International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 5 Issue 12 ǁ December. 2016 ǁ PP.70-77

Studies on Performance of Multiwalled Carbon Nanotubes (MWCNTs) Based Thermal Interface Materials-Nanofluids For Efficient Heat Transfer in LED's

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ABSTRACT: *Thermal interface materials based on Multiwalled carbon nanotubes (MWCNTs) were synthesized using different organic base fluids and are proved to exhibit enhanced thermal conductivity in LED luminary. The different nanofluids were prepared using various organic solvents and MWCNTs, using SDS as surfactant by employing sonication method. Further these thermal interface materials were effectively used in 3 watt MR-16 pin type LED Luminary. The performance of this Nanofluids was found to be good in heat sink of LED lights at different watts applied and further increased the life of LED light. It was note-worthy by experimentation that the 0.1mm thickness of the ethylene glycol with MWCNTS thermal interface material recorded the lowest junction temperatures due to efficient heat transfer in LED lights.*

Keywords - *LED light, Multiwalled carbon nanotubes, Nanofluids, Thermal interface materials.*

I. INTRODUCTION

As there is profound increase in the innovative electronic devices used for different purposes, there is a need to develop different efficient cooling techniques and materials. Generally the performance and extensive use of electronics devices depends on the thermal management. The thermal interface materials are used in between that of heat sink and the source for enhanced dissipation of heat. Carbon Nanotubes due to their remarkable physical properties [1] have been used in diverse applications [2] such as flat panel display [3] Nanoelectronics devices [4] structural composites [5] tribology [6] and so on. Another significant application of MWCNTs is in heat sinks as thermal interface materials (TIMs) of electronics devices for their thermal management. Carbon nanotubes was first developed by Dr. Choi from Argone National Laboratory [7] as an efficient thermal managing material. CNTs were found to be superior [8] in thermal management compared to other materials [9,10]. Light emitting diodes have been extensively used as light source as they possess long life, low power consumption and eco-friendly . At present LED manufacturers are focusing on heat dissipation in high power LED's to make efficient lighting systems [11]. Presently, LED's thermal management in industries is by using fin-heat sink as a focal method [12]. There are other novel methods like thermoelectric cooling [13], micro-channel cooler [14], micro-jet array cooling [15], electrodynamics approach [16], and piezoelectric fan [17]. But the above methods have some disadvantages like poor cooling, reliability, complex design process etc. By looking into these parameters we have made an attempt to design the MWCNTs as thermal interface materials which was synthesized, purified by H. Kathyayini, et al [18] and characterized by different analytical techniques. These MWCNTs were used in the preparation of thermal interface material which was used in the heat sink of 3 watt MR-16 pin type LED luminary.

Typical interface material fills the void and grooves created by imperfect surface finish of the two mating surfaces [19].TIM in the form of paste is more attractive as it offers many advantages such as ease of application by screen printing and feasibility of application to a large variety of surfaces[8]. For most of the polymer based TIMs, when thin bondlines are used their thermal performance may be dominated by interface resistance [20]. The thermal resistance of a system consisting of a TIM sandwiched by a heat source and a heat sink can be modelled by thermal resistance in series. $R=BLT/kA+Rc1+Rc2$, where BLT is the bondline thickness, A is the area of thermal contact, k is the thermal conductivity of the TIM, R is the thermal resistance of the sandwich, and Rc1 and Rc2 are the contact resistances of the interface between the TIM and the two surfaces that sandwich the TIM [21].To improve the heat dissipation across the interface it is important to minimize the value of R [22].

These materials were found to give enhanced and efficient heat transfer in LED lights, thus improving the life of the product.

II. BACKGROUND

In order to maintain a low junction temperature to keep good performance of an LED, every method of removing heat from LEDs should be considered. Conduction, convection and radiation are the three means of heat transfer. MR16 3W LED down light is made up of aluminum material. Suitable MCPCB with LED mounted at one end face of aluminum heat at the top surface of MCPCB. Fig.1 shows MR16 3W LED down light.

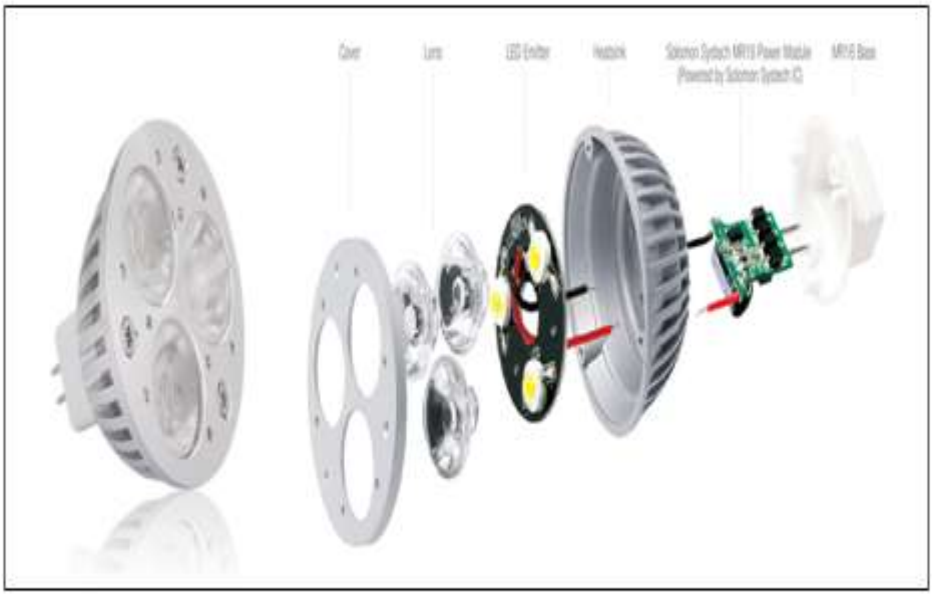

Fig.1. Exploded view of MR16 3W LED

Typically, LEDs are encapsulated in a transparent resin, which is a poor thermal conductor. Nearly all heat produced is conducted through the back side of the chip. Heat is generated from the P-N junction by electrical energy that was not converted to useful light and conducted to outside ambience through a long path, from junction to solder point, solder point to board and board to the heat sink and then to the atmosphere as shown in Fig. 2.a.The junction temperature will be lower if the thermal impedance is smaller and likewise, with a lower ambient temperature. To maximize the useful ambient temperature range for a given power dissipation, the total thermal resistance from junction to ambient must be minimized. Simplified model of the thermal path is a series thermal resistance circuit, as shown in fig.2.b.

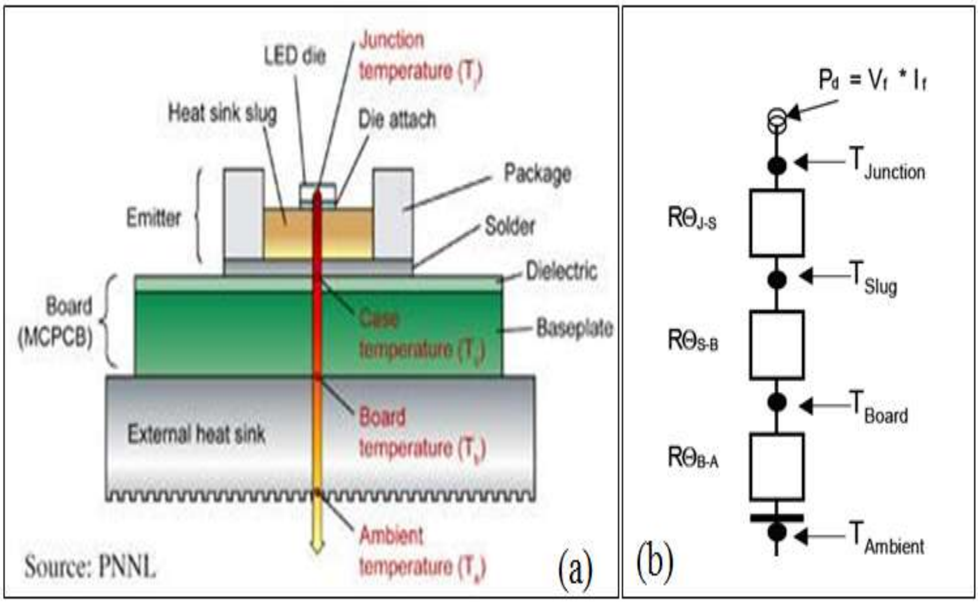

Fig.2.(a) Thermal management of LED, (b).Series Resistance Thermal Circuit

RΘ Junction- Ambient = RΘ Junction -Slug + RΘ Slug -Board+ RΘ Board –TIM + RΘ TIM –Ambient
Where:
RΘ Junction-Slug = RΘ between die, die attach epoxy and the slug.
RΘ Slug-Board = RΘ between adhesive and the aluminum heat spreader.
RΘ Board –TIM= RΘ between board and TIM
RΘ TIM –Ambient = RΘ between the TIM and the aluminum heat spreader and the heat sink.
One of the primary mathematical tools used in thermal management design is thermal resistance (RJ-fin).
Thermal resistance is defined as the ratio of temperature difference to the corresponding power dissipation.

$$\text{Thermal Resistance, } R_{J-fin} = \frac{T_J - T_{fin}}{Power, W} \quad \text{…(Eq.1)}$$

Where:
Tj = The junction temperature
Tfin =The temperature of the fin of the heat sink

III. EXPERIMENTAL

a. Sample preparation of MWCNT TIM

Purified Multiwall carbon nanotubes synthesized (14-16nm diameter size) by CCVD were used in the synthesis of Nanofluids. All the organic base fluids used were of analytical reagent AR grade and they are Acetone, Ethyl alcohol, Ethylene Glycol, Paraffin Oil and Engine Oil. A small quantity of Sodium Dodoceyl Sulphate(SDS) was used during the preparation of Nanofluids, which helps in the dispersion of MWCNTs. In a typical procedure, thermal interface materials (Nanofluids) was prepared using organic liquids like Ethylene Glycol, Paraffin oil, Engine oil, Ethyl alcohol and acetone etc. In a typical sample preparation procedure, about 10mg of CNTs, 10-20mg of SDS and 20-40ml of organic liquid/s were mixed thoroughly in an ultrasonicator. Thirteen different Nanofluids were prepared, which exhibited different with respect to its density, dispersity and thickness as mentioned below.

1. Ethylene glycol (20ml) + MWCNT (10mg) + SDS (20mg)
2. Engine oil (20ml) + MWCNT (10mg) + SDS (20mg)
3. Paraffin oil (20ml) + MWCNT (10mg) + SDS (20mg)
4. Acetone (20ml) + MWCNT (10mg) + SDS (20mg)
5. Ethyl alcohol (20ml) + MWCNT (10mg) + SDS (20mg)
6. Ethylene glycol (40ml) + MWCNT (10mg)
7. Engine oil (40ml) + MWCNT (10mg)
8. Paraffin oil (40ml) + MWCNT (10mg)
9. Ethylene glycol (20ml) + MWCNT (10mg)
10. Engine oil (20ml) + MWCNT (10mg)
11. Paraffin oil (20ml) + MWCNT (10mg)
12. Acetone (20ml) + MWCNT (10mg)
13. Ethyl alcohol (20ml) + MWCNT (10mg)

Among thirteen nanofluids, six nanofluids were converted to grease form after sonication and found suitable for LED application. Samples/mixtures 4,5&12 are dried in nature due to evaporation of acetone and Ethyl alcohol and samples 1,7,9&11 are in fluid state. The mixtures considered for further analysis are as below:

i. Mixture 1: Engine oil (20 ml) + MWCNT (10mg) + SDS (20 mg)
ii. Mixture 2: Paraffin-oil (20 ml) + MWCNT (10mg) + SDS (20 mg)
iii. Mixture 3: Ethylene glycol (40 ml) + MWCNT (10 mg)
iv. Mixture 4: Paraffin oil (40 ml) + MWCNT (10 mg)
v. Mixture 5: Engine oil (20 ml) + MWCNT (10 mg)
vi. Mixture 6: Ethyl alcohol (20 ml) + MWCNT (10 mg)

b. Experimental Setup

To investigate the enhancement of thermal conductivity of Nanofluids, the following set up has been used selected thermal interface materials developed were tested for their thermal behavior on a MR-16 3W LED lighting load.

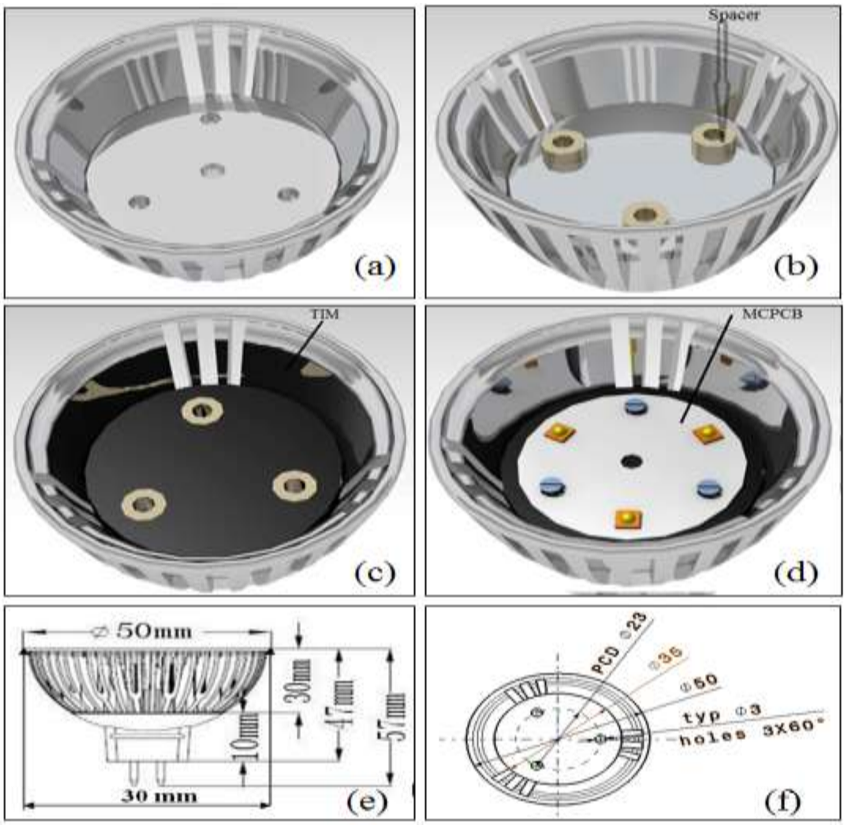

Fig.3.Sequence of assembly of LED lighting load with TIM (a) Heat Sink (b) Spacers in place(c) TIM spread (d) MCPCB placed above TIM; (e) and (f) Dimensioned views of the Lighting.

The TIM was applied between the multi Core Printed Circuit Board (MCPCB) and aluminum heat sink as a thick layer. The thickness of the TIM deposited on the heat sink was varied to optimize the thickness. Thickness of the TIM was 0.1 mm and further varied from 0.25 mm to 1 mm in steps of 0.25 mm. The layer thickness was measured by using spacers between the MCPCB and heat sink. The spacer thickness was measured by using Vernier caliper and slip gauge. The sequence of assembly of the MCPCB and heat sink with TIM is shown in fig.1a to 1d. The spacers were placed at 120 degrees to each other in the heat sink. The TIM was then applied from one end to the other to ensure uniform application of the TIM Material.Fig.1e and 1f show the dimensions of the LED load.

In the experimental setup, total six thermocouples are employed. Three thermocouples were bonded on to the MCPCB (LED Junction) at Pitch Circle Diameter is 23mm at 120° equal interval , other two thermocouples were bonded on the side face of the heat sink at 20 mm from bottom of PCB and remaining thermocouple used to measure ambient temperature. From MCPCB and Heat sink all thermocouple were connected to the data acquisition system for recording temperature data. Positions of thermocouples are as shown in Fig.4.a, b & c.

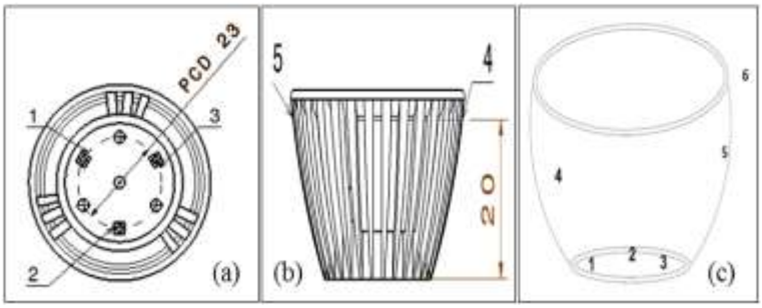

Fig.4.Thermocouple locations (a) Three on MCPCB (b) Two thermocouples on side face of heat sink (c) Schematic showing the thermocouple position. Thermocouple 6 measures ambient temperature.

Fig. 5 shows the schematic arrangement of the data acquisition system. The LED lighting load was connected to the data logger (Tracer make). The data-logger was logged onto a desktop for data storage. The sampling rate of the data logger is 12/min. T- type thermocouples were used for temperature measurement. The experiments were repeated five times for repeatability. The average and standard deviation were computed and one standard deviation was marked on either sides of the average value as error span.

Fig.5. LED lighting load with data logger (Tracer make) circuitry

IV. Results and discussion

Tests were done without the thermal interface material and with the MCPCB directly connected to the heat sink using fasteners. The variation of temperature as a function of time without the use of thermal interface material is shown in fig.6. Tests were conducted on all the six select TIMs to measure the junction temperatures. The thermal resistance of the film was computed using the junction and heat sink temperatures (eq. “1”).
Junction temperature and sink temperature for all mixtures

The power supplied (W) to the LED module is 3.12 W (Forward current= 0.26 A, Forward Voltage = 12 V). The measured junction temperature without the application of TIM between MCPCB and heat sink has recorded average junction temperature of 68 °C. The average sink temperature was 58 °C. The MCPCB and heat sink were fastened together using clamp. The junction temperatures would be high due to small area of contact between them (contact would be at high points only).

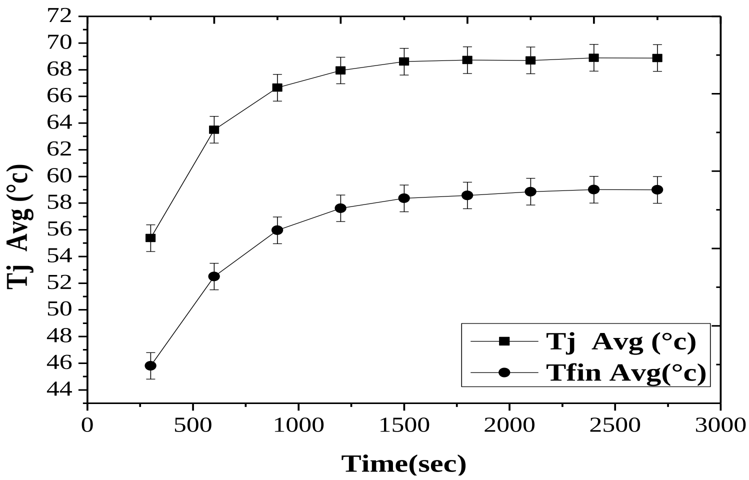

Fig. 6.Variation of temperature as a function time without thermal interface material

For the TIM thickness of 0.1 mm, the lowest average junction temperature (Tj)) and average fin temperature (Tfin) on the heat sink side recorded for the mixture 3 were 61.15°C and 59.55°C respectively. This would be because of the higher thermal conductivity of the base fluid.

The junction temperature, fin temperature, thermal resistance for varying thickness of the TIM for all mixtures is presented in Table 1.The next lowest junction temperature was recorded by mixture 5 followed by mixtures 4, 2, 1 and 6 respectively. The difference in junction temperatures between mixtures is very small. Though mixture 3 has shown better performance than the others, other mixtures also perform closely.
The measured temperatures on the sink side for the mixture 3 is lower than the other mixtures which otherwise should have been highest. But, the sink temperature, an average of two temperatures measured on either side of the sink, might have been influenced by ambient temperature.

Mixture Number & Name	TIM Thickness (mm)	Max Tj(°C)	Max Th(°C)	Max Tamb(°C)	Rj-th((m2K)/W)
Mixture 1. Engine Oil (20ml)+MNCT(10 mg)+SDS(20mg)	0.1	67.79	65.27	29.75	0.81
	0.25	68.33	65.75	30.44	0.83
	0.5	68.77	65.95	30.52	0.9
	0.75	69.52	66.15	29.5	1.08
	1	71.91	67.79	30.12	1.32
Mixture 2. Paraffin-Oil (20ml)+MNCT(10 mg)+SDS(20mg)	0.1	64.06	61.92	29.44	0.69
	0.25	64.69	62.33	29.5	0.76
	0.5	65.40	62.95	29.32	0.79
	0.75	66.28	63.21	29.3	0.98
	1	66.82	63.55	29.25	1.05
Mixture 3. Ethylene glycol (40ml)+MNCT(10 mg)	0.1	61.55	59.55	29.85	0.64
	0.25	61.96	59.75	29.75	0.71
	0.5	62.81	60.15	30.63	0.85
	0.75	67.37	63.77	30.5	1.15
	1	71.22	65.79	30.55	1.74
Mixture 4. Paraffin oil (40ml)+MNCT(10 mg)	0.1	63.53	61.26	29.85	0.73
	0.25	67.25	63.36	29.4	1.25
	0.5	68.90	64.68	29.95	1.35
	0.75	69.47	65.12	29.75	1.39
	1	70.03	65.32	30.75	1.51
Mixture 5. Engine Oil (20ml)+MNCT(10 mg)	0.1	62.09	59.35	30.66	0.88
	0.25	69.34	66.23	30.3	1
	0.5	70.29	66.77	30.46	1.13
	0.75	72.79	67.03	30.21	1.84
	1	73.15	68.07	29.96	1.63
Mixture 6. Ethyl alcohol(20ml)+ MNCT (10mg)	0.1	65.50	63.33	29.5	0.7
	0.25	68.82	65.75	30.98	0.98
	0.5	70.05	67.02	30.52	0.97
	0.75	70.62	69.35	30.765	1.05
	1	75.79	70.66	30.6	1.64

Table.1.Temperature Profile Data for LED MR16 3W for all mixtures

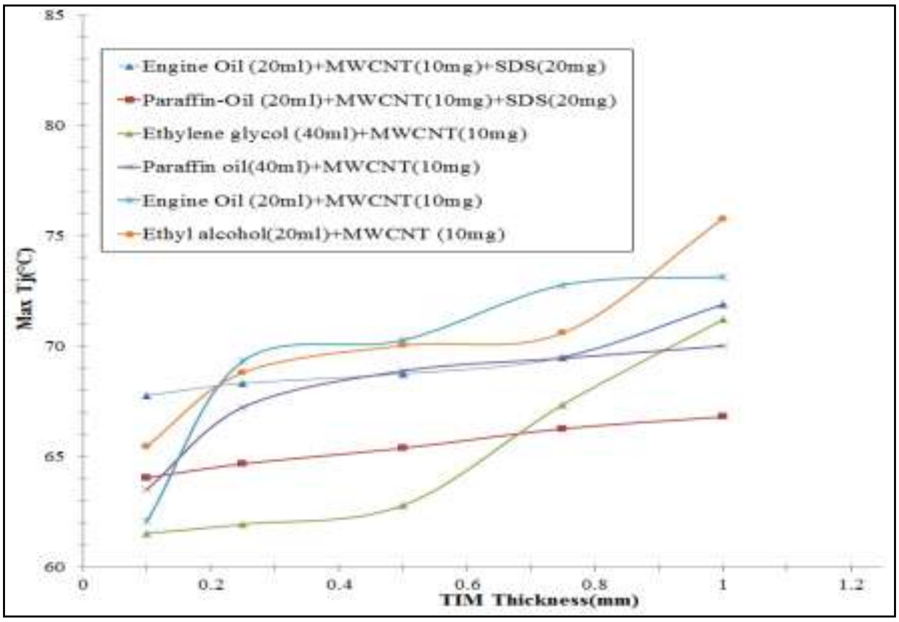

Fig.7.Variation of junction temperature with respect to thickness of various TIM

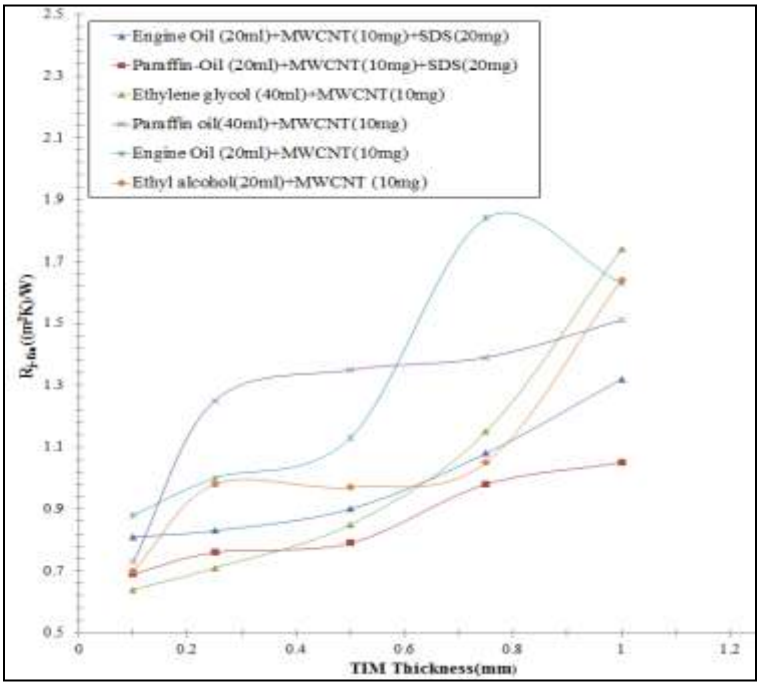

Fig.8.Variation of thermal resistance with respect to thickness of various TIM

Effect of thickness of film

It was found that the smaller the thickness of the film better is the heat transfer through the TIM. The thickness of the film was decreased starting from 1 mm to 0.1 mm. Though screen printing is one of the options for applying the TIM, it could not be used because of the shape (bottom surface of conical shape) of the heat sink. The thermal resistance increased with increase in thickness for all mixtures.

V. CONCLUSION

In summary, we have synthesized MWCNTs based nanofluids. Among thirteen different Nanofluids prepared, Ethylene glycol with MWCNTs TIM was found to be an efficient thermal interface material in LED lights and recorded lowest junction temperatures. Smaller the thickness of the TIM film better is the heat transfer. A TIM film of 0.1 mm thickness was found to have better heat transfer. The results of this work suggests that MWCNT based nanofluid TIM synthesized here could be used with relatively simple and repeatable processing steps to reduce contact resistances for heat transfer in electronic applications.

Acknowledgements

Authors thank Director, CIIRC for his constant support in encouraging this research work.

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