Improvement of Heat Sink Performance by Using Graphene Nanosheets Coated by Chemical Spray Method

A. A. Jaafar¹, S. A. W. Al-abassi²*, H. A. Alhattab², M. A. Albaghdad², A. A. Mosa², H. K. Al-Musawi², L. M. Abo Gneem²

¹Department of Computer Technical Engineering, College of Technical Engineering, The Islamic University, Najaf, Iraq
²Electronic and Communications Engineering, Department, University of Kufa, Najaf, Iraq

salam.waheed@uokufa.edu.iq

Abstract. Graphene nanosheets were fabricated on a metal (Al) substrate by using a chemical spray method. Annealing process has been applied to reducing the concentration of carbon and to increase the sheet hardness. Surface morphology measured by metallurgical microscope Device Corporation, X 1600. Thermal camera was used to measure the performance of coated heat sink. The temperature was measured from the two sides, one from heat sink side, and the other one is from power transistor side. The results showed that the temperature of the transistor was decreased by about 4.3 °C in the case of heat sink coating with 80 µm layer thickness while decreased by 6.9 °C in the case of the heat sink coating with 120 µm layer thickness.

1. Introduction
The rapid development within the field of semiconductor devices have resulted in a very vital increase in number of integrated chips per space units with needing to devices with very high-speed response, and the inception of imbedded systems, all that causing an increasing in generation of heat flux at chip level [1, 2].

For reaching this purpose many ideas have been proposed such as utilizing of micro heat sink [3-5], or coating of heat sink by high conductivity materials [6].

Some studies have been proposed multi approach to address significantly enhance the heat dissipation potential of conventional aluminium (Al) heat sinks by mechanically coated graphene nanosheets [7]. The study had significant enhancement of metal heat dissipation from mechanically exfoliated graphene nanosheets through thermal radiation effect. It is found that with the increase in coating coverage from 0 to 100%, the steady- state temperature is decreased by 7°C at a heat flux of 1.8 Wcm-1[8].

Thermally conductive graphene nanosheets (GNs) adorned with Cu nanoparticles or Nano clusters are manufactured through an efficient microwave-assisted (MA) by thermal reduction. As a result, this study proves that the robust designing of Cu/GN heterogeneous film offers an integrated skeleton for thermal diffusivity, benefiting practical applications such as Si-based integrated chip. In addition, where explored the possibility of integrating 1D CNT and 2D graphene into a 3D covalently bonded structure, i.e. a graphene-CNT hybrid material for thermal management application. It is found graphene-CNT hybrid material might be suitable to be used as both TIMs and heat spreader
simultaneously. The graphene-CNT hybrid material was later investigated morphologically and thermally to observe its heat dissipation capability [9].

In this study, the heat transport of heat sink was improved by coating heat sink with graphene nanosheets fabricated by mechanical method. It is expected that the graphene nanosheets will improve the performance of heat sink because of high thermal conductivity of graphene.

2. Materials and Methods

2.1. Manufacturing of homogeneous mixture of ethanol and graphene

50 ml of ethanol (C2H6O) with density of 0.7893 g/cm3 [10], 0.5% natural graphene powders with density of 2.267 g/cm3 [11], to decide the percentage of graphene in solution the following equation (equation 1) has been used [12].

\[
W_g = \frac{W_{\text{ethanol}} \times \rho_{\text{graphene}} \times \text{rate}}{\rho_{\text{ethanol}} (1-\text{rate})}
\]  

Where:

- \( W_g \) = weight of the graphene
- \( W_{\text{ethanol}} \) = amount of ethanol
- \( \rho_{\text{ethanol}} \) = density of ethanol
- \( \rho_{\text{graphene}} \) = density of graphene
- Rate = amount of graphene to the amount of ethanol = 0.05

Amount of 60 µg of graphene was used and measured by a high sensitivity balance. Graphene and ethanol were mixed by using hotplate and stirrer for 20 minutes. For more homogeneity of solution, the mixture was putted in Ultrasonic mixer for 20 minutes with power-on time of 2S and power-off time of 2S. Obtained solution shown in figure 1 and can be used for chemical spray process.

![Figure 1. Prepare Liquid of graphene.](image)

2.2. Coating system

Before coating process heat sink was cleaned by MTI ultrasonic cleaner device for 20 minutes.

Coating system is shown in figure 2 is a full auto controlled system designed by our lab to have a precious controlling in spray time and the distance between substrate and nozzle, additionally the substrate temperature also controlled by a heater. These features give to fabricated graphene nanosheets a homogenous appearance as shown in figure 3. Fabrication of nanosheets was under substrate temperature of 200 °C. Put the amount of solution prepared in the spray machine and coating the samples with a various spraying time to get a various thickness. Sample (a) was spired for 20 times each one for 2 second and between one and another 2 second, while sample (b) spired for 30 times...
each one for 2 second and between one and another 2 second. After this process, the samples were annealed under 120°C. Thickness was measured by use optical thin film measurement device, Lambda scientific Pty ltd. (LIMF-10). Surface morphology measured by metallurgical microscope Device Corporation, X 1600.

2.3. Testing of samples
To test the heat sinks that were fabricated power transistor type LM 7805 has been used. Three power transistors with three heat sinks were connected to electrical circuit. at same time the power switched on. Thermal camera FLIR ONE where used to measure the temperature before and after power on. One of these circuits use a heat sink that is not coating while the other circuits, one of them use heat sink coating thickness 80µm and the other use heat sink coating thickness 120µm. the measurement of heat sinks temperature was after applying a 2.6 watt for each circuit after 10 minutes, thermal camera was installed in front of it and take a picture to transistors from both sides.

Temperature of room was measured before measurement process which was 28°C.

3. Results and Discussion
Figure 4 shows the surface morphology of fabricated samples which indicating a rough surface in sample (a) and (b). This figure showing an island shape graphene surface due to substrate heating and
annealing process which was make a main role to reducing of concentration of Carbone atoms on surface and shaped a graphene island [13].

Figure 5 shows the thermal camera picture for both samples and uncoated sample too. The temperature of the coated part, which may be almost double compared to the uncoated sample.

The temperature of the transistor connected with uncoated heat sink equal 94.3°C, while the transistor connected with heat sink coated thickness 80 µm (sample (a)) have been kept at a temperature equal 90°C, and the other transistor, which is connected with heat sink coated thickness 120 µm (sample(b)) have temperature equal 87.4°C.

From the results, the improvement in heat sinks that were coated by Graphene, occurred due to two reasons, first one is the roughness and surface morphology, which was increased causing increasing in surface area which came from island shape make the surface area larger than uncoated heat sink [14].

The second reason of this the improvement is due to a high conductivity of graphene [15]. Generally, the thermal energy is dissipated through convection and radiation, as shown in the equations below (Rea and West 1976) [16].

\[
Q_{\text{convection}} = h \times A \times (T - T_{\text{room}}) \quad (2)
\]

\[
Q_{\text{rad}} = \epsilon \times \delta \times A \times (T^4 - T_{\text{room}}^4) \quad (3)
\]

\[\text{h} = \text{the Planck's constant (6.62607004 \times 10^{-34} \text{ m}^2 \text{kg/s})}\]
\[ \delta = \text{Stefan–Boltzmann constant} \ (5.67 \times 10^{-8} \ \text{W m}^{-2} \ \text{K}^{-4}). \ \in \text{the emissivity of bare and coated samples.} \]

\[ A = \text{the surface area. T represents the steady-state temperature of bare and coated samples.} \]

\[ \text{Troom = signifies the ambient temperature.} \]

The obtained results shown that the temperature of the transistor decreased by about 4.3 °C degrees in the case of heat sink coating with 80µm layer thickness, while decreased by about 6.9 °C in the case of heat sink coating with 120µm layer thickness.

4. Conclusions
In this study, improved system to heat transport enchantment of power transistor using coating of graphene nanosheets by using a chemical spray method. This work abled to fabricate graphene nanosheets by chemical spray method on a metal substrate (AL). The improvement in coated samples came from increasing of surface area which was a result of island shape of coated graphene nanosheets, beside the high conductivity of graphene. Low cost and simple method showed a significant improvement in performance of heat sink.

References
[1] Murshed S S, De Castro C N 2017 A critical review of traditional and emerging techniques and fluids for electronics cooling Renew. Sustain. Energy Rev. 78 821-33.
[2] Ramalingam V, Anandan S S 2008 Thermal management of electronics: A review of literature Thermal Sci. 12(2) 5-26.
[3] Naqiuddin N H, Saw L H, Yew M C, Yusof F, Poon H M, Cai Z, San Thiam H 2018 Numerical investigation for optimizing segmented micro-channel heat sink by Taguchi-Grey Method Appl. Energy 222 437-50.
[4] Hadad Y, Ramakrishnan B, Pejman R, Rangarajan S, Chiarot P R, Pattamatta A, Sammakia B 2019 Three-objective shape optimization and parametric study of a micro-channel heat sink with discrete non-uniform heat flux boundary conditions Appl. Therm. Eng. 150 720-37.
[5] Alhattab H A, Albaghdadi M A, Hashim R S, Ali A H 2016 Design of micro heat sink for power transistor by using CFD Al-Sadeq International Conference on Multidisciplinary in IT and Communication Science and Applications (AIC-MITCSA) 1-5 IEEE.
[6] Bistritzer R, MacDonald A H 2009 Electronic cooling in graphene Phys. Rev. Lett. 102(20) 206410.
[7] Hu J, Xu J, Zhu C, Li Q, Ullah Z, Liu F, Li W, Guo Y, Zhao X, Liu L 2017 Significant enhancement of metal heat dissipation from mechanically exfoliated graphene nanosheets through thermal radiation effect AIP Adv. 7(5) 055315.
[8] Hsieh C T, Chen Y F, Lee C E, Chiang Y M, Hsieh K Y, Wu H S 2017 Heat transport enhancement of heat sinks using Cu-coated graphene composites Mater. Chem. Phys. 197 105-12.
[9] Yan Z, Liu G, Khan J M, Balandin A A 2012 Graphene quilts for thermal management of high-power GaN transistors Nat. Commu. 3 827.
[10] Goldemberg J 2007 Ethanol for a sustainable energy future Sci. 315(5813) 808-10.
[11] Geim A K 2009 Graphene: status and prospects Sci. 324(5934) 1530-4.
[12] Dhiaa A H 2016 Investigation of thermal transport properties enhancement of nanoparticles suspensions in the application of nanofluids Ph.D. thesis, University of Baghdad.
[13] McCarty K F, Feibelman P J, Loginova E, Bartelt N C 2009 Kinetics and thermodynamics of carbon segregation and graphene growth on Ru (0 0 0 1) Carbon 47(7) 1806-13.
[14] Khan W A, Culham J R, Yovanovich M M 2006 The role of fin geometry in heat sink performance J. Electr. Packag. 128(4) 324-30.
[15] Aliofkhazraei M (Ed) 2013 Advances in Graphene Science BoD–Books on Demand.
[16] Rea S, West S 1976 Thermal radiation from finned heat sinks IEEE Transactions on Parts, Hybrids, and Packaging 12(2) 115-7.