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EVALUATION ON HIGH POWER LED WITH Cu-Al_2O_3 THIN FILM AS THERMAL INTERFACE MATERIAL: THERMAL RESISTANCE AND OPTICAL OUTPUT ANALYSIS

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Deposition of copper aluminium oxide (Cu-Al_2O_3) on Al substrate were carried out by performing the RF magnetron sputtering through layer stacking technique at ambient temperature. The synthesized films were then undergo annealing process at various temperature (200°C, 300°C, 400°C and 500°C) for 6 hours under N_2 environment. AFM analysis was done on the films to examine the changes in surface roughness. Thermal transient analysis and optical measurement were performed in order to investigate the influence of Cu-Al_2O_3 thin films on the performance of given LEDs. Annealed Cu-Al_2O_3 (300°C) coated Al substrate displayed a significant difference in total thermal resistance (ΔR_{th}= 5.28K/W) *and* junction temperature (ΔTj= 12.3°C)compared to bare Al substrate at driving current of 700mA. Meanwhile, the low surface roughness (2.84nm) value by AFM helped in enhancing the thermal path, thereby reducing the thermal resistance recorded with annealed Cu-Al_2O_3 (300°C) film. Optical measurement also explained that the annealed Cu-Al_2O_3 (300°C) coated substrate demonstrated advantages in terms of lux value and color-correlated temperature, CCT compared to other samples. Based on these results, it can be speculated that Cu-Al_2O_3 films can be used as thermal interface material for the thermal management of LEDs.

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Keywords: Thermal resistance, optical properties, Cu-Al_2O_3 thin film, thermal interface material, LEDs

1. Introduction

Over the last few decades, lighting emitting diodes (LEDs) have been widely used in numerous applications such as street lighting, traffic signals, advertisement board, automotive and residential lighting as their overall performance was comparable to the conventional lighting device [1-3]. It was well known that the LEDs captured the attention of several lighting manufacturers due to their exceptional well performance in terms of color saturation, lifetime, brightness, and power consumption and it was believed that the solid state lighting industry capable in achieving high annual growth rate by 2017 [4-6].In recent years, remarkable advancement can be seen in the development of LEDs technology and therefore miniaturization of the package size can be achieved. The miniaturization of packages also led to the high heat generation rate within the package and yet, there were still lots of challenge to overcome and improvements to be made, particularly in the heat dissipation and light power issues. Thus heat dissipation and thermal management has become essential in optimising their performance [7].

In optimising the thermal management for the LEDs, two major issues must be considered: (i) high heat flux generated within the package which required excellent heat spreaders in dissipating such heat loads from the package and (ii) LED arrays are integrated in order to compensate the requirement of high luminous flux, and this will lead to the large heat loads generated which could affect the entire heat dissipation at system level [8]. These two effects can caused elevated junction temperature which can be linked to the reduction of quantum efficiency,

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*Corresponding author: richiewq90@hotmail.com shifting of emission wavelength and ultimately catastrophic failure of the device. Approximately almost 90% of the thermal energy was dissipated from the chip level through the conduction and at the system level, convection to the surrounding ambient which was the primary way for the thermal dissipation and it could occurred through natural or forced convection [9]. Therefore, it was critical for maintaining expected LED lifetime and light output, that the thermal performance parameters be defined, by design, at the package and system level as well, which includes the heat sinking methods and interface materials.

Since junction temperature, T_j significantly influenced the LEDs durability and reliability, low junction temperature operation was desirable in optimising the LED's performance and lifespan. Cost-effective heat dissipation solution is needed in implementation of thermal management to prevent the T_j from exceeding the permitted range. Metal-based materials have been most favoured in the manufacturing of printed circuit boards (PCBs) for high power LED assembly. Metal core printed circuit board (MCPCB) integrated high thermal conductivity materials such as copper or aluminium as heat spreader in enhancing the thermal dissipation. However due to the presence of insulating layer between circuit and metal layer, the overall performance of MCPCB is greatly affected [10-11]. In order to improve the thermal performance of the MCPCBs, application of thermal interface materials (TIMs) was recommended as it was capable of filling the air gap and conducting the heat effectively [12]. Choices of TIMs were vital as TIMs with high thermal conductivity more favourable. TIMs include thermal greases, phase change materials, gel, adhesive and thin films. Since heat is one of the key factor for possibility of device failure, it is necessary to enhance the heat transfer mechanism within the device and improving the reliability of the entire system. It can be said that the thermal conductivity and diffusivity of thin films can deviate significantly from its bulk form due to variation in structure dimension and phonon transport mechanism [13]. Layer stacking technique involves the deposition of a stack layer of copper and aluminium oxide by radio frequency (RF) sputtering and thermal annealing under the inert atmosphere carried out to produce the resultant film. Naveed *et. al.* synthesized the AlInN films on Si substrates by implementing the layer stacking technique (AlN&InN) through RF sputtering [14] Cruz *et. al.* also deposited CdTe films on the glass substrates using the stacking technique and the resultant film is verified through XRD analysis [15].

Among the ceramics incorporated as electronic substrates or packages, aluminium oxide, aluminium nitride and boron nitride were widely used as TIMs for thermal dissipation purpose in the LEDs package due to their high thermal conductivity. Shanmugan*et. al.* reported the deposition of BN thin films on Cu substrates through RF sputtering and observed lower value of total thermal resistance and junction temperature compared to the bare Cu substrate [16]. Zeng Yin *et. al.* also studied the thermal conductivity behaviour of boron doped aluminium nitride (B-AlN) thin films as TIM deposited on Cu substrate using RF coupled DC sputtering. From his work, it was discovered that B-AlNthn film synthesized under the gas ratio Ar 7: N_2 13and annealed at 200°C exhibited lower value of thermal resistance and junction temperature among the tested samples [17]. Shanmugan*et. al.* also deposited Al_2O_3 thin films with two different thickness (400nm and 500nm) on Cu substrate using RF sputtering and found that 400nm Al_2O_3 thin film demonstrated lower value of thermal resistance as well as junction temperature compared to 500nm Al_2O_3 thin films [18]. However, it is found out that nitride based thin film TIM is difficult to be synthesized when compared to oxide. Compared to ceramics such AlN and BN, Al_2O_3 exhibited high resistant to chemical and water, good mechanical and dielectric strength and the ability to provide hermetic seals.

Though numerous papers have reported on the properties of Cu-Al_2O_3 and application of Al_2O_3 as TIM, less information are found regarding the application of Cu-Al_2O_3 stack thin films as TIM on metal substrate for effective heat dissipation of high power LED [19]s. Thus, this finding would be useful for researchers working on application of thin films in thermal performance field. In this work, layer stacking method is employed as an approach to deposit the Cu-Al_2O_3 thin films through RF sputtering by deposition of Cu thin films followed by Al_2O_3 layer on it. The thermal performance of high power white LED employed on Cu-Al_2O_3 films coated Al substrate are studied by performing thermal transient measurement using T3Ster system. The results based on cumulative structural functions are interpreted using software and are discussed here. Besides that, the influence of the thin films on the optical properties of the LED package is also evaluated by performing optical measurement using spectrometer.

2. Experimental Procedure

2.1 Synthesis of Cu-Al_2O_3 stack thin films

Cu-Al_2O_3 stack thin films were synthesized on the Al substrate (2.5cm X 2.5cm) through RF sputtering (Model name: HHV Auto-500) using pure Cu (99.99%) and Al_2O_3 (99.99%) targets at ambient temperature. Prior to the deposition process, the substrates were cleaned in ethanol solution using ultrasonic cleaner. The cleaned substrates were then loaded into the vacuum chamber which was evacuated to base pressure of $2.16x10^{-5}$ mbar. Ar gas (99.99%) was flowed at the rate of 12sccm for both Cu and Al_2O_3 deposition process. In this work, layer stacking technique was used. In order to obtain Cu-Al_2O_3 layer stack, the Cu and Al_2O_3 layers were stacked in the sequence of single stack Cu/Al_2O_3 on the Al substrate. The thickness of the Cu and Al_2O_3 layers were found fixed to be 50 nm and 350 nm respectively using digital thickness monitor during deposition. Here after, Cu-Al_2O_3 will represent Cu/Al_2O_3 throughout the manuscript. Both the Cu and Al_2O_3 layers were deposited at the working pressure of $4.16x10^{-3}$ mbar and $3.98x10^{-3}$ mbar respectively. Pre-sputtering was carried out on both Cu and Al_2O_3 targets for 15mins before the deposition to remove any surface oxidation on the targets. The deposition rate and power were maintained at 0.6 kÅ/ s and 250W for Al_2O_3 deposition whereas Cu layer were deposited with 2.0 kÅ/ s deposition rate and 100W power respectively. To ensure uniform thickness on the substrates, rotary drive assembly with 25 RPM was implemented.

Post annealing process were performed on the synthesized stacked film in order to produce the resultant Cu-Al_2O_3 film besides improving the crystallinity of the film. The annealing process was performed in single-zone quartz furnace tube under N_2 atmosphere at various temperatures (200°C, 300°C, 400°C and 500°C) at 6 hours. The N_2 flow rate was maintained at 10 sccm and controlled throughout the annealing period by the mass flow controller. The surface topography of the synthesized films was investigated using atomic force microscope (AFM) (Model: Dimension Edge, Bruker).

2.2 Thermal Transient and Optical Analysis

To evaluate the performance of Cu-Al_2O_3 as TIM, Cu-Al_2O_3 coated Al substrates were implemented as heat sinks for 5Whigh power white LED package attached to metal core printed circuit board (MCPCB). The schematic diagram of setup using Cu-Al_2O_3 coated Al substrate as heat sink for the LED package is shown in figure 1. The thermal measurement was performed in still-air chamber (300mm X 300mm X 300mm) under natural convection using T3Ster measurement system according to JEDEC JESD-51 standard.

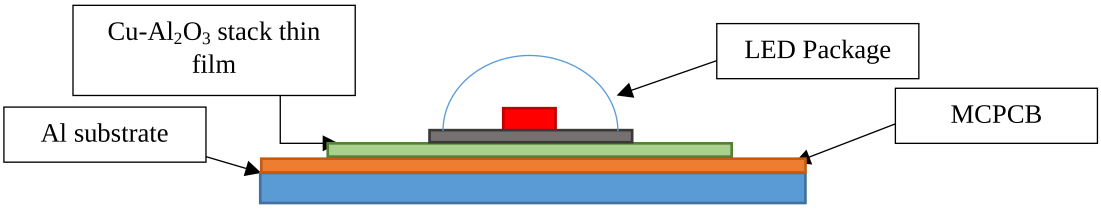


Fig. 1 Schematic diagram of LED package fixed on Cu-Al_2O_3 coated Al substrate as heat sink.

Before the thermal measurements were carried out, the tested LED package was calibrated using thermostat and T3Ster system as the power supply. The product of *K* and difference in temperature sensing voltage, ΔV_F produces the device junction rise:

$$\Delta T_j = \Delta V_F K \tag{1}$$

$$K = \Delta T_j / \Delta V_F \tag{2}$$

where K is the K-factor of the tested LED.

1mA driving current was used to power up the tested LED during the calibration to prevent self-heating effect on the LEDs, Through the features of thermostat, the ambient temperature of LEDs was able to varied from 25 to 75°C in terms of 10°C temperature step. The voltage drop across the junction was recorded at each ambient temperature point and the results were analysed after the calibration was done. The K-factor of the LED was determined from the plotted graph of junction voltage (voltage drop) against the ambient temperature shown in figure 2 where the obtained value of K-factor is 0.00159V/°C.

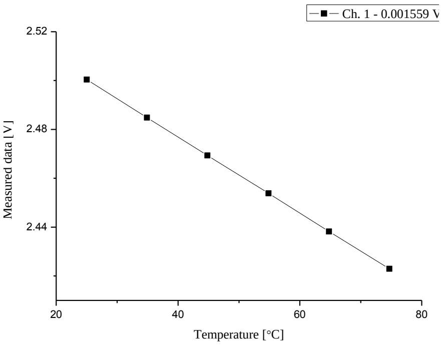


Fig. 2K factor calibration curve for given white LED

For the thermal transient measurement, the LED package were measured in four different driving currents (100mA, 300mA, 500mA, and 700mA) in the still-air chamber at temperature of 25±1°C for 900s. Once the tested LED reached the steady state, immediately it is turned off and the cooling transient curve was captured for another 900s. The captured transient curve were evaluated and interpreted using TSter Master Software. The optical performance of LEDs on Cu-Al_2O_3 coated Cu substrates was studied through UPRtek MK350 spectrometer. The optical parameters such as Color-correlated temperature (CCTP, Color rendering index (CRI), brightness (lux) and wavelength were recorded for 15mins.

3. Results and Discussion

3.1 Thermal Transient Analysis

The thermal transient measurements for the given LED fixed on Cu-Al_2O_3 thin films coated Al substrates and bare Al substrate were measured for 100mA, 300mA, 500mA and 700mA using T3Ster system The captured thermal transient curves were then evaluated into the cumulative structure function through T3Ster Master Software. Cumulative structure function was used to identify the characteristics of layers within the tested device or system and hence it was capable in elaborating the entire heat transfer profile of the device under test (DUT), from chip level to the ambient for specified driving current. The processed cumulative structure function graphs observed at various driving currents were presented in the figures 3(a) - (d). In figures 3 especially figure 3(a), deviation between cumulative function graphs can be noted which was mostly attributed to the dissimilar thermal behaviour exhibited by the films under the influence of annealing temperature. Due to the effect of annealing temperature, atom rearrangement was possible with different extent and thus the thermal properties of the Cu-Al_2O_3 films were altered. Thus, total thermal resistance (R_{th}) displayed by the Cu-Al_2O_3 films coated Al and bare Al substrates were distinct [20].

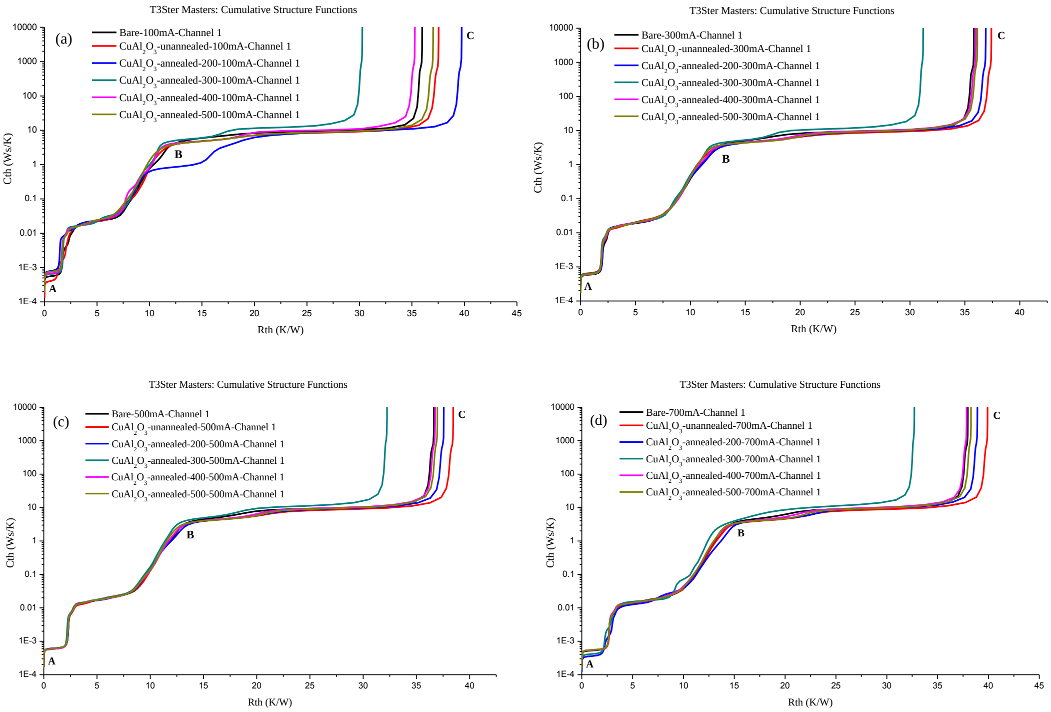


Fig 3. Cumulative structural functions of LED on Cu-Al_2O_3 coated Al and bare Al substrate at four driving currents: (a) 100mA, (b) 300mA, (c) 500mA and (d) 700mA.

Cumulative structure functions in figures 3 illustrated the R_{th} of the tested LED on Cu-Al_2O_3 coated and bare Al substrates. Through figures 3, the effectiveness of Cu-Al_2O_3 films as TIM in minimizing the R_{th} of DUT can be noticed. The observed value of R_{th} of the DUT on Cu-Al_2O_3 coated Al and bare Al substrates were presented in table 1. Based on table 1, the R_{th} values were indicated to be increased as the driving current increases which was attributed to the few mechanisms such as heat generation caused by the release of phonons as a result of non-radiative recombination and joule heating at the interface between the tested LED package and the substrate [21]. This will affect the thermal transfer mechanism within the DUT, and thus higher the R_{th} of the tested device. Referring to the four driving currents, figures 3 also revealed that the R_{th} of Cu-Al_2O_3 sample annealed at 300°C was the lowest while un-annealed Cu-Al_2O_3 sample was found to have the highest R_{th} value among the tested samples. At 700mA, it can be seen that the Cu-Al_2O_3 coated Al substrate annealed at 300°C exhibited lower R_{th} compared to the bare Al substrate where a significant difference of R_{th} (ΔR_{th} = 5.28 K/W) was noted as seen in table 1. These observations showed that the effect of annealing temperature had reasonable impact on the microstructure of Cu-Al_2O_3 films which had contributed in the reduction of R_{th} of the DUT. It was said that increase in grain size due to annealing effect might be helped in improving the thermal behaviour of Cu-Al_2O_3 films, thereby lowering the R_{th}. The grain growth influenced the thermal behaviour of the films through the grain boundary interfacial thermal resistance. Moreover, it was mentioned that the annealing temperature effect triggered the Grain Rotation Induced Grain Coalescence (GRICC) mechanism which led to the increase in grain growth. The increase in grain growth caused the number of grain boundaries to decrease, further reducing the contribution of grain boundary to the phonon scattering and thereby improving the thermal performance of the films [22].

Further analysis was performed on the cumulative structure functions in figures 4 to extract the values of substrate to ambient thermal resistance, $R_{th\ s\text{-}a}$ for the four stated driving currents. The values of R_{th} and $R_{th\ s\text{-}a}$ were summarized in table 1. From table 2, it can be seen that the LED fixed on 300°C annealed Cu-Al_2O_3 thin film coated substrate displayed low $R_{th\ s\text{-}a}$in regards to other sample throughout all four driving currents. A significant difference in $R_{th\ s\text{-}a}$ ($\Delta R_{th\ s\text{-}a}$ = 3.67 K/W) can be noted between the annealed Cu-Al_2O_3 (300°C) thin film and bare Al boundary conditions. This difference was attributed to changes occurred on the structural properties of the film as a result of annealing temperature. It was suggested that increase in the annealing temperature reduced the number of defects and boundaries thereby enhance the scattering of phonon, and thereby improved the thermal performance of the films [23]. It was also speculated that since Cu had higher value of thermal conductivity (385 Wm/K) compared to Al_2O_3 (38.5 Wm/K), the rise in annealing temperature triggered the atom rearrangement within the film which led to the increase rate of diffusion of Cu atoms into the Al_2O_3 crystal structure and thereby improved the thermal conductivity of the film [24].

Table 1: Thermal resistance and rise in junction temperature of LED on Cu-Al_2O_3 coated Al and bare Al substrate.

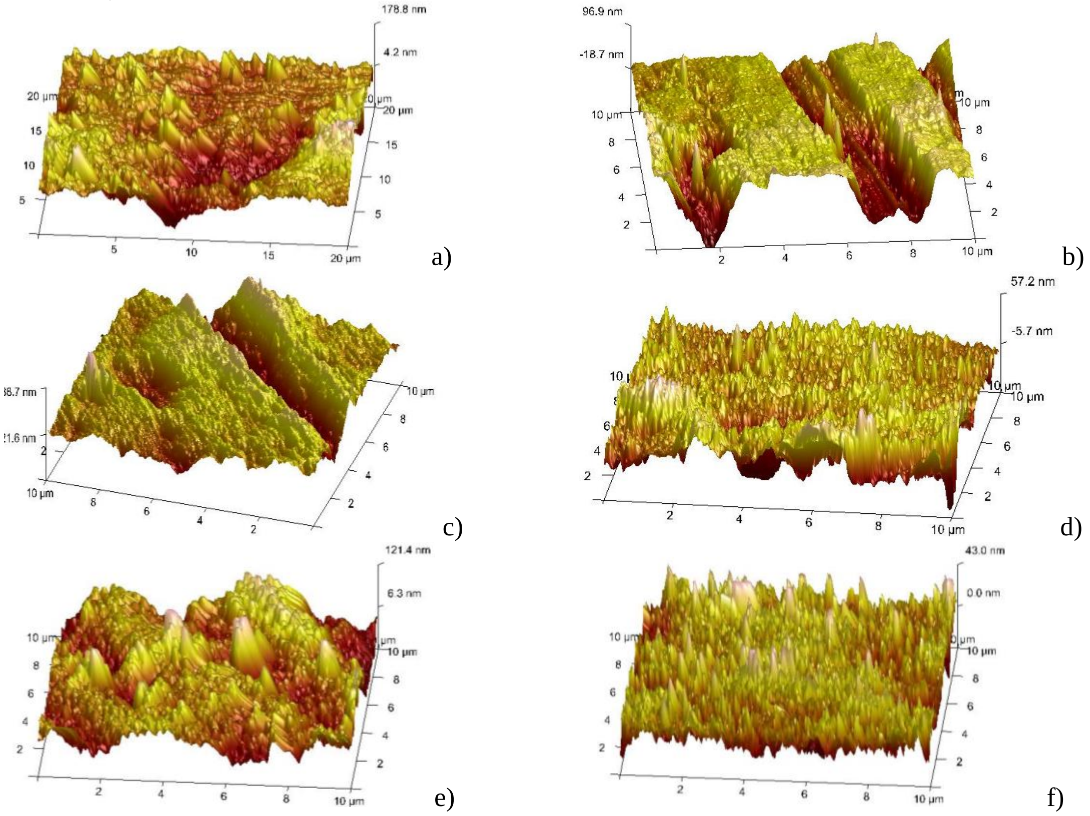
Driving current (mA)	Bare Al	Cu-Al_2O_3 un-annealed	Cu-Al_2O_3 annealed (200°C)	Cu-Al_2O_3 annealed (300°C)	Cu-Al_2O_3 annealed (400°C)	Cu-Al_2O_3 annealed (500°C)
Total thermal resistance, R_{th}(K/W)						
100	35.97	37.53	39.74	30.27	35.27	37.02
300	35.82	37.42	36.90	31.20	35.98	36.14
500	36.63	38.45	37.57	32.23	36.76	36.96
700	37.98	39.91	38.91	32.70	37.85	38.29
Substrate to ambient thermal resistance, $R_{th\ s\text{-}a}$ (K/W)						
100	23.65	26.04	22.37	19.23	24.30	26.49
300	23.34	25.02	24.61	19.45	23.55	24.24
500	23.27	25.41	24.38	19.95	24.06	24.44
700	23.25	25.74	24.11	19.58	23.89	24.36
Junction temperature, T_j(°C)						
100	10.27	10.70	11.32	8.67	10.09	10.63
300	34.24	35.83	35.15	30.12	34.41	34.59
500	62.06	65.12	63.92	55.34	62.35	62.82
700	95.51	100.14	97.83	83.23	95.44	96.31

The analysis also revealed that further increase in the annealing temperature (≥ 300°C) had adverse effect on the thermal conductivity of the film. This was likely attributed to the increase in surface roughness due to the annealing temperature [25]. The increase in roughness was found to be detrimental to the thermal behaviour of the films as there was a reduction in charge carrier density and thus affected the conductivity of film [26]. The annealing process also induced thermal stress to the film as a result of difference in coefficient thermal expansion (CTE) between Cu ($17x10^{-6}$ /K) and Al_2O_3 ($4.5 – 10.9X10^{-6}$ /K). [27] It was deduced that the thermal mismatch of Cu, Al_2O_3 and Al substrate and crystallographic flaws induced the residual stress within the film which greatly affected thermal behaviour of the films [28]. An increase in the R_{th} can be associated with the decrease of the phonon number within the crystal structure. With the reduction in the number of phonon available, the heat conduction was greatly affected and the decrease in the phonon number was suggested due to effect of further increase in annealing temperature [29].

The rise in the junction temperature of the tested LED on Cu-Al_2O_3 films coated Al substrate and bare Al substrate was obtained from the smoothed response curve of the software and presented in the table 1. Table 1 indicated that there was no significant changes noted on the junction temperature at low driving current and this was attributed to the reason that molecular agitation only occurred at high temperature [30]. Based on table 1, it was obviously noted that Cu-Al_2O_3 thin film annealed at 300°C sample demonstrated low junction temperature compared to bare Al substrate and also a noted difference in junction temperature (ΔT_j= 12.23°C) was high when compared between Cu-Al_2O_3 thin film annealed at 300°C and bare Al boundary conditions. The low junction temperature exhibited by the annealed Cu-Al_2O_3 (300°C) was in accordance with the value of R_{th} showed by the sample. Besides this, table 1 also revealed that the junction temperature of the tested LEDs increased as the driving current was increased. The rise in the junction temperature was due to the current crowding effect induced by the increase in driving current. High injection current density as a result of the rise in the driving current led to the self-heating effect of the LEDs, and the self-heating promoted the rate of heat generation within the package which eventually caused the increase in junction temperature of the LEDs [31]. Due to the increase in the junction temperature and rate of heat generation, the rate of heat dissipation to the ambient was greatly affected.

3.2 AFM Analysis

The surface topography of bare Al and Cu-Al_2O_3 film coated Al substrates were examined through the studies on AFM images to investigate the influence of the contact resistance on the thermal performance of the tested LEDs. Figures 4 illustrated the AFM images of the bare Al and Cu-Al_2O_3 film coated Al substrates. The values of surface roughness of the films were measured from the images through AFM software and presented in table 2. From table 2, it could be observed that the surface roughness of annealed Cu-Al_2O_3 film (300°C) was the lowest among the tested samples (2.84 nm) and this clearly suggested that surface roughness played certain role in affecting the thermal behaviour of the film. Generally, surface with low roughness improved the thermal performance of the DUT as it provided low contact resistance and enhanced the heat path. Furthermore, literature also reported that high contact conductance was also attributed to the presence of smooth surface [32]. It was speculated that the increase in the annealing temperature caused the increase in the surface roughness and the rise in surface roughness reduced the number of contact points between the coated substrate and the tested LED package, thereby increased the thermal contact resistance of the Cu-Al_2O_3 thin films. The annealing process induced the recrystallization mechanism within the film structure and led to the coalescence process of Cu and Al_2O_3 particles [33]. It might deduced that the annealing process gave rise to the number of defects present within the film, thereby affecting thermal behaviour of the film. Moreover, a rough surface might imposed stronger scattering on phonons, which in turn shortened the mean free path of phonon and thereby reduced the thermal properties of the film [34]. Through the explanation, it was concluded that annealed Cu-Al_2O_3 (300°C) coated substrate had positive impact on the reduction of thermal resistance and the AFM result showed by it matched with the thermal transient analysis.



a) b) c) d) e) f)

Fig 4.AFM of (a) bare Al substrate and Cu-Al_2O_3films at (b) as-deposited, annealing temperature of (c) 200, (d) 300°C, (e) 400°C and (f) 500°C.

Table 2: Surface roughness of Cu-Al_2O_3 coated Al and bare Al substrate.

Sample type	Surface roughness (nm)
Bare Al	4.07
Cu-Al_2O_3 un-annealed	5.08
Cu-Al_2O_3 annealed (200°C)	4.59
Cu-Al_2O_3 annealed (300°C)	2.84
Cu-Al_2O_3 annealed (400°C)	4.80
Cu-Al_2O_3 annealed (500°C)	5.05

The depth-valley analysis was also performed on bare Al and Cu-Al_2O_3 film coated Al substrates through the AFM software in order to analyse the surface profile of the films. The observed surface profile was illustrated in the figures 5. The Y-axis was described as the percentage of depth available on the surface of the thin film which explained the overall ratio of depth-valley percentage in particular distance measured in nm scale (X-axis). It can be observed that a high percentage of depth-valley profile displayed higher possibility for the presence of rough surface. Thus it can deduced that the surfaces of un-annealed and annealed Cu-Al_2O_3 (200°C, 400°C and 500°C) thin film were rough due to the high percentage of depth exhibited by the profile. Besides annealed Cu-Al_2O_3 (300°C) coated substrate, other substrates were indicated to show wider distribution range of depth-valley based on the figures 5. It could be speculated that the number of contact points increased and thereby gave rise to the contact resistance and thus high values of R_{th} could be measured on these samples.

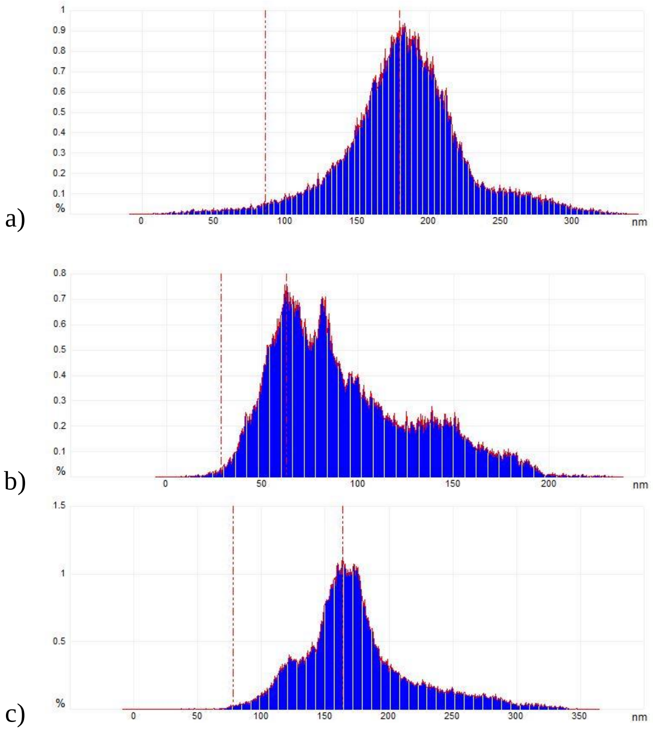


Fig 5.Depth-valley historgram surface plot of (a) bare Al substrate and Cu-Al_2O_3 coated Al substrates at (b) un-annealed, (c) annealing temperature of 200°C,

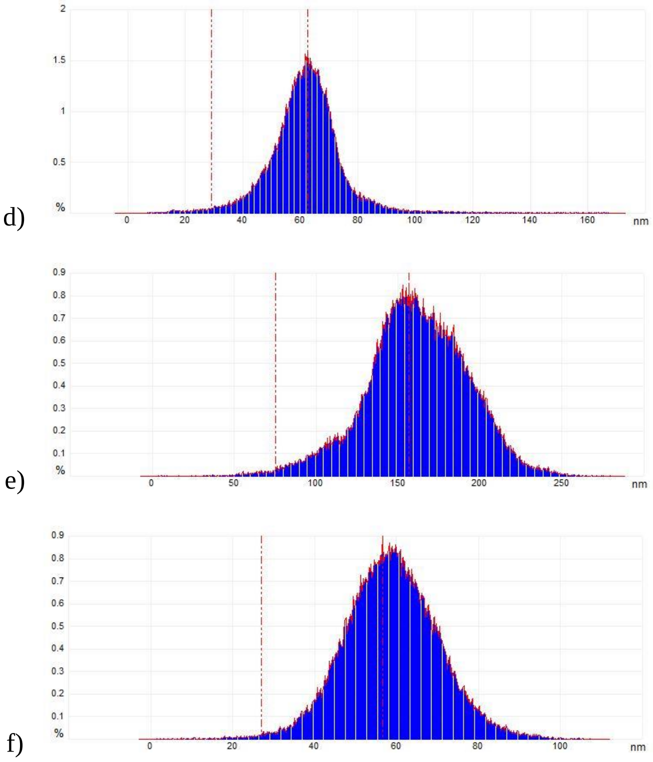


Fig 5.Depth-valley historgram surface plot (d) annealing temperature of 300°C, (e) annealing temperature of 400°C amd (f) annealing temperature of 500°C.

3.3 Optical Analysis

Optical properties of the tested LED in terms of CCT, CRI and brightness were measured in order to analyse the effect of Cu-Al_2O_3 films as TIM on the optical properties of LEDs. Figures 6 illustrated the variation of CCT for the tested LEDs under the influence of four driving currents (100mA, 300mA, 500mA and 700mA). Color consistency was one of the important criteria in evaluating the quality of both color and white light LEDs and thus color-correlated temperature (CCT) was used to describe the changes of color of the light source when it was heated to a particular temperature. Maintaining the color consistency was a major concern among the LEDs manufacturers as shifting of CCT beyond the range will deteriorate the performance of the LEDs. From figures 6, it was evidently showed that the CCT of the LEDs has increased as the driving current increases and in particular the shifting of CCT of bare Cu was observed to be highest (~8600K) among the tested samples at 700mA. The observation on figures 6 has indicated that the shifting of CCT for annealed Cu-Al_2O_3 (300°C) was the lowest whereas indication of high values of shifting of CCT for annealed Cu-Al_2O_3 (500°C) can be found from figures for all driving currents. The increase in the CCT was attributed to the high rate of heat generation within the LEDs package [35]. The increase in the driving current induced the current crowding effect at the chip level and this event in turns increased the heat generation rate within the LED package and consequently the temperature of the tested LED, hence the CCT of the LEDs shifted towards higher values as a result of changes in temperature. It was speculate that the effective thermal dissipation can assist in maintaining the color consistency of the LEDs as the shifting of CCT can be maintained at the lowest. Therefore in this case, annealed Cu-Al_2O_3 (300°C) can be serve as an alternative TIM material for effective thermal management solution.

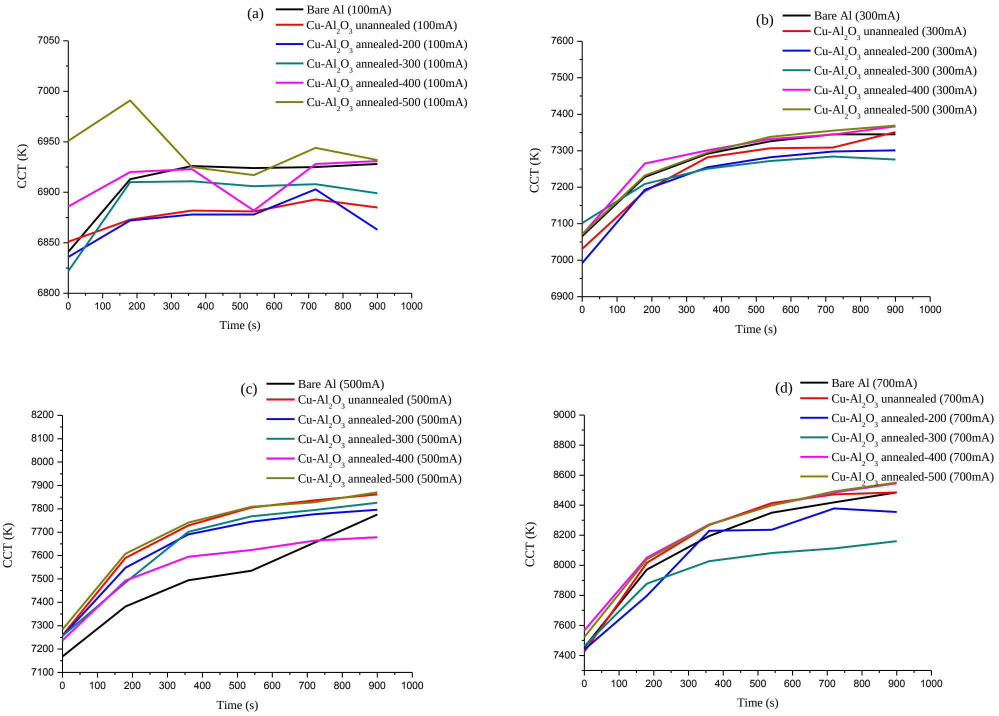


Fig 6. Color-correlated temperature (CCT) of LEDs on Cu-Al$_2$O$_3$ coated Al and bare Al substrates at four driving current: (a) 100mA, (b) 300mA, (c) 500mA and (d) 700mA.

Table 3 also indicated the variation of brightness (lux) of the tested LED under four driving current (100mA, 300mA, 500mA and 700mA). Table 3 indicated that the brightness of tested LED increased as the driving current increased and this was ascribed to the rise in the rate of radiative recombination at the chip level due to the high injection current density [36]. However, the lux values of the LEDs were found to be decreased as the time progressed. The reduction of lux values can be attributed to the high heat generation rate within the LEDs which led to ineffective dissipation to the ambient. Table 3 showed that the decrease in the lux values for the annealed Cu-Al$_2$O$_3$ (300°C) sample was lesser compared to other samples and it can be said that the increase in annealing temperature had adverse effect on the performance of thin films. The optical results of annealed Cu-Al$_2$O$_3$ (300°C) sample was said to be in accordance with the thermal transient analysis. Based on the observation of the lux values, the light quality of the LEDs was greatly influenced by the overall thermal behaviour of the Cu-Al$_2$O$_3$ thin films. The rise in the driving current triggered the self-heating effect within the LEDs which increased the junction temperature, and this in turn led to the increased rate of phonon generation within the chip level. The produced phonon disrupted the generation of photon and thereby the brightness of the LEDs decreased [37]. Due to above mentioned effect, the deterioration of optical properties of the LEDs can be observed.

Table 3: Variation of lux value of LEDs on Cu-Al$_2$O$_3$ coated Al and bare Al substrate at four driving currents.

Time(s)	Bare Al	Cu-Al$_2$O$_3$ un-annealed	Cu-Al$_2$O$_3$ annealed (200°C)	Cu-Al$_2$O$_3$ annealed (300°C)	Cu-Al$_2$O$_3$ annealed (400°C)	Cu-Al$_2$O$_3$ annealed (500°C)
100mA						
0	289	292	299	291	296	289
180	289	293	296	289	293	289
360	287	292	299	288	296	296
540	288	290	298	289	295	297
720	290	293	296	284	292	295
900	278	294	302	286	294	295
300mA						
0	769	777	763	762	781	784
180	748	753	761	750	758	762
360	739	740	757	744	744	754
540	729	738	756	739	743	746
720	733	737	754	736	740	743
900	731	725	750	732	735	740
500mA						
0	973	1179	1166	1153	1172	1175
180	937	1101	1104	1104	1084	1100
360	919	1063	1066	1080	1076	1059
540	906	1052	1059	1067	1056	1045
720	899	1040	1047	1054	1047	1043
900	901	1037	1043	1066	1047	1041
700mA						
0	1466	1492	1491	1467	1455	1467
180	1316	1326	1244	1345	1308	1324
360	1242	1253	1210	1303	1248	1244
540	1207	1203	1202	1273	1218	1212
720	1184	1172	1181	1253	1202	1187
900	1167	1171	1160	1250	1188	1160

The influence of Cu-Al$_2$O$_3$ stack film as TIM on other optical properties of the LED such as color rendering index (CRI) and wavelength (λ) was also analysed through the spectrometer. From the recorded results, it was found that there was no significant changes on the CRI nor the wavelength of LEDs when the driving current was increased. The variation of CRI value for the LED throughout four driving current was approximately ±4. According to the published result, the difference in CRI values of less than 5 were not significant [38]. According to the Wien's displacement law, the spectral peak shifted toward shorter wavelengths for higher temperatures. Contrarily, the wavelength peak shifted toward higher wavelength from 451 to 455nm. Based on these results, it was concluded that Cu-Al$_2$O$_3$ stack film will not affect the color rendering of the LED, hence allowing the LED to maintain its original color.

4. Conclusions

Cu-Al$_2$O$_3$ stack thin films were synthesized on Al substrates using layer stacking technique through RF sputtering. The Cu-Al$_2$O$_3$ films were then annealed at various temperatures and the films were considered as thermal interface material (TIM) to analyse their influence on the thermal and optical behaviour of the LEDs. From the thermal transient analysis, it was revealed that annealed Cu-Al$_2$O$_3$ (300°C) coated substrate exhibited low R_{th}value compared to others in all driving currents. It was also found that annealed Cu-Al_2O_3 (300°C) displayed low T_j among the tested samples.

Moreover, annealing process did helped in improving the thermal properties of the films, however further increased in annealing temperature had adverse effect on the properties of the film. Surface morphology result showed that changes in the surface roughness affected the thermal resistance of the films where low surface roughness enhanced the thermal path thereby reducing the thermal resistance of the film. In addition, annealed Cu-Al_2O_3 (300°C) film displayed a better performance in terms of optical properties compared to other samples. From the observed result, it is speculated that annealed Cu-Al_2O_3 (300°C) stack film can be used as an alternative thermal interface material for high power LED in future.

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