IEC TR 61189-3-914

Edition 1.0 2017-03

TECHNICAL REPORT

colour inside

Test methods for electrical materials, printed boards and other interconnection structures and assemblies –
Part 3-914: Test method for thermal conductivity of printed circuit boards for high-brightness LEDs – Guidelines

IEC TR 61189-3-914:2017-03(en)

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TEST METHODS FOR ELECTRICAL MATERIALS, PRINTED BOARDS AND OTHER INTERCONNECTION STRUCTURES AND ASSEMBLIES –

Part 3-914: Test method for thermal conductivity of printed circuit boards for high-brightness LEDs – Guidelines

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IEC TR 61189-3-914, which is a technical report, has been prepared by IEC technical committee 91: Electronics assembly technology.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
91/1378/DTR	91/1403/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 61189 series, published under the general title *Test methods for electrical materials, printed boards and other interconnection structures and assemblies*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

Development of this technical report has been discussed at TC 91 Plenary meeting in Dongguan, China, October 30, 2015 as per 91/1343A/RM dated on January 22, 2016.

This document was developed as a supplementary document to the IEC 61189-3-913. Therefore, this document has been developed as technical report.

This document is given for information only.

TEST METHODS FOR ELECTRICAL MATERIALS, PRINTED BOARDS AND OTHER INTERCONNECTION STRUCTURES AND ASSEMBLIES –

Part 3-914: Test method for thermal conductivity of printed circuit boards for high-brightness LEDs – Guidelines

1 Scope

This document specifies the detailed procedures and precautions for IEC 61189-3-913.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60194, *Printed board design, manufacture and assembly – Terms and definitions*

IEC 60068-1:2013, *Environmental testing – Part 1: General and guidance*

IEC 61189-3-913, *Test methods for electrical materials, printed boards and other interconnection structures and assemblies – Part 3-913: Test method for thermal conductivity of electronic circuit boards for high-brightness LEDs*

EIA/JEDEC STD 51-2, *Integrated circuits thermal test method – Environmental conditions – Natural convection (still air)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60194 apply, unless otherwise specified.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 Test condition

4.1 Standard condition

Unless otherwise specified, tests should all be operated under the following standardized conditions in accordance with the IEC 60068-1:2013, Clause 4:

- temperature: 15 °C to 35 °C;
- relative humidity: 25 % to 75 %;
- atmospheric pressure: 86 kPa to 106 kPa.

If there is any doubt concerning the testing results under standardized condition, or upon a request to check the atmospheric condition, the re-examination should be operated under atmosphere in accordance with IEC 60068-1:2013.

If the standardized atmosphere is difficult to provide, testing under non-standardized atmosphere is acceptable as long as the atmospheric condition does not affect the testing results.

4.2 Specified condition

The specified condition should be in accordance with the condition specified in IEC 60068-1:2013, Clause 4:

- temperature: 20 °C ± 2 °C;
- relative humidity: 60 % to 70 %;
- atmospheric pressure: 86 kPa to 106 kPa.

5 Pre-condition

Pre-conditioning should be in accordance with a) or b) below:

a) leave the specimen for 24 h in the standard condition;
b) leave the specimen for 60 min in a thermostat chamber at 85 °C ± 2 °C and then leave the specimen for 24 h ± 4 h in the standard atmospheric condition.

NOTE This test element group (hereafter, referred to as TEG) chip includes a heater with a temperature measuring sensor. In this document, the TEG chip indicates a chip with a temperature measuring sensor.

6 Heat dissipation characteristics

6.1 General

For the test method for thermal conductivity of a printed circuit board (hereafter referred to as PCB) for high-brightness LEDs, the following factors are considered.

- The test method is applied to evaluate the relativity of both heat transfer and thermal conductivity of PCBs consist of heterogeneous materials as shown in Figure A.2 in Annex A which describes the heat transfer coefficient parameter as X-axis and thermal conductivity parameter as Y-axis.
- The IEC 61189-3-913 employs a TEG chip as the heat source to replicate the heat generated by LED chips.
- Heat dissipation characteristics of PCBs depend not only on the thermal conductivity of the material properties, but also on the structure.
- In addition, convection and radiation from the specimen surface should be considered as factors to affect the testing results.
- Considering the anisotropic nature of the heat dissipation of PCBs, different test methods are employed for the plane (horizontal) and across the thickness (vertical) direction. The combination of these tests should replicate a realistic environment.
- A TEG chip is employed with following considerations:
  – measuring a small heat source such as an LED with thermocouples;
  – accuracy of the designated thermal emissivity may affect the measurement results of the radiation thermometer.
- The size of the specimen and the power of the heat source are based upon the general application of LEDs and PCBs.

- Considerations concerning the selection of materials:
  – select materials with a large thermal conductivity for the PCB across the thickness (vertical) heat radiation structure for edge lighting and alternative LED lights to fluorescent lamps as shown in Figure 1;
  – select materials with a large heat transfer coefficient for the PCB in the horizontal direction (direction of plane) as shown in Figure 2.

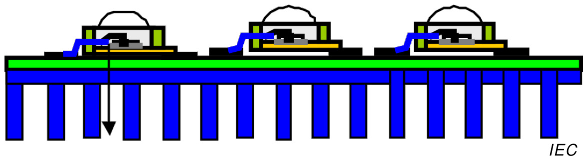


Figure 1 – Example of PCB with large thermal conductivity

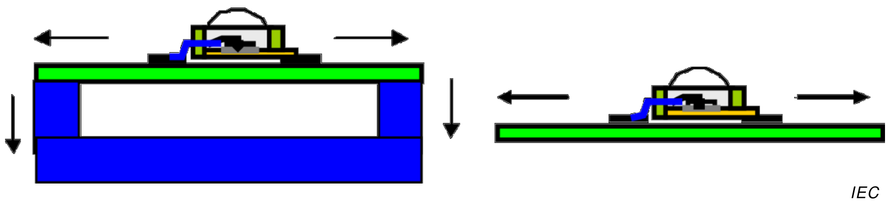
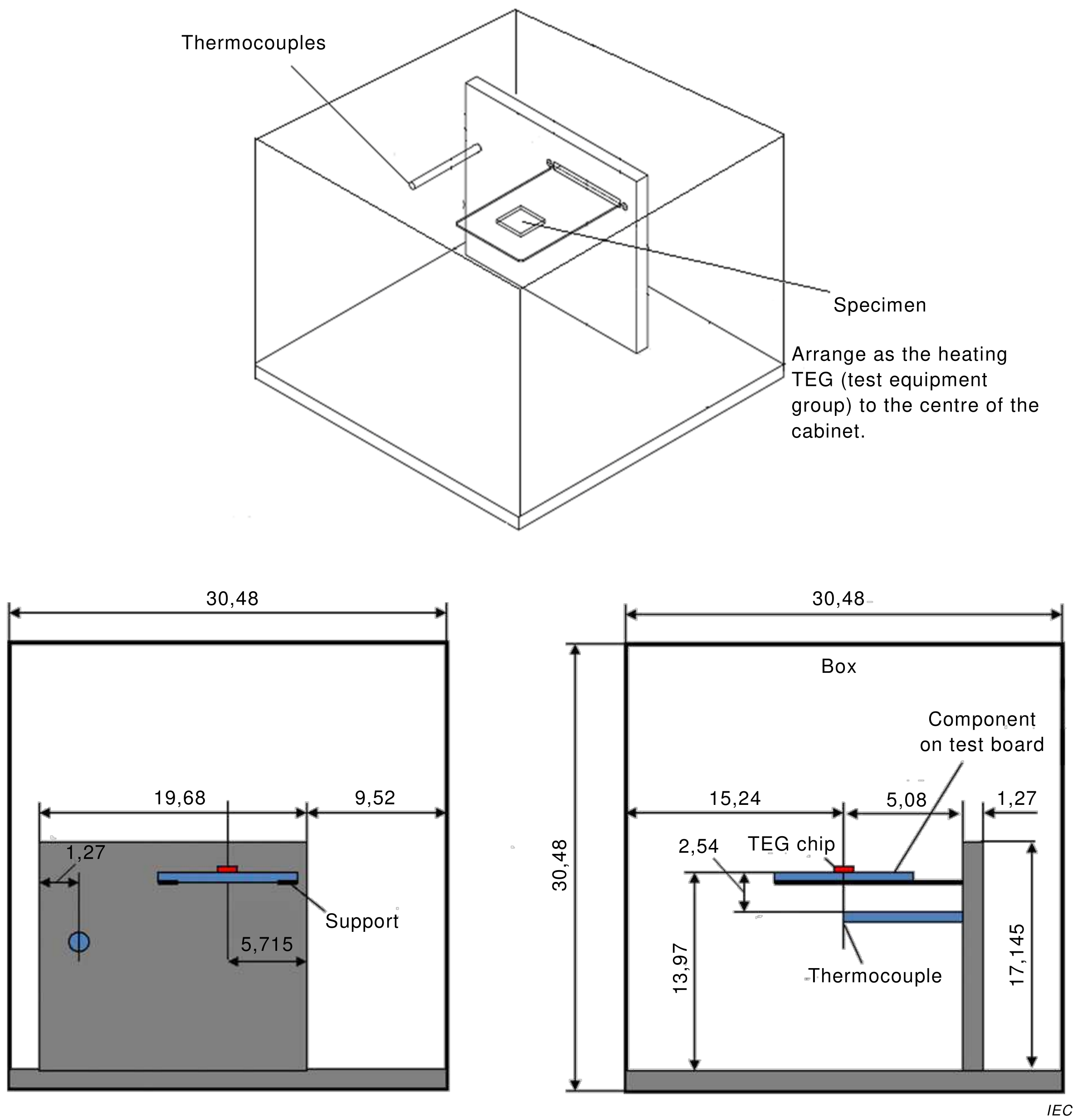


Figure 2 – Examples of PCBs with large heat transfer coefficients

6.2 Measurement of thermal resistance on the plane

a) Equipment
  – Use the equipment specified in EIA/JEDEC STD 51-2 (*Integrated circuits thermal test method – environment conditions – natural convection* (*still air*)), or equivalent.
  – Set a specimen and a thermocouple at the centre of the chamber.
  – The chamber should be a cubic shape and a side of the chamber should be 30 cm.
  – The schematic diagram of the equipment is shown in Figure 3.

Dimensions in centimetres



1) Arrange the TEG chip at the centre of the cabinet.

2) Air temperature in the box should be measured by the thermocouple at 25 mm below the specimen.

Figure 3 – Illustration of thermal resistance test (for information)

b) Specimen

– The specimen should be as illustrated in Figure 4.

– Use a 5 mm × 5 mm TEG chip that is wire-bonded at the centre of the specimen as a heat source.

Dimensions in millimetres

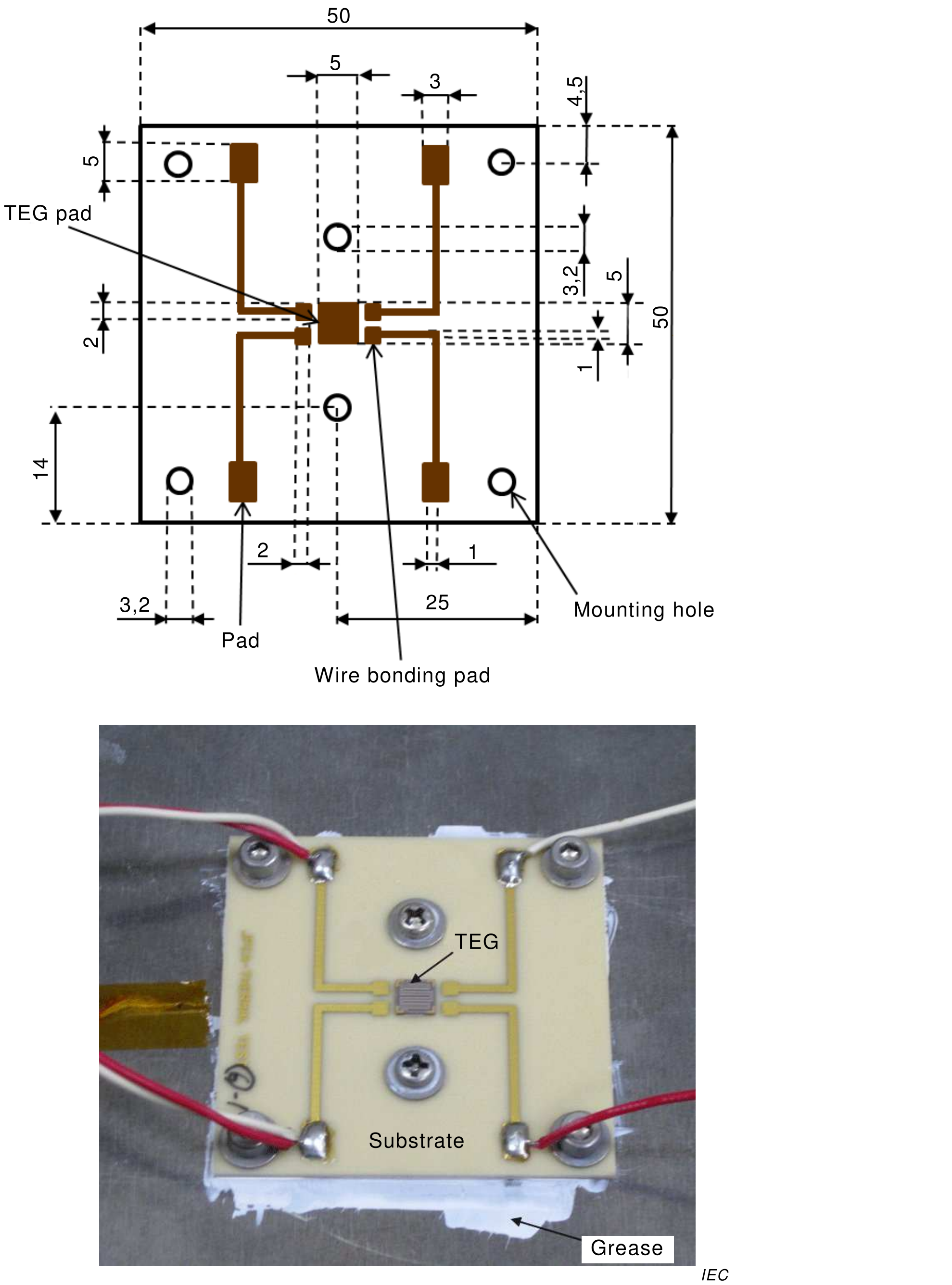


Figure 4 – Layout of the specimen surface for the thermal resistance test

c) Pre-condition

– Pre-conditioning should be in accordance with Clause 5.

d) Test

– The temperature coefficient of the TEG chip should be obtained before testing.

– The specimen should be horizontally fixed in the chamber.

– After the completion of the set-up, apply power to the TEG chip.

– The power applied to the TEG chip, W, depends upon the thermal resistance, R_p.

– The value of R_p should be selected from Table 1.

– Measure the temperature of the TEG chip, T_s, and the air temperature of the chamber, T_a, after the temperature of the TEG chip has reached stable state.
– The thermal resistance on the plane, R_p, should be calculated as follows:

$$R_p = (T_s - T_a)/W \text{ (K/W)}$$

– Heat transfer parameter, he, should be calculated from the following equation using R_p:

$$he = \frac{1}{R_p \times 0{,}0025} \text{ (W/m}^2\text{K)}$$

Table 1 – Load heat (W) corresponding to range of thermal resistance on the plane (K/W)

Applied power (W)	**Range of thermal resistance on the plane** (R_p) (K/W)
0,1	300 < R_p
0,2	200 < R_p < 300
0,3	150 < R_p < 200
0,4	100 < R_p < 150
0,75	60 < R_p < 100
1,0	30 < R_p < 60
2,0	20 < R_p < 30
3,0	150 < R_p < 20
5,0	5 < R_p < 5
10,0	R_p < 5

6.3 Thermal resistance across the thickness

a) Equipment

Equipment should consist of a metal block (aluminium or copper) that can hold the specimen specified in 6.2 d) and a cooling system to keep the temperature of the metal block constant. The apparatus is shown in Figure 5.

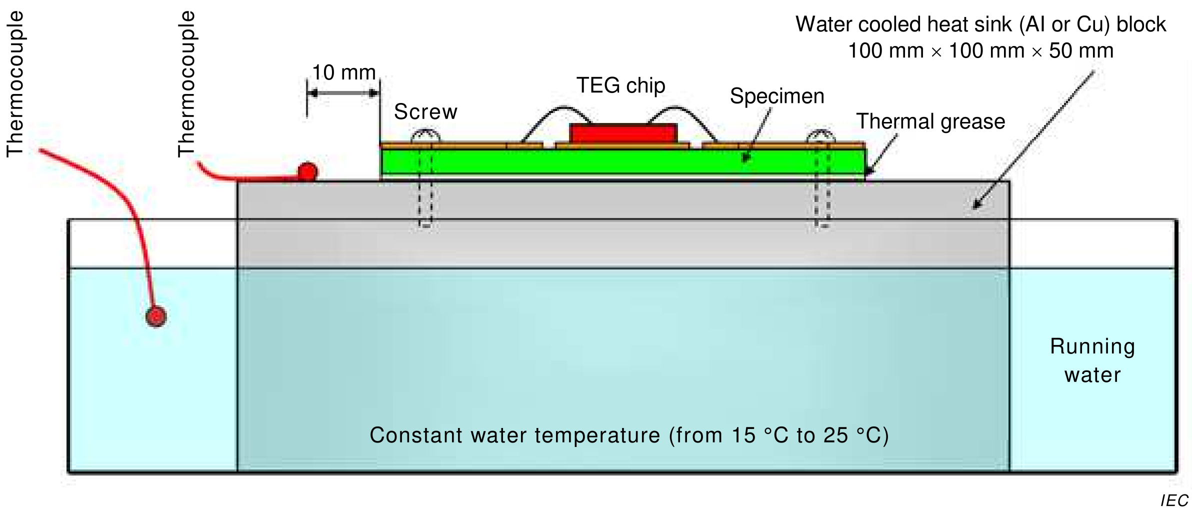


Figure 5 –Test equipment for thermal resistance across the thickness

b) Specimen

Specimen should be as specified in 6.2 d).

c) Pre-conditioning

Pre-conditioning should be as specified in Clause 5.

d) Test

A specimen with TEG chip, whose temperature coefficient has already been obtained, should be fixed to the metal block with screws.

Thermal conductive material such as thermal grease should be applied in between the specimen and the metal block to reduce thermal resistivity.

Set a thermocouple on the metal block within 10 mm from the edge of the specimen.

Another thermocouple is applied in the coolant water to measure the water temperature.

As shown in Figure 5, place the metal block in the cooling system, and stabilize the water temperature.

Apply the power to the TEG chip with load heat, W. The load heat, W, should be selected from Table 2 depending on the thermal resistance across the direction R_t.

Temperature of the TEG chip, T_s, should be measured with the following procedures:

– check and confirm T_s is in the stable stage;
– check and confirm difference in the temperature between the metal block surface and coolant water is less than 2 °C;
– measure T_s and T_b, the temperature of the metal block.

Thermal resistance across the thickness, R_t, should be calculated as follows:

$$R_t = (T_s \quad T_b) / W \text{ (K/W)}$$

Thermal conductivity parameter, Ke, should be calculated as follows using R_t:

$$Ke = \frac{t}{R_t \times 2{,}5 \times 10^{-5}} \text{ (W/mK)}$$

where

t is the thickness, expressed in metres (m)

$2{,}5 \times 10^{-5}$ is the mounting area of temperature measuring sensor, expressed in m^2.

Table 2 – Load heat (W) corresponding to range of thermal resistance to the direction of the thickness (K/W)

Applied power W	**Range of thermal resistance across the thickness** K/W
0,1	$300 < R_t$
0,2	$200 < R_t < 300$
0,3	$150 < R_t < 200$
0,4	$100 < R_t < 150$
0,75	$60 < R_t < 100$
1,0	$30 < R_t < 60$
2,0	$20 < R_t < 30$
3,0	$15 < R_t < 20$
5,0	$5 < R_t < 15$
10,0	$R_t < 5$

6.4 Thermal resistance measurement procedures and precautions

6.4.1 General

Procedures are as follows:

- upon measurement, the resistance value should be read during the stable state;
- measurement should be made in the standard atmospheric condition.

6.4.2 Die attach

The TEG chip should be attached to the PCB by metal paste (materials of better thermal conductivity such as Ag paste, etc.). No void is allowed between the TEG chip and the PCB.

The thickness of the metal paste should be approximately less than 40 µm. The thickness should be measured by a measuring microscope.

6.4.3 Wire bonding

The TEG chip and PCB should be wire connected. In order to avoid the abnormal heat generation, the specification of wire should be as follows.

- Bonding wire: gold wire φ 50 µm × 4 wires × 4 corners.

6.4.4 Temperature measuring sensor (calibration)

The temperature of the sensor should be measured in a constant temperature bath. The measurement items are as follows:

- voltage of the sensor;
- temperature in the constant temperature bath.

The temperature should be measured at least 3 times, e.g. 40 °C, 80 °C, and 120 °C. Measure the voltage of the sensor and the temperature in the constant temperature bath, 1 h after the temperature in the bath has been stabilised. The following conditions are recommended:

- 1 mA for the sensor current;
- 4-terminal for voltage measurement;
- type T thermocouple for temperature measurement.

6.4.5 Measurement of thermal resistance on the plane

Apply an arbitrary current to the TEG chip and measure the thermal resistance after reaching the exothermic saturation.

It takes 30 min to 60 min to reach the exothermic saturation after application of the arbitrary current.

The same power supply should be used for the TEG chip and measurement of the TEG chip temperature coefficient.

The same voltmeter should be used for the TEG chip and measurement of the TEG chip temperature coefficient.

The same thermometer should be used for the TEG chip and measurement of the TEG chip temperature coefficient.

In order to avoid a heat generation in a cable caused by a current, the cable that connects the heater terminal to the power supply should be of an appropriate thickness.

During measurement, the permissible range of the change in ambient temperature should be within the ±0,2 °C.

The measurement should be 30 min to 60 min after the placement of the specimen in the chamber. Examples are shown in Figure 6 and Figure 7.

Measurement items are as follows:

- voltage at the sensor;
- voltage at the heater;
- current at the heater;
- ambient temperature;
- flatness of the surface.

The following measuring conditions are recommended:

- 1 mA for the sensor current;
- 4-terminal for voltage measurement at the sensor and heater.

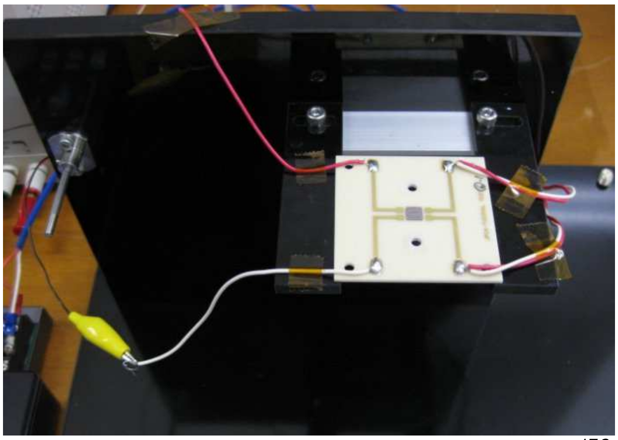
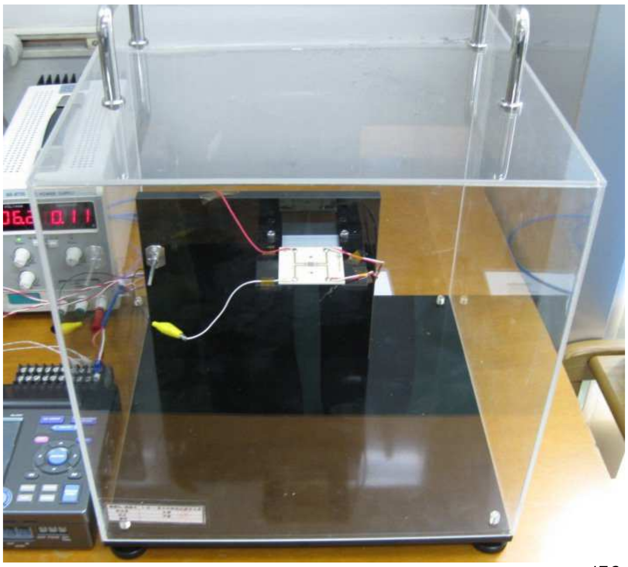


Figure 6 – Example of attachment of the specimen



IEC

Figure 7 – Example of measurement of the thermal resistance on the plane

6.4.6 Thermal resistance across the thickness using cold plate

While measuring the thermal conductivity across the thickness using a cold plate, particular attention should be paid to the following:

- in order to avoid voids, silicone grease should be applied in between the cold plate and PCB as shown in Figure 8;
- apply an arbitrary current to the TEG chip and measure the thermal resistance after reaching the exothermic saturation;
- the measurement should be 30 min to 60 min after reaching the exothermic saturation;
- the same power supply should be used for the TEG chip and the measurement of the TEG chip temperature coefficient;
- the same voltmeter should be used for the TEG chip and the measurement of the TEG chip temperature coefficient;
- the same thermometer should be used for the cold plate and the measurement of the TEG chip temperature coefficient;
- in order to avoid a heat generation in a cable caused by a current, the cable that connects the heater terminal to the power supply should be of an appropriate thickness;
- the PCB should be vertically attached to the cold plate as shown in Figure 9 and Figure 10;
- it takes 30 min to 60 min to reach the stable condition for measurement;
- measurement items are the following:
  – voltage at the sensor;
  – voltage at the heater;
  – current at the heater;
  – temperature of the cold plate;
  – thickness (across the thickness – vertical).

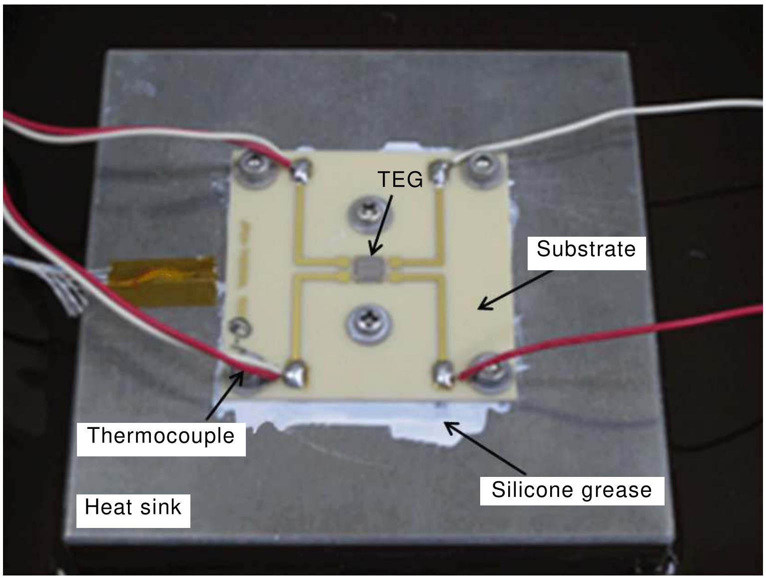


Figure 8 – Use of the silicone grease

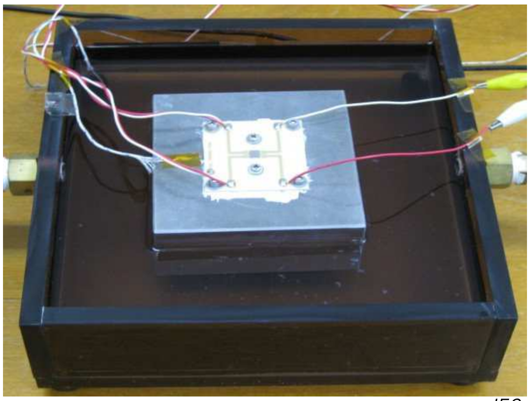


Figure 9 – Test equipment for thermal resistance across the thickness (running water tank specification)

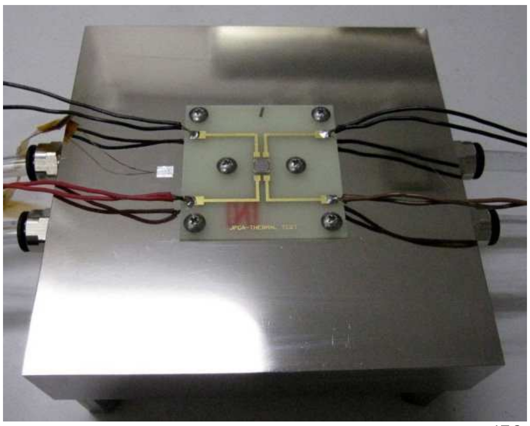


Figure 10 – Test equipment for thermal resistance across the thickness (cold plate)

The following measuring arrangements are recommended:

- 1 mA for the sensor current;
- the tightening torque should be 0,3 Nm when bolting (or screwing) the specimen to the cold plate;
- if the warping of the specimen is marked, a reinforcement especially of the circumference of the TEG chip to the cold plate should be applied;
- the thermal conductivity of the silicone grease should be ≥1 W/m·K;
- the cold plate should be water-cooled;
- the change of the coolant water temperature during the measurement should be within ±0,2 °C;
- the temperature of the coolant water should be monitored and controlled;
- 4-terminal for voltage measurement at the sensor and heater.

Annex A
(informative)

Classification and class of the PCB

The classification and class of the PCB in this document should be in accordance with the thermal conductivity and insulation properties indicated in Table A.1.

- The primary classification is based upon the thermal conductivity.
- The secondary classification is based upon the insulation property.

Table A.1 – Application and classification

Primary classification (thermal conductivity)	**Definition**	**Secondary classification (insulation property)**	**Definition**	**Thermal conductivity parameter** W/(mK)	**Heat transfer parameter** W/(m^{2}K)	**Thermal impedance** (Km^2 / W)
A	Standard boards	I	No specification	<1	<10	Thermal impedance can be calculated from the measurement of thermal conductivity and the inverse heat transfer parameter.
		II	Electric strength <1 000 V			
		III	Electric strength ≤1 000 V			
B	Thermal conductive boards	I	No specification	≥1	<10	
		II	Electric strength <1 000 V			
		III	Electric strength ≤1 000 V			
C	High thermal conductive boards	I	No specification	≥1	≥10	
		II	Electric strength <1 000 V			
		III	Electric strength ≤1 000 V			
Electric strength is shown as ‘V’, which is the rated voltage.						

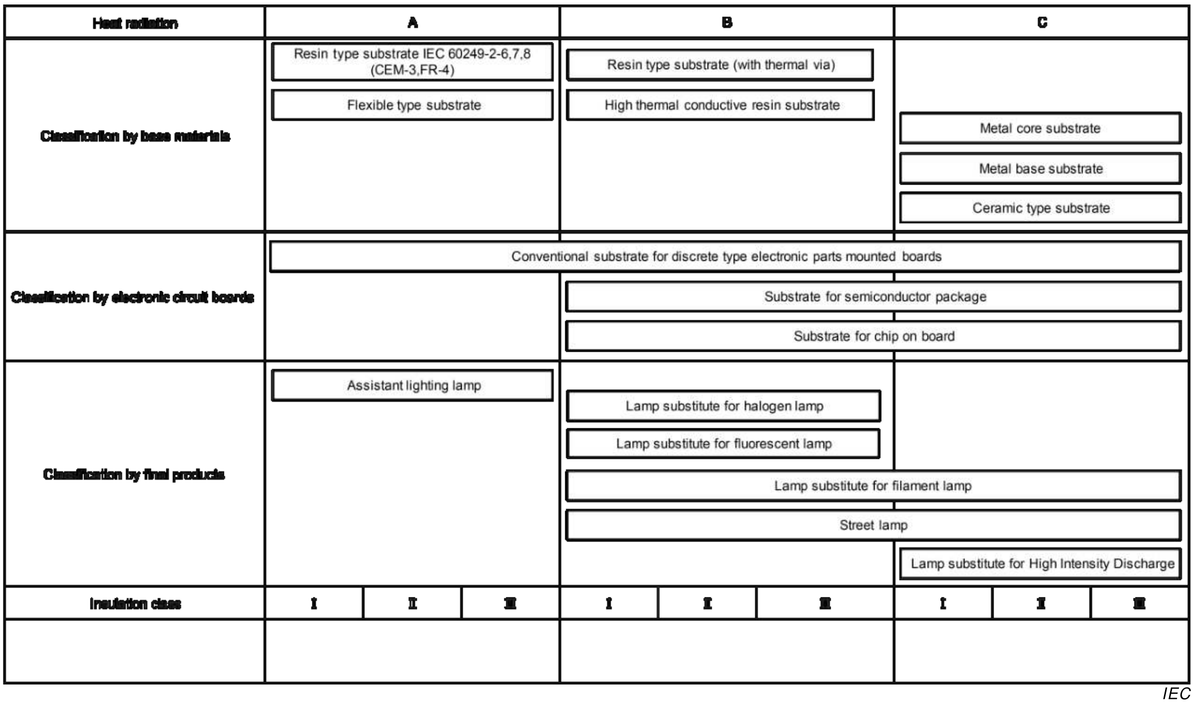


Figure A.1 – Example of classification and their application by base materials, PCBs and final products

Figure A.1 indicates the following items:

- relation of primary and secondary classification;
- classification of materials;
- PCB applications;
- classification of PCB based upon applications.

Classification based upon Table A.1 should be as agreed between the user and the supplier.

Two parameters representing thermal properties of PCB materials are the thermal conductivity parameter and the heat transfer parameter.

The examination of these two properties made it possible to classify PCBs consistent with thermal characteristics.

Resin-based materials (resin-type substrate) can be classified as below by thermal conductivity parameters based upon the existence/non-existence of thermal vias and thermal conductivity parameters:

- more than 1 W/(mK);
- less than 1 W/(mK).

In addition, by using the heat transfer parameter, the following classifications are possible:

- resin-based materials (resin type substrate) – less than 10 W/(m^2K);
- ceramic/aluminium based materials (metal core substrate/ceramic-type substrate) – more than 10 W/(m^2K).

Figure A.2 and Table A.2 indicate the detailed information on the classification and class of the PCBs for high-brightness LEDs based upon the thermal conductive parameter and heat transfer coefficient parameter.

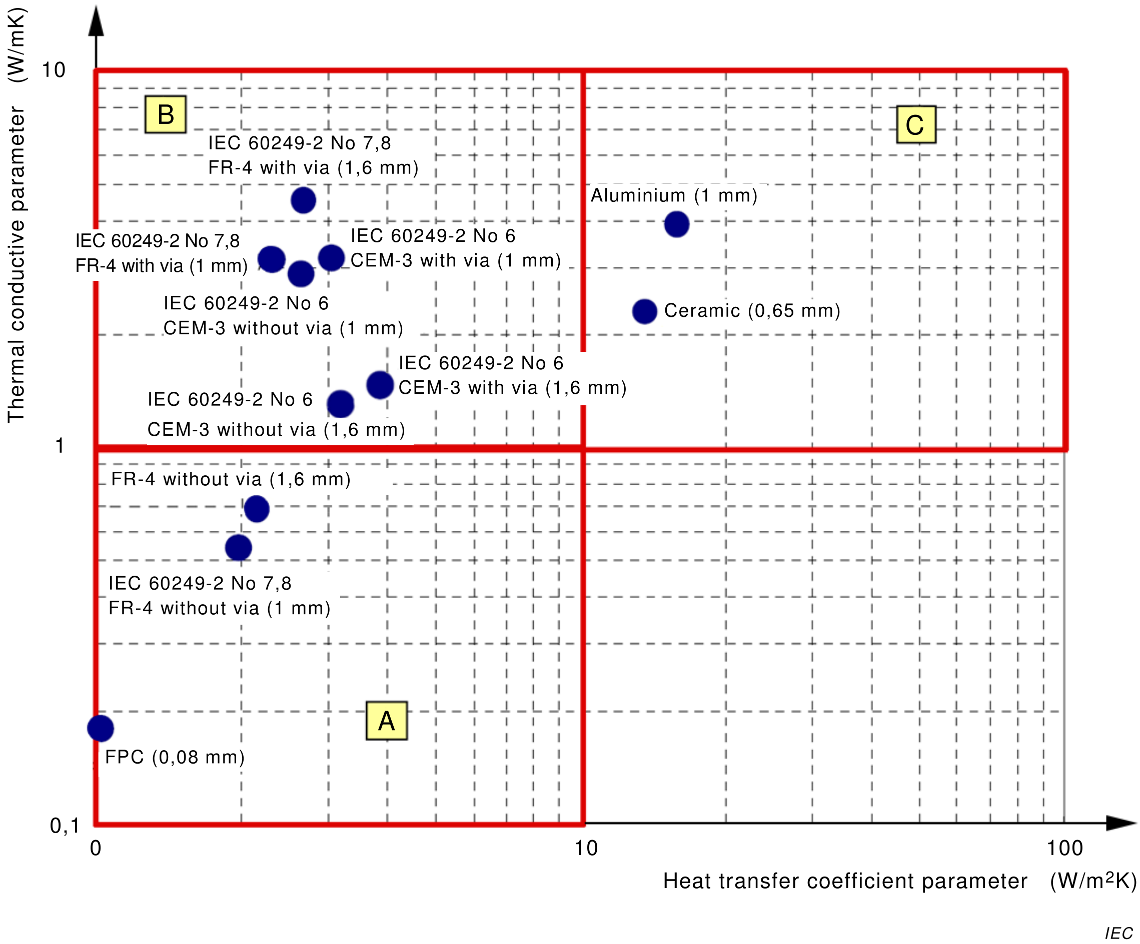


Figure A.2 – The relation between thermal conductive parameter (W/(mK)) and heat transfer coefficient parameter (mapping by substrate)

Table A.2 – The relation between thermal conductive parameter (W/(mK)) and heat transfer coefficient parameter (mapping by zone)

Items		**Heat transfer coefficient parameter** W/(m²K)	
		<10	10≤
Thermal conductive parameter W/(m K)	<1	A	–
	1≤	B	C

Annex B
(informative)

Measurement comparison between companies (plane)

Thermal resistance on the plane $R_p = (T_s - T_a)/W$ (K/W)

T_s: temperature of the TEG chip, in °C;

T_a: the air temperature of the chamber, in °C;

W: power applied to the TEG chip, in W.

Heat transfer parameter $he = 1/R_p \times 0{,}0025$ (W/m²K)

SHIIMA ELECTRONICS INC.

CEM-3 1.6mmt Non TH Plating

T_s [°C]	m/s	T_a [°C]	Power [W]
74,8	0	24,5	0,40

$Rp = (74{,}8 - 24{,}5)/0{,}40$ (K/W) $he = 1/125{,}8 \times 0{,}0025 = 3{,}18$ (W/m²K)

Chemitox, Inc.

CEM-3 1,6mmt Non TH Plating

T_s [°C]	m/s	T_a [°C]	Power [W]
72,2	0	25,6	0,40

$R_p = (72{,}2 - 25{,}6)/0{,}40$ (K/W) $he = 1/116{,}5 \times 0{,}0025 = 3{,}43$ (W/m²K)

Difference: About 7%

Measurement comparison between workers (plane)

Thermal resistance on the plane $R_p = (T_s - T_a)/W$ (K/W)

T_s: Temperature of the TEG chip

T_a: The air temperature of the chamber

W: Power applied to the TEG chip

Heat transfer parameter $he = 1/R_p \times 0{,}002\,5$ (W/m²K)

SHIIMA ELECTRONICS INC.

FR-4 1.6mm TH Plating

	T_s [°C]	m/s	T_a [°C]	Power [W]
Measurer A	75,2	0	24,2	0,34
Measurer B	75,9	0	24,3	0,34
Measurer C	75,1	0	24,2	0,34

Measurer A: R_p = (75,2 − 24,2)/0,34 (K/W) he = 1/150,0 × 0,0025 = 2,67 (W/m^{2}K)
Measurer B: R_p = (75,9 − 24,3)/0,34 (K/W) he = 1/151,8 × 0,0025 = 2,64 (W/m^{2}K)
Measurer C: R_p = (75,1 − 24,2)/0,34 (K/W) he = 1/149,7 × 0,0025 = 2,67 (W/m^{2}K)

Difference: About 1 %

Measurement comparison between companies (thickness)

Thermal resistance across the thickness $R_t = (T_s - T_b)/W$ (K/W)

T_s: Temperature of the TEG chip

T_b: Temperature of the metal block

W: Apply the power to the TEG chip with load heat

Thermal conductivity parameter $ke = t/R_t \times 2{,}5 \times 10^{-5}$($W$/mK)

SHIIMA ELECTRONICS INC.

Ceramic 0.67mmt

Ts [°C]	m/s	*Tb* [°C]	Power [W]
76,0	0	22,4	4,42

R_t = (76,0 − 22,4)/4,42 (K/W) ke = 0,000671/12,1 × 0,000025 = 2,21(W/mK)

Chemitox, Inc.

Ceramic 0,67mmt

Ts [°C]	m/s	*Tb* [°C]	Power [W]
85,1	0	22,5	5,00

R_t = (85,1 − 22,5)/5,00 (K/W) ke = 0,000671/12,5 × 0,000025 = 2,15 (W/mK)

Difference: About 3 %

Measurement comparison between workers (thickness)

Thermal resistance across the thickness $R_t = (T_s - T_b)/W$ (K/W)

T_s: Temperature of the TEG chip

T_b: Temperature of the metal block

W: Apply the power to the TEG chip with load heat

Thermal conductivity parameter ke = t/R_t × 2,5 × 10^{-5} (W/mK)

SHIIMA ELECTRONICS INC.

FR-4 1.6mmt TH Plating

	T_s [°C]	m/s	T_b [°C]	Power [W]
Measurer A	75.8	0	22,1	3,84
Measurer B	75.9	0	22,3	3,85
Measurer C	75.8	0	22,2	3,80

Measurer A: R_t = (75,8 − 22,1)/3,84(K/W) ke = 0,00016/14,0 × 0,000025 = 0,46 (W/mK)

Measurer B: R_t = (75,9 − 22,3)/3,85(K/W) ke = 0,00016/13,9 × 0,000025 = 0,46 (W/mK)

Measurer C: R_t = (75,8 − 22,2)/3,80(K/W) ke = 0,00016/14,1 × 0,000025 = 0,45 (W/mK)

Difference: About 2 %

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