

- The proposal of thermal runaway test for bypass diode
- T<sub>j</sub> 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.

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# 1. The proposal of thermal runaway test for bypass diode

## Current situation ;

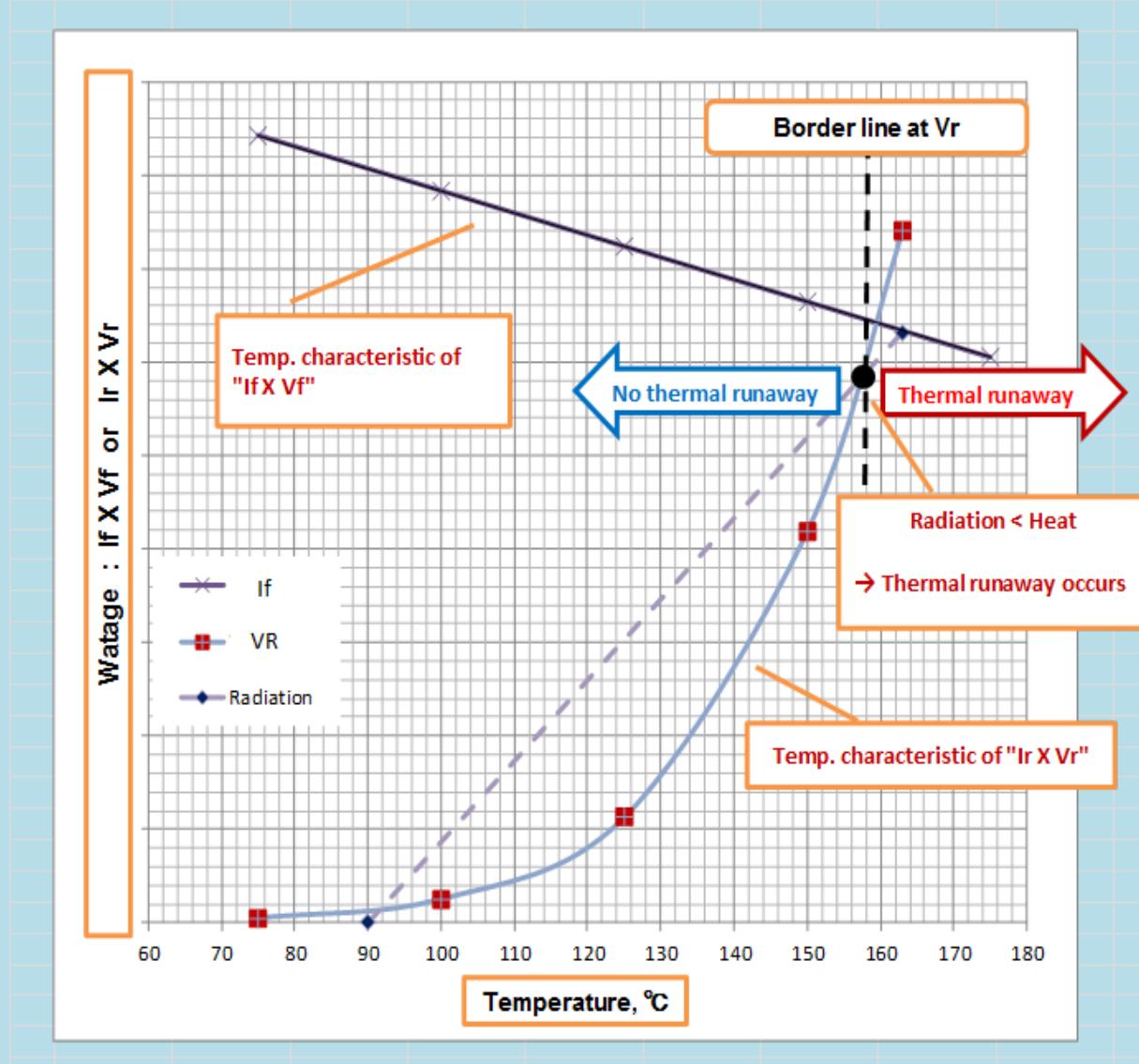
NWIP draft for “Thermal runaway test for bypass diode” was submitted to TC82/WG2 on Jan. 18, 2014 and is expected to be discussed in the next WG2 meeting in June.

### **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

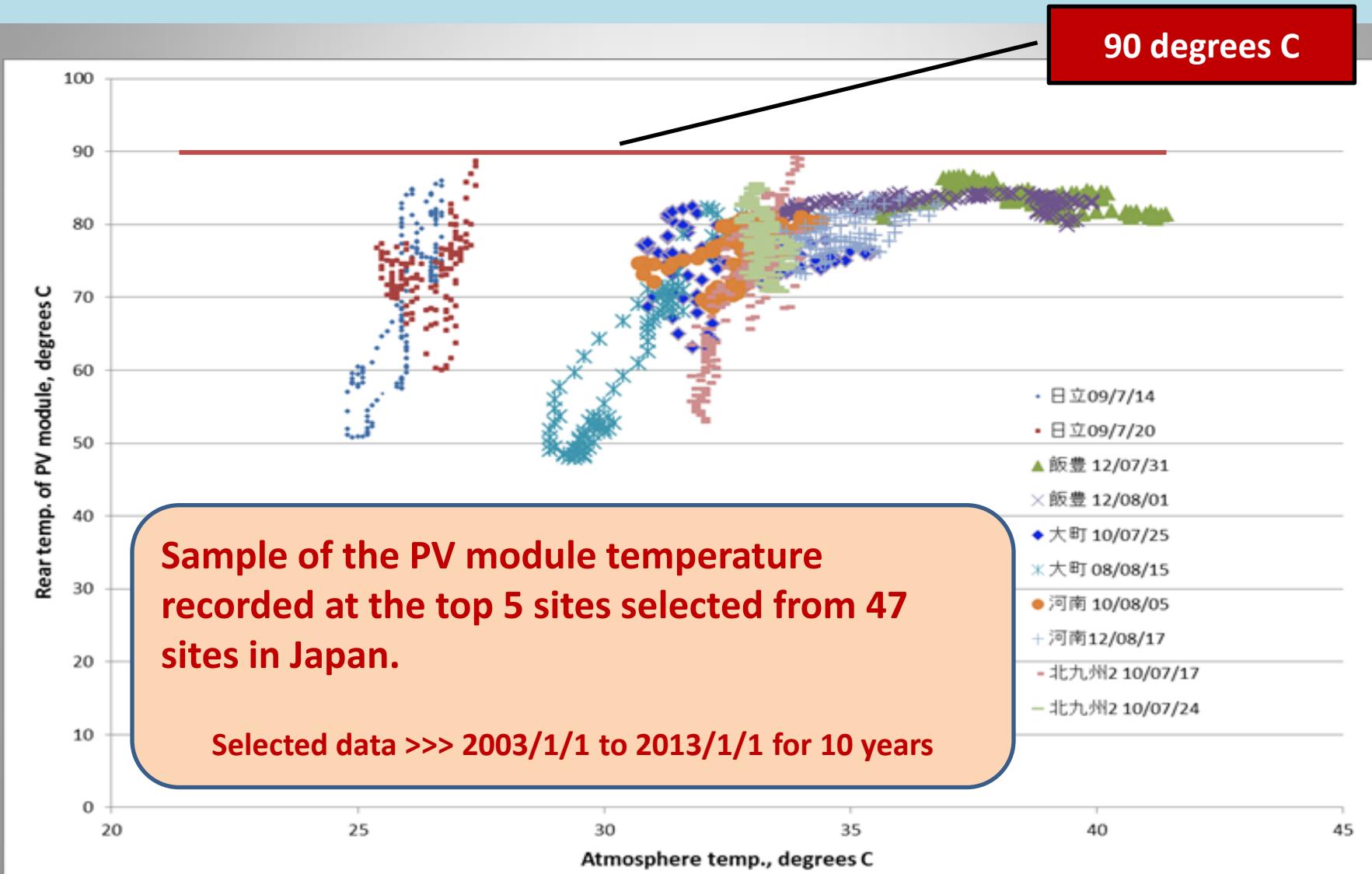
When the amount of heat generated in the diode is greater than the capability of radiation to extract the heat, thermal runaway occurs.



# 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.



## 2. T<sub>j</sub> measurement method for Bypass diode (BD)

At NREL workshop last year, we discussed "Vf-T<sub>j</sub> method" and "T<sub>case</sub> / lead method" of T<sub>j</sub> measurement of BD.

This time, I will indicate the issues of T<sub>case</sub>/lead method by the specific examples.

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### Case 1 ;

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

#2 ; T<sub>j</sub> by Vf-T<sub>j</sub> method is higher than T<sub>j</sub> by T<sub>lead</sub> method.

#### 【 Chamber temp. ; 75°C】

		Left diode		Center diode		Right diode	
		T <sub>lead</sub> , °C	Vf-T <sub>j</sub> , °C	T <sub>lead</sub> , °C	Vf-T <sub>j</sub> , °C	T <sub>lead</sub> , °C	Vf-T <sub>j</sub> , °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    T<sub>lead</sub> : T<sub>j</sub> by "T<sub>lead</sub> method"

T<sub>j</sub> = T<sub>lead</sub> + (Vf X If X R<sub>th</sub>)      R<sub>th</sub> ⇒ 2.5°C/W provided by diode manufacturer

Note 2    Vf-T<sub>j</sub> : T<sub>j</sub> by "Vf-T<sub>j</sub> method" in accordance with "IEC61646 Ed.2"

10.18 Bypass diode thermal test / Procedure 2"

## Case 2 ;

Measured R<sub>th</sub> (Thermal resistance) varies widely, even if the sampled diodes are taken from the same type lot.

For example ;

Sample	R <sub>th</sub> (°C/W) at 9A
Diode – A	3.0
Diode – B	5.0
Diode - C	4.8

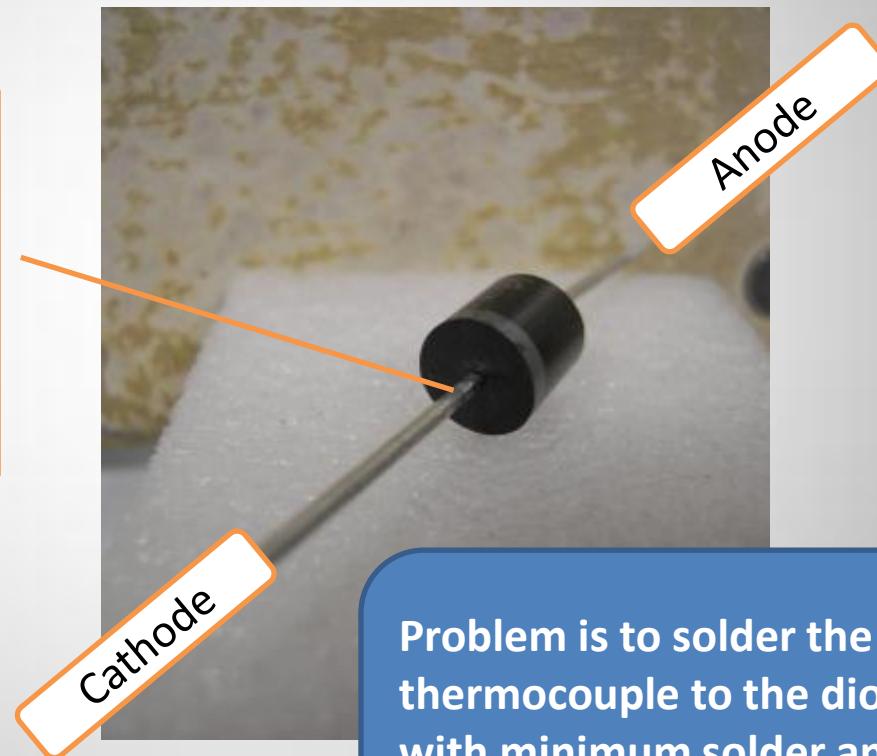
Note 1 ; R<sub>th</sub> presented by diode manufacturer is 2.5 °C/W.

Note 2 ; These R<sub>th</sub> 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.

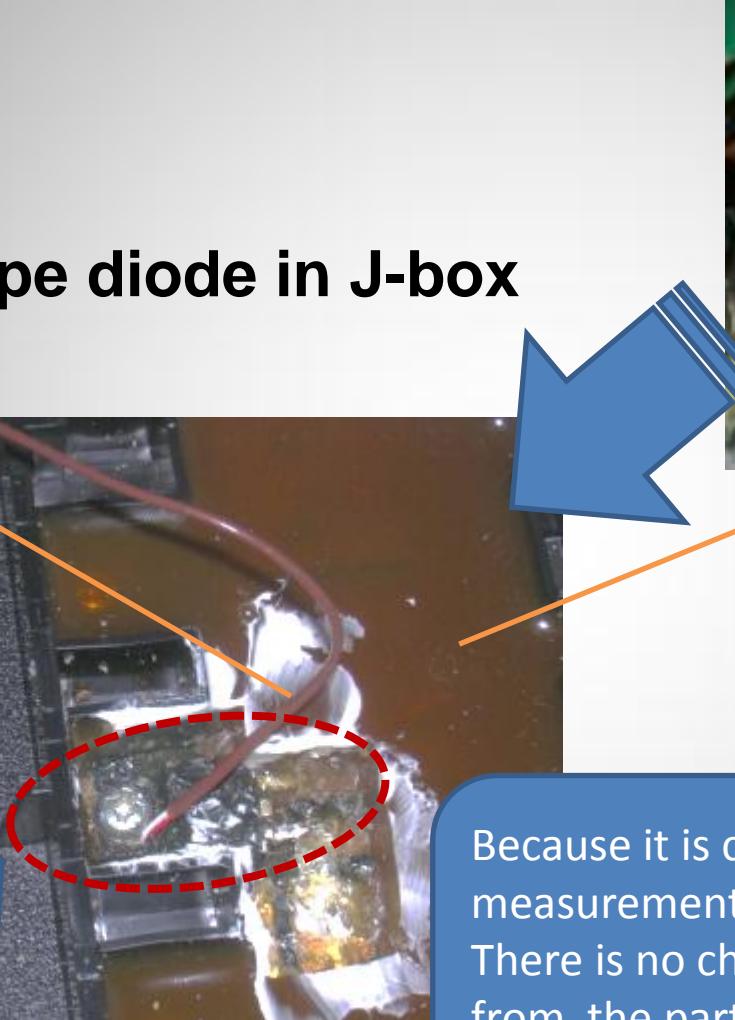
## Case 4 ; Problem of Tcase measurement

### ■ TO220 type diode in J-box

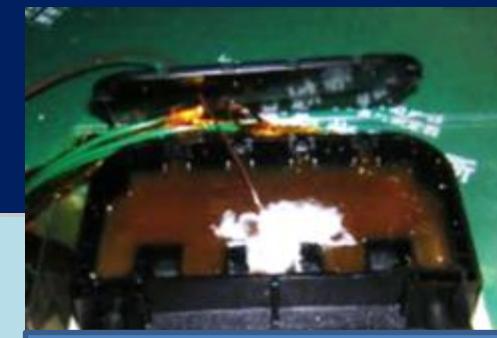
Thermo-couple

Molded resin

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”



## ■ Tcase method

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

T<sub>case</sub> : 95.6°C (Temp. of diode's case)

V<sub>f</sub> : 0.3391V

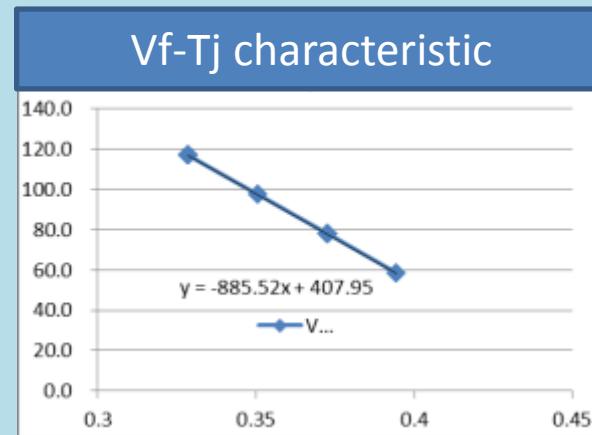
(Saturated voltage after 1h operating)

I<sub>f</sub> : 9A (Forward current)

R<sub>th</sub> : 1.5°C/W presented by manufacturer

## ■ Vf-Tj method

Test sample

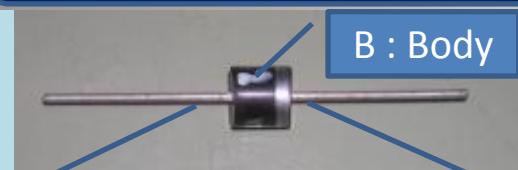


$$T_j = 95.6(\text{°C}) + 0.3391(\text{V}) \times 9(\text{A}) \times 1.5(\text{°C/W})$$
$$= \underline{\underline{100.2\text{ °C}}}$$

$$T_j = -885.52 V_f + 407.95$$
$$= -885.52 \times 0.3391 + 407.95$$
$$= \underline{\underline{107.7\text{ °C}}}$$

The R<sub>th</sub> changes depending on where the diode is placed in the J-box.

# Heat flow from Diode chip

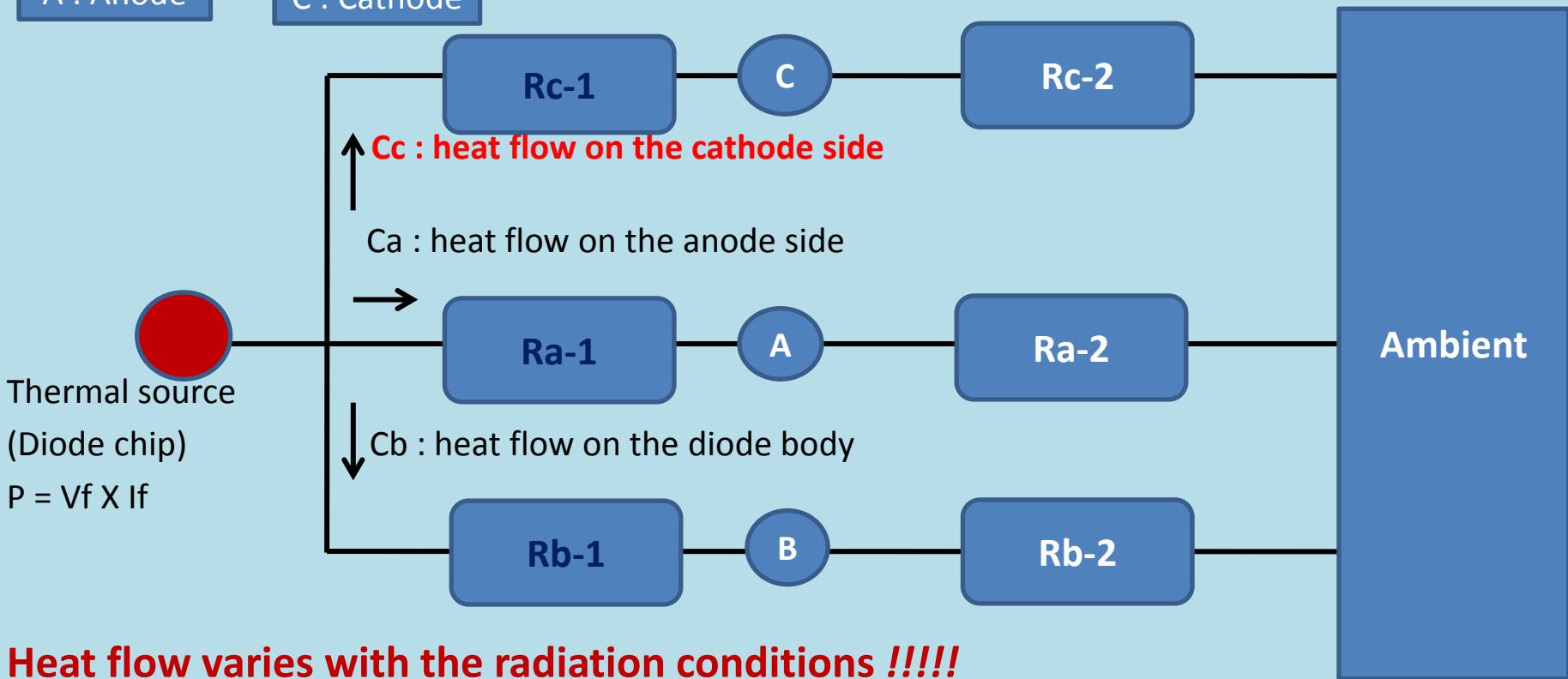


B : Body

A : Anode

C : Cathode

$$Rc-1 \doteq Ra-1 \ll Rb-1$$



Heat flow varies with the radiation conditions !!!!

$$T_j = T_{lead} + Vf \times If \times \boxed{Cc \times Rth (\rightarrow \text{real } Rth)} \rightarrow \text{apparent } Rth$$

# Heat flow from diode chip.

**In the case of a R<sub>th</sub> 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<sub>c</sub> would vary depending on the heat radiation conditions.
- When the diode is mounted in the J-box, this constant changes.
- Therefore, the apparent R<sub>th</sub> changes.

# T<sub>j</sub> that is calculated,

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

The temperature of T<sub>case/lead</sub> 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<sub>th</sub> presented by the diode manufacturer changes.

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

# Conclusion of Tcase/lead method

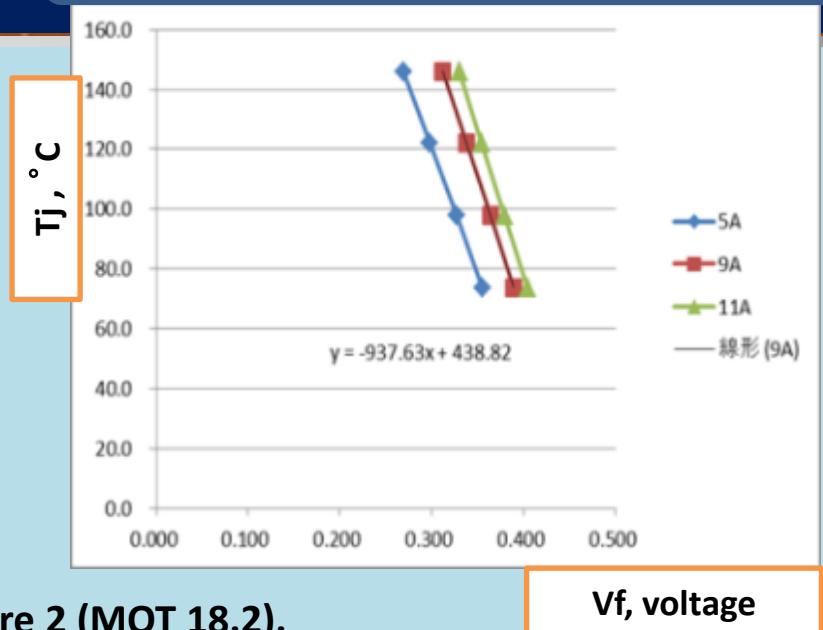
Due to the Rth change and the Tcase/lead measurement error, the calculated value of the  $T_j$  has some error compared to the real  $T_j$ .

**Therefore, the judgment by using  $T_j$  value which is calculated by Tcase/lead method is misleading !!!!**

# Vf – Tj method

Case of Vf-Tj characteristics

- 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.



$V_f$ , voltage

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