E55

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Heat Dissipation of LED Module with Design of Thermal Via

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1. Introduction

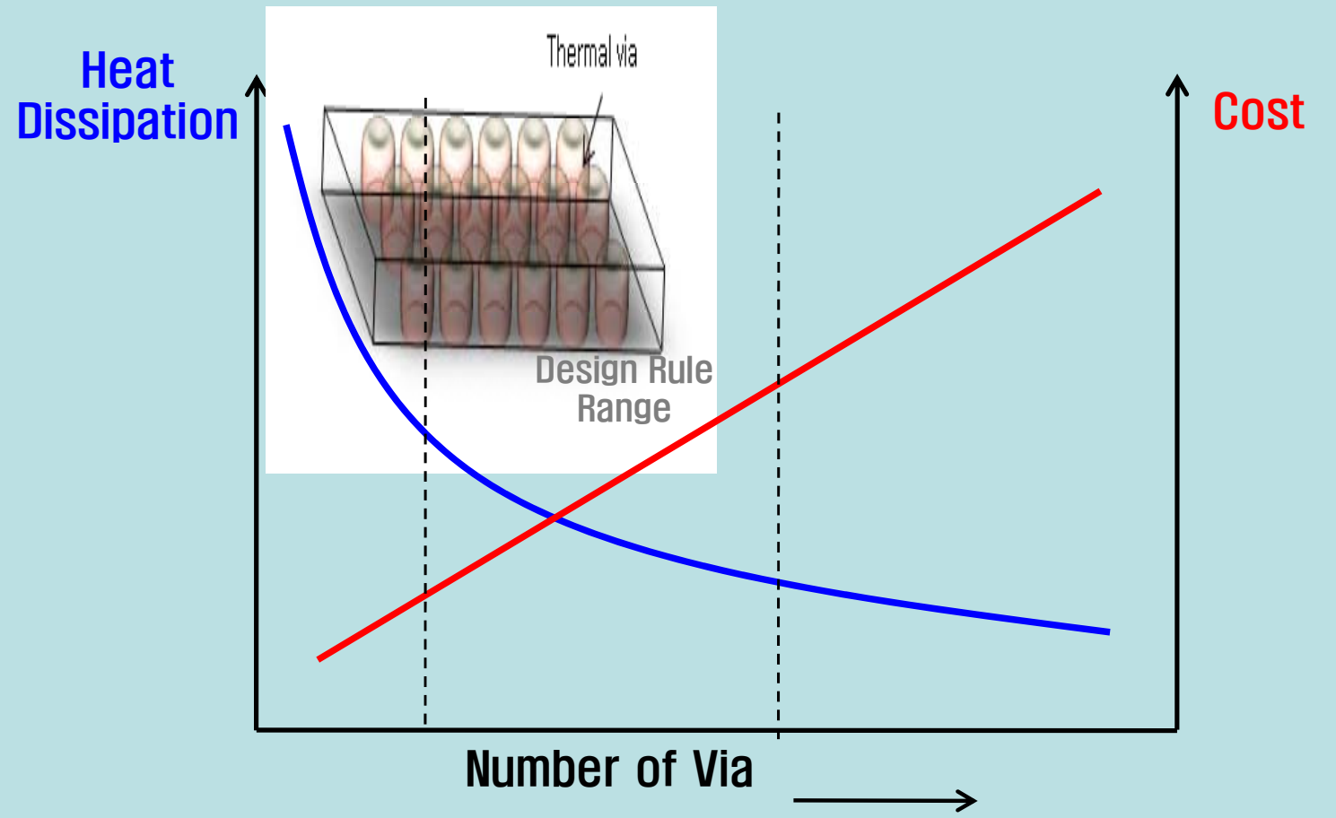

Fig 1. Effect of Number of Via on Heat dissipation and Cost

Light Emitting Diode (LED) is largely used in industry of consumer electronics such as cell-phones, PDAs, and computers. Since all light sources convert electric power into radiant energy and heat, LED also does the same. However, it only converts 15~25% of electric power into visible light; the rest of the power, 75~85%, is converted into heat. This excess heat should be conducted away from the LED die to circuit boards or heat sinks since heat directly affects performance of the LED. As a short term effect, which is reversible, it will bring color shift and reduced light output. Furthermore, lifecycle of the LED will shorten non-reversibly if the problem continues. In order to prevent LED from these negative effects, low thermal resistance path needs to be achieved so that heat conducts from the LED to underlying circuit board. Thus, thermal-via optimization study is performed through experiment. 1W and 3W LED assembled printed circuit board (PCB) with 16 different via design is set up to measure its temperature for 4 hours in a real time. Via design is differed by number, diameter, and pitch of vias. For 1W LED assembled PCB, 350mA was given; and for 3W LED assembled PCB, 700mA was given.

2. Experiments

2.1 LED Design Specification

LED : 1W, 3W
Via size : 0.2~1.2mm
Via pitch : 0.5~5.0mm
Cu thickness : 0.59~0.68mm
White ink : Made by S company
thickness - 0.028mm

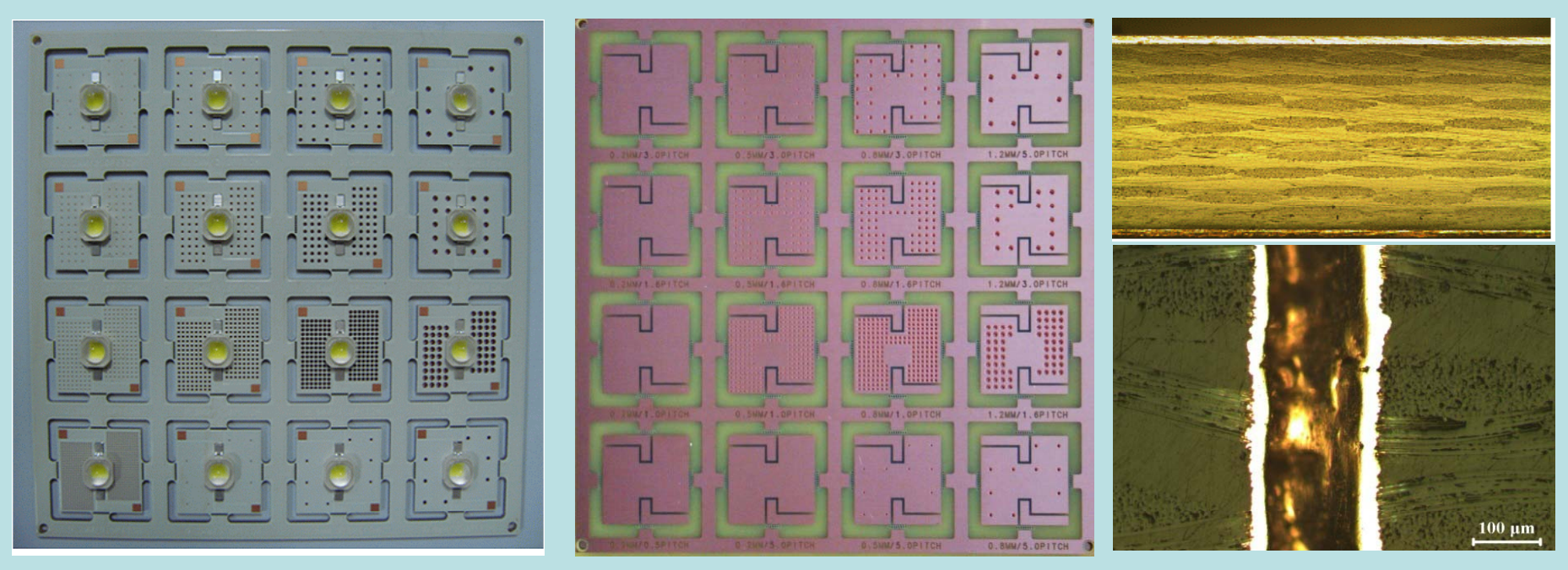

Fig 2. (a) Final LED assembled PCB with 16 different via design -left
(b) PCB with electrodeposited Cu before white ink application -center
(c) Electrodeposited Cu layer -right

2.2 Experiment

2.2.1 Temperature Profiler Test

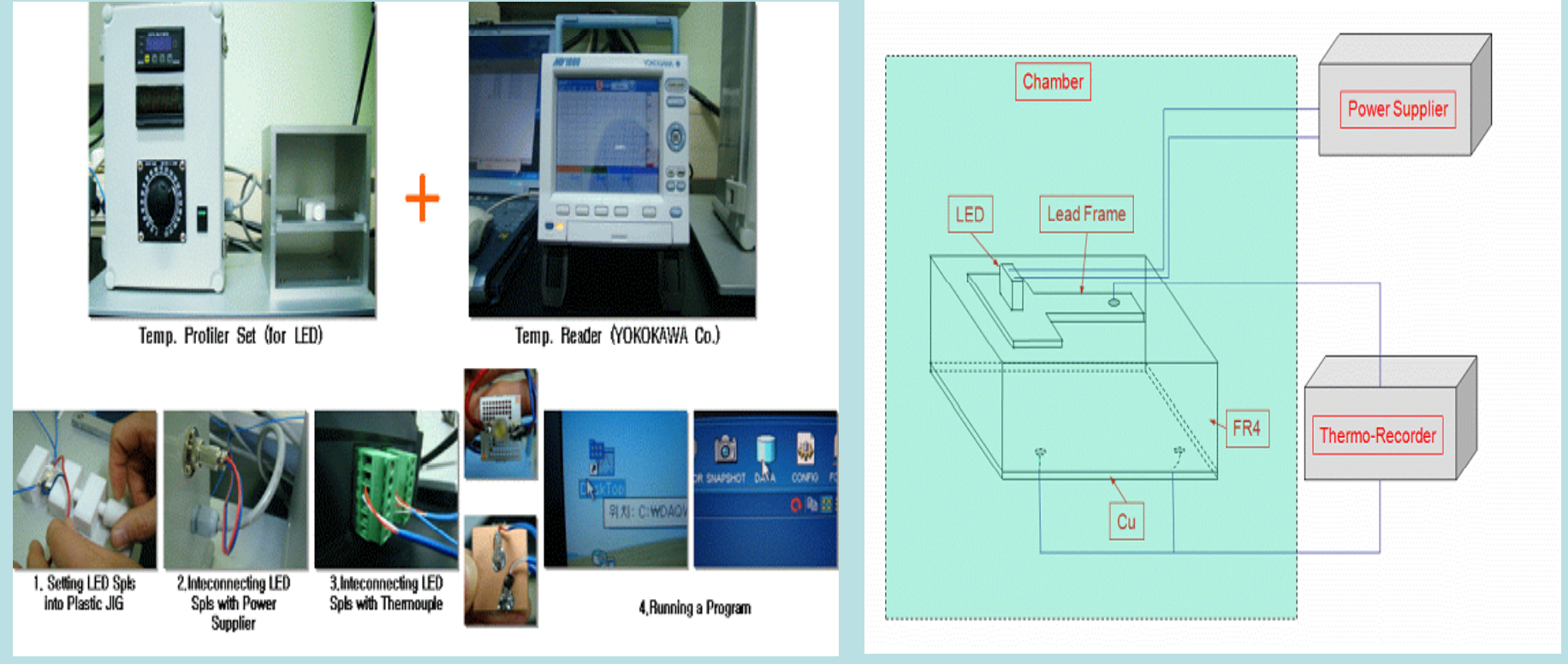

Fig 3. (a) Temperature Profiler Test Procedure –left (b)
General Concept Drawing of Temperature Profiler -right

1st channel : inside the Chamber
2nd channel : LED edge – back side
3rd channel : LED center – back side
4th channel : LED center – front side

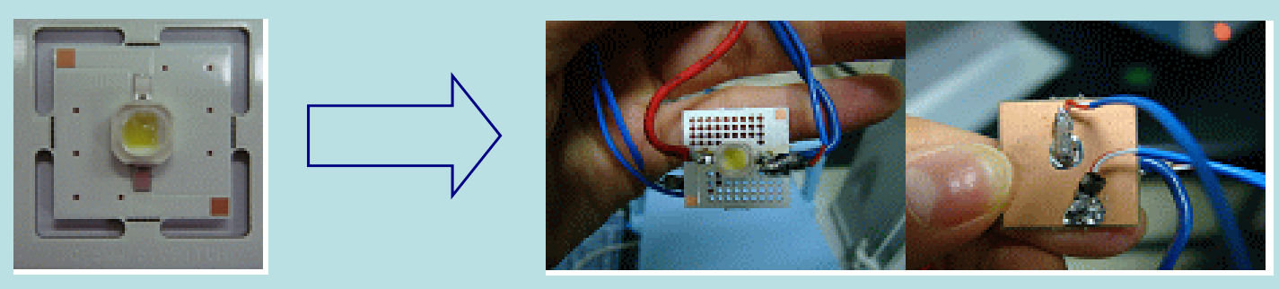

Fig 4. Sensor connected to LED for Temperature Profiler Test

2.2.2 Thermal Transient Test (T3Ster)

processed to obtain heat resistance of LED assembled PCB

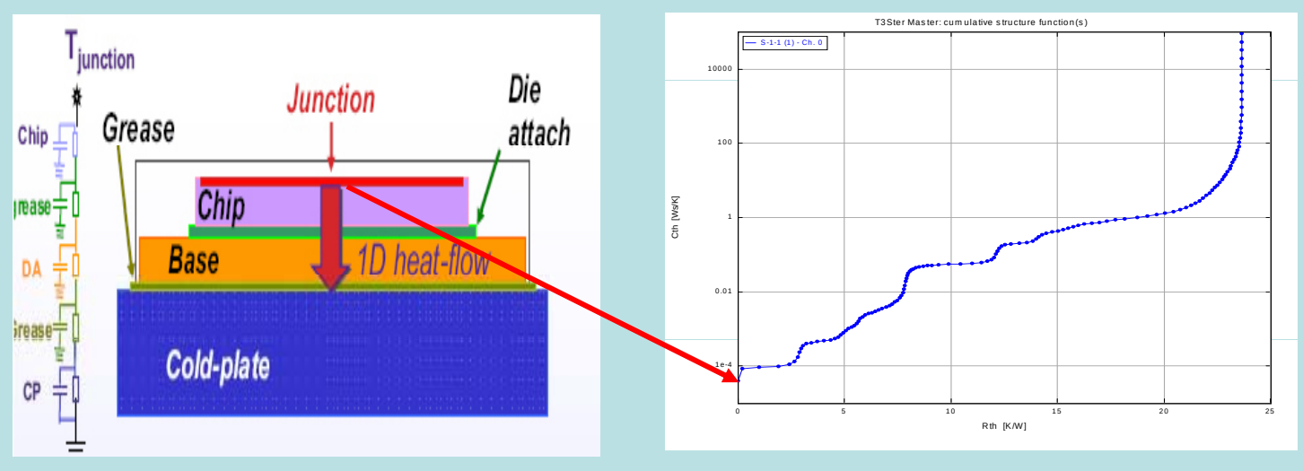

Fig 5. Theoretical picture of T3Ster measurement

Thermal impedance measured from the junction of PCB (Fig4) is created in the form of cumulative structure function.

3. Results

In order to verify which factors effect directly on the heat diffusivity, heat resistance measured with T3ster equipment is obtained. Below graphs are to observe the tendency between heat resistance and via diameter, via pitch, area fraction, and temperature gap.

3.1 Heat Resistance VS Via Diameter

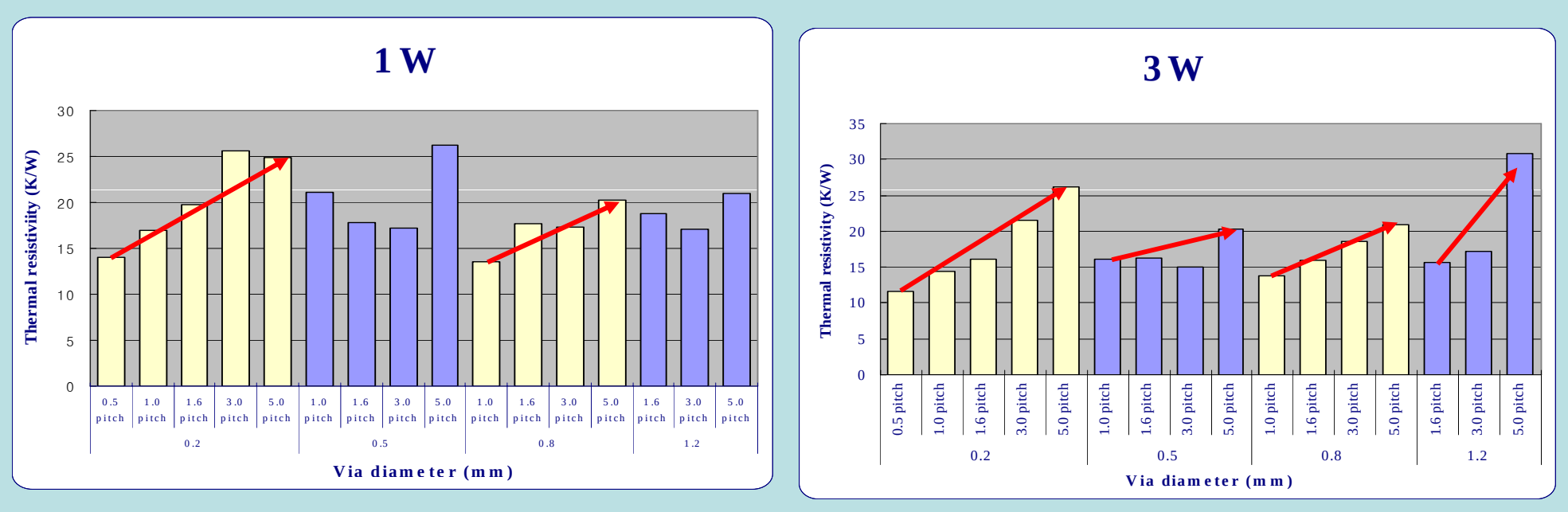

Fig 6. Heat Resistance VS Via Diameter (a) 1W -left (b) 3W –right

- not much pattern was observed when comparing thermal resistivity for each via size but the increase in heat resistance appeared when there was increase in pitch size with same via diameter.

3.2 Heat Resistance VS Via Pitch

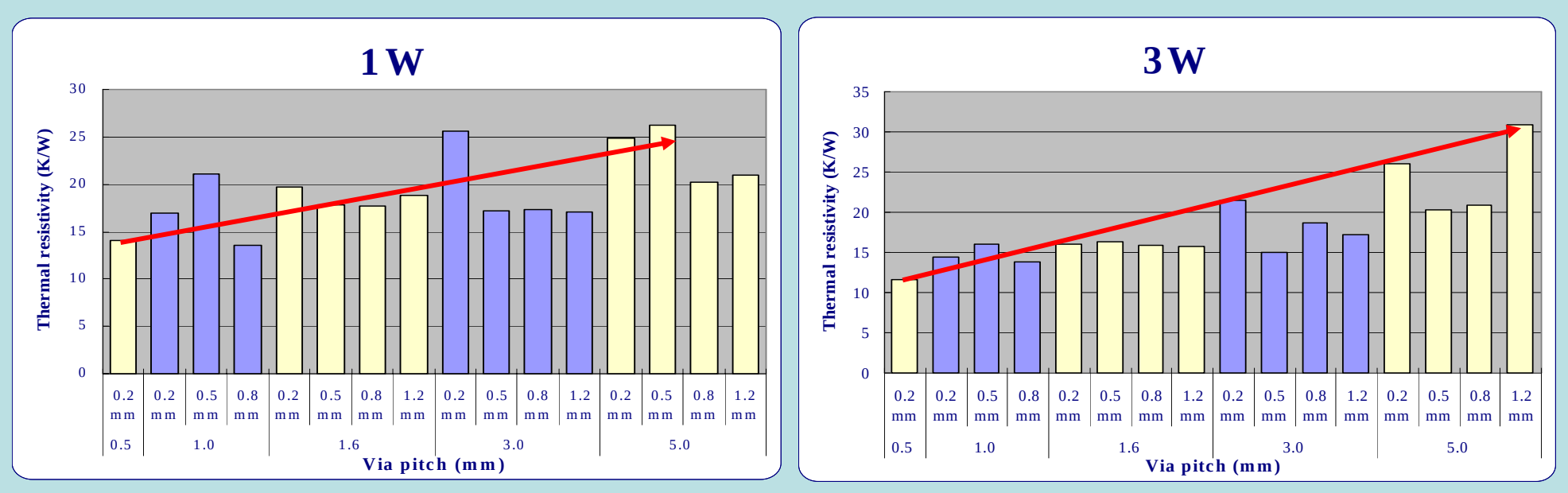

Fig 7. Heat Resistance VS Via Pitch(a) 1W -left (b) 3W -right

- like the result shown in 3.1, an increase in heat resistance was shown in the graph 2 (a) and (b).

3.3 Heat Resistance VS Area Fraction

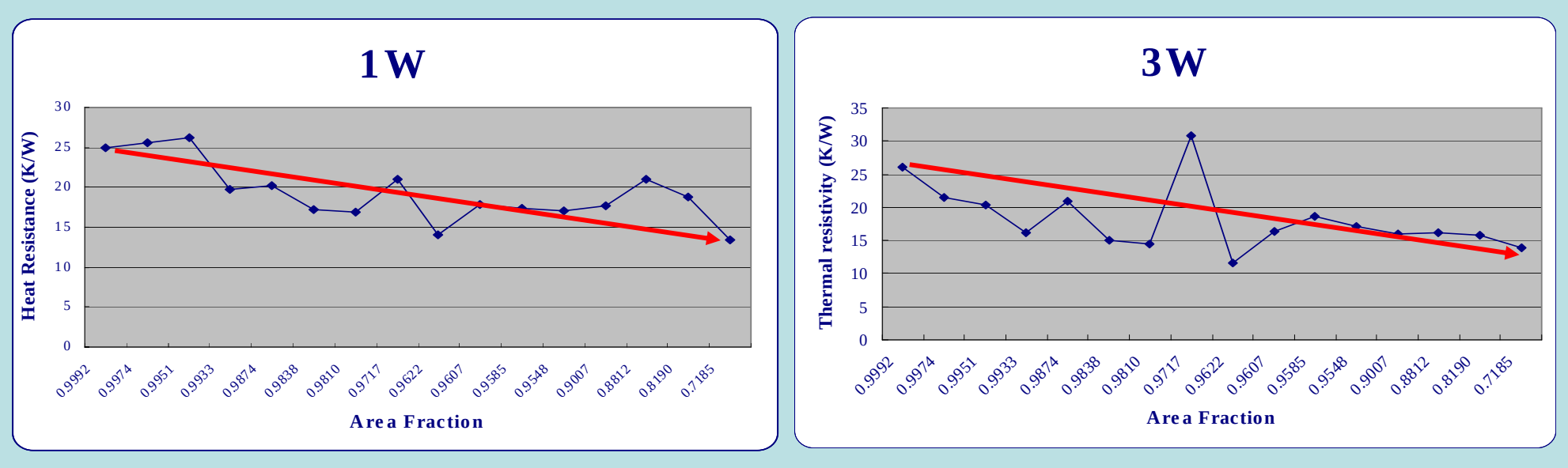

Fig 8. Heat Resistance VS Area Fraction (a) 1W -left (b) 3W -right

-assuming that the total area is 1 when there is no via, area fraction decreases as number of via increases and pitch size decreases. Therefore, decrease in heat resistance was observed with decrease in area fraction.

3.4 Heat Resistance VS Temperature Gap

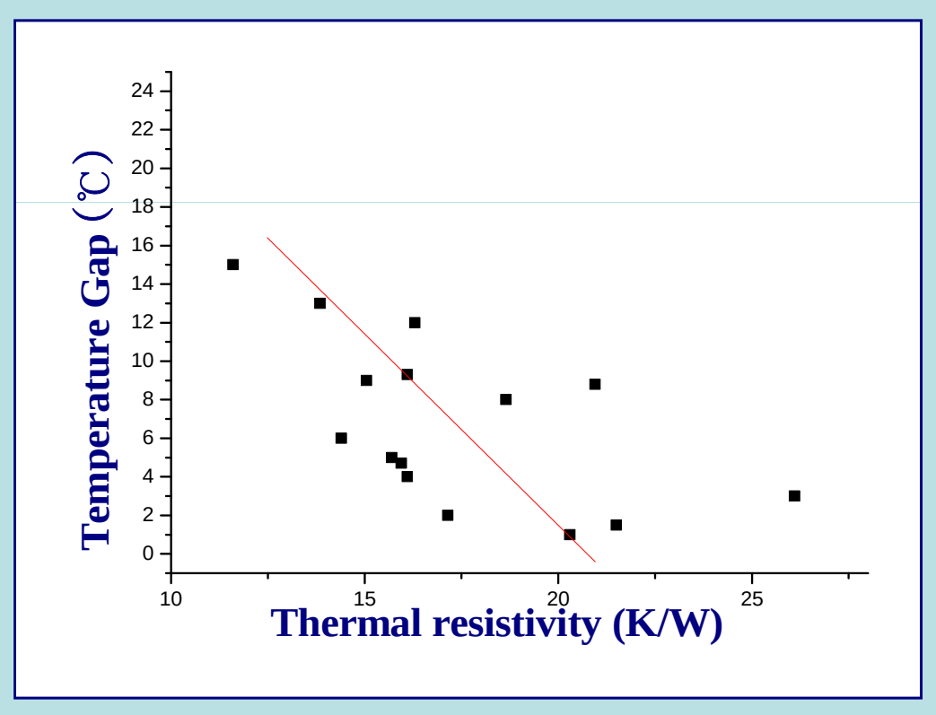

Fig 9. Temperature Gap VS Thermal Resistivity

-Temperature measured on the LED center and edge of the back side showed a constant gap.

-Larger temperature gap means higher heat dissipation and vise versa.

4. Discussion

4.1 Conduction Path and its Calculated Resistance

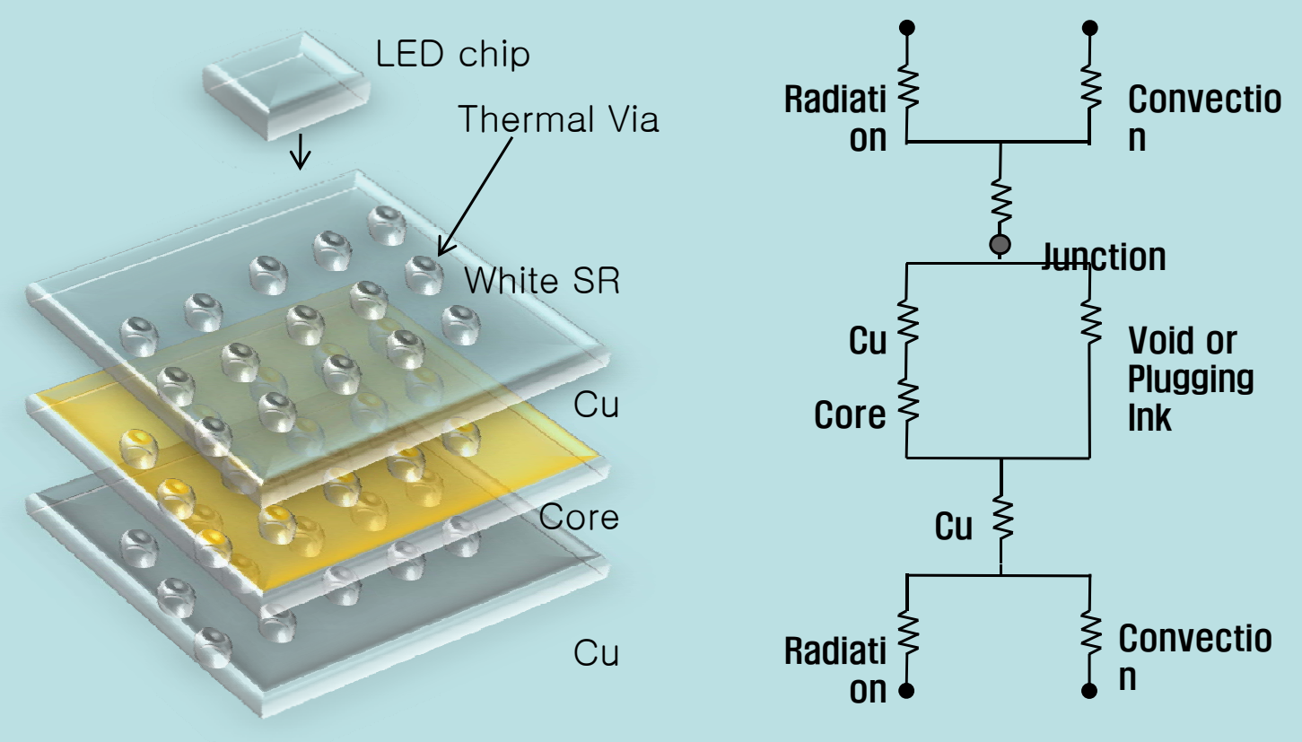

Fig 10. Conduction Path of LED Module

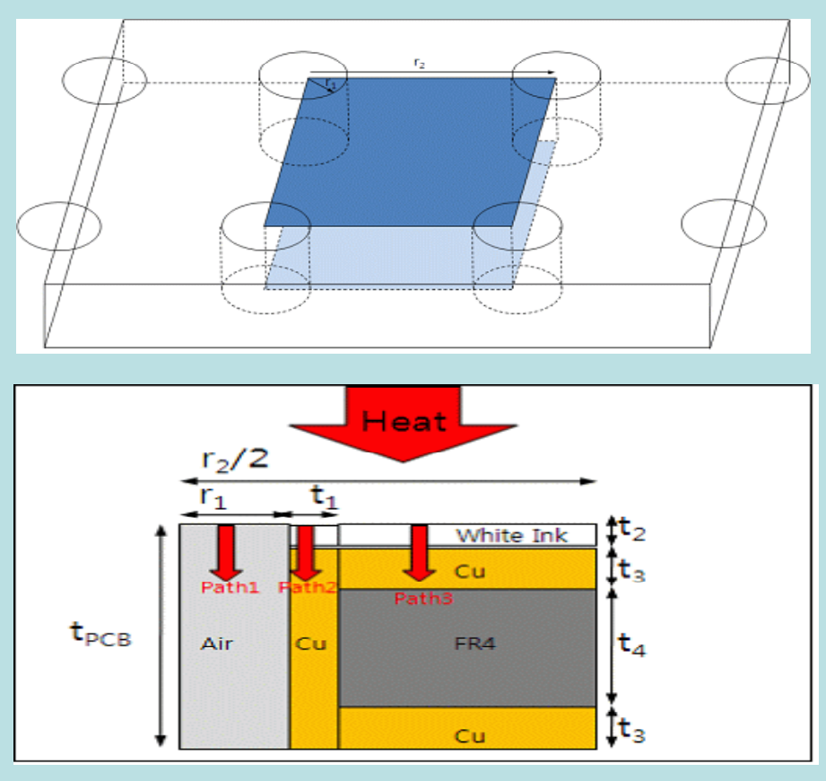

Fig 11. Simplification of LED Module

4.1.1 Theoretical Approach

Boundary Condition

$$t_{PCB} = t_2 + 2t_3 + t_4$$

$$R = \frac{1}{K} \cdot \frac{L}{A}$$

Where, R: Thermal tesistivity (k/w)
K: Thermal conductivity (w/mk)
L: Thickness of PCB
A: Area of PCB normal to heat transfer

Major Equations

$$\therefore R_{air} = \frac{1}{K_{air}} \cdot \frac{t_{PCB}}{\pi r_1^2}$$

$$\therefore R_{WI1} = \frac{1}{K_{WI}} \cdot \frac{t_2}{\pi \cdot t_1 \cdot (t_1 + 2r_1)}$$

$$\therefore R_{Cu} = \frac{1}{K_{Cu}} \cdot \frac{t_3}{\left(\frac{r_2}{2}\right)^2 - \pi (r_1 + t_1)^2}$$

$$\therefore R_{Cu-inner} = \frac{1}{K_{Cu}} \cdot \frac{2t_3 + t_4}{\pi \cdot t_1 \cdot (t_1 + 2r_1)}$$

$$\therefore R_{WI2} = \frac{1}{K_{WI}} \cdot \frac{t_2}{\left(\frac{r_2}{2}\right)^2 - \pi (r_1 + t_1)^2}$$

$$\therefore R_{FR4} = \frac{1}{K_{FR4}} \cdot \frac{t_4}{\left(\frac{r_2}{2}\right)^2 - \pi (r_1 + t_1)^2}$$

$$\therefore R_{Cu-inner} = \frac{1}{K_{Cu}} \cdot \frac{2t_3 + t_4}{\pi \cdot t_1 \cdot (t_1 + 2r_1)}$$

$$\Downarrow$$

$$\frac{1}{R_{PCB}} = \frac{1}{R_{air}} + \frac{1}{R_{whiteink\,1} + R_{cu-inner}} + \frac{1}{R_{whiteink\,2} + 2R_{cu} + R_{FR4}}$$

$$\Downarrow$$

$$\therefore \frac{1}{R_{pcb}} = \frac{K_{air} \cdot \pi r_1^2}{t_{pcb}} + \frac{K_{WI} \cdot K_{Cu} \cdot \pi \cdot t_1 \cdot (t_1 + 2r_1)}{K_{Cu} \cdot t_2 + K_{WI}(2t_3 + t_4)} + \frac{K_{WI} \cdot K_{Cu} \cdot K_{FR4} \cdot \left|(r_2/2)^2 - \pi (r_1 + t_1)^2\right|}{K_{Cu} \cdot K_{Cu} \cdot t_2 + K_{WI} \cdot K_{FR4} \cdot t_3 + K_{WI} \cdot K_{Cu} \cdot t_4}$$

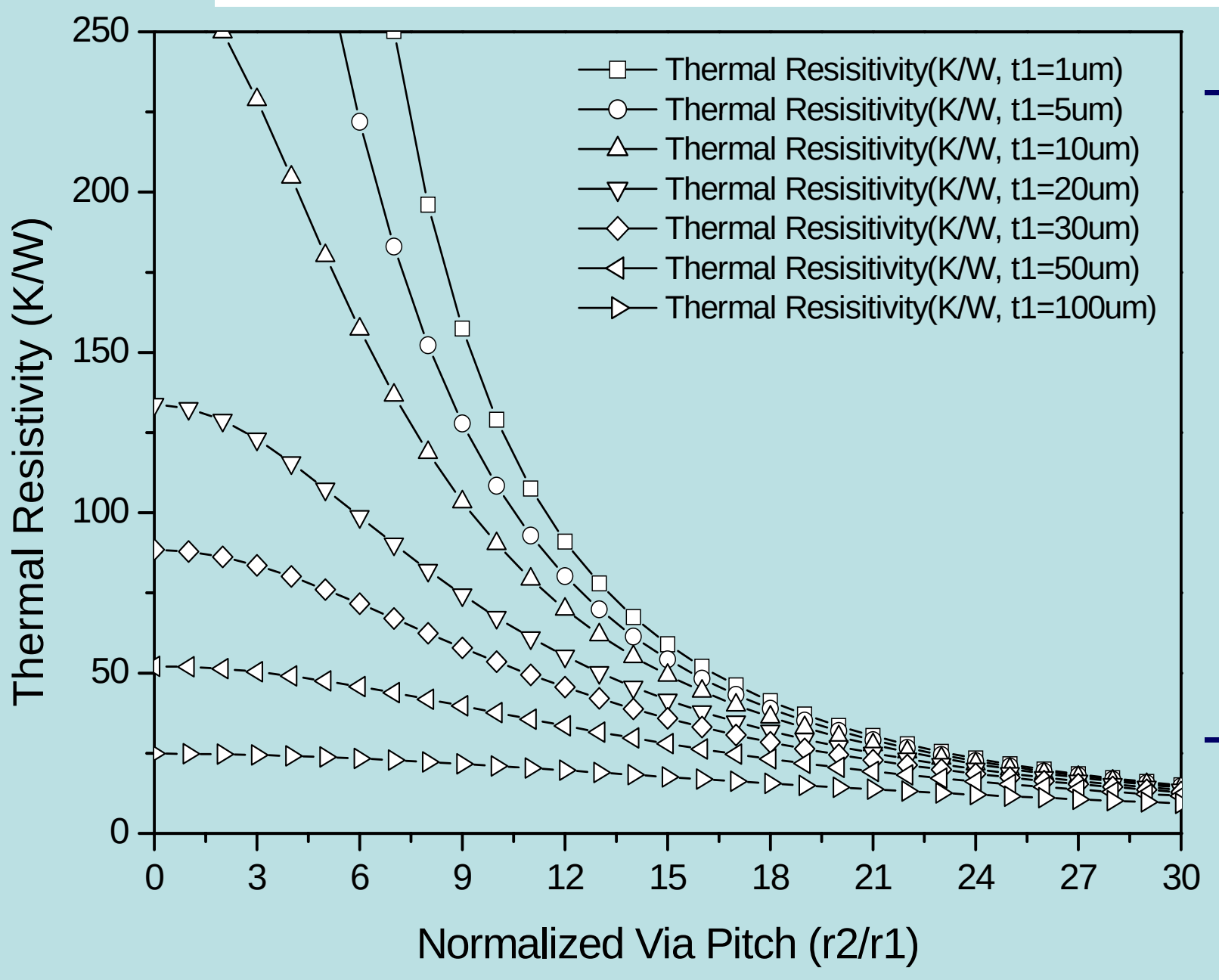

Fig 12. Thermal Resistivity VS Normalized Via Pitch

-Fig 12, which illustrates the calculated value from theoretical equation above, shows the pattern of thermal resistivity according to normalized via pitch for each thickness of electrodeposited Cu in via.

-Increase in normalized via pitch leads to decrease in thermal resistivity

-Increasing thickness of electrodeposited Cu in via leads to decrease in thermal resistiviy → managing Cu conduction path in via is important

5. Conclusion

Thermal-via optimization studied by the Temperature Profiler Test and Thermal Transient Test was analyzed to observe the effect of each main parameters of via design on the heat resistance, which directly relates to heat dissipation of LED. Therefore, as a conclusion, via pitch was the main factor to effect on the heat resistance. This also means that number of via is very important, and this led us to observe the area fraction of via on the PCB. When the PCB was largely occupied by vias, low heat resistance was observed, which means faster heat dissipation. Furthermore, this led to larger temperature gap between the center and the edge of PCB, since the heat produced from the LED was able to dissipate faster. These experimental results were observed with theoretical equations, and equation was graphed out. Increase in normalized via pitch was observed as thermal resistivity decreases. Also, increase in Cu layer was found to be important in managing Cu conduction path to lower thermal resistivity.