Heat Transfer Enhancement of a Thermal Interface Material for Heat Sink Applications Using Carbon Nanotubes

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Abstract. A functional material of carbon nanotubes composite is investigated to be utilised as a thermal interface material in the low voltage power supply electronics as part of the upgrade of the ATLAS detector at CERN. These electronics, located inside the detector, produce heat by Joule heating and it is important to dissipate the generated heat in order to maintain the continuous full operation of the detector. The thermal interface material is a composite in a paste form, based on carbon nanotubes and Silicone heat transfer compound. The goal behind the implementation of the carbon nanotubes in the thermal interface material was to increase the thermal transfer from the electronics to the heat sink by the intermediary of the aluminium oxide (Al_2O_3) posts. The temperature of the thermal posts was read by means of an automated test stand built in house and controlled with a LabVIEW interface. The composite of carbon nanotubes and silicone compound were prepared by simple process in order to achieve a homogeneous mixture. Also, the study included the investigation of the effect of the carbon nanotubes in the nano-composite from which it is found that the optimum heat transfer is reported for a thermal interface material of 1% of carbon nanotubes.

1. Introduction

As part of the phase-II upgrade of the ATLAS detector at CERN, a new Low Voltage Power Supply (LVPS) brick is being manufactured at the University of Witwatersrand (figure 1) [1–3]. The LVPS brick is a six squared layer board with a dimension of 80.26 mm^2, and comprises electronic components such as transformers, transistors, and inductors. In these electronics, the flowing electrical current coupled with the resistance cause the generation of heat. Hence, the main electronic components are bonded to cylindrical ceramic posts (Al_2O_3), by means of a thermal compound, in order to sink the heat. The important role of the LVPS is the generation of the power (voltage and current) to the Tile Calorimeter (TileCal is a apart of ATLAS) distributed front-end electronics [4]. The accelerator is designed to host the electronics inside the particle detector [2,3] and therefore, the electronics operate in extreme conditions; exposure to radiation, direct current magnetic field, limitation of the space, and with a cooling system based on water [4]. Hence, for a proper functioning of the detector, it is mandatory to protect the electronics operating under a such condition from damage, overheating, and to expand their life-span.

The most practical way to solve the issue of overheating within the electronic devices is to employ thermal conductors used in thermal applications such as thermo-electric devices [5] and functional materials [6]. In order to dissipate the heat, as it is the case with the LVPS brick, it is required to use a functional Thermal Interface Materials (TIMs).

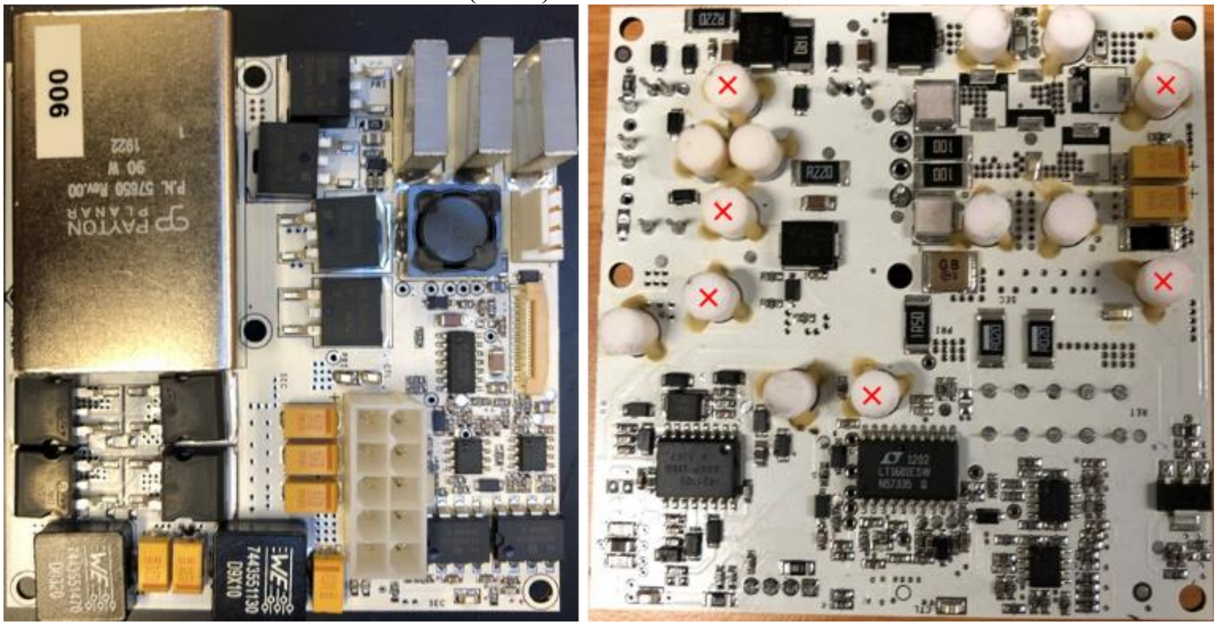

Figure 1. The LVPS brick manufactured at Wits. The marks (x) locate the cylindrical Al_2O_3 posts that conduct the generated heat to the sink. A thermal compound is applied between the interfaces of the electronics and the posts to maintain a good thermal conduction.

TIMs are materials with high thermal conductivity placed between a heat source and a heat sink to dissipate the heat effectively, increase the contact area and reduce the air gaps [7]. The conventional and commercial TIMs are made of polymer-based material (silicone) impregnated with highly thermally conductive particles, mainly alumina, zinc oxide, graphite, silver. As far as the technological development is concerned, the heat transmission offered by the commercial TIMs is still considered to be inefficient for many contemporary applications either in micro or nano-electronics [8,9].

In this proceedings, we report on the enhancement of the heat transfer of a commercial TIM by incorporating Carbon Nanotubes (CNTs) impregnation. The implementation of CNTs in heat sink applications are motivated by their good thermal conductivity of 4840-5300 $W.m^{-1}.K^{-1}$ [6,9] and also by their mechanical properties needed since the TIMs have to be molded between two interfaces and under high pressure. In this study, we use an experimental setup that simulates the operating of the LVPS brick in order to improve the heat transfer. A simple process to prepare the TIMs was developed and the effect of the amount of CNTs on the heat transfer was investigated as well.

2. Experimental methods

The investigated TIMs in this study is a composite of CNTs and a thermal epoxy. The CNTs were synthesized by chemical vapour deposition in the department of chemistry, University of Witwatersrand. For more details in regard to the synthesis method, one can refer to [10,11]. The commercially purchased thermal epoxy (Unick Chemical Corp.) is a silicone based compound in which zinc oxide particles were diffused.

The preparation of the TIM based on CNTs follows a precisely developed protocol (figure 2), which is considered simple in comparison to methods reported in the literature [12–16]. First, the conglomerated CNTs in a powder form were dispersed in acetone by sonication at room temperature for 30 minutes, then, the thermal epoxy was added. The solution comprised CNTs, epoxy and acetone and was sonicated for a second time for a duration of not less than 60 minutes at 55°C. At a such temperature, the diffusion of the CNTs in the epoxy can be facilitated together with the evaporation of the acetone in order to fabricate the TIM in a required paste (greasy) form. Also in order to investigate the effect of the

CNTs on the heat transfer improvement, the amount of CNTs was varied in a range between 0 to 10 % of CNTs within the TIMs.

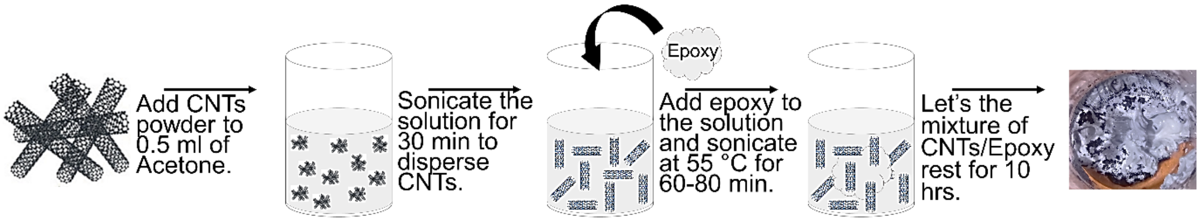

Figure 2. The different steps for the preparation of TIM based on CNTs. The picture shows the TIM of CNTs ready for use. The black spots are non-dispersed CNTs that were hanging on the acetone surface before evaporation.

In order to test the improvement of heat transfer, an experimental setup that simulates the functioning of the LVPS brick was designed, as shown in figure 3. The setup is composed of resistors for heat generation and an aluminum plate as heat sink. The conduction of the heat from the resistors to the heat sink was maintained by means of ceramic posts (Al_2O_3), as in the LVPS brick. The temperature was measured using of thermocouples connected to the posts throughout the experiment and recorded by a Data Acquisition system which is controlled by LabVIEW software.

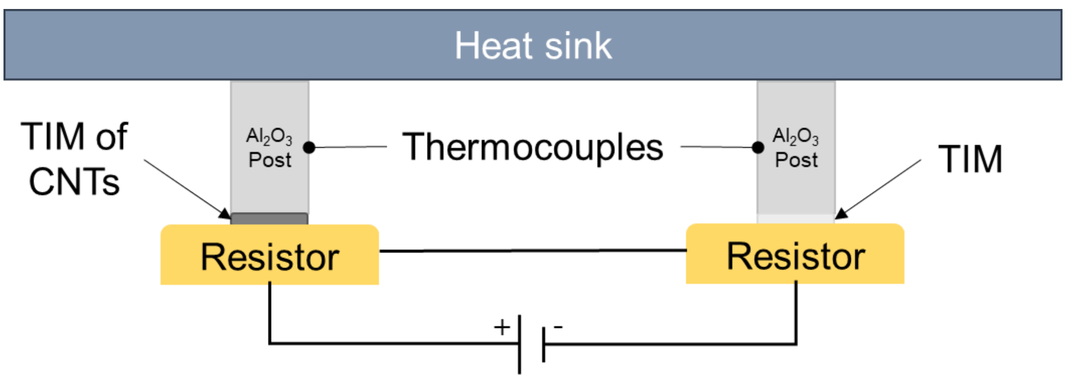

Figure 3. The experimental setup in use to mimic the LVPS bricks to test the TIMs. It consists of two identical resistors, aluminum plate, Al_2O_3 posts, thermocouples, and power supplies. In order to compare the heat transfer, the TIM of CNTs was applied on one post and the commercial TIM non-containing CNTs on the second post. The temperatures were recorded continuously with a data acquisition system for more than 8 hours.

3. Results and discussion

The recorded temperatures of the posts are presented in figure 4. The plots show the progress of temperatures in the posts for a duration of over 8 hours using TIMs with composition of 0 (without CNTs), 0.5, 1, 5, and 10 % of CNTs.

In figure 4, all the curves have similar trend and are characterised by a temperature rise during the first hours, after which a visible plateau is reached. In fact, the steady behaviour of the temperature was preserved over the 24 hours of measurements, as reported in figure 5 (graph on the left).

In addition, the plots show a temperature gap between the two posts (between the orange and blue lines). It is shown clearly that the temperatures of the posts with TIMs containing CNTs are lower by comparison to temperatures of posts with TIMs only (0% of CNTs), except for the TIM with 10% of CNTs. These results are highly reproducible and consistent as confirmed by a large number of measurements. Moreover, this temperature gradient, noted T_{diff}, varied as a function of the amount of CNTs incorporated in the TIM, as summarized in the right graph of figure 5.

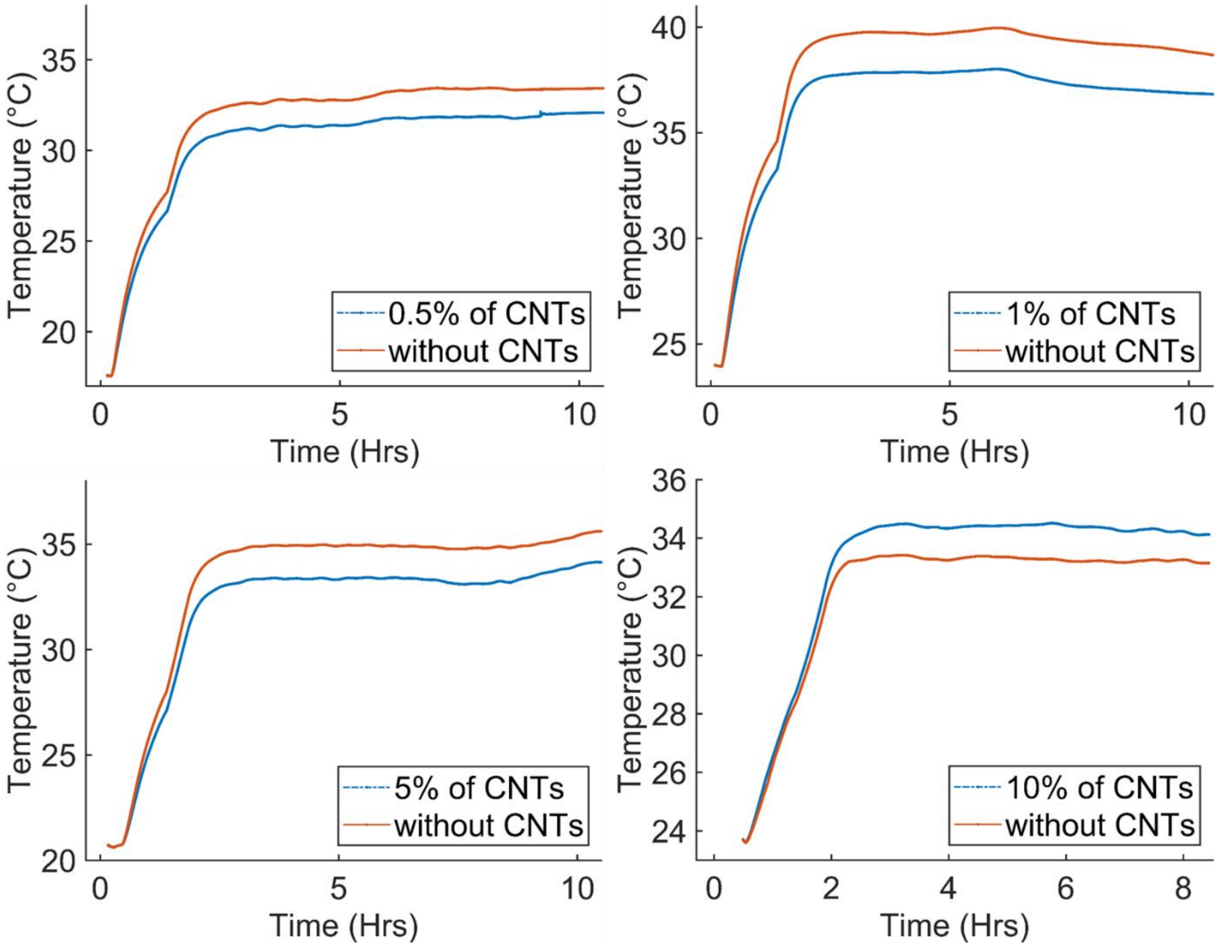

Figure 4. The measured temperatures of the two posts by the use of the setup described in figure 3. The plots show the dependence of the temperature gradient to the amount of CNTs in the TIMs. The gradient temperature is observed to be positive except for TIM with 10 % of CNTs.

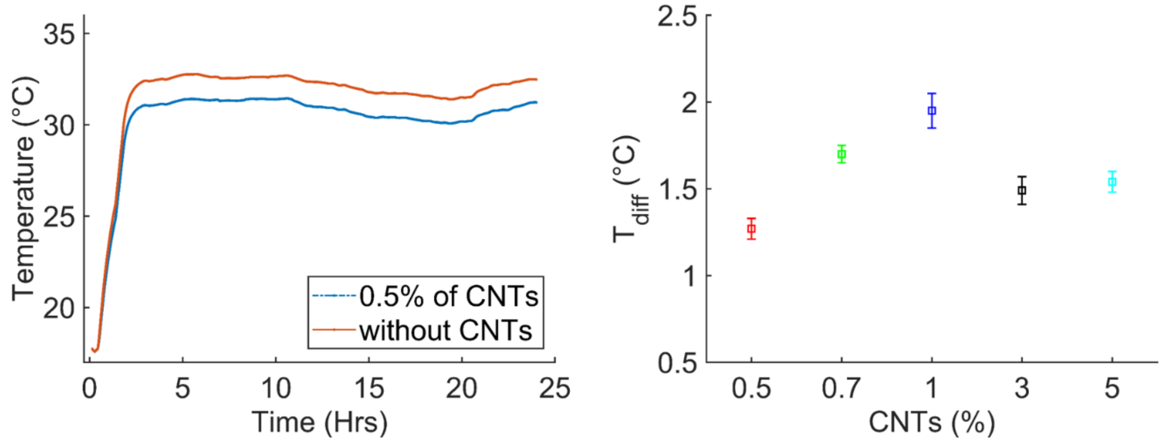

Figure 5. The measured temperatures for over 24 hours for TIM with (0.5%) and without CNTs (left). The plot shows the steady temperature gradient over the flat part of the curve. On the right, the temperature gradients T_{diff} ($T_{diff} = T_{without\ CNTs} - T_{CNTs}$) for different TIMs. The calculated T_{diff} is the average along the plateau of the curve.

From the results reported above, the heat transfer is found to improve substantially by incorporating CNTs in the thermal compound. This claim is supported by the proportionality between the heat transfer (Q) and the temperature difference ΔT ($\Delta T = T_{in} - T_{out}$) over the posts. Thus, by comparing the temperatures of the posts, noted as T_{out}, one can deduce whether an improvement of the heat transfer takes place. The amount of offered heat to the post corresponding to temperatures T_{in} was equal at the interfaces (resistors and applied voltage were identical while running the experiment), which means a lower temperature T_{out} implies a higher heat transfer Q.

Based on figure 4, the integration of CNTs in the thermal epoxy to a certain amount (<5%) showed an increase in the heat transfer from the heat source to the heat sink. The increase reached a maximum with the use of TIMs with 1% of CNTs (figure 5). The improvement of the heat transfer can be due to a homogenous dispersion of the CNTs within the TIMs, as well as to the coupling between the CNTs and thermal epoxy which results in the enhancement of the thermal conductivity of the prepared TIMs. Also, it was observed that by the use of a large amount of CNTs, it became difficult to mix and disperse the carbon nanomaterials in the epoxy homogeneously, and the outcome was mostly a TIM in a solid state. The fabricated TIM with 10% of CNTs was a clear example of the late observation which explains the deterioration of the heat transfer.

4. Conclusions

In this work, the enhancement of the thermal properties of a commercial compound by CNTs impregnation was presented. The preparation of the TIM with CNTs followed a simple process based on sonication. The results showed the improvement of the heat transfer due the application of TIMs containing CNTs at the interface of the posts. Also, the achieved experiments revealed the increase of the heat transfer in function of the amount of CNTs injected and the reproducibility of the results. In addition, it was deduced that the optimum heat transfer was observed for TIMs with 1% of CNTs. Moreover, the fabricated TIM offers a potential use in applications to protect expensive components from overheating such as micro and nano-electronics. The use of the fabricated TIM in the LVPS brick will increase the transfer of the heat to the sink and protect the electronics from overheating and damage, which will maintain the detector in a constant full operation. In a future work, different types of carbon nanomaterials will be investigated, as well the increase of their homogeneous dispersion in the epoxy.

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