

Experimental investigation of carbon nanotube coated heat sink for LED thermal management

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Abstract

In this paper, brushing technique was used to coat carbon nanotubes (CNT) on 6063 aluminium alloy in order to investigate the heat transfer performance for Light Emitting Diode (LED) application. The two different thickness such as 0.5 mm and 1 mm coating of CNT was applied an aluminium plate. Performance parameters, like LED case and junction temperatures and heat sink thermal resistance were studied. The results showed that the LED case temperature for 0.5 mm thick CNT coated heat sink decreased by 16.25 % when compared to aluminium plate at 400 mA. For the 400 mA, the 0.5 mm CNT coated heat sink has junction temperature 89 °C while the junction temperature of 1 mm CNT coated heat sink is 111 °C, reduced by 19.81 %. Heat sink thermal resistance for 0.5 mm thick CNT coated heat sink was reduced by 37.72 % compared with that of the 1 mm thick CNT heat sink at 300 mA. The CNT coating thickness of 0.5 mm was identified to produce efficient heat dissipation.

Keywords: CNT; LED junction temperature; Coating, Heat sink thermal resistance

1. Introduction

Heat dissipation is a primary issue in Light Emitting Diode (LEDs) [1], [2]. LEDs are currently used in various applications such as indoor/outdoor lighting systems, automotive, marine, street lighting. Compared to conventional lighting system, LED owning more advantages like long life, high visibility and high energy efficiency. However, 20 % of electrical energy convert into visible light, and remaining 80 % goes as waste heat to ambient [3]. This waste heat would significantly increase the junction temperature of the LED leading to a decrease in LED lifetime and colour shifts [4]. In this context, urgent need of better LED thermal management to avoid failure of the LEDs. Commonly passive and active cooling techniques are widely used in LED lighting system to remove the heat from the P—N junction [5], [6], [7], [8], [9], [10]. The passive cooling system is extensively used for LED device because it don't have moving accessories and fans. Use of active cooling system is limited, because of bulk volume, more noise, high maintenance cost. The many heat dissipation methods have been developed on the basis of conduction and convection principle, while the transmission of radiative heat was not considered as metal aluminum surface emissivity is relatively low. Consequently, if the surface of the aluminum alloy substrate can be effectively modified to increase its emissivity, the overall heat dissipation performance may be improved for high-power LED applications [11], [12], [13]. Zou et al. [14] investigated the heat transfer performance of the Al₂O₃

graphene oxide double-layer coated heat sink for high power LED application. Results reveals that at 5 W, the LED temperature of Al₂O₃/rGO double-layer coated heat sink is 14 °C, which was 12.5 % lower than that of the uncoated aluminium alloy heat sink. Udaya kumar et al. [15] Investigated and compared the heat transfer performance of the four type heat sinks namely copper surface heat sink, grooved heat sink, CNT coated heat sink and CNT grooved heat sink. The experimental results revealed that heat transfer performance of CNT grooved heat sink improved up to 96 %, compared to copper surface heat sink. The Cu-MWCNTs composite developed by Mandal et al. [16] for coating on 6061 Aluminum alloy and investigated the thermal-electro property. The results shown that thermal conductivity of Cu-MWCNTs (1 gL⁻¹) was improved by 50.79 % compared to uncoated aluminium alloy 6061. Tsai et al. [17] developed the ceramic powders (Al₂O₃, SiO₂, and graphite) coated heat sink for high power LED. The results indicated that the temperature of ceramic powders coated heat sink was about 11 °C lower than that of uncoated aluminium alloys heat sinks.

Arshad et al. [18] experimentally investigation of copper oxide coated on copper metal-foam with various filling thickness ratio (0.0, 0.5, 1.0) and phase change material (PCM) with coated metal form based heat sink under two different Volumetric fraction of PCM (0.0 and 1.0). They concluded that copper metal-form filling thickness ratio of 0.5 with PCM volumetric fraction of 1.0 based heat sink was superior heat transfer performance compared to other heat sinks. Shanmugan and Mutharasu [19] experimental investigated the LED thermal resistance of the AlN/Cu coated based heat sink. Significant reduction of thermal resistance was observed for AlN/Cu coated based heat sink compared with bare Cu substrate. Thin et al. [20] experimental investigation of zinc oxide (ZnO) coated on Al as a thermal interface material (TIM) based heat sink for the LED cooling performance. In this study show that CNT coated, the junction temperature was lower by 3.33 °C compared to Al based. The goal of present study to investigate the heat transfer performance of two different thickness CNT (0.5 mm and 1 mm) coating over an aluminium plate using manual coating for high power LED lighting system.

2. Experimental procedure

2.1. Material

A flat plate heat sink made of aluminium (6063) alloy, cut into 60 × 60 × 5 mm. The substrate is roughened with sand paper and dipped in NaOH solution (5 wt%) for a duration of 30 s. This improves the adhesive property of the substrate's surface. The nominal 5–20 nm diameter of multiwall carbon nanotube (CNT) was purchased from United Nanotech Innovation Pvt Ltd., Bangalore, India.

2.2. Coating procedure

The CNT powder was then mixed with a silicon thermosetting resin and toluene at a mixture ratio of 5:15:2 by weight using brushing technique. The obtained solution is then manually coated onto the substrate using an OHP sheet. This process required skill to obtain uniform coating. The coating was placed in an oven to remove moisture and other aqueous components at 100 °C for a duration of 20 min. The duration varied with the amount of toluene in the solution. The coating thickness is further increased by repeating the

procedures. Fig. 1 shows the CNT coated heat sink. In this study, coating thickness was varied 0.5 mm CNT to 1 mm CNT to study the effect of the coating thickness.

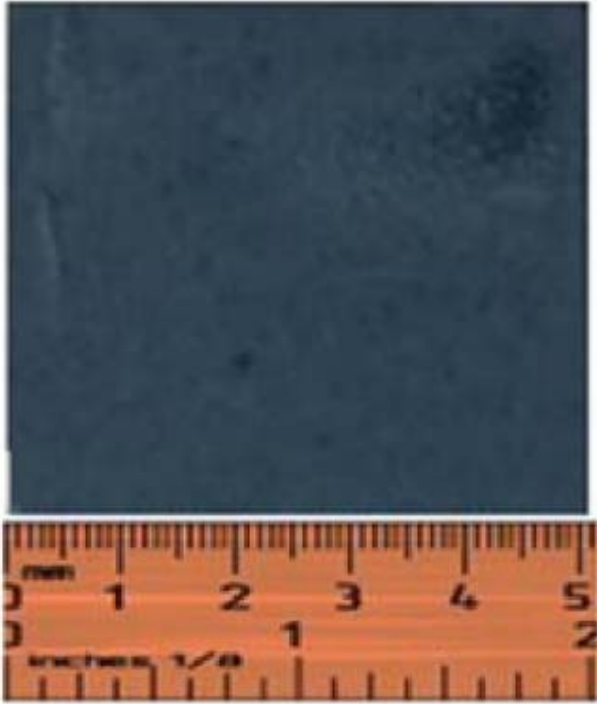


Fig. 1. CNT coating on aluminium heat sink.

2.3. Heat transfer experimentation

To investigate the heat dissipation performance of the aluminium (6063) with CNT coated heat sink LED (LUSTRON LL610F'- 'Cool white (5700 K) module. The CNT coated heat sink was mounted to LED module surface with help of screws. The forward current apply to LED using variable DC power supply (KUSAM-MECO, 302D, India) was used. In this study-four level of forward current (100 mA, 200 mA, 300 mA and 400 mA) was consider. Case temperature of the LED module is found every-one minute using a K type thermocouple which was soldered to its negative terminal. The LED module Junction temperature calculated by the following Equations.

$$T_j = T_c + (R_{j-c} \times P_d) \tag{1}$$

$$R_h = (T_b - T_a)/P_d \tag{2}$$

Where T_j , T_c , R_{j-c} , P_d , R_h , T_b , and T_a are the LED junction temperature ($^{\circ}\text{C}$), LED case temperature ($^{\circ}\text{C}$), thermal resistance at the junction ($^{\circ}\text{C}/\text{W}$), dissipated power (W), thermal resistance of heat sink ($^{\circ}\text{C}/\text{W}$), temperature of interface material ($^{\circ}\text{C}$) (from the datasheet provided by the manufacturer) and ambient temperature respectively. Fig. 2 shows the overview of the experimental setup. Power is supplied to the LED module by the usage of DC power supply. Show Fig. 2 experimental setup, Thermocouple are placed at negative terminal

in the LED module and the aluminum heat sink. The Thermocouple are then connected to a Data Acquisition Card through which signals from the thermocouple are processed and data is supplied to the computer.

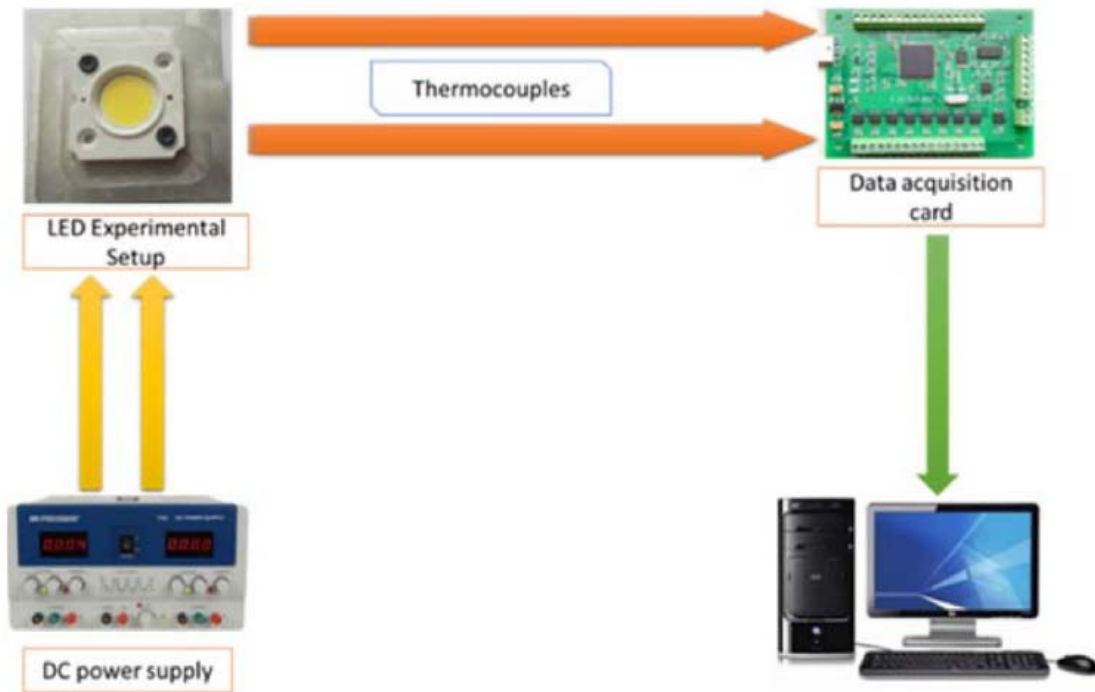


Fig. 2. Experimental setup.

3. Results and discussion

3.1. Effect of the LED case temperature under different input power

Fig. 3 compares the LED case temperature of aluminum plate, heat sink 0.5 mm CNT coated and 1 mm CNT coated at 100 mA, 200 mA, 300 mA and 400 mA. The case temperature increased as the input power increased, while the CNT coated heat sinks case temperature were decreased. Fig. 3 observed the results that 1 mm thickness of CNT coated sink are least effective heat transfer for all case. This is because excessive thickness of the coating caused an increase in the thermal resistance offered by the coating thus the heat could not be efficiently conducted from the LED module. The LED case temperature recorded after 60 min, are 80 °C, 67 °C and 89 °C for aluminium plate, 0.5 mm thick CNT coating heat sink and 1 mm thick CNT coating heat sink respectively at 400 mA. The results showed that the LED case temperature 0.5 mm thick CNT coating heat sink decreased by 16.25 % when compared to the aluminium plate at 400 mA. The better heat transfer performance of the 0.5 mm thick CNT coating heat sink was due to the reduced case temperature.

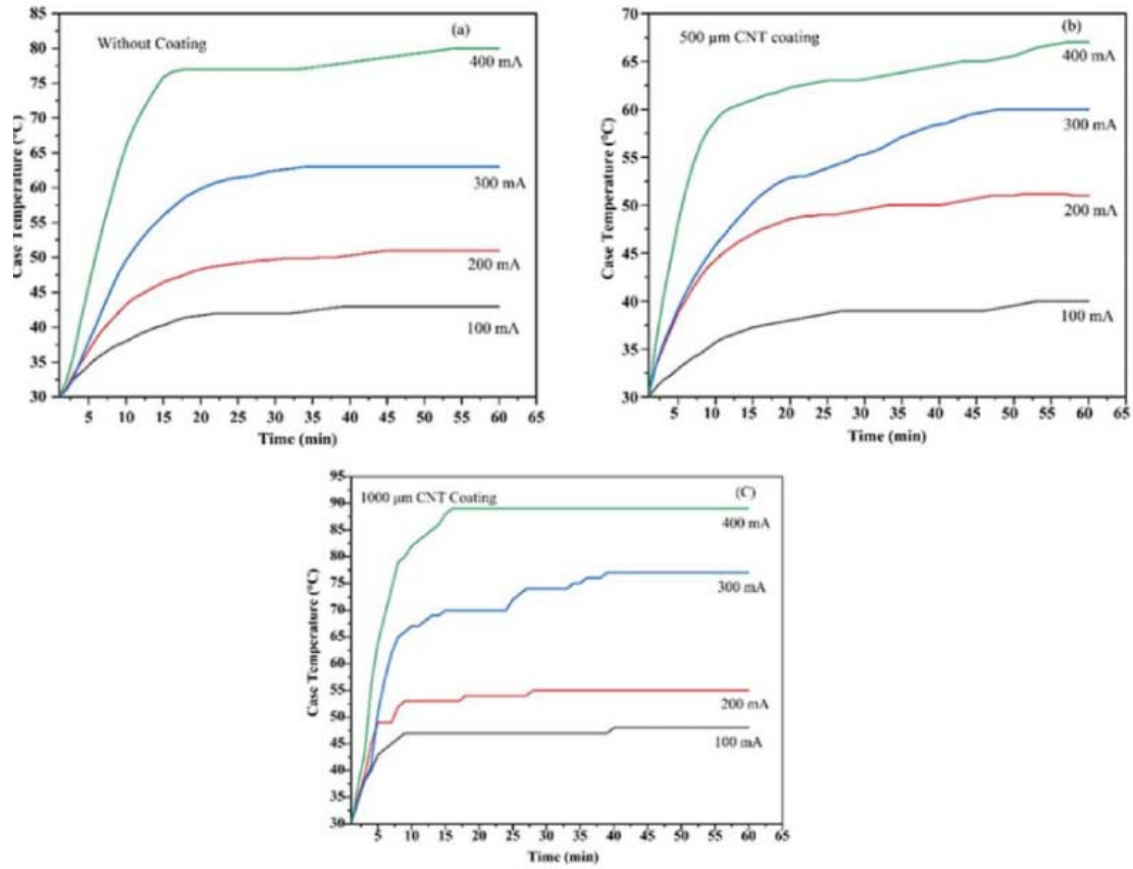


Fig. 3. Variation of case temperature curves (a) aluminium plate (b) 0.5 mm thick CNT coated heat sink (c) 1 mm thick CNT coated heat sink.

3.2. Effect of the LED junction temperature under different input power

The LED junction temperature is very important life desired parameter and it is maintained within an allowable limits. The LED junction temperature calculated using equation (1) for heat transfer analysis. Fig. 4 show the LED Junction temperature versus time for different forward current. The results revealed that 0.5 mm CNT coated heat sink superior heat transfer performance compared with other heat sinks. For the 400 mA, the 0.5 mm CNT coated heat sink has junction temperature 89 °C while the junction temperature of 1 mm CNT coated heat sink is 111 °C, reduced by 19.81 %. For 300 mA, 200 mA and 100 mA of junction temperature of the 0.5 mm CNT coated heat sink are reduced by 18.2 %, 6.1 % and 15 % respectively.

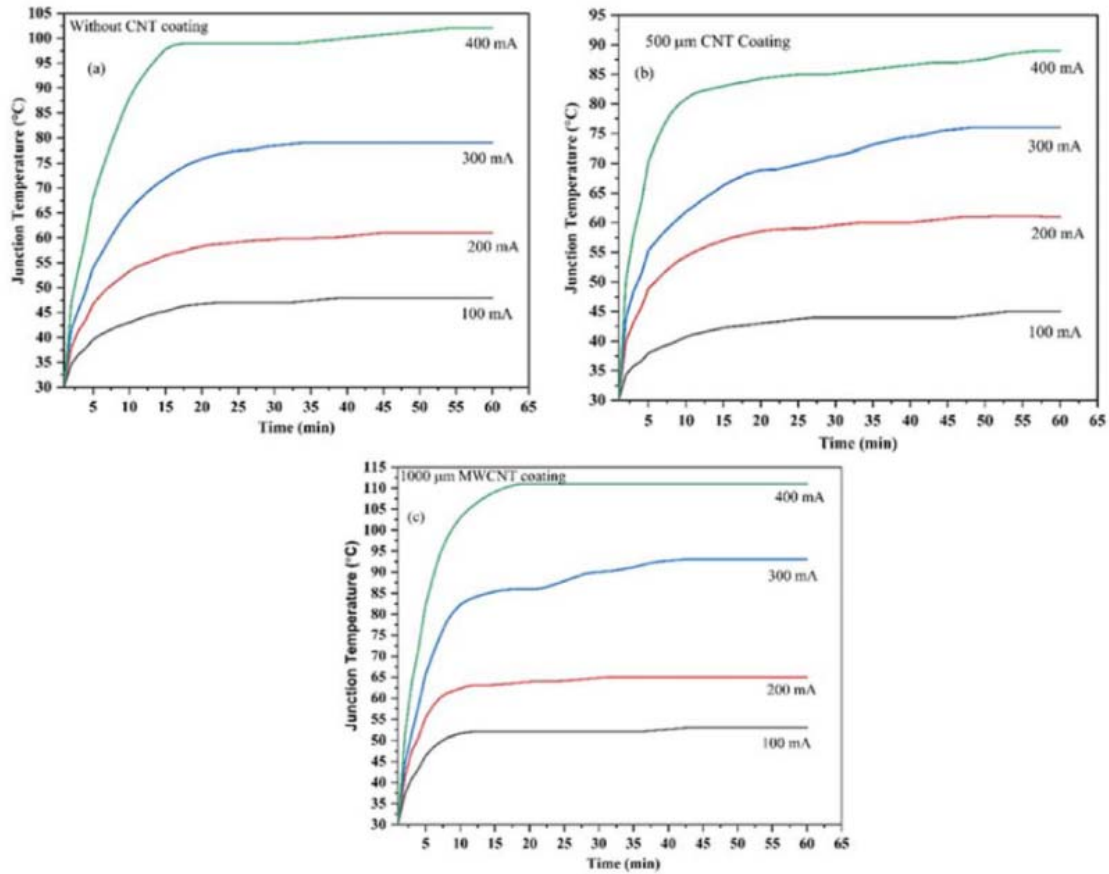


Fig. 4. Variation of junction temperature curves (a) aluminium plate (b) 0.5 mm thick CNT coated heat sink (c) 1 mm thick CNT coated heat sink.

3.3. Heat sink thermal resistance

The heat sink thermal resistance was calculated using equation (2). Fig. 5, can be observe that 0.5 mm thick CNT coated heat sink offered lower heat sink thermal resistance, compared to two other heat sinks. The heat sink thermal resistance of 0.5 mm thick CNT coated heat sink was 3 °C/W at 400 mA, which was 39.75 % lower than that of the 0.5 mm thick CNT heat sink. Similarly, heat sink thermal resistance for 0.5 mm thick CNT coated heat sink was reduced by 37.72 % compared with that of the 1 mm thick CNT heat sink at 300 mA. The superior heat sink thermal resistance of the 0.5 mm thick CNT coated heat sink was due to the reduced junction temperature due to high heat conduction, compared to other two heat sinks.

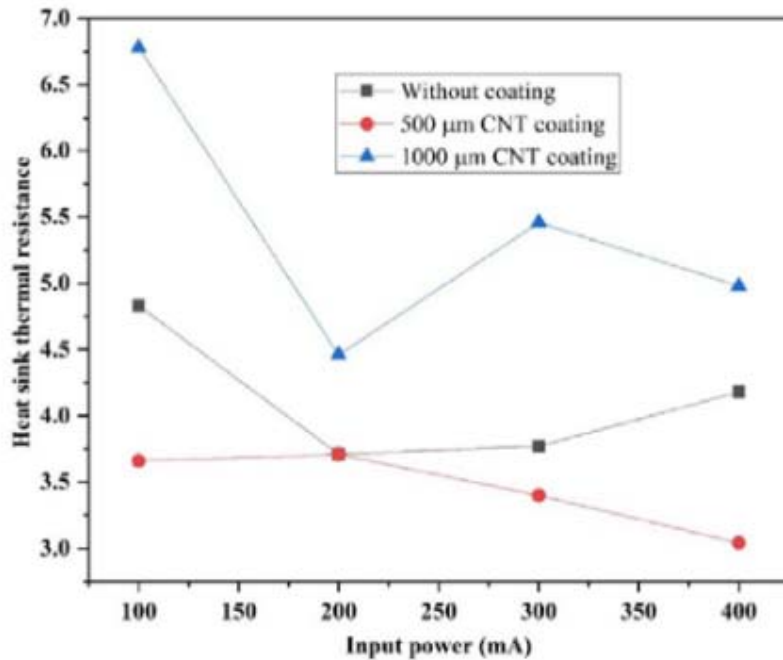


Fig. 5. Heat sink thermal resistance.

4. Conclusions

In this experimental work, CNT coating was made for the heat sink with CNT, Terpeneol and Ethyl cellulose at weight percentages 3.61 wt%, 84.33 wt% and 12.04 wt% respectively. The coating was applied manually using OHP sheet on the aluminum substrate. The substrate was cured at 100 °C for 20 min to obtain a suitable coating for the conduction of the experiment. A k type thermocouple is soldered to the negative terminal of the LED module to measure the LED case temperature. The following conclusions were made from this study.

- Increase in coating thickness increase the thermal resistance offered by the coating thereby affecting its conductive properties.
- The LED case temperature recorded after 60 min, are 80 °C, 67 °C and 89 °C for aluminium plate, 0.5 mm thick CNT coating heat sink and 1 mm thick CNT coating heat sink respectively at 400 mA.
- The heat sink thermal resistance of 0.5 mm thick CNT coated heat sink was 3 °C/W at 400 mA, which was 39.75 % lower than that of the 1 mm thick CNT heat sink.
- The coating thickness of CNT of 0.5 mm is identified to produce efficient heat dissipation.

CRedit authorship contribution statement

Thangamani Ramesh: Conceptualization, Investigation, Methodology, Writing – original draft. **Ayyappan Susila Praveen:** Validation. **Praveen Bhaskaran Pillai:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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