2)}\):

\[
P_R(1) = 5W, \quad P_R(2) = 5W
\]

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

\[
P = P_F(1) + P_F(2) + P_R(1) + P_R(2) = (6 + 6) + (5 + 5) = 22W
\]

1-5-3. Junction temperature \(T_j\) estimation method

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

The junction temperature \(T_j\) during steady operation can be found with the following formula using the thermal resistance between the junction and lead \(R_{th(j-l)}\).

\[
T_j = P \times R_{th(j-l)} + T(l-a) + T(\text{ope})
\]

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 \( P = 0.8 \)W)

b) Use the rating table electrical characteristics values for thermal resistance between the junction and lead \( R_{th(j-l)} \)

(assuming \( R_{th(j-l)} = 10 ^\circ \text{C/W} \))

c) Find the lead – ambient temperature increase \( T_l-a \) using actual measurements.

\[ T(l-a) = T_l - T_a \]

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

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

(assuming \( T_a = 25 ^\circ \text{C}, T_l = 80 ^\circ \text{C} \))

\[ T_l-a = T_l - T_a \]

\[ T_l \]: lead temperature (Refer to Fig. 22, depends on package type)

\[ T_a \]: Ambient temperature (locations which are not directly affected by generation of heat)

(assuming \( T_a = 25 ^\circ \text{C}, T_l = 80 ^\circ \text{C} \))

d) Ambient temperature \( T_a(ope) \) depends on design.

(assuming \( T_a(ope) = 50 ^\circ \text{C} \))

Calculating using the above conditions results in:

\[ T_j = P \times R_{th(j-l)} + T(l-a) + T_a(ope) = 0.8 \times 10 + (80-25) + 50 = 113 ^\circ \text{C} \]

From the above, the \( T_j \) estimated value will be \( 113 ^\circ \text{C} \).

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

The junction temperature \( T_j \) during steady operation can be found with the following formula using the thermal resistance between the junction and ambient area \( R_{th(j-a)} \).

\[ T_j = P \times R_{th(j-a)} + T_a(ope) \]

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 \( P = 0.85 \)W)

b) Use the rating table electrical characteristics values for thermal resistance between the
junction and ambient temperature \( R_{th(j-a)} \).

\[ \text{(Assuming } R_{th(j-a)} = 110{\degree}C/W) \]

c) Ambient temperature \( T_a(\text{ope}) \) depends on design

\[ \text{(Assuming } T_a(\text{ope}) = 45{\degree}C) \]

Calculating using the above conditions result in:

\[ T_j = P \times R_{th(j-a)} + T_a(\text{ope}) = 0.85 \times 110 + 45 = 138.5{\degree}C \]

From the above, the \( T_j \) estimated value will be 138.5{\degree}C

3) Method for estimating \( T_j \) in printed circuit board with heat dissipation fin

The junction temperature \( T_j \) when using fin can be found with the following formula using the thermal resistance between the junction and case \( R_{th(j-c)} \)

\[ T_j = P \times R_{th(j-c)} + T(c-a) + T_a(\text{ope}) \]

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.

\[ \text{(Assuming } P = 14.5W) \]

b) Use the rating table electrical characteristics values for thermal resistance between the junction and case \( R_{th(j-c)} \)

\[ \text{(Assuming } R_{th(j-c)} = 2{\degree}C/W) \]

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

\[ \text{(For example, if } T_c = 80{\degree}C, T_a = 25{\degree}C : T(c-a) = T_c - T_a = 80 - 25 = 55{\degree}C) \]

d) Ambient temperature \( T_a(\text{ope}) \) depends on design.

\[ \text{(Assuming } T_a(\text{ope}) = 45{\degree}C) \]

Calculating using the above conditions results in:

\[ T_j = P \times R_{th(j-c)} + T(c-a) + T_a(\text{ope}) = 14.5 \times 2 + 55 + 45 = 129{\degree}C \]

From the above, the \( T_j \) estimated value will be 129{\degree}C

Fig.23 forward power dissipation curve
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 ($\theta=180^\circ$) 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 $t_p$ 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 $1\text{ms} \leq t_p < 10\text{ms}$, use the current squared time $I^2t$, and if

$$I^2t \geq \int_0^{t_p} I^2 dt$$

is satisfied, it can be judged as allowable.
Ex. If a sine wave is applied at \( T_j=25^\circ C \) as in Fig. 24, the applied current waveform will be the sine wave for peak current \( I_p=180 \text{ A} \), however current squared time \( I^2t \) will be regulated as a square wave.

1) Convert from a sine wave to a square wave

\[
180 \div \sqrt{2} = 127.3 \text{A}
\]

2) Calculate \( I^2t \)

\[
I^2t = 127.3 \times 127.3 \times 0.002 = 32.4 \text{A}^2\text{s}
\]

From the above, there will be no problems with use at \( T_j=25^\circ C \) if a diode for which \( I^2t \) is \( 32.4 \text{A}^2\text{s} \) or higher is selected.

1-6-3. Inrush current at high temperature

In the rating table only \( T_j=25^\circ C \) 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 \( I^2t \) rating value from the Fig.25 surge forward current derating characteristics chart.

Ex. If a sine wave is applied at \( T_j=100^\circ C \) as in Fig.24, use the value calculated at \( T_j=25^\circ C \) for 2) to read the derating.

If the derating at \( T_j=100^\circ C \) from Fig.25 is read, the value will be 70%, so if the rated value is set to \( 60 \text{A}^2\text{s} \):

\[
I^2t = 60 \times 70\% = 42 \text{A}^2\text{s} (T_j=100^\circ C)
\]

From the above, there will be no problems with use because the Fig.24 current waveform will be equal to or less than \( I^2t < 42 \text{A}^2\text{s} \).
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 $P_{RRSM}$

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 $T_j$ and pulse width $t_p$ 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 $V_{F\text{max}}$ characteristics and $V_{F\text{min}}$ characteristics diode as shown in Fig.28, the $V_{F\text{min}}$ characteristic diode will have a higher current load than the $V_{F\text{max}}$ 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](image)

![Fig.28 Forward voltage characteristics variance](image)

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, $tr_r$ 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.
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:

$$\text{Temperature increase} \rightarrow \text{Reverse current increase} \rightarrow \text{Reverse power dissipation increase} \rightarrow \text{Temperature increase}$$

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 $P_r$ will rapidly increase, so in terms of $P_{total}$, the impact of $P_r$ increase is greater than that of $P_f$. 

![Fig.30 Relationship between diode junction temperature and dissipation](image-url)
$P_T$ decrease.

The $P_{\text{total}}$ 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 $I_{\text{th}}$, have an increased risk of thermal runaway, so always thoroughly verify the element usage conditions and heat dissipation conditions before use.