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Development of Low Resistance Thermal Interface Material (TIM) Using Nanomaterials

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ABSTRACT: *A comparative study of effective thermal contact resistance of various thermal interface materials (TIM) was determined using an indigenously fabricated test rig with aluminum heat sink and copper plate as heating plate. Experiments were carried out for different power inputs in the range of 25-75 watts. TIM in the form of thermal paste was prepared using copper nanoparticle as thermally conductive filler particles. The base fluids used to prepare the thermal paste were tricosane paraffin wax (Loba chemicals, India), and commercially available carbon nanotube patse (CNT) (Techo nano, Taiwan). The thermal paste was prepared by mixing the nanoparticles and base fluid in the following concentrations of 10 wt%, 20 wt%, and 30 wt% using sonicator (Heilscher, Germany). Thermal contact resistance of base fluids was determined by finding the variation of heater temperature with time at reduced pressure (RP) and full pressure (FP) and compared with commercially available TIM's (Indian standard and imported). The particle size of copper nanoparticles was determined using scanning electron microscope (SEM, Jeol) and was found to be in the range of 60-150 nm. Effect of weight percents of Cu nanoparticle on effective thermal resistance of prepared grease was observed at different pressures. The present results show that copper nanoparticle mixed in nano silver paste at a critical weight percent of 20 wt% gives the lowest reading of resistance 0.27 ºC/W.*

Keywords: *CNT paste, Copper nanoparticles, Effective thermal contact resistance, Thermal interface material,*

I. INTRODUCTON

The rising integration level and the miniaturization of electronic components cause an ever increasing power density in microelectronics. They consume more power and generate greater heat. Heat generated within the component must be removed to the ambient environment to maintain it within permissible temperatures, thereby to gain high reliability and longer life for the electronic devices [1]. Effective transfer of heat by conduction requires materials (such as heat sink material) of high thermal conductivity. In addition, it requires a good thermal contact between the two surfaces such as the surface of a heat sink and the surface of a printed circuit board) across which heat transfer occurs. To attain good thermal contact, thermal interface materials are necessary [2]. Thermal interface materials are mainly classified as coatings [3] thermal fluids [4], thermal grease [5], and resilient thermal conductors [6]. Metals such as tin, aluminum, silver and copper [7] are mostly used as coating materials because of their low hardness, which increases the total contact area of the joint, and their high thermal conductivity. However, metal coatings usually need to be sintered, electroplated, or deposited on the desired substrate surfaces, and the processing is more complicated than using other thermal interface materials.

Thermal greases are predominantly based on polymers particularly silicone [8]. The main disadvantages of silicone greases are low fluidity, messiness and difficulty of removal by dissolution. A resilient thermal conductor often requires an applied pressure to hold it between the mating surfaces and hence is sometimes inconvenient for use [9]. Fluidic pastes based on polyethylene glycol filled with thermally conductive particles are also used as gap filling materials for filling the valleys in surfaces that are in contact [10]. To improve the efficiency of thermal greases filler particles with high thermal conductivity are used. Carbon nanotubes have recently been proposed as filler materials in polymers to be used as thermal interface material due to the anisotropic high thermal conductivity of individual nanotubes [11-13]. Theoretical calculations show a thermal conductivity value of 6000 $Wm^{-1}K^{-1}$ for a single wall carbon nanotube [14] while

experimental thermal conductivity measurements showed a value of 3000 $Wm^{-1}K^{-1}$ for isolated multiwall carbon nanotubes [15]. These nanotubes are usually mixed with different types of polymer to achieve a homogeneous composite film [16-19], which is easy to handle and to apply as thermal interface materials. Graphene-enhanced phase-change materials (PCMs) are examples of polymer composite TIM [20-22].
The aim of this work is to investigate the effects of pressure, temperature, and weight percent of copper nanoparticle content on the thermal contact resistance of prepared thermal interface materials with paraffin wax and silver nanopaste as base fluids.

II. EXPERIMENTAL METHODS

2.1 Preparation of thermal interface material

The copper nanoparticle (diameter, 60-150 nm) was purchased from Techonano, Taiwan to be used as filler particles. The paraffin wax was supplied by Loba Chemical, India, and was supplied by Techonano, Taiwan. Different samples of thermal interface materials were prepared by mixing 10, 20 and 30 wt% of Cu nanoparticles individually in the base fluids paraffin wax and . The samples were manually mixed first and sonicated for 20 minutes for uniform mixing of nanoparticles in the base fluids. Two commercially available thermal interface materials were used as reference materials. The resulting paste (a thermal interface material) was applied as a thin paste between the copper heater and aluminum sink of the indigenously fabricated test rig (Fig. 3.). The interface thickness or bond line thickness was about 30 µm at full pressure (FP), as measured by a micrometer. At reduced pressure (RP) the thickness was observed to be 42 µm. Experiments were carried out at approximately nil pressure/reduced pressure (RP) and full pressure (FP) applied by tightening the screws of the aluminum sink all set of experiments were conducted at the power inputs of 25, 50 and 75 W.

2.2 Test set up

Heat sink experiment was used to determine effective thermal resistance ($R_{th,\ eff}$) of various samples. Fig..1. shows schematic of the test rig.

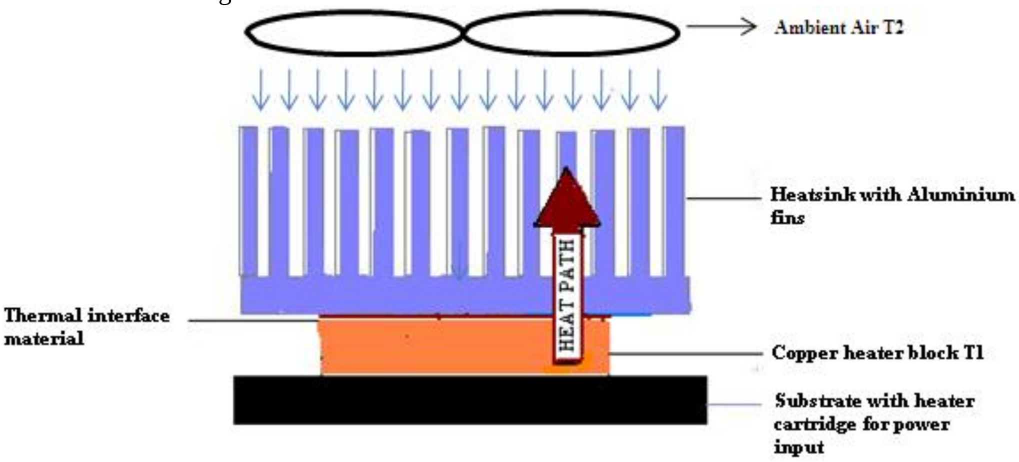

Figure 1. Principle schematic for test set up

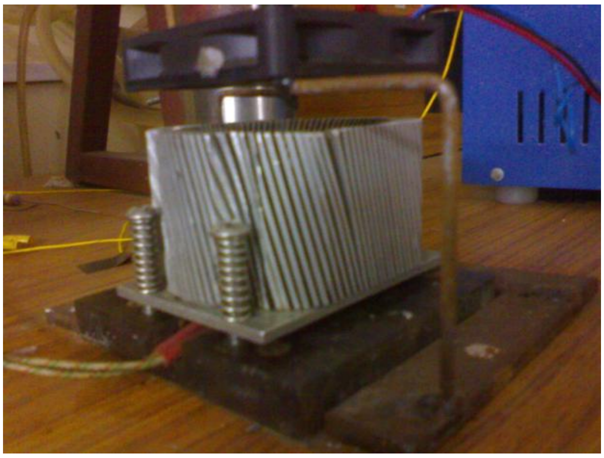

Figure 2. Copper heater block and aluminium sink used in the experimental set up

Effective thermal resistance ($R_{th,\ eff}$) calculated in preliminary experiments with the prepared thermal interface material is given as:

$$R_{th,\ eff} = R_{th} + Rth_0, \text{Cu-TIM} + R_{th0}, \text{TIM-Al} + R_{th0}, \text{Al-Air} \qquad (1)$$

Where,

R_{th} = Thermal resistance of TIM material

R_{th0}, Cu-TIM = Thermal interface resistance between the copper heater block and thermal interface material

R_{th0}, TIM-Al = Thermal interface resistance between the aluminum heat sink and thermal interface material

R_{th0}, Al-Air = Thermal interface resistance between the aluminum heat sink and air

In Fig. 3 & 4, the details of the experimental set up for measuring $R_{th,\ eff}$ is given.

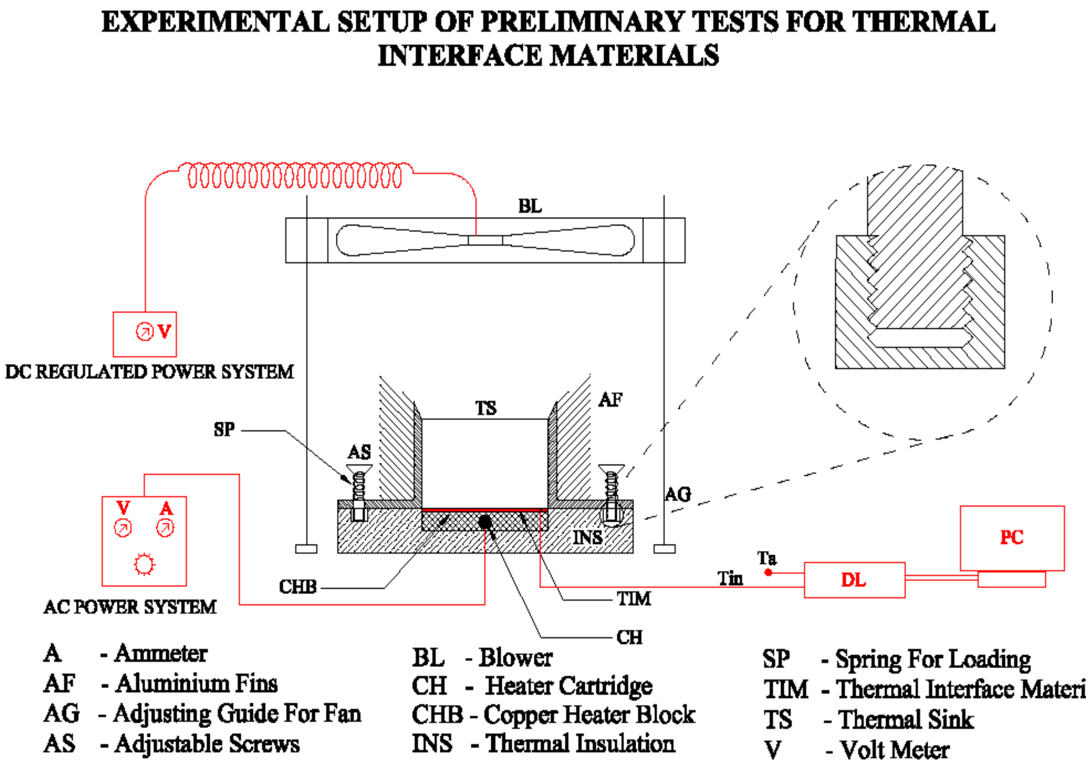

Figure 3. Fabrication details of aluminum heat sink test rig

In the above given test rig (Fig..3.) the ac power system provides power to the heater cartridge (CH) which heats the copper heater block (CHB) and Chrome-Alumel thermocouple system is used to sense the temperature. The temperature sensors were calibrated-in-house to an overall accuracy of **±5^{0}C**. Thermal sink (TS) with aluminum fins (AF) is used, which is fixed to the copper heater block using adjustable screws (AS) with spring for loading (SP). Thermal interface material is applied over the requisite area on copper heater block and aluminum sink is fixed over it. By loosening the screws, applied stress on thermal interface material can be varied. A blower (BL) is fixed over heat sink arrangement with the help of adjusting guide (AG). Difference between heater temperature and ambient temperature is measured during experimentation at varied power inputs. Velocity of the blower at 12 dc volt was calculated using anemometer and found to be 6.8 m/s. It was kept constant throughout the experiment.

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Figure 4. Experimental set up for finding thermal contact resistance of TIM

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

Effective thermal resistance ($R_{th, eff}$) based on the fabricated set up is calculated as

$$(R_{th, eff}) = (T_2 - T_1)^0C / P \text{ (watts)} \qquad (2)$$

Where T_2 and T_1represents the heater temperature and ambient temperature and P is the applied power.

3.1 Variation of Heater Temperature with Time and Pressure

Fig. 5(a) to 5(e) gives the variation of heater temperature with time for different materials at reduced pressure (RP) and full pressure (FP) which includes base fluids such as paraffin wax and CNT paste and commercially available TIM's (Indian standard and imported). Also the heater temperature was measured with time when no interface material was applied between the mating surfaces. Each experiment was carried out at different power inputs of 25W, 50W and 75W. The comparative study of effective thermal resistance calculated on the basis of these graphs at full pressure and reduced pressure is depicted in fig. 5(f). ($R_{th, eff}$) is significantly less for CNT paste as compared to paraffin wax and hence makes it a suitable base fluid. Another prominent observation is made that at full pressure ($R_{th, eff}$) for all the materials is less as compared to the value at reduced pressure.

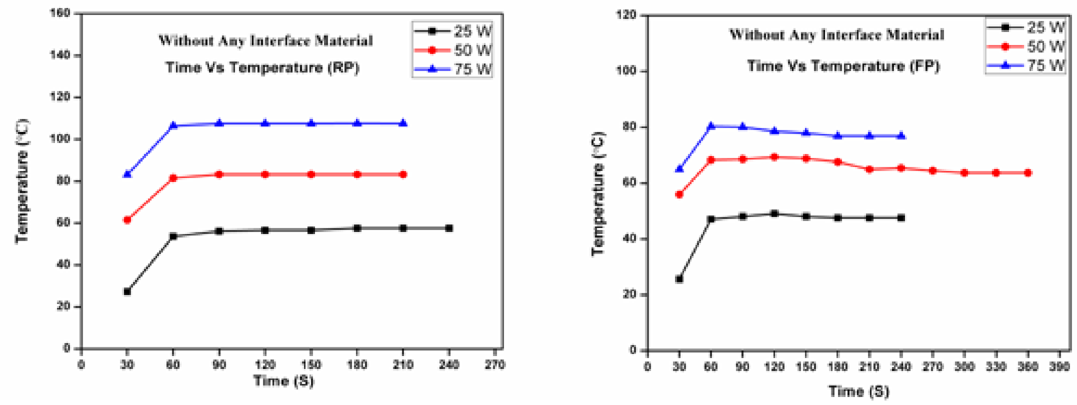

Figure 5 (a). Graph of time Vs heater temperature for without any interface material at different power inputs of 25 W, 50 W and 75 W and at full pressure (FP) and reduced pressure (RP)

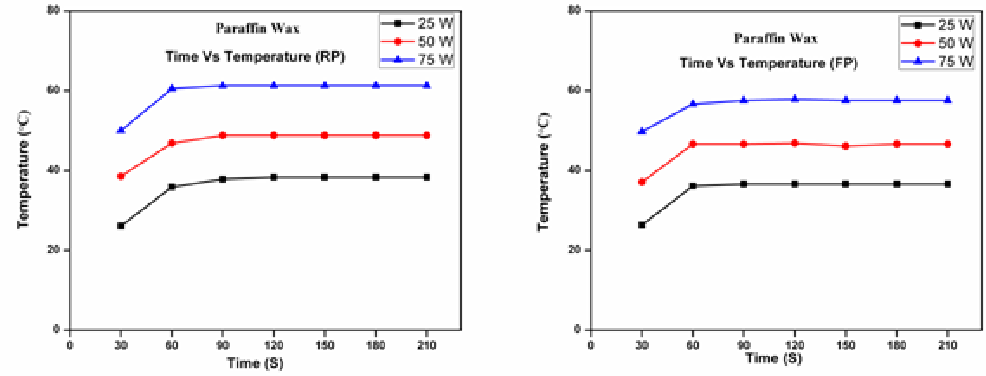

Figure 5(b). Graph of time Vs heater temperature for paraffin wax at different power inputs of 25 W, 50 W and 75 W and at full pressure (FP) and reduced pressure (RP)

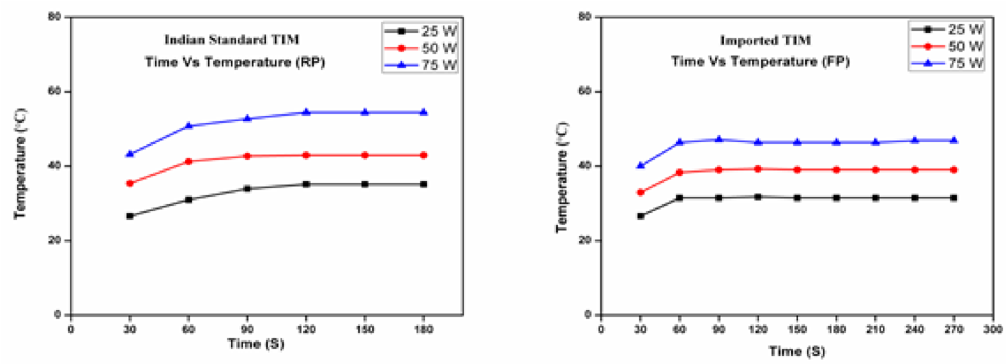

Figure 5(c). Graph of time Vs heater temperature for a Indian Standard TIM material at different power inputs of 25 W, 50 W and 75 W and at full pressure (FP) and reduced pressure (RP)

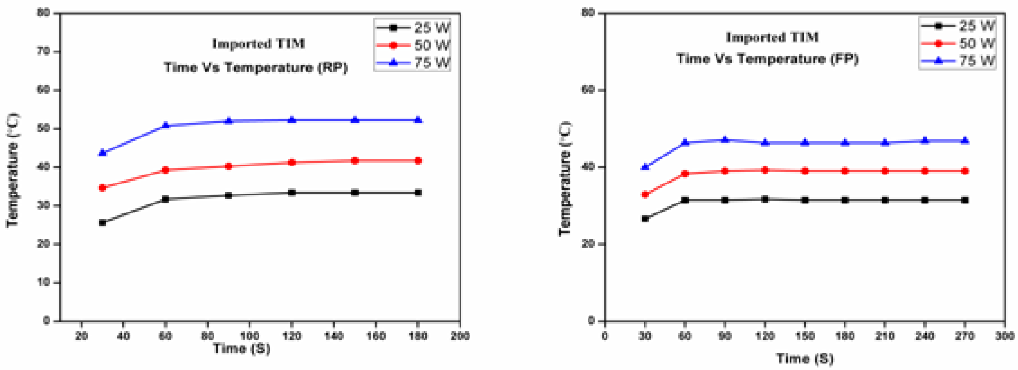

Figure 5(d). Graph of time Vs heater temperature for imported TIM material at different power inputs of 25 W, 50 W and 75 W and at full pressure (FP) and reduced pressure (RP)

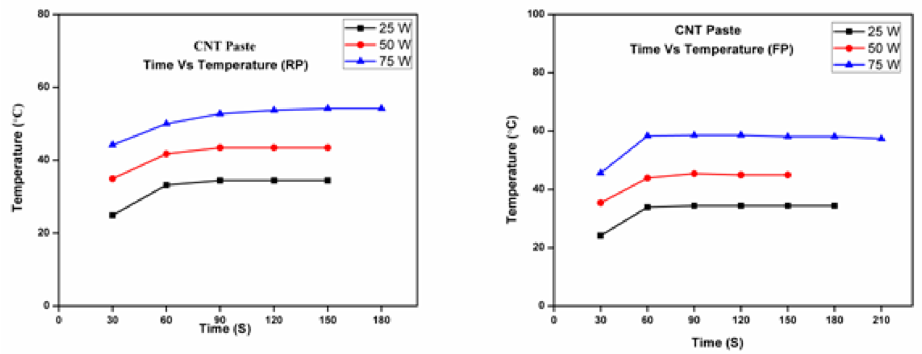

Figure 5(e). Graph of time Vs heater temperature for at different power inputs of 25 W, 50 W and 75 W and at full pressure (FP) and reduced pressure (RP)

The reason for low ($R_{th,\ eff}$) at full pressure can be attributed to decrement in bond line thickness and better contact between TIM and aluminum sink which helps in good dissipation of heat.

3.2 Effective thermal resistance of nanoparticle based TIM

Effective thermal resistance for different weight percents of Cu nanoparticle mixed in paraffin wax and (0%, 10%, 20%, and 30%) was determined at the power inputs of 25 W, 50 W and 75 W using the experimental set up given above. Experiments were performed at full pressure and reduced pressure.

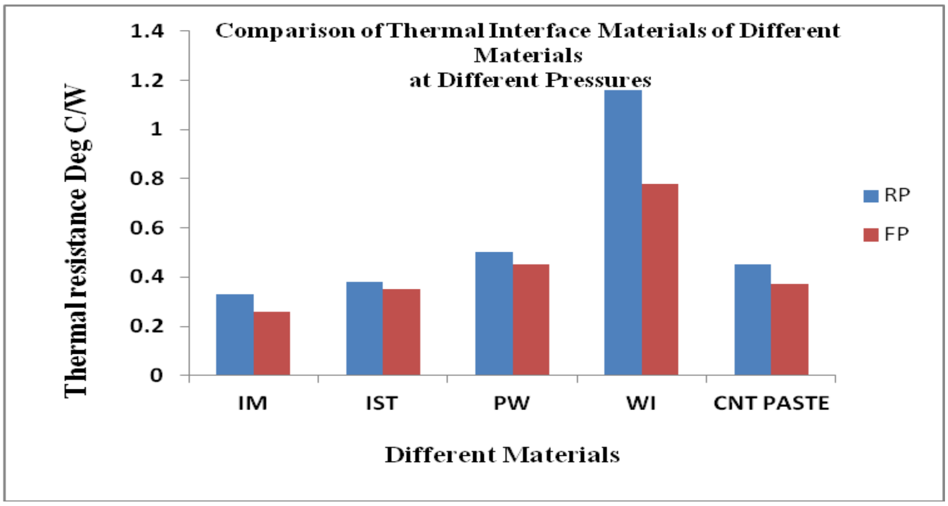

Figure 5(f). Effective thermal resistance of different materials compared at different pressures. (FP-Full pressure, RP-Reduced pressure)

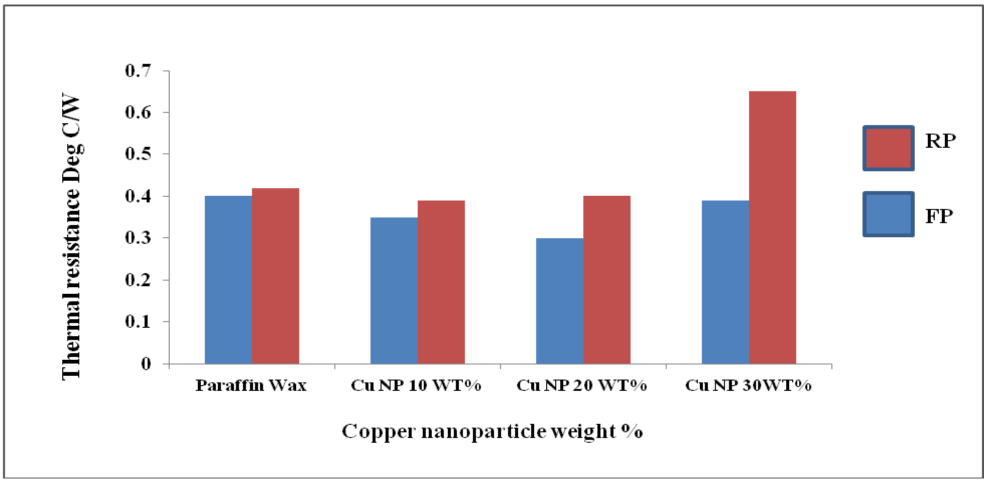

Figure 6 (a). Effective thermal resistance of Cu nanoparticles (0%, 10%, 20% and 30%) mixed in paraffin wax at different pressures. (FP-Full pressure, RP-Reduced pressure).

From Fig. 6 (a) it is observed that addition of Cu nanoparticle to the paraffin wax decreases the effective thermal resistance. Increment of copper nanoparticle weight percent decreases effective thermal resistance but at critical weight percent only low values are observed. At 10 wt% decrement in thermal contact resistance is observed, the added nanoparticle helps in better heat conduction owing to its higher surface to volume ratio. The same trend is observed for 20 wt% and further dipping in ($R_{th,\ eff}$) is observed. Again enhanced results are observed at full pressure. As the weight percent of nanoparticle is increased further, reversed effect is observed i.e. ($R_{th,\ eff}$) increases multifold. Agglomeration of nanoparticle might have occurred in the base fluid over time hindering heat absorbance and dissipation. Another significant observation is made that at 30 wt% and reduced pressure drastic increment in ($R_{th,\ eff}$) occurs. These results strongly imply the important role of bondline thickness in performance of TIM.

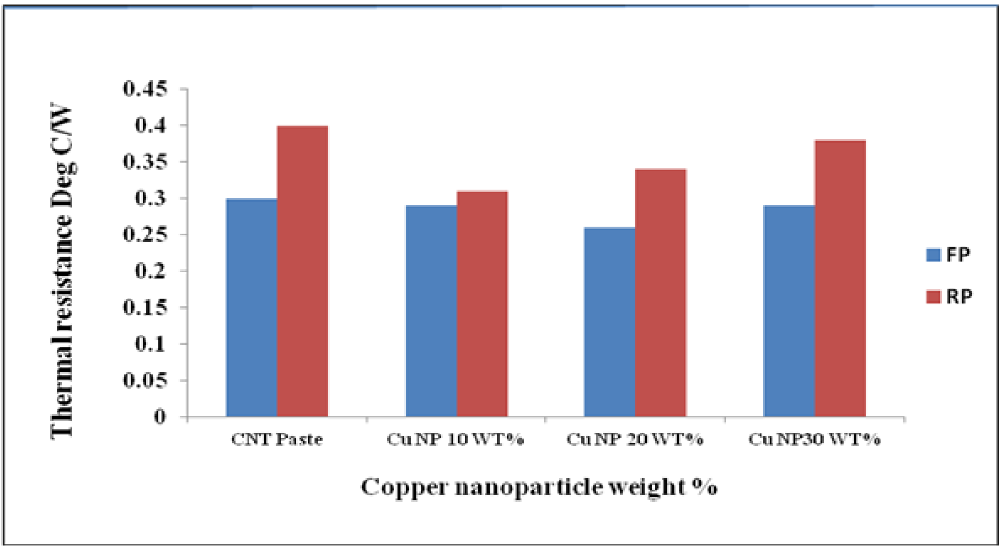

Figure 6 (b). Effective thermal resistance of Cu nanoparticles (0%, 10%, 20 % and 30 %) mixed in CNT paste at different pressures. (FP-Full pressure, RP-Reduced pressure).

Fig.6 (b) represents the ($R_{th, eff}$) data for Cu nanoparticle and CNT paste based TIM. Nonetheless, from Fig. 5(f) it is observed that ($R_{th, eff}$) for CNT paste is less compared to paraffin wax. Studies were carried out to observe the effect of addition of copper nanoparticle as well. From the graph it is clearly observed that addition of cu nanoparticle at all weight percents significantly reduces ($R_{th, eff}$) compared CNT paste alone. Both copper and CNT are very good conductors of heat. The nanoscale of both the particles certainly influences heat conduction. Again, critical weight percent of nanoparticle marks its importance on ($R_{th, eff}$) as lowest values are observed at 20 wt% only.

IV. CONCLUSION

This work reports comparative study of effective thermal resistance ($R_{th, eff}$) measured for various thermal interface materials prepared as thermal paste using tricosane paraffin wax and CNT paste as base fluids and copper nanoparticles as filler particles at different weight percents. Indigenously fabricated test rig using aluminum sink and copper heater was used to carry out heat sink experiments. Among the base fluids nano silver paste had the lowest value of ($R_{th, eff}$) owing to the presence of silver nanoparticles and hence excellent thermal conductive properties. Addition of copper nanoparticles in both base fluids significantly improved the dissipation of heat and hence lower values of ($R_{th, eff}$) were observed for Cu nanoparticle based TIM. Another noteworthy observation was made regarding the experiments carried out at full pressure and reduced pressure, that ($R_{th, eff}$) drastically lessens for all samples at full pressure which truly fortifies the importance of bondline thickness which decreases at full pressure. At 20 wt % of copper nanoparticles only superlative performance of prepared thermal paste were observed paving the way for importance of certain critical weight percent of filler particles to give enhanced dispelling of heat to the ambience. From the above data it can be inferred that that copper nanoparticle mixed in CNT paste at a critical weight percent of 20 wt% gives the lowest reading of resistance 0.27 ºC/W. Further studies are to be carried out to find thermal conductivity of the prepared thermal paste to reinstate the results.

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