On the occurrence of thermal runaway in Diode in the J-box

J-TG 4 activities of QA Forum

QA Task Force 4 ; Diode, Shading & Reverse Bias

Feb. 26-27, 2013 ***@ Denver, USA***

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

Y. Konishi / ONAMBA CO.,LTD.

T. Okura / SOMA OPTICS, LTD.

J-TG4 Activity Report

J-TG4 activities had been reported in the following events ;

1. Dec.08, 2011 — 2nd. QA Forum Tokyo
2. Feb. 28, 2012 — NREL PV Module Reliability Work-shop
3. May 07, 2012 — WG2 STRESA meeting
4. Oct.01, 2012 — WG2 Oslo meeting
5. Nov.27, 2012 — 3rd. QA Forum Tokyo
6. **Feb.26,27, 2013 — NREL PV Module Reliability Work-shop**

Background

→ Trend of Bypass diode from P/N Si diode to SBD

■ This trend is because of the addition of “Bypass diode thermal test” in IEC 61215 Ed2. (2005-04),

①When applying current of Isc at 75℃, diode junction temperature shall not exceed max. rated Tj.

②When applying current of "1.25XIsc" at 75 ℃, the function of diode shall not be impaired.

On top of the above requirements, due to the pressure of the price reduction of diode and suppression of heat-up, the bypass diode has switched to the SBD with low Vf .

Test reports

Test① Continuous current test for J-box
- ①-1 for Diode-A
- ①-2 for J-box-A

Test② Intermittent current test for Diode
- ②-1 for Diode-A
- ②-2 for Diode-B

Reported at WG2 Oslo meeting.

Test③ Reverse bias test at high temperature (Thermal runaway test)

- ③-1 for J-box-A / with potting
- ③-2 for J-box-B-1 / without potting
- for J-box-B-2 / without potting
- ③-3 for J-box-C / without potting

Contents of this report

1. **Thermal runaway test results of J-boxes**

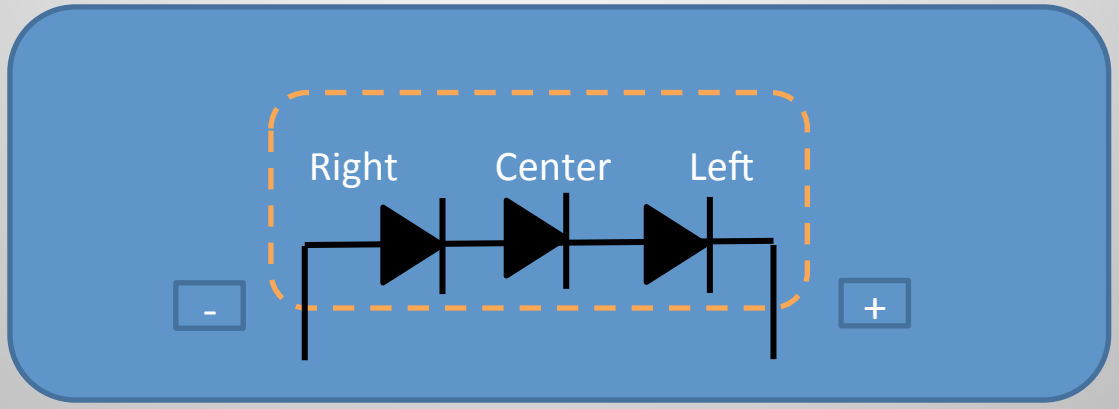
2. Tj measurement method for Bypass diode

J-boxes for Thermal-runaway tests

J-box-A

J-box-B

J-box-C



Summary of “Reverse bias test at high temperature” ;

Test ③-1 ; J-box-A / with potting (Test sequence : ①center→②right→ ③left)

■ Chamber temp. : 90℃

		Reverse bias / Vr			
		15V	20V	25V	30V
If / Forward current	9A	1. Center ○	2. Center ○	3. Center ○	
	11A	4. Center ○	5. Center ○	6. Center ×	
	12A	7. Right ○	8. Right×		
	13A	9. Left ×			

○ ; No thermal runaway
× ; Thermal runaway

The numbers mean a test sequence.

Summary of "Reverse bias test at high temperature" ;

Test ③-2 ; J-box-B-1 / without potting

■Chamber temp. : 75℃

Reverse bias / Vr

		15V	20V	25V	30V
If / Forward current	8A	1. Center ○	3. Center ○		
	9A	2. Center ○	5. Center ○		
	11A	4. Center ○			
	12A				

○ ; No thermal runaway
× ; Thermal runaway

The numbers mean a test sequence.

■ Chamber temp. : 90℃

		15V	20V	25V	30V
If / Forward current	8A	6. Center ○	8. Center ○		
	9A	7. Center ○	10. Center ○		
	11A	9. Center ○	11. Center ×		
	12A				

Summary of "Reverse bias test at high temperature" :

Test ③-2 ; J-box-B-2 #3 / without potting (Test sequence : ①center→②right→ ③left)

		Left diode		Center diode		Right diode	
VR; reverse voltage		15VR	20VR	15VR	20VR	15VR	20VR
■ Chamber temp. : 75C							
If	8A	Not done	Not done	1. ○	3. ○	1. ○	3. ○
	9A	Not done	Not done	2. ○	5. ○	2. ○	5. ○
	11A	Not done	Not done	4. ○	Not done	4. ○	Not done
■ Chamber temp. : 90C							
If	8A	Not done	Not done	6. ○	8. ○	6. ○	9. ○
	9A	Not done	1. ○	7. ○	—	7. ○	10. ○
	11A	2. ○	3. ×	9. ×	—	8. ○	11. ○
	12A	—	—	—	—	12. ○	13. ×

Summary of "Reverse bias test at high temperature" ;

Test ③-3 ; J-box-C / without potting

■Chamber temp. : 75℃

Reverse bias / Vr

If / Forward current	15V	20V	25V	30V
8A	1. Center ○	3. Center ○		
9A	2. Center ○	5. Center ○		
11A	4. Center ○			
12A				

○ ; No thermal runaway
× ; Thermal runaway

The numbers mean a test sequence.

■ Chamber temp. : 90℃

If / Forward current	15V	20V	25V	30V
8A	6. Center ○	8. Center ○		
9A	7. Center ○			
11A	9. Center×			
12A				

Temperature of each diode in J-box under the forward current

J-box-A-3 / Chamber temp. ; 75℃

If	Left diode Tj, ℃	Center diode Tj, ℃	Right diode Tj, ℃
9A	130.2	131.2	129.2

J-box-B-1 / Chamber temp. ; 75℃

If	Left diode Tj, ℃	Center diode Tj, ℃	Right diode Tj, ℃
9A	160.1	173.3	158.7
11A	178.7	192.7	176.8
12A	187.5	201.5	184.5
13A	195.5	212.1	193.7

J-box-B-1 / Chamber temp. ; 90℃

If	Left diode Tj, ℃	Center diode Tj, ℃	Right diode Tj, ℃
9A	171.0	182.6	169.8
11A	189.2	201.4	186.4
12A	197.2	211.3	194.3
13A	205.3	220.1	203.7

The temperature of the center diode is affected by the left and right diodes and becomes the highest.

Note ;
The Tj was obtained from the Vf value using Vf-Tj relation.

Results of the study -1

1. We were able to confirm the thermal runaway of the SBD during high-temperature reverse bias.

2. As for the thermal runaway, the timing of switching from forward to reverse is important.

3. We have confirmed that the conditions for the thermal runaway was different according to the type of J-box (ex. ; J-box shape and with or without the potting materials).

   → We are planning to perform the thermal runaway test for some more J-boxes with different diodes.

4. In case of typical J-box with 3 diodes in the box, the temperature of the center diode is affected by the left and right side diodes and becomes the highest.

Contents of this report

1. Thermal runaway test results of J-boxes

2. Tj measurement method for Bypass diode

T_{lead} method vs Vf-Tj method

From our experiment,

As for Diode Tj, the difference was confirmed in "Vf-Tj method" and "T_{lead} method".

→ with experimental data on the next page.

Test sample ; J-box-B-2

[Chamber temp. ; 75℃]

		Left diode		Center diode		Right diode	
		Tlead, ℃	Vf-Tj, ℃	Tlead, ℃	Vf-Tj, ℃	Tlead, ℃	Vf-Tj, ℃
If	9A	158.1	160.1	165.0	173.3	143.1	158.7
	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℃]

		Left diode		Center diode		Right diode	
		Tlead, ℃	Vf-Tj, ℃	Tlead, ℃	Vf-Tj, ℃	Tlead, ℃	Vf-Tj, ℃
If	9A	168.8	171	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"
Tj = Tlead + (Rth × Vf × If), Rth= 2.5℃/W provided by diode maker
Note 2. : Vf-Tj ; Tj by "Vf-Tj method"
in accordance with "IEC61646 Ed.2 10.18 Btpass diode thermal test / Procedure 2"

Why always
Tlead < Vf-Tj ?

Tlead method

The correct Tj can not be obtained by Tlead method.

Because, the thermal resistance (Rth) could vary.

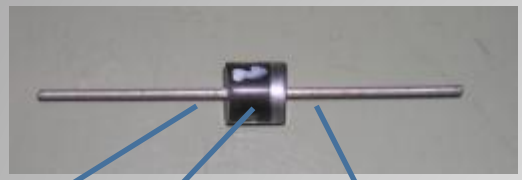
$$Tj = Tlead + (Rth \times If \times Vf)$$

The reason that thermal resistance varies is as follows;

there is a difference in heat radiation conditions because diodes are installed in various J-box.

→ **We are now measuring in order to obtain the support data.**

Heat flow from Diode chip



Rc-1 < Ra-1 << Rb-1

Cathode

Rc-1 — C — Rc-2

Cc : heat flow on the cathode side

Ca : heat flow on the anode side

Thermal source
(Diode chip)
P = Vf X If

Ra-1 — A — Ra-2

Anode

Cb : heat flow on the diode body

Rb-1 — B — Rb-2

Body

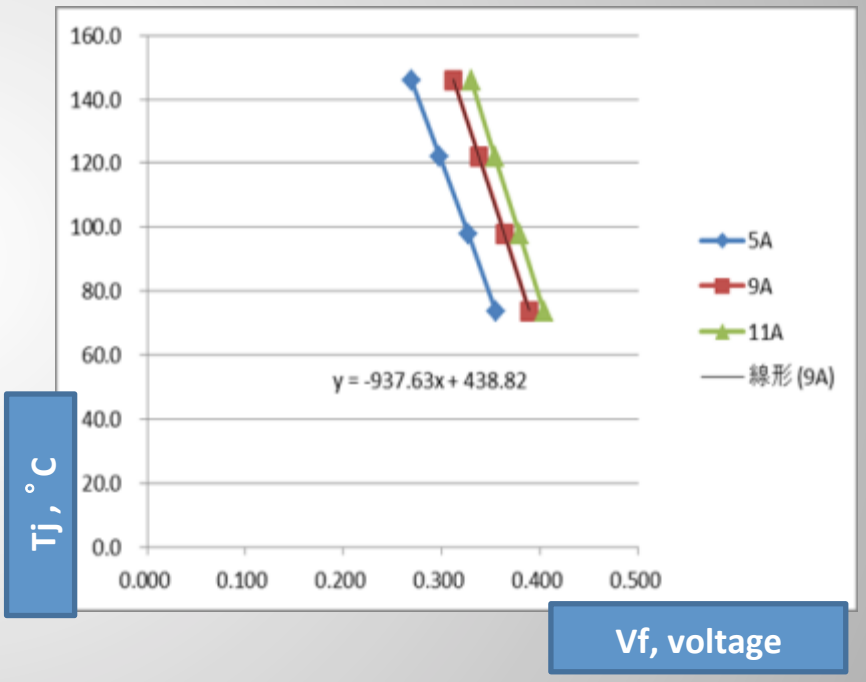
Ambient

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

Tj = Tlead + Vf×If × Cc × Rth (→ real Rth) → **apparent Rth**

Vf – Tj method

- **Once Vf-Tj relation is obtained, Tj is easily 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.



Results of the study -2 (1/2)

From this experiment, the difference was confirmed in Vf-Tj method and Tlead method as for Tj of diode.

Regarding the thermal resistance (Rth) by Tlead method, Rth is provided by Diode maker.

When it is assembled into the J-box, an apparent Rth will vary because of the influence of wiring left and right side diodes, including Heat-sink.

$$Tj = Tlead + (Rth \times If \times Vf)$$

Results of the study -2 (2/2)

Therefore, we should use the Vf-Tj method in accordance with "paragraph 10.18 Bypass diode thermal test / procedure 2 specified in IEC61646".

In order to continue accumulating technical data for Tj of diodes, we would like to propose a Vf-Tj method.

Next activities

1. Establishment of a method of thermal design verification test for J-box, and preparation of a draft standard

2. Development and manufacturing of thermal runaway test equipment

3. Suggestions for improvement of Diode Tj measurement method

4. In order to discuss the rating system, we have to confirm the changes of the characteristics of reverse bias after long term reliability test.

Thank you for your attention.

Acknowledgment ;
I would like to thank those who have helped us i.e. SHARP, Onamba, Nihon Inter Electronics, Sanken Electronic and SOMA Optics.