

This presentation contains no confidential information.

Tj measurement of bypass diode for PV modules

(J-TG 4 activities of QA Forum / QA Task Force 4 ; Diode, Shading & Reverse Bias)

This work was performed in cooperation with Onamba, Sanken Electric, Nihon Inter Electronics, Kyocera and SHARP.

Feb. 24-25, 2015 @ *Denver Colorado, USA*

Yasunori Uchida

JET (Japan Electrical Safety & Environment Technology Laboratories)

1. Introduction (1)

In the bypass diode (BD) thermal test required by IEC61215 Cl.10.18 and IEC61646 Cl.10.18, it is necessary to measure the junction temperature (T_j) of the BD. But it is not possible to measure it directly.

Two methods are conceivable, which are “**Vf-Tj method**” and “**Tlead method (or Tcase method)**”.

“**Vf-Tj method**” is based on the physical characteristics of the diode where the V_f (at certain forward current I_f) and the T_j are related.

Thus “Vf-Tj method” is considered as a primary method.

1. Introduction (2)

“Tlead method”, in comparison, is considered as a secondary method. Because it uses the parameter R_{th} (thermal resistance) to relate the lead temperature to the junction temperature.

“Tlead method” is commonly used because of its simplicity. But it may involve larger error.

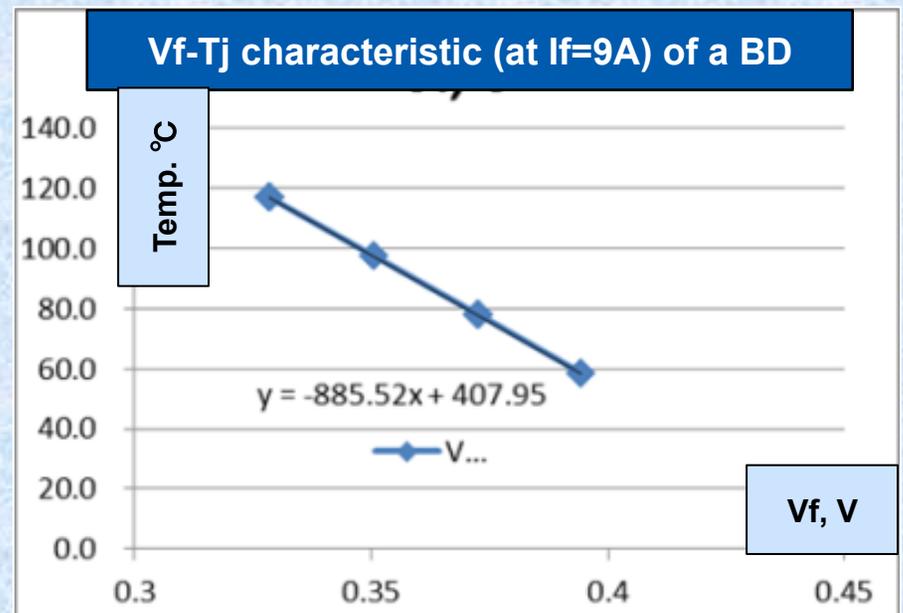
This paper deals with the analysis and the experiments about how much error **“Tlead method”** may have.

2-1. Vf-Tj method

In “**Vf-Tj method**” it is necessary to obtain first the “Vf-Tj characteristics” which is practically linear as shown below. The formula to show the characteristics will change by an individual diode and the forward current applied.

An example of Vf-Tj characteristics:

$$T_j = -885.52 \times V_f + 407.95$$



2-2. Tlead method

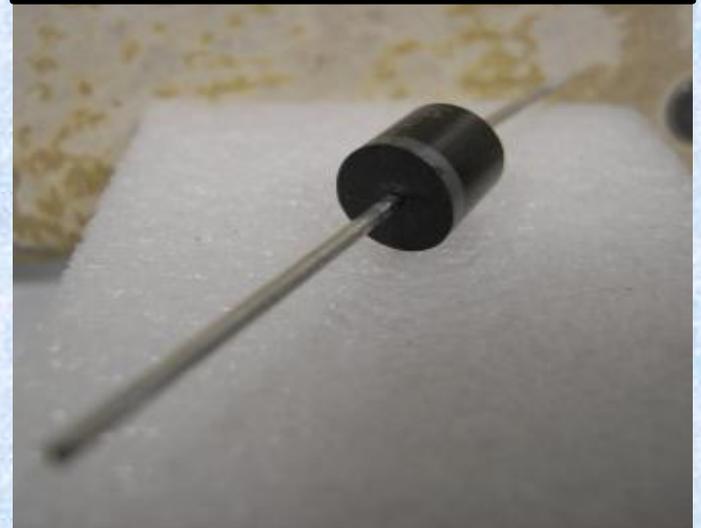
The relation between T_j and T_{lead} is expressed as below using the parameter of thermal resistance (R_{th}).

$$T_j = T_{lead} + (V_f \times I_f \times R_{th})$$

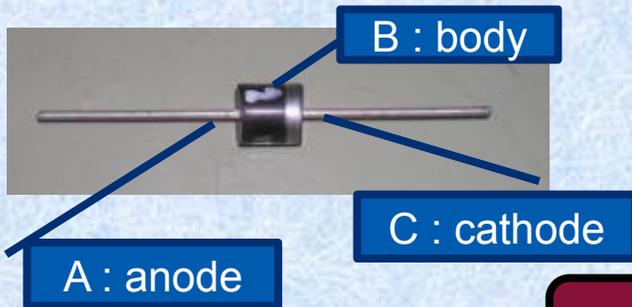
The value of R_{th} is usually supplied by the diode manufacturer.

The problem is that the value supplied is not a real R_{th} , but an apparent value of R_{th} which will vary according to the heat dissipating condition where the diode is installed. (see next slide)

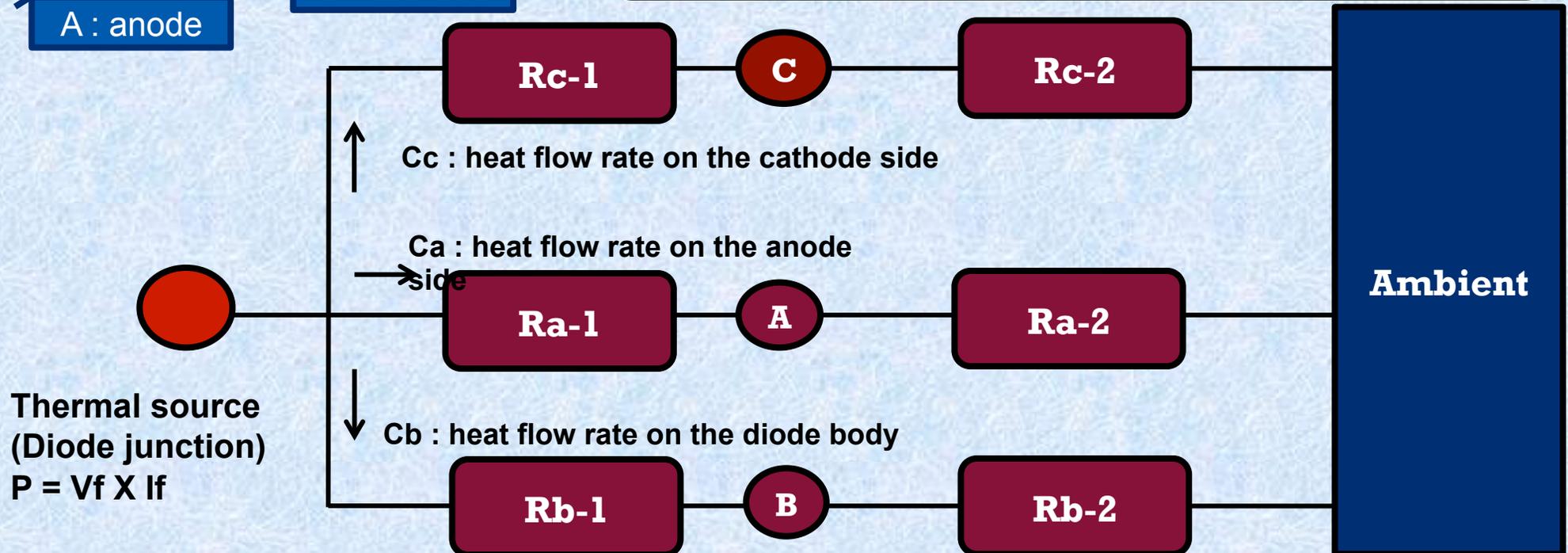
Axial type diode



2-3. Heat flow and Rth



★ presented at NREL PVMR Work-shop 2013 ★
 Thermal resistance varies by the difference of heat dissipating condition such as a J-box.



Apparent Rth will vary according to the heat flow ratio which varies with the radiation condition of each route !!!!!

$$T_j = T_{lead} + V_f \times I_f \times \boxed{C_c \times R_{th}(real)} \rightarrow R_{th}(apparent)$$

3-1. Comparison tests

The purpose is to compare "the T_j (T_{j2}) obtained by the **Vf-Tj method**" and "the T_j which is determined by the **Tlead method** from the R_{th} values supplied by the diode manufacturer" (T_{j1}).

The procedure is as follows;

- ➊ After applying forward current ($I_f=9A$) to the diode for one hour, the forward voltage (V_f) and T_{lead} are measured.
- ➋ By using R_{th} supplied by diode manufacturer, the junction temperature (T_{j1}) is calculated by T_{lead} method.
$$T_{j1} = T_{lead} + R_{th-d} \times V_f \times I_f$$
- ➌ By using "the functional formula between V_f and T_j " obtained from the V_f - T_j characteristic, T_{j2} is calculated.
$$T_{j2} = a \times V_f + b \quad : \quad a \text{ and } b \text{ are the characteristic constants}$$
- ➍ " T_{j1} " and " T_{j2} " are compared.

3-2. Test samples

Four different types of BD were incorporated in the J-boxes.

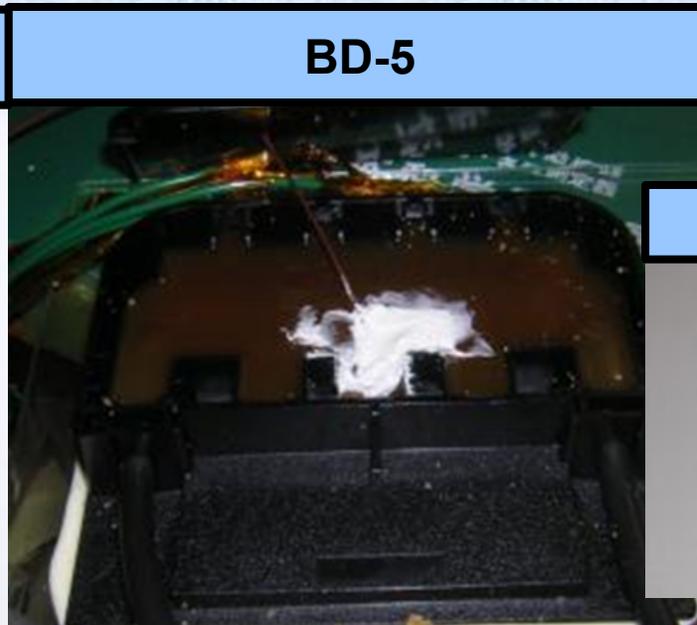
- BD-1, BD-3 and BD-4 are axial type diodes.
- BD-5 is a surface mount type diode (TO-220)

All J-boxes are potted by Si resin. Thermocouples were attached as indicated by the manufacturer, for example 3mm from the diode body.

BD-1,3,4



BD-5



TO-220 diode



3-3-1. Comparison (T_j ; Junction temperature, $^{\circ}\text{C}$)

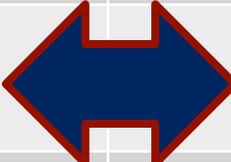
T_j values indicated below show the measured results and the difference between " T_{j_1} " and " T_{j_2} ".

Kind of BD	T_{j_1}	T_{j_2}	$T_{j_2} - T_{j_1}$
BD-1 / axial	151.7 $^{\circ}\text{C}$	159.8 $^{\circ}\text{C}$	8.1 $^{\circ}\text{C}$
BD-3 / axial	150.2 $^{\circ}\text{C}$	162.1 $^{\circ}\text{C}$	11.9 $^{\circ}\text{C}$
BD-4 / axial	151.8 $^{\circ}\text{C}$	157.7 $^{\circ}\text{C}$	5.9 $^{\circ}\text{C}$
BD-5 / TO-220	100.8 $^{\circ}\text{C}$	108.5 $^{\circ}\text{C}$	7.7 $^{\circ}\text{C}$

The test results showed the difference about 10 $^{\circ}\text{C}$.

3-3-2. Comparison (Rth ; Thermal resistance, W/°C)

BD ID#	① Presented by diode manufacturer	② Single BD	③ In J-box
BD-1	2.5	4.5	5.8
BD-3	3.5	6.3	9.2
BD-4	2.5	3.9	4.6



Actually Rths from the values obtained by the above measurement (②&③) are different to the values supplied by the manufactures. This indicates the risk of using “Rth values ①” supplied by diode manufacturer.

4. Comparison results with other facilities

The measurements cooperatively made by other organizations (a diode manufacturer and a module manufacture) confirmed that the similar results were be obtained.

◆ **Rth (W/°C) : JET vs Diode manufacturer A / sample : Axial diode V-1**

① Rth supplied by diode manufacturer V	at forward current (If)	② Rth by JET	③ Rth by diode manufacturer A
2.5	5A	2.3	3.2
	9A	3.0	3.5
	11A	3.2	3.4

◆ **Rth (W/°C) : JET vs PV module manufacturer A / sample : Axial diode V-2**

① Rth supplied by diode manufacturer V	at forward current (If)	② Rth by JET	③ Rth by PVM Manufacturer A
2.5	5A	4.7	3.0
	9A	4.9	3.8
	11A	4.9	3.7

Conclusion and proposal

- ◆ The test results showed that about 10°C difference may exist between the calculated T_j by “Tlead method” and the real T_j (T_j measured by Vf- T_j method).
- ◆ This difference could not be overlooked. It is considered appropriate to revise the pass criteria of the test to have 10°C margin to the diode manufacturer’s maximum junction temperature rating in the case of the “Tlead method” is used.
- ◆ It is recommended and considered desirable to apply the “Vf- T_j method” as far as possible, as a better method of measurement.
- ◆ It would be desirable if other organizations could perform the similar tests.