

- The proposal of thermal runaway test for bypass diode
- T_j measurement method for bypass diode

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

This presentation contains no confidential information.

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

Feb. 25-26, 2014 @ Denver, USA

Y. Uchida / JET (Japan Electrical & Environment Technology Laboratories)

1. The proposal of thermal runaway test for bypass diode

Current situation ;

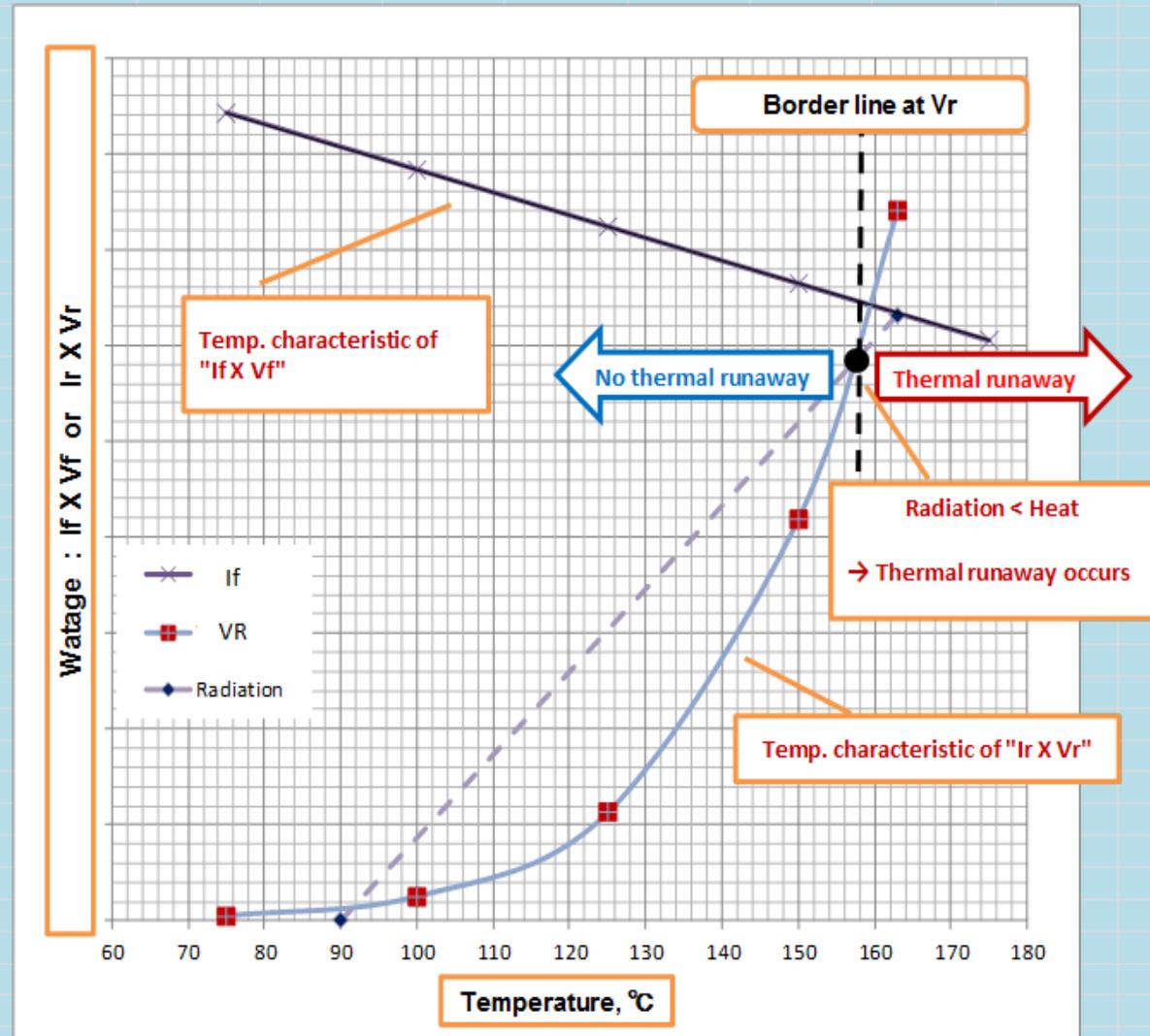
NWIP draft for “Thermal runaway test for bypass diode” was submitted to TC82/WG2 on Jan. 18, 2014 and is expected to be discussed in the next WG2 meeting in June.

Scope and Purpose

This international standard provides a method for evaluating whether a bypass diode as mounted in the module is susceptible to thermal runaway or if there is sufficient cooling for it to survive the transition from forward bias operation to reverse bias operation without overheating.

The concept of thermal runaway occurrence

When the amount of heat generated in the diode is greater than the capability of radiation to extract the heat, thermal runaway occurs.



Test procedure

(1) In the preheated climate chamber at 90°C, apply the forward current equal to “the 1.25 X STD short circuit current of the module” until the diode temperature stabilizes

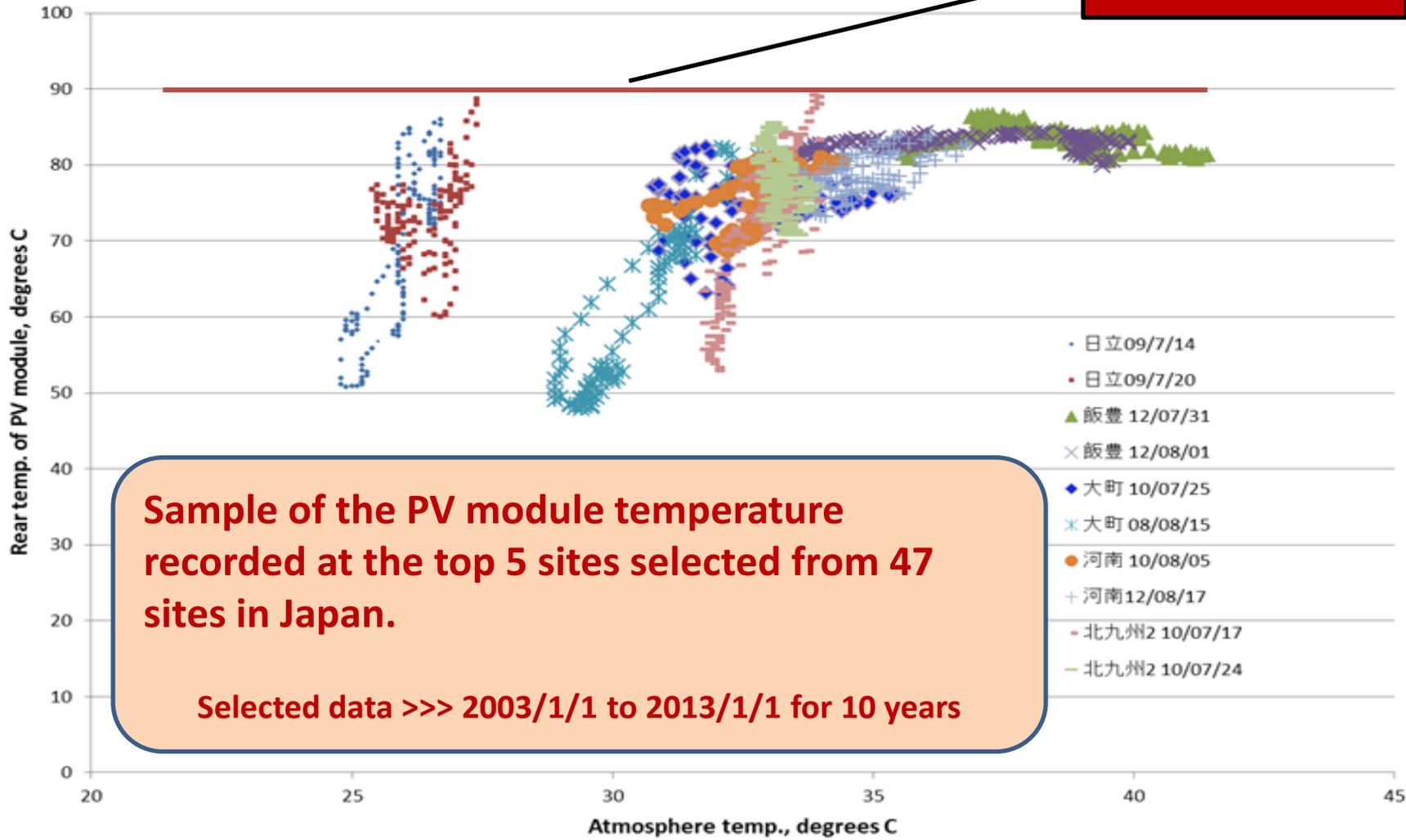
(2) Within 10ms after shutting off the forward current supply, apply the reverse bias voltage (V_r^*) to the diode and keep it for one minute unless the temperature of the diode extraordinarily increases.

* V_r = Sum of V_{oc} of the cells protected by one bypass diode

(3) If the temperature stabilizes or begins to decrease during one minute, remove the J-box from the chamber and verify that the diode is still operational.

The test condition “90°C” is proposed assuming the worst case according to the following results.

90 degrees C



Sample of the PV module temperature recorded at the top 5 sites selected from 47 sites in Japan.

Selected data >>> 2003/1/1 to 2013/1/1 for 10 years

2. Tj measurement method for Bypass diode (BD)

At NREL workshop last year, we discussed "Vf-Tj method" and "Tcase / lead method" of Tj measurement of BD.

This time, I will indicate the issues of Tcase/lead method by the specific examples.

Case 1 ;

#1 ; The temperature of the center diode in the J-box becomes always the highest.

#2 ; Tj by Vf-Tj method is higher than Tj by Tlead method.

【 Chamber temp. ; 75°C 】

		Left diode		Center diode		Right diode	
		Tlead, °C	Vf-Tj, °C	Tlead, °C	Vf-Tj, °C	Tlead, °C	Vf-Tj, °C
If	9A	158.1	160.1	165.0	173.3	143.1	156.7
	11A	175.2	178.7	183.4	192.7	156.9	176.8
	12A	183.5	187.5	192.4	201.5	164.0	184.5
	13A	192.0	195.5	201.2	212.1	170.7	193.7

【 Chamber temp. ; 90°C 】

If	9A	168.8	171.0	175.2	182.6	154.2	169.8
	11A	185.4	189.2	192.8	201.4	168.1	186.4
	12A	193.7	197.2	201.9	211.3	174.7	194.3
	13A	201.7	205.3	210.4	220.1	181.3	203.7

Note 1 Tlead : Tj by "Tlead method"

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

$R_{th} \Rightarrow 2.5^\circ\text{C/W}$ provided by diode manufacturer

Note 2 Vf-Tj : Tj by "Vf-Tj method" in accordance with "IEC61646 Ed.2

10.18 Bypass diode thermal test / Procedure 2"

Case 2 ;

Measured Rth (Thermal resistance) varies widely, even if the sampled diodes are taken from the same type lot.

For example ;

Sample	Rth (°C/W) at 9A
Diode – A	3.0
Diode – B	5.0
Diode - C	4.8

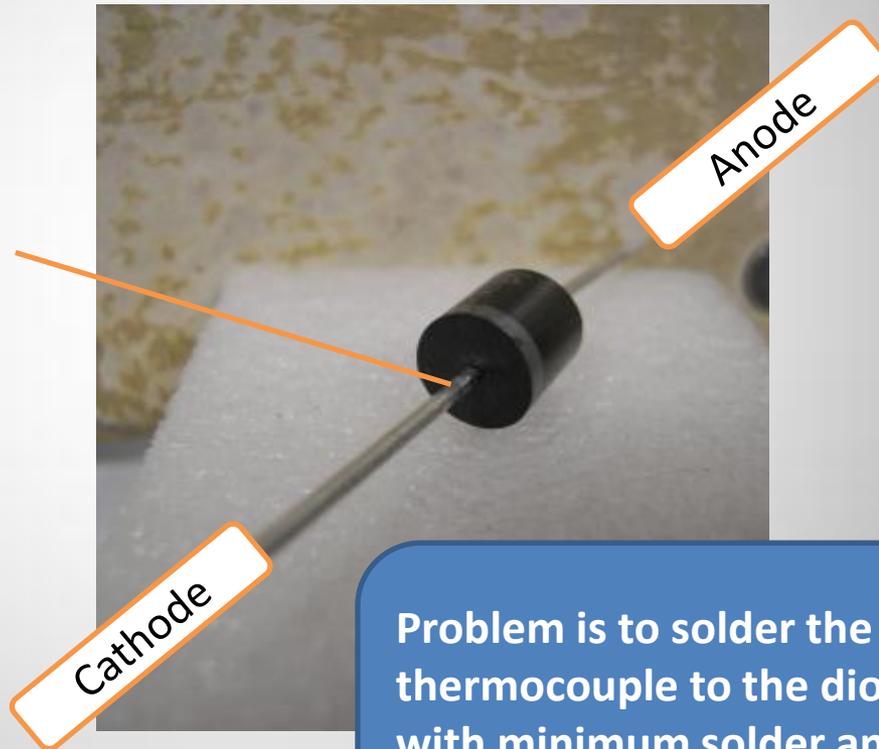
Note 1 ; Rth presented by diode manufacturer is 2.5 °C/W.

Note 2 ; These Rth were measured by JET.

Case 3 ; Problem of Tlead measurement

■ Axial diode

Theory ;
should be soldered as close
as possible to the cathode
terminal of diode.

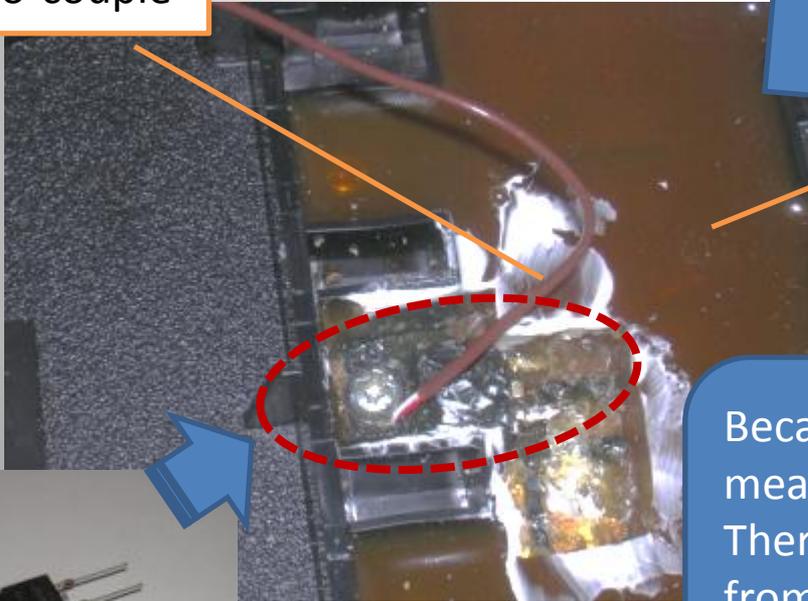


Problem is to solder the
thermocouple to the diode lead
with minimum solder and as close
as possible to the diode body.

Case 4 ; Problem of Tcase measurement

■ TO220 type diode in J-box

Thermo-couple



Molded resin



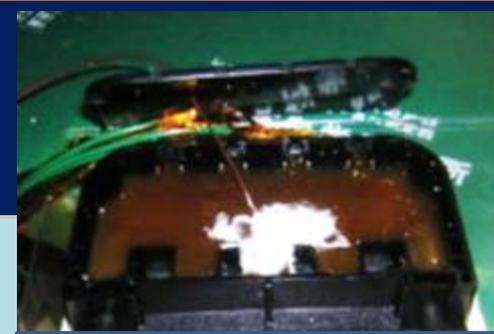
TO220 type diode



Because it is covered by the molded resin, the measurement of Tcase is difficult. There is no choice but to get the measurement from the part of the screw.

Comparison results

between “Tcase method” and “Vf-Tj method”



Test sample

■ Tcase method

$$T_j = T_{case} + V_f \times I_f \times R_{th}$$

T_{case} : 95.6°C (Temp. of diode's case)

V_f : 0.3391V

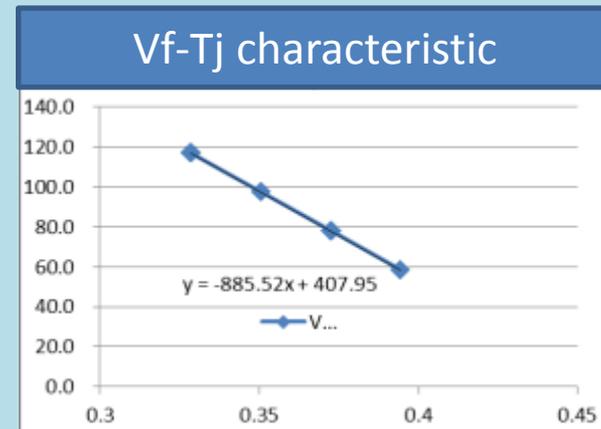
(Saturated voltage after 1h operating)

I_f : 9A (Forward current)

R_{th} : 1.5°C/W presented by manufacturer

$$\begin{aligned} T_j &= 95.6(^{\circ}\text{C}) + 0.3391(\text{V}) \times 9(\text{A}) \times 1.5(^{\circ}\text{C}/\text{W}) \\ &= \underline{\underline{100.2^{\circ}\text{C}}} \end{aligned}$$

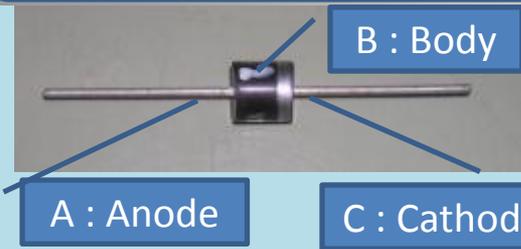
■ Vf-Tj method



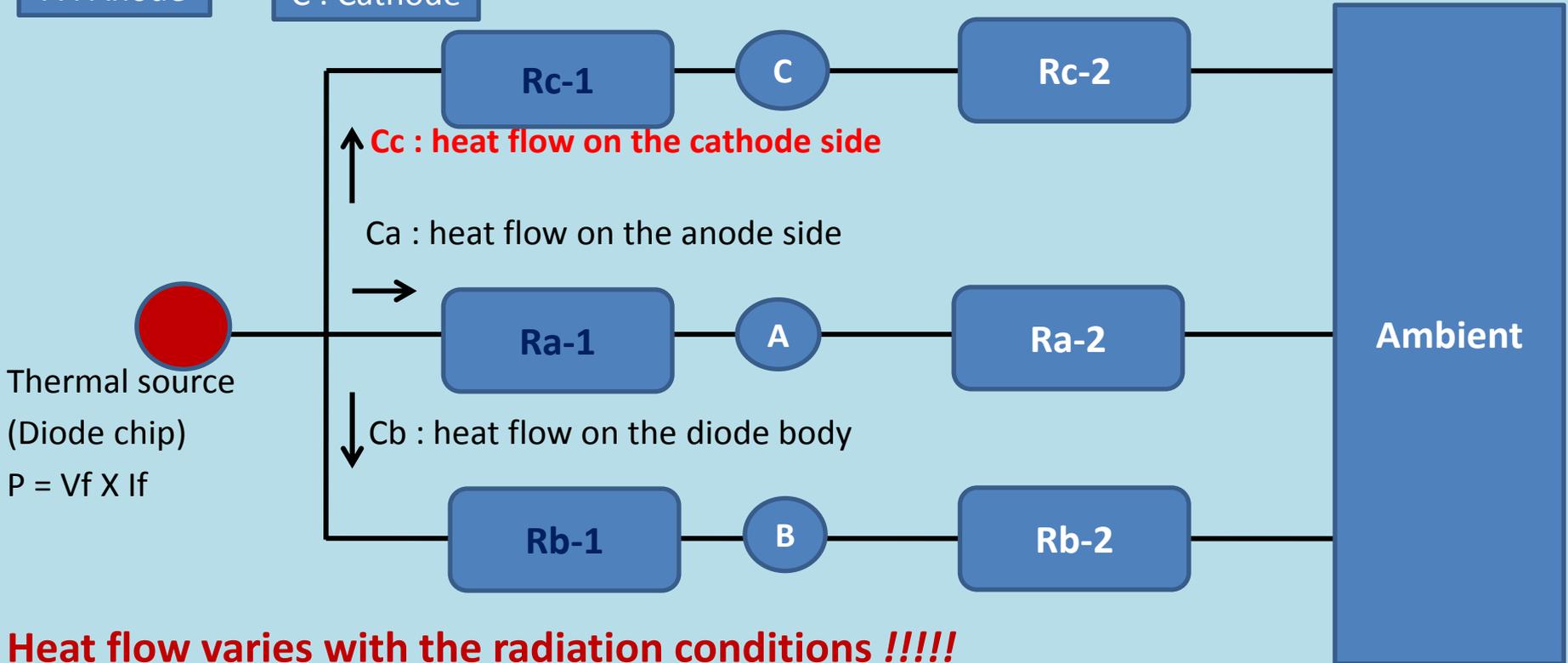
$$\begin{aligned} T_j &= -885.52 V_f + 407.95 \\ &= -885.52 \times 0.3391 + 407.95 \\ &= \underline{\underline{107.7^{\circ}\text{C}}} \end{aligned}$$

The R_{th} changes depending on where the diode is placed in the J-box.

Heat flow from Diode chip



$$R_{c-1} \cong R_{a-1} \ll R_{b-1}$$



Heat flow varies with the radiation conditions !!!!!

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

Heat flow from diode chip.

In the case of a R_{th} measurement for single diode,

- First of all, diode chip will be heat up by the applying current into J-box.
- Then, this heat will flow to C, A and B divergently.
- In this case, the constant C_c would vary depending on the heat radiation conditions.
- When the diode is mounted in the J-box, this constant changes.
- Therefore, the apparent R_{th} changes.

Tj that is calculated,

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

The temperature of $T_{case/lead}$ is very difficult to measure correctly, because there are the issues of the soldering technique including the soldering place and the amount of solder.

By being incorporated in the J-box, R_{th} presented by the diode manufacturer changes.

As a result, the error of the calculated value may become large.

Conclusion of $T_{\text{case/lead}}$ method

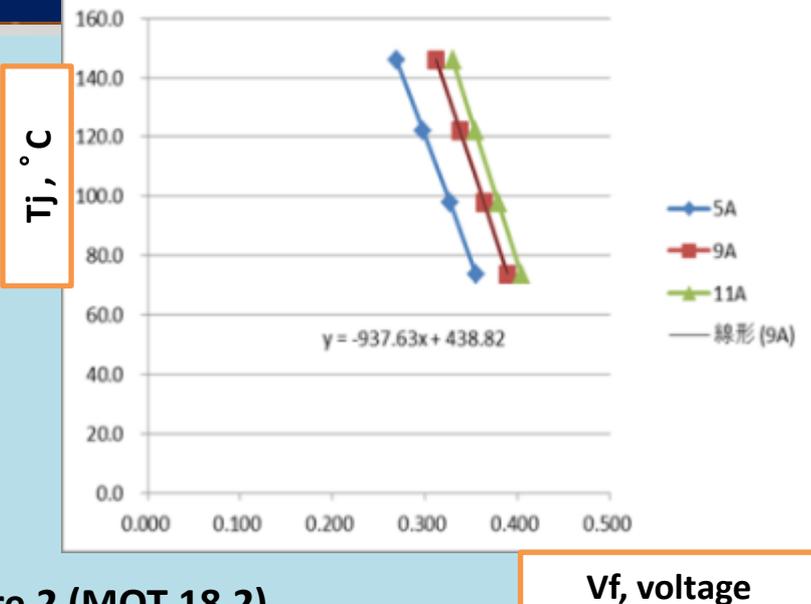
Due to the R_{th} change and the $T_{\text{case/lead}}$ measurement error, the calculated value of the T_j has some error compared to the real T_j .

Therefore, the judgment by using T_j value which is calculated by $T_{\text{case/lead}}$ method is misleading !!!!!

Vf – Tj method

- Once Vf-Tj relation is obtained, Tj is easily and accurately decided from the value of Vf.
Vf-Tj relation can be acquired by measuring the temperature of the lead and the voltage across the diode in thermal equilibrium condition.
- It is specified in IEC61215-2 Ed.1 draft / 4.18.2 Procedure 2 (MQT 18.2).
- To achieve this, the preparation of some special measuring equipment is required.

Case of Vf-Tj characteristics



Therefore, I will continue to explore the practical measuring method.