Analysis of High-Power LED Packages with Diamond and CNT Film

Cheng Yi Hsu and Yuli Lin

***Abstract*—In this study, analysis using high thermal conductive material for measuring junction temperature (Tj) in high power GaN-based light emitting diodes (LED) was presented. Thermal characteristics of high power Light-emitting-diode have been analyzed by using various different structure conduction models. The forward operation voltage is advantageously used to measure the junction temperature of light emitting diodes. Using this method, junction temperature (Tj) of LED under various structures and chip mounting methods was measured. It was found that the junction temperature can be reduced considerably by using diamond film substrates and CNT film substrates. In this study, for model F structure, the junction temperature using diamond film can be decreased by about 10.8% under 1.5W power, decreased by about 12% under 2.6W power and decreased by about 11.6% under 4.2W power for 1 mm square die. The junction temperature using CNT film can be decreased by about 12.7% under 1.5W power, decreased by about 14.1% under 2.6W power and decreased by about 14.2% under 4.2W power for 1 mm square die. The thermal resistance (RT) of diamond film can be measured to be 12.6°C/W under 4.2W power and the thermal resistance (RT) of CNT film can be measured to be 12.2°C/W under 4.2W.**

***Index Terms*—Junction temperature, diamond film, light-emitting-diode, CNT film.**

I. Introduction

For green energy, the Light Emitting Diode (LED) can be optimally used for general lighting. However, high temperature problem have to be resolved when it is to be used in long time and higher power lighting. Accordingly, the lighting applications of LED technologies have been developed to have lower junction temperature and lower thermal resistance (RT). However, the input electrical energy into the LED device which becomes photons and are immediately emitted out of the device, while the rest photons remains inside the LED device which produced heat, that increases the junction temperature. Sapphire substrate is used in the tradition LED. This material has poor heat dissipation characteristic. And poor reliability in LED structure always exists depends on the thermal temperature and package structure [1]-[12]. Therefore, the problem of heat dissipation in LED is certain to happen in high-power applications. In this paper, we will report the result of High-Power LED packages with diamond and CNT film in various heat dissipation structures.

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TABLE I: Physical Parameters of Various Dissipation Modes Used in This Study

Structure	Model A	Model B	Model C	Model D	Model E	Model F
LED Dimensions (L * W * H)	GaN (1mm*1mm* 5μm)					
	Sapphire (1mm*1mm*90μm)					
Adhesion Material	Silver epoxy 5μm					
High thermal conductivity Material (Heat Sink) Dimensions L * W * H	1. No Heat Sink 2. Diamond Film (1mm*1mm*20μm) 3. CNT Film (1mm*1mm*1μm)					
Adhesion Material	Silver epoxy 5μm					
Board Material (L * W * H)	Al plate (80mm* 40mm *0.1mm)	Al plate (80mm* 40mm *0.2mm)	Al plate (80mm* 40mm *0.4mm)	Cu/Al plate (80mm *40mm *0.1/0.3mm)	Cu/Al plate (80mm *40mm *0.2/0.2mm)	Cu plate (100mm *80mm *3mm)

II. Experiment Procedure

The samples utilized in this work are diamond film and CNT film, which were put on three different substrates. The thickness of the diamond film is 20μm and the thickness of the CNT film is 1μm. In this work, we established four kinds of heat dissipation models. Table I shows the physical parameters of the models. In our models, normal GaN /Sapphire blue high power LED was utilized. And the samples are 40 mil blue GaN LED chips obtained from an LED manufacturer. Fig. 1(a) schematically shows the first heat dissipation model which is symbolized as model A. In this model of Al plate with 0.1 mm of thickness have three different structures, first, the high power LED GaN Epitaxy with sapphire substrate was not mounted onto the heat sink structure which is symbolized as model A-1. Second, the high power LED GaN Epitaxy with sapphire substrate was mounted onto a high thermal conductive material of diamond film using silver epoxy which is symbolized as model A-2. Third, the high power LED GaN Epitaxy with sapphire substrate was mounted onto a high thermal conductive material of CNT film using silver epoxy which is symbolized as model A-3. The thicknesses of the nitride film and sapphire substrate are 5μm and 90μm, Fig. 1(b) shows the second heat dissipation model which is symbolized as model B. In this model of Al plate with 0.2 mm of thickness has three different structures which were no heat sink and diamond film and CNT film which is symbolized as model B-1, B-2 and B-3. Fig. 1(c) shows the third heat dissipation model which is symbolized as model C. In this model of Al

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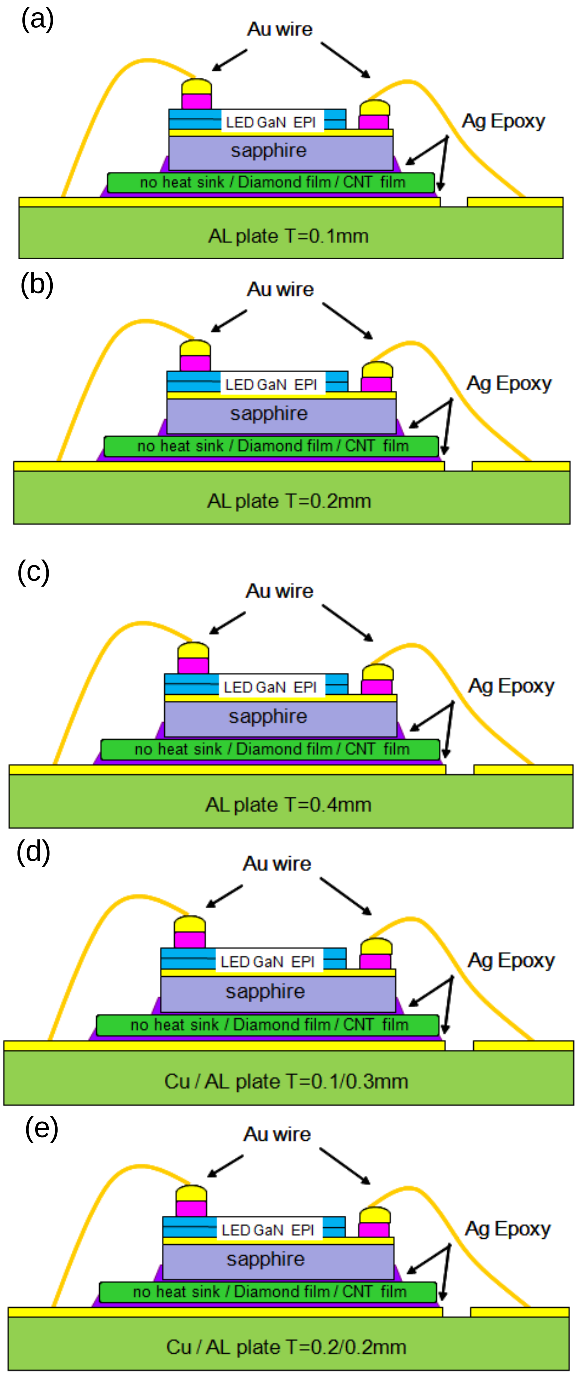
plate with 0.4 mm of thickness has three different structures which were no heat sink and diamond film and CNT film which is symbolized as model C-1, C-2 and C-3. Fig. 1(d) shows the fourth heat dissipation model which is symbolized as model D. In this model of Cu /Al plate with 0.1/0.3 mm of thickness has three different structures which were no heat sink and diamond film and CNT film which is symbolized as model D-1, D-2 and D-3. Fig. 1(e) shows the fifth heat dissipation model which is symbolized as model E. In this model of Cu /Al plate with 0.2/0.2 mm of thickness has three different structures which were no heat sink and diamond film and CNT film which is symbolized as model E-1, E-2 and E-3. Fig. 1(f) shows the sixth heat dissipation model which is symbolized as model F. In this model of Cu plate with 3 mm of thickness has three different structures which were no heat sink and diamond film and CNT film which is symbolized as model F-1, F-2 and F-3.



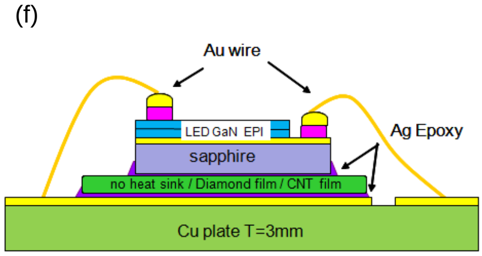


Fig. 1. Configurations of six heat dissipation structures: LED with 3 different type films on (a) Al plate with 0.1 mm of thickness and (b) Al plate with 0.2 mm of thickness and (c) Al plate with 0.4 mm of thickness and (d) Cu/Al plate with 0.1/0.3 mm of thickness and (e) Cu/Al plate with 0.2/0.2 mm of thickness and (f) Cu plate with 3 mm of thickness.

III. Results and Discussions

From the experiments result, for model A structure, Fig. 2 shows the junction temperature of diamond film can be decreased by about 9.6% under 4.2W power and the junction temperature of CNT film can be decreased by about 11.8% under 4.2W power for 1 mm square die. Fig. 3 shows the thermal resistance of junction to air on model A structure, the thermal resistance (RT) of diamond film can be measured to be 13.6℃/W under 4.2W power and the thermal resistance (RT) of CNT film can be measured to be 13.2℃/W under 4.2W power which is the lower than A-1 and A-2 structures. Table II demonstrates the experimental results for junction temperature and thermal resistance measurements on model A structure.

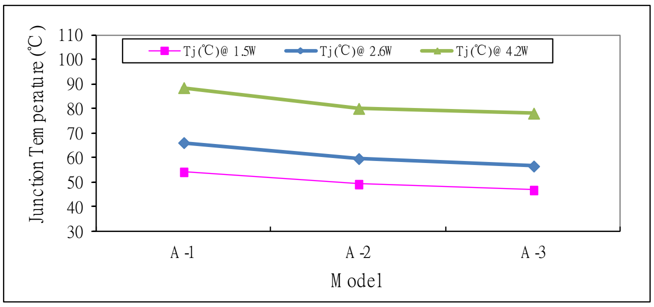


Fig. 2. Junction temperature measurement under 1.5W, 2.6W and 4.2W conditions on model A structure.

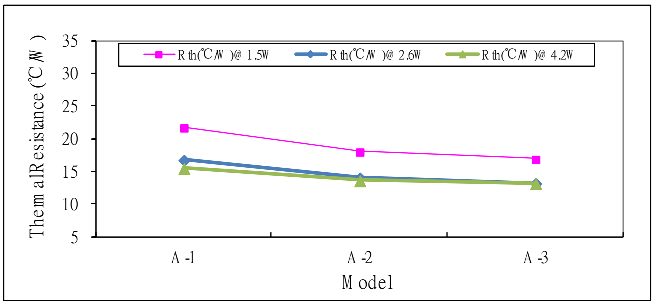


Fig. 3. Thermal resistance measurement under 1.5W, 2.6W and 4.2W conditions on model A structure.

TABLE II: Experimental Results of Junction Temperature and Thermal Resistance on Model A Structure

Model	Structure	Rth (℃/W) @1.5W	Tj (℃) @1.5W	Rth (℃/W) @2.6W	Tj (℃) @2.6W	Rth (℃/W) @4.2W	Tj (℃) @4.2W
A-1	LED Structure (no heat sink)	21.75	54.30	16.80	66.24	15.52	88.66
A-2	LED on Diamond Film	18.06	49.30	14.07	59.72	13.64	80.19
A-3	LED on CNT Film	16.93	46.90	13.25	56.68	13.20	78.23

From the experiments result, for model B structure, Fig. 4 shows the junction temperature of diamond film can be decreased by about 9.6% under 4.2W power and the junction temperature of CNT film can be decreased by about 13.5% under 4.2W power for 1 mm square die. Fig. 5 shows the thermal resistance of junction to air on model B structure, the thermal resistance (RT) of diamond film can be measured to be 13.8℃/W under 4.2W power and the thermal resistance (RT) of CNT film can be measured to be 13.0℃/W under 4.2W power which is the lower than B-1 and B-2 structures. Table III demonstrates the experimental results for junction temperature and thermal resistance measurements on model B structure.

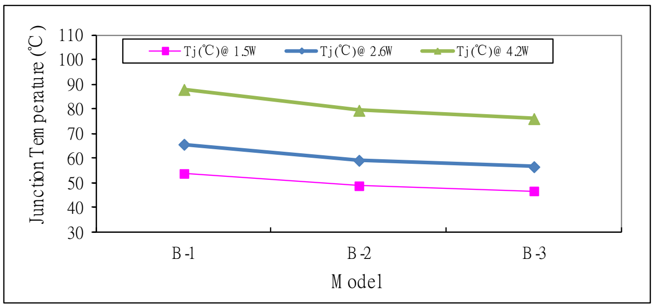


Fig. 4. Junction temperature measurement under 1.5W, 2.6W and 4.2W conditions on model B structure.

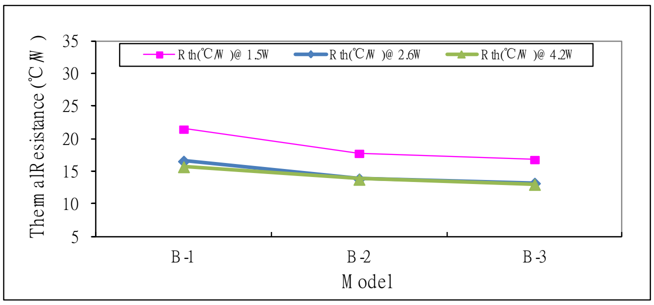


Fig. 5. Thermal resistance measurement under 1.5W, 2.6W and 4.2W conditions on model B structure.

TABLE III: EXPERIMENTAL RESULTS OF JUNCTION TEMPERATURE AND THERMAL RESISTANCE ON MODEL B STRUCTURE

Model	Structure	Rth (℃/W) @1.5W	Tj (℃) @1.5W	Rth (℃/W) @2.6W	Tj (℃) @2.6W	Rth (℃/W) @4.2W	Tj (℃) @4.2W
B-1	LED Structure (no heat sink)	21.55	53.90	16.64	65.76	15.77	88.04
B-2	LED on Diamond Film	17.83	48.90	13.91	59.24	13.84	79.56
B-3	LED on CNT Film	16.88	46.80	13.25	56.65	13.06	76.20

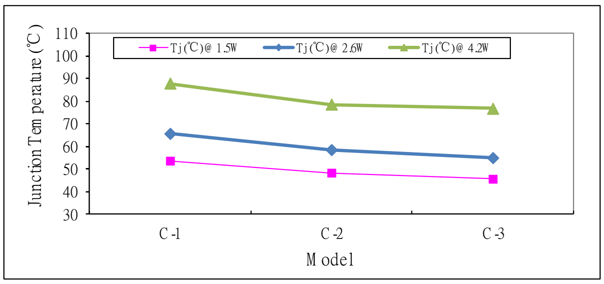


Fig. 6. Junction temperature measurement under 1.5W, 2.6W and 4.2W conditions on model C structure.

From the experiments result, for model C structure, Fig. 6 shows the junction temperature of diamond film can be decreased by about 10.6% under 4.2W power and the junction temperature of CNT film can be decreased by about 12.7% under 4.2W power for 1 mm square die. Fig. 7 shows the thermal resistance of junction to air on model B structure, the thermal resistance (RT) of diamond film can be measured to be 13.2℃/W under 4.2W power and the thermal resistance (RT) of CNT film can be measured to be 12.8℃/W under 4.2W power which is the lower than C-1 and C-2 structures. Table IV demonstrates the experimental results for junction temperature and thermal resistance measurements on model C structure.

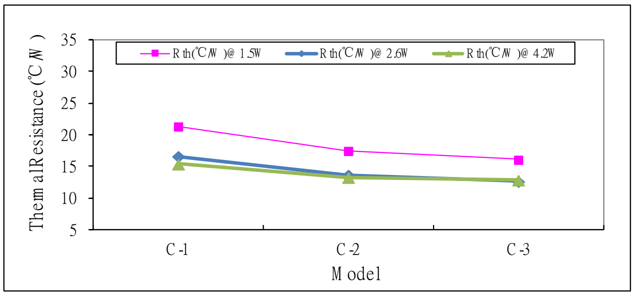


Fig. 7. Thermal resistance measurement under 1.5W, 2.6W and 4.2W conditions on model C structure.

TABLE IV: EXPERIMENTAL RESULTS OF JUNCTION TEMPERATURE AND THERMAL RESISTANCE ON MODEL C STRUCTURE

Model	Structure	Rth (℃/W) @1.5W	Tj (℃) @1.5W	Rth (℃/W) @2.6W	Tj (℃) @2.6W	Rth (℃/W) @4.2W	Tj (℃) @4.2W
C-1	LED Structure (no heat sink)	21.34	53.60	16.61	65.65	15.37	87.90
C-2	LED on Diamond Film	17.47	48.30	13.65	58.49	13.25	78.59
C-3	LED on CNT Film	16.07	45.60	12.62	54.95	12.84	76.75

From the experiments result, for model D structure, Fig. 8 shows the junction temperature of diamond film can be decreased by about 11.3% under 4.2W power and the junction temperature of CNT film can be decreased by about 15.3% under 4.2W power for 1 mm square die. Fig. 9 shows the thermal resistance of junction to air on model B structure, the thermal resistance (RT) of diamond film can be measured to be 13.3℃/W under 4.2W power and the thermal resistance (RT) of CNT film can be measured to be 12.5℃/W under 4.2W power which is the lower than D-1 and D-2 structures. Table V demonstrates the experimental results for junction temperature and thermal resistance measurements on model D structure.

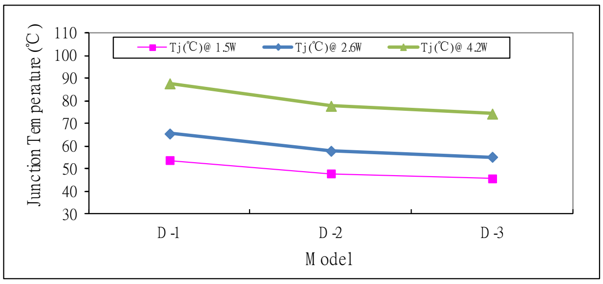


Fig. 8. Junction temperature measurement under 1.5W, 2.6W and 4.2W conditions on model D structure.

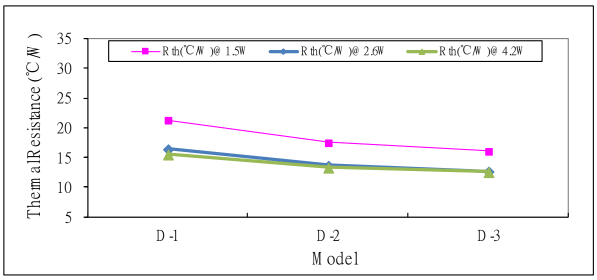


Fig. 9. Thermal resistance measurement under 1.5W, 2.6W and 4.2W conditions on model D structure.

From the experiments result, for model E structure, Fig. 10

shows the junction temperature of diamond film can be decreased by about 10.9% under 4.2W power and the junction temperature of CNT film can be decreased by about 13.2% under 4.2W power for 1 mm square die. Fig. 11 shows the thermal resistance of junction to air on model B structure, the thermal resistance (RT) of diamond film can be measured to be 12.7°C/W under 4.2W power and the thermal resistance (RT) of CNT film can be measured to be 12.4°C/W under 4.2W power which is the lower than E-1 and E-2 structures. Table VI demonstrates the experimental results for junction temperature and thermal resistance measurements on model E structure.

TABLE V: EXPERIMENTAL RESULTS OF JUNCTION TEMPERATURE AND THERMAL RESISTANCE ON MODEL D STRUCTURE

Model	Structure	Rth (℃/W) @1.5W	Tj (℃) @1.5W	Rth (℃/W) @2.6W	Tj (℃) @2.6W	Rth (℃/W) @4.2W	Tj (℃) @4.2W
D-1	LED Structure (no heat sink)	21.33	53.70	16.44	65.43	15.55	87.61
D-2	LED on Diamond Film	17.53	47.80	13.66	57.79	13.34	77.68
D-3	LED on CNT Film	16.09	45.60	12.69	55.14	12.59	74.23

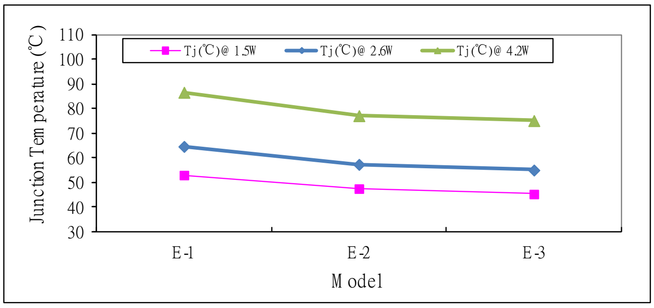


Fig. 10. Junction temperature measurement under 1.5W, 2.6W and 4.2W conditions on model E structure.

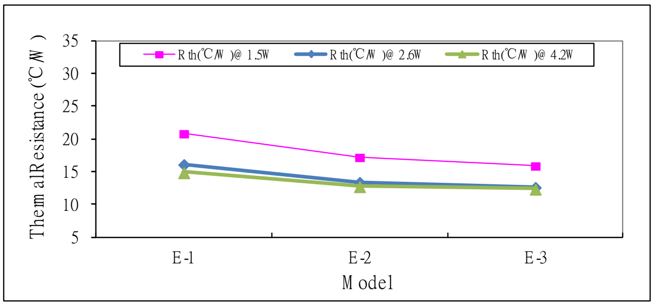


Fig. 11. Thermal resistance measurement under 1.5W, 2.6W and 4.2W conditions on model E structure.

TABLE VI: EXPERIMENTAL RESULTS OF JUNCTION TEMPERATURE AND THERMAL RESISTANCE ON MODEL E STRUCTURE

Model	Structure	Rth (℃/W) @1.5W	Tj (℃) @1.5W	Rth (℃/W) @2.6W	Tj (℃) @2.6W	Rth (℃/W) @4.2W	Tj (℃) @4.2W
E-1	LED Structure (no heat sink)	20.87	53.10	16.16	64.74	14.92	86.71
E-2	LED on Diamond Film	17.26	47.60	13.43	57.44	12.79	77.22
E-3	LED on CNT Film	15.94	45.40	12.67	55.14	12.40	75.23

From the experiments result, for model F structure, Fig. 12 shows the junction temperature of diamond film can be decreased by about 11.6% under 4.2W power and the junction temperature of CNT film can be decreased by about 14.2% under 4.2W power for 1 mm square die. Fig. 13 shows the thermal resistance of junction to air on model B structure, the thermal resistance (RT) of diamond film can be measured to be 12.6°C/W under 4.2W power and the thermal resistance (RT) of CNT film can be measured to be 12.2°C/W under 4.2W power which is the lower than F-1 and F-2 structures. Table VII demonstrates the experimental results for junction temperature and thermal resistance measurements on model F structure.

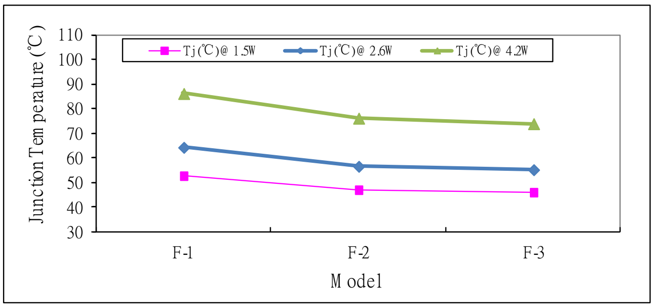


Fig. 12. Junction temperature measurement under 1.5W, 2.6W and 4.2W conditions on model F structure.

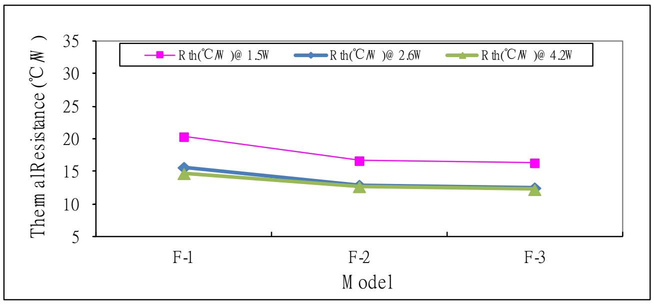


Fig. 13. Thermal resistance measurement under 1.5W, 2.6W and 4.2W conditions on model F structure.

TABLE VII: EXPERIMENTAL RESULTS OF JUNCTION TEMPERATURE AND THERMAL RESISTANCE ON MODEL F STRUCTURE

Model	Structure	Rth (℃/W) @1.5W	Tj (℃) @1.5W	Rth (℃/W) @2.6W	Tj (℃) @2.6W	Rth (℃/W) @4.2W	Tj (℃) @4.2W
F-1	LED Structure (no heat sink)	20.36	52.90	15.64	64.42	14.69	86.30
F-2	LED on Diamond Film	16.67	47.20	12.89	56.71	12.68	76.27
F-3	LED on CNT Film	16.34	46.20	12.49	55.34	12.23	74.03

From above experiments result, for model F-3 structure, the junction temperature and the thermal resistance (RT) of CNT film under 4.2W power which is the lowest. Because the CNT film has higher thermal conductivity than others. In physics, thermal conductivity is the property of a material to conduct heat. Secondary, for model F-2 structure, the junction temperature and the thermal resistance (RT) of diamond film under 4.2W power which is the second lower than other structures. Therefore, the F structure has best lower than other structure base in the big size area of Cu plat which can dissipate heat and transfer it outside.

For model E-3 structure, the junction temperature and the thermal resistance (RT) of CNT film under 4.2W power which is lower than that of other E-2 and E-1 structures. Secondary, for model E-2 structure, the junction temperature and the thermal resistance (RT) of diamond film under 4.2W power which is the second lower than E-1 structures. Therefore, the E structure is second lower than other structure base in the area of Cu/AL plat which can dissipate heat and transfer it outside. Finally, the thermal conductivity and material area will impact the thermal resistance and junction temperature.

IV. SUMMARY

1) LED GaN Epitaxy with sapphire mounted on CNT film was found the most effective package method in heat

dissipation.

2) The junction temperature of diamond films on model F structure can be decreased by 11.6% under 4.2W condition. The junction temperature of CNT film on model F structure can be decreased by 14.2% under 4.2W condition, respectively comparable to that on no heat sink structure.
3) The thermal resistance of junction to air on model F structure is measured to be 12.6℃/W at 4.2W condition of diamond film. The thermal resistance of junction to air on model F structure is measured to be 12.2℃/W at 4.2W condition of CNT film, respectively which is the lowest than that of other structures.

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