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Thermal Analysis of laminated (Copper – Graphite) as Heat Spreader Material

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Abstract: - Copper-Graphite laminate material design has been analysed, and this proposed composite has the ability to enhance heat dispersing more efficiently compared to the traditional high thermal conductivity with weight associated copper and high thermal resistance graphite. A finite element analysis (FEA) is carried out using the material (Cu – Gr) properties to investigate this proof. The design, thermal properties (temperature, total thermal resistance) are compared with existing and proven mathematical model. The dimensionless expression is used to compute the maximum spreading thermal resistance, surface temperature and this is compared with thermally simulated temperature and the total resistance of the spreader material. The performance is tested using length (l), width (w), thickness (t) and the total thermal resistance (R) (Dimensions for material). The results for the thermal conductance of (Cu-Gr) obtained is 2.5 x 105W/ (m^2K) with negligible error percentage to predict the 2-D design as a suitable heat spreading material.

Keywords:- *Heat Spreader, Thermal Resistance, Laminate, composite, Finite Element Analysis, dimensionless.*

I. INTRODUCTION

Heat spreader is an effective solution for dealing with heat sources with a high heat – flux density (high heat flow per unit area) and where the secondary heat exchanger in itself is not an effective method of dispersing heat due to space limitations, energy use, cost etc. As a result, thermal management of electronic gadgets has become an important issue in circuit reliabilities and performance. The International Technology Roadmap for semiconductors (ITRS) announced the high performance processor to have maximum power of 365W in 2006 and predicted to be 512W by 2011 while the junction temperature to decrease from 100^0C, to 90^0C by 2011 [1]. [2] indicated that the heat flux dissipation will go up to 150W/cm^2 and may be 1kW/cm^2 in a few years, which emphasizes the need for material design with high heat flux to spread the heat.

Heat spreader enables the heat flow from the source to extended surfaces. There are numerous studies on extended surfaces, but very few detailed publications on how to select the best material for heat spreader optimization [3].

The use of extended surface is also limited by the total surface area that is available in a given package.

The effective heat transfer coefficient, defined by HTC based on cross sectional area of the heat spreader to incorporate the total convective heat transfer is proportional to the available heat transfer surface area. However, the geometry of the typical electronic enclosure has a very limited volume for extended surfaces.

The rate of heat flow through a solid conducting material depends on the factors of temperature difference, time, thermal conductivity, specific heat and densities of the conducting materials. The spreading resistance depends on the thermal conductivity of the spreader material and the thermal resistance depends on the spreading surface environment (air, forced convention air or liquid etc.)[4].

Graphite/Copper is a unique composite in several ways. Copper exhibits the highest thermal conductivity of any metal and as a result, it reduces the spreading resistance, but has a high density and a high coefficient of thermal expansion (CTE). By combining copper with graphite, the density and the longitudinal expansion are significantly reduced while the thermal conductivity remains quite high.

Copper-graphite composites therefore combine the positive characteristics of their components i.e. high thermal and electrical conductivity from the copper and low CTE and higher thermal resistance from graphite

[5]. This unique combination of features has made, Gr/Cu a leading candidate material for high heat transfer applications in which low weight is a design consideration. These applications include heat spreader for aircraft/spacecraft, vehicles etc. The use of natural graphite material as a heat spreader was examined in CFD models by Tzeng et al [6]. In a simplified model, Tzeng showed that an anisotropic heat spreader, with properties similar to those of natural graphite, could lower the maximum temperature of a localized heat source.

(Gr-Cu) composite might seem ideal for many applications, but drawbacks do exist. Graphite surface is not easily wetted by copper. Non-uniform fiber distribution has also been identified as another problem that might affect the properties and performance [7].

A numerical study was conducted [8] in 2002, to estimate simultaneously the heat flux generated by friction, the thermal contact conductance and the intrinsic heat partition coefficient for the problem of two sliding contact materials. In order to define the appropriate conditions for accurate estimation of the thermal parameters, a sensitivity analysis was also performed.

II. MODEL

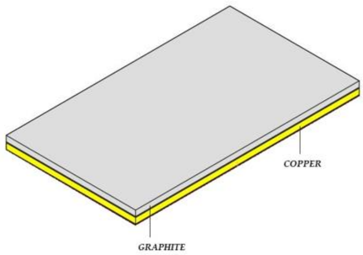


Figure 1: Cu-Gr material in contact

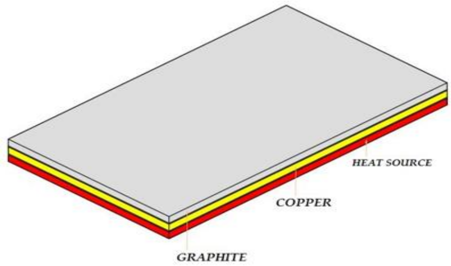


Figure 2: Cu-Gr material in contact with heat source

In this model, (Fig 1& 2) a two-dimensional (Cu – Gr) material in contact is proposed for steady-state. The thermal resistance, heat flux have been thoroughly investigated using Finite Element Analysis (FEA) in ANSYS software.

The aim of this study is to analyze thermal properties of Copper/Graphite as a material for heat spreader. Besides, the study describes the parameters of modeling upon which the spreading resistance is dependent and how the dimensionless parameters (non-dimensional length and non- dimensional thickness), are related to each other and what the dependence of the spreading resistance on these parameters are.

However, for the case of thermal management, finding the dimensions of heat spreader has been rarely addressed. [9, 10] discussed the approach in their analysis. They revealed that the dimension can be found by minimizing the total resistance offered to the heat spreader material when heat flows from the source to the convective medium. The heat spreader is designed on the basis of two specifications; convective resistance and the spreader dimensions. There exists also a dimensionless thickness of the heat spreader, where the total resistance is found to be minimum (Feng & Xu) [9, 10] for a given cross section.

Some analytical and numerical solutions have been performed for symmetric and non-symmetric planer geometric subjected to uniform heat flux based on a semi-infinite body model [11 - 13]. Kennedy [14] developed a series solution for a special case where the bottom of the spreader material is assumed to be at a constant temperature, and this solution has been widely used in the packaging industry for over thirty-five years. Lee et al. [15, 16] setup extensional model to Kennedy's isothermal solution, which was based on non-isothermal with more boundary conditions to improve the solution accuracy.

Selection of material parameters for designing a high heat flux, heat spreader: the parameters include the convective heat transfer coefficient *h* and thermal conductivity of the material (Cu-Gr) *k*.

High conductivity composites based on copper and graphite have good potential for use as heat spreaders.

In this work, the following tasks are proposed:

- To provide guidelines for the FEA material (Cu-Gr) design of heat spreaders for heat spreading;
- To find out the effects of the thermal conductivity of the combined material and the dimensions of the performance of a heat spreader material;
- To investigate the threshold performance limit of the heat spreader material in terms of thickness (*t*), width (*w*), length (*l*).
- To evaluate the performance as a spreader material based on various compositions (pure copper, Graphite, combination (Cu-Gr).Using thermal resistance *R* and thermal conductance as variables.

IIa. Material Properties used for the Model

Input properties of Copper and Graphite materials used for the thermal analysis in FEA have been tabulated (Table 1).

Table1: Input properties of Cu and Gr

Properties	Unit	Cu	Gr
Density	kg / m^3	8933	2210
Thermal Conductivity	W / mk^{-1}	398 Isotropic	1390, 4.090 anisotropic
Specific Heat capacity	J/Kg/K	383	992

Temperature–dependent thermal properties (thermal conductive constant k and specific heat Capacity (C) and physical (density ρ) make thermal analysis non-linear since these factors depend on the temperature. Thermal properties at high temperature are quite difficult to obtain, only few data available in the literature [17].

IIb. ANSYS Modelling (FEA) Steps

Finite element Analysis (FEA) software ANSYS is capable of simulating problems in a wide range of engineering disciplines. The analysis with ANSYS addresses several different thermal problems, for instance: Heat transfer-steady state or transient conduction, convection and radiation. Phase Change: Melting and freezing. Thermo-mechanical Analysis: Thermal analysis results are employed to compute displacement, stress, and strain field due to differential thermal expansion and electro-magnetism. The following steps were followed:

i. **Modelling**: Includes the system geometrical definition and material property selection. In this step, 2-Dimensional was used for the Model to represent the problem.
ii. **Meshing**: This step involved discretizing the model according to a predefined geometry element. The discretization applied was based on: Number of cells along the length, L and number of cells along the breadth, B
iii. **Solution**: In this step, the boundary conditions are applied and loads to the system and solves the problem.
iv. **Post Processing**: This involves plotting the nodal temperature solutions which are unknown.

The finite element analysis was carried out using ANSYS 12.0 software. There are two options which can be used. Ansys Parametric Design Language (APDL) and Graphical User Interface (GUI). In this study, APDL mode was used since flexibility and greater ease of modification is provided [18 - 20].

III. PROBLEM

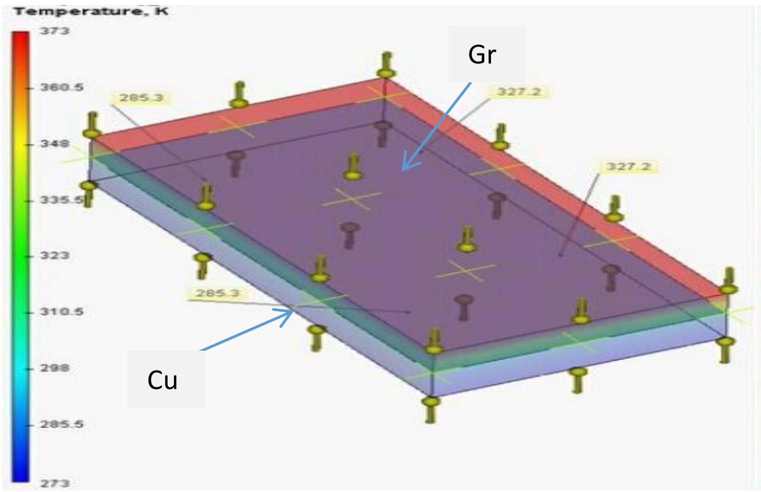


Fig 3: FEA Analysis obtained with temperature distribution with a source heat of 400K

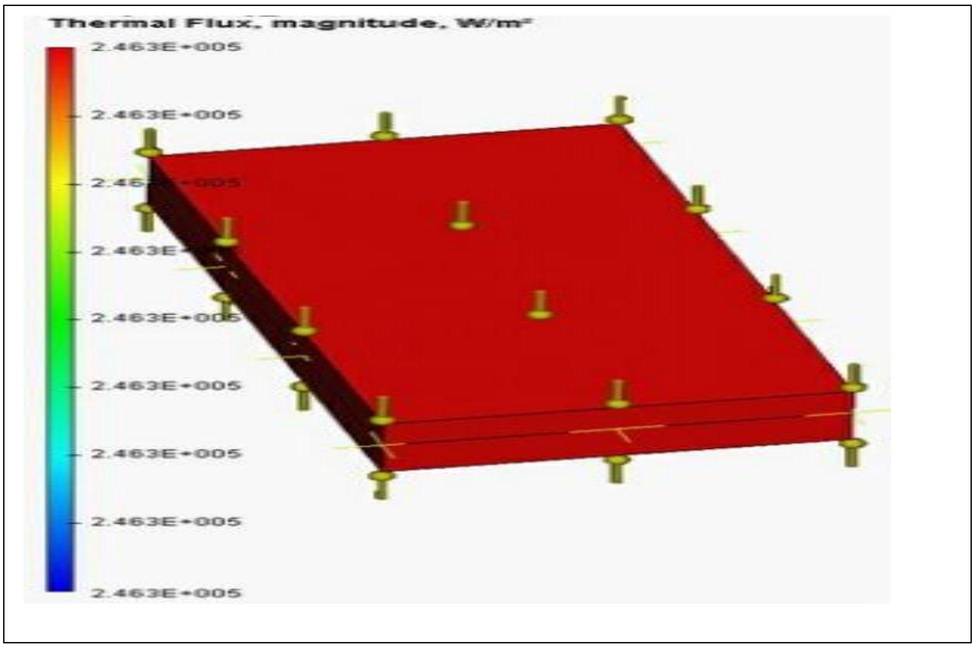
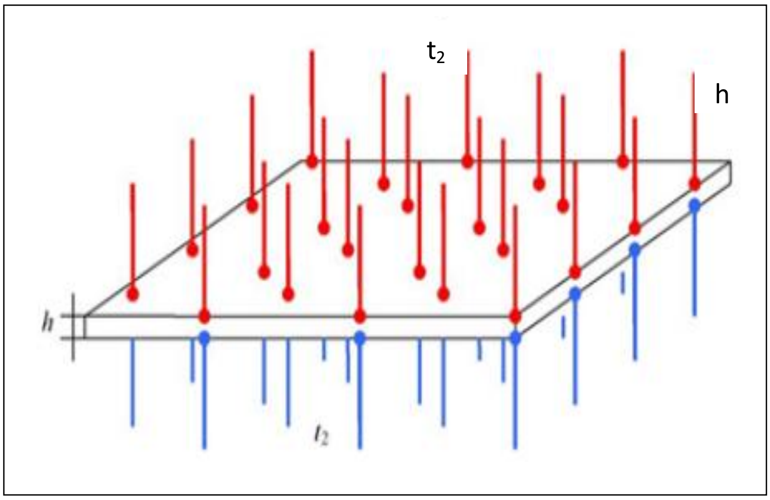


Fig 4: FEA Analysis obtained for thermal flux with a source heat of 400K

Fig.3&4, Copper–Graphite composite material. These materials have rectangular surfaces.
The (Cu-Gr) composite material is assumed to be in good contact with the source heat of the same dimension (Fig 2). The materials are assumed to be insulated thermally on the top and sides. For the transient, two-dimensional heat conduction is modeled for the composite material.
The temperature gradient and heat flux are reported. The contours of temperature, a plot of temperature distributions is also captured as shown in the (Fig. 3 & 4).

IVA. Mathematical Modeling
a) Steady –state temperature for the composite material layer
In this mathematical model, elemental extract was used.



t_1

Fig5: Elemental composite material with heat flow in the plate of thickness *h* and surfaces held at temperatures t_1 and t_2

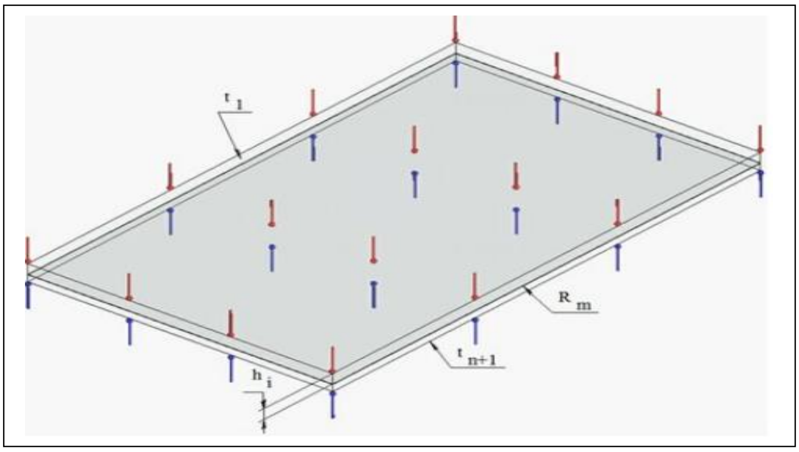


Fig. 6: Composite material (Cu-Gr), with theoretical initial basis.

Defining the change in temperature along the thickness of the plate h;

$$\frac{\partial T}{\partial Z}=\frac{t_1-t_2}{h}, t_1>t_2 \qquad (1)$$

The heat flux at any point in the material can therefore be evaluated using eq.(1);

$$q=-k\frac{\partial T}{\partial Z}=k\frac{t_2-t_1}{h}=\frac{t_2-t_1}{R}, R=\frac{h}{k}, \qquad t_1>t_2 \qquad (2)$$

Where R_{max} is the maximum thermal spreading resistance, q the heat flux.
If we consider again the plate composite, consisting of n layers with thicknesses, $h_1, h_2, \dots \dots h_n$ *and thermal conductivity* $k_1, k_2 \dots \dots k_n$ respectively. Then the heat flux for each layer $q_1, q_2 \dots \dots q_n$ can be formulated as

$$q=k_1\frac{(t_{1+i}-t_1)}{h}=\frac{(t_{1+i}-t_1)}{R_i}, R_i=\frac{h_i}{k_i} \qquad (3)$$

Where $t_{1+i} > t_i,\ i=1,2 \dots\dots n$ (this study n is limited to two layers)
If we consider the material layers to have ideal thermal contact (Assumption in the FEA) across the interfaces, then the flux is continuous from one layer to another. The temperature composite profile therefore will be the sum of the temperature changes in each single element;

$$(t_1-t_2)+(t_2-t_3)+\cdots+(t_1-t_{1+i})+\cdots\dots\dots(t_n-t_{n+1})=t_1-t_{n+1} \qquad (4)$$

Then

$$t_1-t_{n+1}=q_1R_1+q_2R_2+\cdots.+q_nR_n=q(R_1+R_2+\cdots R_n) \qquad (5)$$

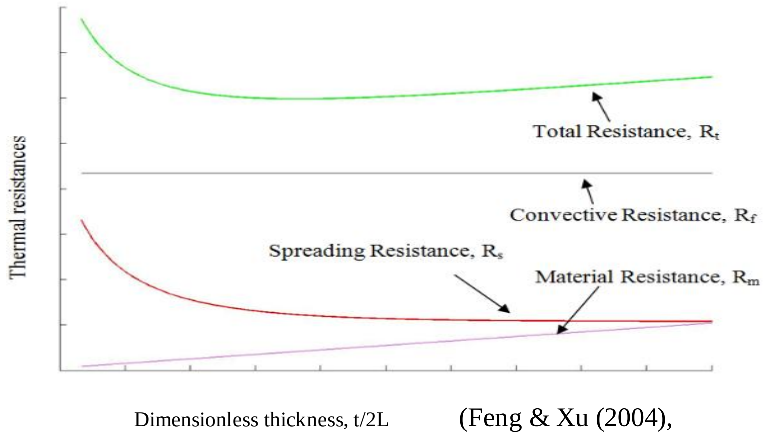
From equation (5) we can deduce that;

$$q=\frac{(t_1-t_{n+1})}{(R_1+R_2+\cdots R_n)} \qquad (6)$$

Equation (6) is similar to Feng and Xu [9, 10] proposed equation (7)
[9.10], deduced on the basis of geometric modeling, to have the best heat spreader the total thermal resistance R should be minimized. The total thermal resistance given the sum of the three resistances,

$$R_t=\frac{T_{max}}{Q}=R_m+R_f+R_s \qquad (7)$$

Where T_{max} the maximum temperature at the heat source, and Q is the total heat transferred through the material (Cu-Gr). $R_m, R_f,$ *and* R_s are the conductive, convective and spreading resistances respectively.



(Feng & Xu (2004),

Fig. 7 Contribution of different resistances, when heat flow from source to environment through a material

IVB. Another mathematical approach for evaluating the thermal resistance of the material used in this study:
A rectangular heat source of dimensions *u* and *w* in close contact with the material (Cu – Gr) spreader; if the length of the spreader is considered *l*. The total depth of the heat penetrating along the thickness of the spreader is *t*. Numerically, if *t* is considered as an average over the length of the heat spreader then the thickness is *t/2.* Since the thermal path involves a change in direction from the through-thickness of the spreader to the in-plane direction of the material spreader.
Therefore the average distance heat that will penetrate the heat spreader is considered to be *t/2*. If the thermal conductivities of the materials are denoted for K_1 and K_2 (through-thickness and longitudinal direction) the total resistance heat conduction path and thickness direction:

$$R_1 = \frac{t}{2(K_1 wu)} \qquad (8)$$

The thermal resistance of the heat conduction path in the longitudinal direction is given by;

$$R_2 = \left(\frac{l}{K_2 ut}\right) \qquad (9)$$

Total thermal resistance is given by; $R_T = R_1 + R_2$
From both equations (8), (9) *R* depend on *t* (Material thickness).
This implies that *t* at which *R* is minimum can be called critical/threshold thickness *(t_c)* of the heat spreader material.
It also means that if the thickness is below t_c the spreader is below the maximum capacity of the material. Thus, t_c can be therefore considered the optional thickness for maximizing the heat spreading while minimizing the thickness *t.*
Differentiating *R* with respect to *t* and setting the result to zero (0). Hence,

$$t_c = \sqrt{\frac{2wl}{K_2/K_1}} = \sqrt{\frac{2wl}{\alpha}} \qquad (10) \qquad \text{Where } \alpha = \frac{K_2}{K_1}$$

From ANSYS, FEA did not consider the thermal resistance associated with the interface between the heat source and (Cu-Gr) heat spreader. Therefore, interface resistance is neglected in this model design.
Lasance [21] carried out a comparative analysis of five approaches for calculating the total thermal resistance and thickness for square heat spreader, which is very close to this work
[9, 10] and Maranzana et al. [22] developed the mathematical model for rectangular heat spreader. [21], showed that the results for the square geometry matched quite well by using an equivalent circular cross section, and this is expected to be true for many different cross sections. Therefore the material combination is analyzed using rectangular geometry in this study (Fig. 3&4).
[9, 10] developed a three-dimensional analytical solution to determine spreading thermal resistance.
The assumption made was that the heat spreader will be receiving a uniform heat flux and this is transferred through the environment. The mathematical model developed is shown:

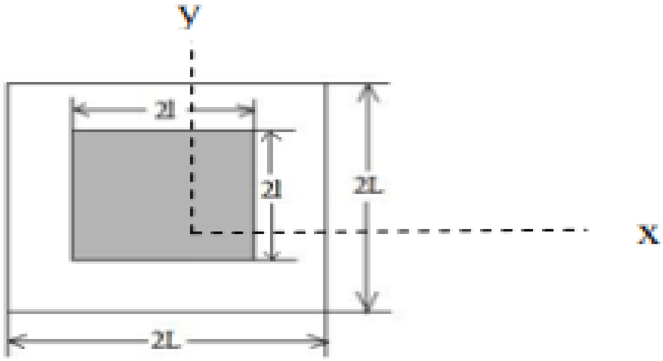


Fig 8.: Schematic diagram of thermal system having square heat source of length 2, square heat spreader of length 2L, thickness t, and a heat flux q applied at the bottom of heat spreaders.

In terms of a non-dimensional variable T*, the three-dimensional conduction equation for steady state heat transfer, assuming the constant thermal conductivity of the material (Condition for simulations in ANSYS) can be written for heat spreader as:

$$\frac{\partial^2 T^*}{\partial x^2} + \frac{1\partial^2 T^*}{\beta^2 \partial Y^2} + \frac{1\partial^2 T^*}{\tau^2 \partial Z^2} = 0 \qquad (11)$$

With boundary conditions as: $\frac{\partial T^*}{\partial x} \downarrow_{X=0} = \frac{\partial T^*}{\partial x} \downarrow_{X=1} = \frac{\partial T^*}{\partial Y} \downarrow_{Y=0} = \frac{\partial T^*}{\partial Y} \downarrow_{Y=1} = 0\,;$

$$\frac{\partial T^*}{\partial Z} \downarrow_{Z=0} = BiT^* \qquad (12)$$

$$\frac{\partial T^*}{\partial Z} \downarrow_{Z=1} = \begin{Bmatrix} 1 \ldots (0 < X \le \varepsilon, & 0 \le Y \le \gamma) \\ 0 \ldots (\varepsilon < X \le 1, & \gamma \le Y \le 1) \end{Bmatrix}$$

Where, $T^* = \frac{hT}{Biq}$ (13)

The results were in series solutions, therefore the closed form equations can be obtained for non-dimensional spreading resistance which is defined as:

$$\Psi_s = k\sqrt{A_s}R_s \qquad (14)$$

Feng & Xu (2004) expressed the dimensionless spreading resistance to be

$$\Psi_{s,Feng} = \sqrt{\frac{\varepsilon\gamma}{\beta}}\left[\sum_{m=1}^{\infty} c_{m0} + \sum_{m=1}^{\infty} c_{0n} + \sum_{m=1}^{\infty}\sum_{n=1}^{\infty} c_{mn}\right] \qquad (15)$$

The deduction made in the present study, the corrected form for the dimensions, spreading resistance was found to be:

$$\Psi_s = \sqrt{\frac{1}{\varepsilon\gamma\beta}}\left[\sum_{m=1}^{\infty} c_{m0} + \sum_{m=1}^{\infty} c_{0n} + \sum_{m=1}^{\infty}\sum_{n=1}^{\infty} c_{mn}\right] \qquad (16)$$

Where

c_{m0}, c_{0n} and c_{mn} are functions of $\varepsilon, \gamma, \beta, Bi, \tau$ in the solution [9, 10] and is expressed as:

$$c_{m0} = \frac{\gamma[(\tau m\pi + Bi)\exp(\tau m\pi) + (\tau m\pi - Bi)\exp(-\tau m\pi)]\sin(\tau m\pi)}{(m\pi)^2[(\tau m\pi + Bi)\exp(\tau m\pi) - (\tau m\pi - Bi)\exp(-\tau m\pi)]} \qquad (17)$$

$$c_{0n} = \frac{\beta\varepsilon\left|(\tau m\pi + \beta Bi)\exp\left(\frac{\tau m\pi}{\beta}\right) + (\tau m\pi - \beta Bi)\exp\left(-\frac{\tau m\pi}{\beta}\right)\right|\sin(\gamma n\pi)}{(n\pi)^2\left[(\tau n\pi + \beta Bi)\exp(\tau n\pi) - (\tau n\pi - Bi)\exp\left(-\frac{\tau n\pi}{\beta}\right)\right]} \qquad (18)$$

$$c_{mn} = \frac{2[(\tau\omega\pi + Bi)\exp(\tau\omega\pi) + (\tau\omega\pi - Bi)\exp(-\tau\omega\pi)]\sin(\varepsilon m\pi)\sin(\gamma n\pi)}{mn\omega\pi^2[(\tau\omega\pi + Bi)\exp(\tau\omega\pi) - (\tau\omega\pi - Bi)\exp(-\tau\omega\pi)]} \qquad (19)$$

$$\omega = \sqrt{m^2 + \left(\frac{n}{\beta}\right)^2} \qquad (20)$$

Using the equations (14) (15), (16), (17), (18), (19) and (20) and plotted, the following were the conclusions made [9, 10]:

i) The graph shows that the heat spreading is a localized phenomenon near the heat source and therefore not affected by changes due to Bi.

ii) If the dimensionless thickness increases beyond 0.7, deduced by [15, 16] and [9, 10] the spreading resistance are no longer dependent on Biot number.
iii) From fig. 9, it is observed that the spreading resistance is higher at lower thickness and lower Bi because heat has to spread over a larger area.

The plot using the geometric parameters (constant) $\beta = 0.25, \varepsilon = 0.25, and\ \gamma = 0.75$

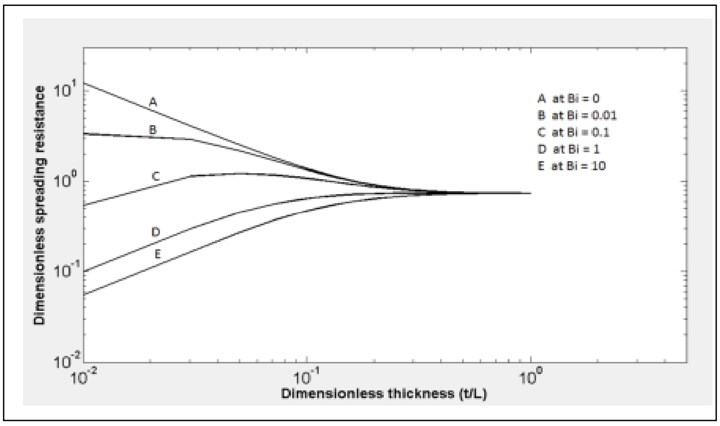


Fig. 9: Spreading resistance as a function of Bi and τ, while other geometric parameters are constant as $\beta = 1$, $(square\ heat\ spreader), \varepsilon = \gamma = 0.167$

IV. RESULTS AND ANALYSIS

The maximum temperature is expected to occur at the projected source (heating area) or on the base of the material spreader (Cu-Gr) as shown in (Fig. 2&3).
Therefore the maximum temperature occurs at x = y = 0 and z = t with, $\varepsilon = \gamma = \frac{t}{L}$ $and\ \beta = \frac{w}{L} = 1\ where$
$X = \frac{x}{L}, Y = \frac{y}{L}, Z = \frac{z}{t}$ Which implies that,

$$R_t = \frac{T^*{}_{X=0,Y=0,Z=1^*} t}{kA_s} \qquad (21)$$

Where $T^*{}_{X=0,Y=0,Z=1^*}$ is the dimensionless maximum temperature at the top heat spreader material.

V. RESULTS

FEA Contour Plots from the spreader Materials design

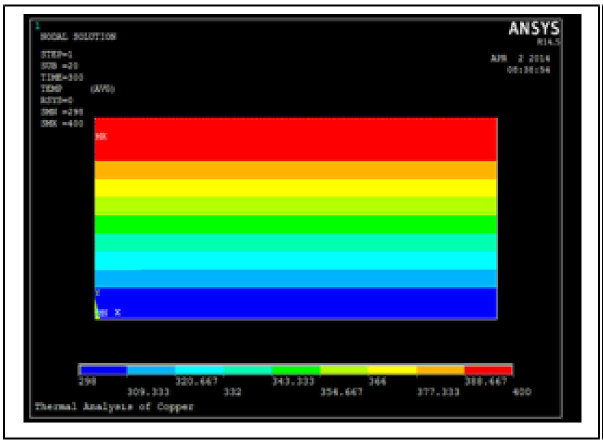


Fig. 9a: Contour plot of Copper (ANSYS)

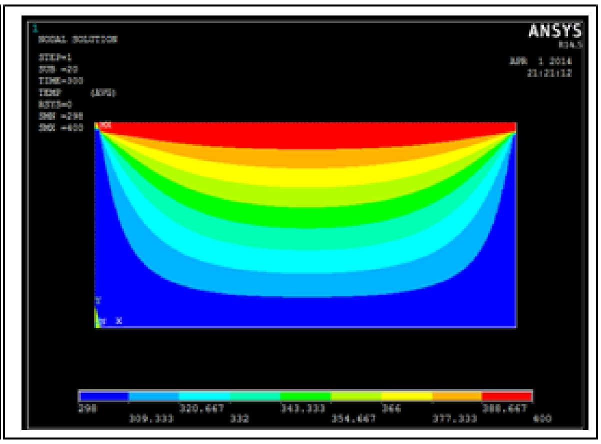


Fig. 9b: Contour plot of graphite (ANSYS)

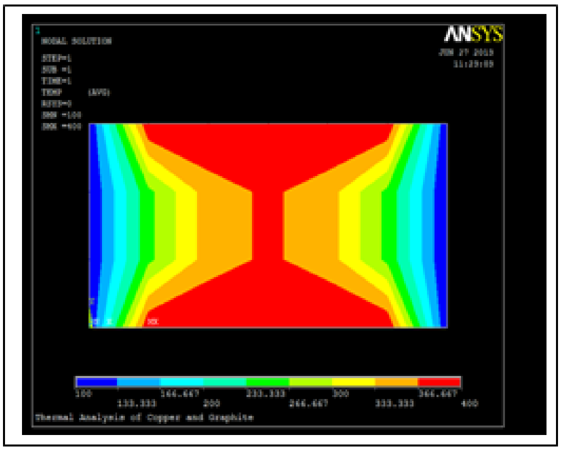


Fig. 10a: Contour plot of Cu – Gr (ANSYS

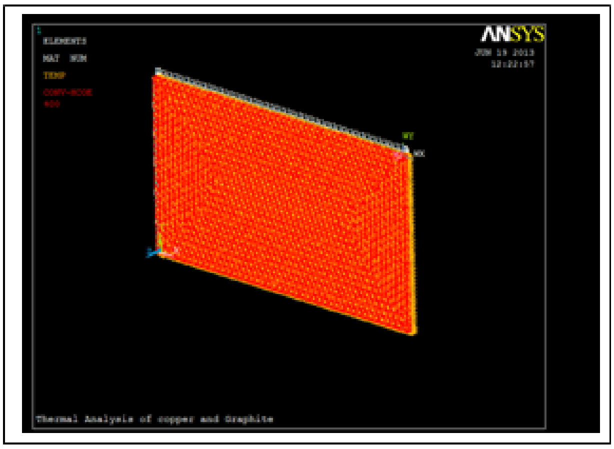


Fig. 10b: FEA map Meshing of Cu – Gr (ANSYS)

The temperature profile differences as a result of elemental thickness can be seen in the area very closed to the heat source. Evaluating these (Figures 9a, 9b, 10a, 10b) it can be concluded that moving a point away from the heat source decreases the temperatures as expected.

Temperature:

Table 2: Profile Temperature from FEA and Calculated Compared

FEA mesh Parameters: **Type of finite element: Linear Tetrahedron (4 – nodes);** **Number of corner nodes: 2786;** **Number of arguments: 2787;** **Number of finite elements: 11511**			$Error\% = \left\lvert \frac{T_{FEA} - T_{Cal}}{T_{FEA}} \right\rvert x100$
Thermal Flux W/m^2 x 10^{+005}	Analytical T_{FEA}/K	Numerical $T_{calculated}$/K	δ/%
2.46	299.00	298.01	0.33
2.46	310.50	305.30	1.68
2.46	323.00	331.00	2.48
2.46	335.50	342.05	2.09
2.46	360.50	358.02	0.69
2.46	383.00	380.50	0.65
2.46	400.00	398.50	0.38

The results of the numerical test depend on the finite element mesh used in the simulations.
The analytical temperatures obtained from the model design is compared with numerical calculations from the equations (7), (11), (12) and (13) and error percentage calculated. Comparing the solution proposed by Feng & Xu using the model calculations, the proposed analytical solutions are closer to the temperature profiles provided by the FEA model (Table 2) with negligible error percentages. This may have happened as a result of the use of non-uniform meshes in the FEA model during the material (Cu-Gr) design.

Performance of various heat spreader materials considering length *l*, width w and thickness *t*:

Table 3: FEA modelling of (Cu-Gr) composite spreader, compared to Cu, Gr, material spreaders (t_c= critical thickness, (*w, u*) =width, *l* = length).* equation (8, 9, & 10).

Thermal conductivity w/(mK)			K_2/K_1	Length	$w = u = 2$mm		$w = u = 1$mm	
Material	K_1	K_2	α	l/mm	t_c/mm	R(K/W)	t_c/mm	R(K/W)
Cu	398	398	1.00	10.00	6.32	4.03	6.32	8.15
Gr	1390	4090	2.94	10.00	6.35	7.12	10.00	6.20
Cu-Gr	398	1390	3.49	10.00	2.45	8.76	1.73	9.73
Cu-Gr	398	4090	10.27	10.00	1.76	34.5	1.43	48.8
(Cu-Gr) FEA	ANSYS Model			10.00	3.00	4.01	2.74	7.63

The through the thickness thermal conductivity of the composite is taken as 0.73W/(mK), which is the measured value for crossply [23]. Hence the thermal conductivity for the composite (α = 10.27) greater than any of them from the (Table 3).

For the same dimensions (Table 3), the total thermal resistance is lower for graphite than the composites (Cu – Gr) calculated and (Cu-Gr) from the model. For all the materials, irrespective of whether is anisotropic or isotropic, the composite and for the same source dimensions, both the thermal resistances and the critical thickness increase. This result means that the more the heat source the more there is a spreading demand, but the thickness of the material can be smaller. For all the materials, for the same heat source area (*w* x *u*), the thermal resistance increase correspondingly with the critical thickness and the dimensional ratio (*w*/*u*).

Dependence of the performance on the heat spreader material, heat spreader thickness and the heat source area.

Table 4: Dependence of performance on the heat spreader material (Cu, Gr, Cu-Gr), heat spreader thickness and heat source area.

		Thermal resistance R (K/W)	
Material	Thickness (mm)	u= w =2mm	u = w = 3mm
Cu	1.00	64.8	43.1
	2.00	32.9	21.8
	3.00	22.4	14.8
Gr	1.00	49.5	27.0
	2.00	49.5	27.0
	3.00	49.5	27.0
Cu-Gr	1.00	169	92.0
	2.00	169	92.0
	3.00	169	92.0
Cu-Gr	1.00	21.5	37.8
FEA	2.00	25.7	41.6
	3.00	32.0	47.6

The performance of the material as shown (table 4) decreases in the order
i) Cu, $(Cu – Gr)_{FEA}$, Gr, and $(Cu\text{-}Gr)_{calculated}$ when the thickness is 3mm.
ii) $(Cu – Gr)_{FEA}$, Cu, Gr, and $(Cu\text{-}Gr)_{calculated}$ when the thickness is 2mm.
iii) $(Cu – Gr)_{FEA}$, Gr, Cu and $(Cu – Gr)_{calculated}$ when the thickness is 1mm.
With the above ranking, for the same heat spreader thickness and heat source area of 2mm x 2mm and 1mm x 1mm $(Cu – Gr)_{FEA}$ is superior than Copper, Graphite and the calculated combination, $(Cu – Gr)_{Calculated}$.
For thickness of 2mm, Cu is more effective than all the other materials with heat source area of 3mm x 3mm.
The thermal conductance related to removal of heat (heat dissipation) is given as 1/AR, where A is the heat source area and R is the total thermal resistance. The lowest value of R for each source area is given by $(Cu\text{-}Gr)_{FEA}$ as the heat spreader material shown in (Table 3) for the case when the l = 10mm and heat spreader area is 2mm x 2mm the thermal conductance according to the relation;

$$\frac{1}{\rho} = \frac{l}{RA} = \textit{thermal conductance} \qquad (22)$$

is 2.5 x 10^5 W/(m^{2}K) and when the source area is 1mm x 1mm the total conductance is 1.3 x 10^5 W/(m^{2}K). It follows that, the conductance increases with decreasing heat source area and conductance decreases with increase in the length of the spreader material *l*.

VI. DISCUSSION

The tables 2, 3, 4 shows the thermal profile temperature compared with calculated temperature and the resulting thermal contact per unit area obtained from FEA simulations and thermal contact with material thickness, length *l* & width *w, u* variations. The contact resistance per unit area for the (Cu-Gr) material case was the lowest of the three materials. There was no experimental values from this work to use to verify the model profile temperature, thermal resistance results. Meanwhile, the following are discussed to improve future FEA designs for this material model:

i. The Finite Element Analysis (FEA) model presented in this paper has a number of assumptions and limitations of the method, which may be addressed in future work. The Material laminate is assumed to be (Cu-Gr) with material properties used for modelling (Table 1). The material assumed an initial temperature of 100K for the simulations.

ii. The modelled materials in the FEA are assumed to demonstrate linear elastic behavior and assumed to have no temperature dependence. Thermal expansion was not permitted and no thermal expansion coefficient was defined in the ANSYS software.
iii. In this study of the material spreader, the temperatures used to design the model are reasonably low (100K – 400K) so the assumptions used are reasonably valid. This may not as a matter of fact be the case for many other systems that could be modelled.
Future analysis could incorporate material non-linearities, thermal expansion and temperature dependent material properties if desire for better modelling.
iv. Some finite element methods programs, like ABAQUS, support gap dependent thermal conduction, FEA in ANSYS does not at this time. However, ANSYS support convectional across the gap. In this model, each contact element, a convection coefficient was defined equal to the thermal conductivity of the material in air.
v. The study model was solved as a steady-state model. In future, this model could be modified to include time dependence and this may be necessary if the thermal expansion considerations are to be included.
In concluding the discussions, the challenges which are associated with predicting the thermal contact resistance, total surface area and temperatures require significant vector operations in APDL. Micro command files were written to calculate these values to facilitate this work to assess (Cu – Gr) as a spreader material using FEA model design.

VII. CONCLUSION

This study analyses the thermal design of laminate copper – graphite as a heat spreader material using finite element method (FEA/FEM) in ANSYS. The contour plots of the copper, graphite and the copper-graphite (combination) with initial temperature of 100K is studied. A source of heat conducted in a rectangular model material (Cu-Gr) in a two-dimensional co-ordinate system is designed using the copper and graphite material properties (Table 1). The total spreading thermal resistances, heat flux distribution, heat loss of the proposed spreader material is obtained (Tables 2, 3, 4). Non-dimensional mathematical model proposed by [15, 16] which gives numerical solution for optimum dimensions of heat spreader, using a wide range of heat transfer coefficients, thermal conductivity, thermal inductance, non-dimensional length scales and total thermal resistance was reviewed.

The highest conductance obtained in the material in this study is 2.5 x 10^5 W/(m^2K). This value of thermal conductance can be considered to be reasonably expected of interface between the heat source and the heat spreader material in this case is (Cu-Gr) laminate. Looking at the aforementioned results (Tables 1, 2, 3), the FEA method and the solutions obtained, have been proven to be quite accurate with minimal error percentage to predict the 2-D model (Cu-Gr) material suitable as a heat spreading material. Based on the author's investigation, it has been found out that the research on this aspects of composite laminate is relatively limited and may attract more interest in future if structural analysis with minimal assumptions are incorporated.

REFERENCES

[1] Guenin, B. M. (2006, August). Carbon Foams for thermal Management. Carbon, 41,1461 – 1466.
[2] Bar-Cohen, A., Wang, P., & Rahim, E. (2007). Thermal management of High Heat Flux Nanoelectronic Chips. Microgravity Science and Technology, Vol. XIX – 3/4, 48 – 52.
[3] G. Maranzana, I. Perry, D. Maillet, Quasi-analytical simulation of conduction heat transfer through a pyramidal multilayer multiblock by the quadrupole method, Numer Heat Transfer B 42 (2002) 499 – 521.
[4] J. Norley, The Development of a National Graphite Heat-Spreader, 17. IEEE SEMI-Therm Symposium, San Jose, CA, March 20 – 22, 2001.
[5] Rajkumar. K and S. Aravindan, COPPER-GRAPHITE COMPOSITES, International conference on Advanced Materials and Composites (ICAMC-2007), Oct 24-26, 2007.
[6] Tzeng, J, W,. G., Fedor, B. S., Krassowski. D. W., 2000, "Anisotropic Graphite Heat Spreader for Electronics.
[7] Thermal Management," Proceedings, International PCIM/Power Quality Conference, Nuremberg, Germany June 6, 2000.
[8] Bauzin J,. G,. Laraqi N,. 2004, Numerical Heat Transfer PART B 45(4) 313.
[9] Feng T. Q., & Xu, J.L. (2004). An analytical solution of thermal resistance of cubic heat spreaders for electronic cooling. Applied Thermal Engineering, 24(2 - 3), 323- 337.
[10] Feng T. Q., & Xu, J.L. (2004). An analytical solution of thermal resistance of cubic heat spreaders for electronic cooling. Applied Thermal Engineering, 24(2 - 3), 340- 367.
[11] M. M. Yovanovich, Thermal constriction resistance of contacts on a half-space: Integral formulation, in: AIAA Progress in Astronautics and Aeronautics, Radiative Transfer and Thermal Control, vol. 49, New York, 1976, pp. 397 – 418.

[12] M. M. Yovanovich, S. S. Burde, Centroidal and area average resistances of non-symmetric, singy connected contacts, AIAA Journal 15 (10) (1977) 1523 – 1525.
[13] M. M Yovanovich, S.S Burde, J. C. Thompson, Thermal constriction resistance of arbitrary planar contacts with contact flux, in AIAA Progress in Astronautics and Aeronautics. Thermophysics of Spacecraft and Outer Planet Entry Probes, vol. 56, New York, 1977, pp. 127 – 139.
[14] D. P. Kennedy, Spreading resistance in cylinder semiconductor devices, Journal of Applied Physics 31(1960) 1490 – 1497.
[15] S. Song, S. Lee, V. Au, Closed – form equation for thermal constriction/spreading resistances with variable resistance boundary condition, in: Proceeding of the 1994 International Electronics Packaging Conference, Atlanta, Georgia, 1994, pp. 111- 121.
[16] S. Lee, S. Song, V. Au, K. P. Moran, Constriction and spreading resistance model for electronics packaging, in: ASME/JSME Thermal Engineering Conference, vol. 4 Maui, Hawaii, 1995, pp. 199 – 206.
[17] Fukushima, High-thermal-conductivity graphite-particles-dispersion-composite and its production method, US Patent 20090035562].
[18] Ansys Contact Technology Guide Section 6.1, 6.1.1, 6.1.4.1.
[19] Ansys Contact Technology Guide Section 6.1.1.
[20] Ansys Contact Technology Guide Section 6.1.4.1
[21] C. Lasance, “How to estimate heat spreading effect in practice,” ASME Journal of Electronic Packaging, vol. 132, Sept. 2010.
[22] Marazana, G., Perry, I., Maillet, D., & Rael, S. (2004). Design optimization of spreader heat sink for power electronics, International Journal of Thermal Sciences, 43 (1) 21 – 29.
[23] C. Lin and D.D.L Chung, J. Electron. Mater. 37. 1698 – 1709(2008). And D. D. L. Chung, Carbon 50, 3342(2012).
[24] Seungjin. Han and D.D.L, Chung, Compos. Sci. Technol. 71, 1944m- 1952(2011).
[25] Fukushima, High-thermal-conductivity graphite-particles-dispersion-composite and its production method, US Patent 20090035562].
[26] Seungjin. Han and D.D.L, Chung, Compos. Sci. Technol. 71, 1944m- 1952 (2011).
[27] Ansys Contact Technology Guide Section 6.1, 6.1.1, 6.1.4.1.
[28] Ansys Contact Technology Guide Section 6.1.1.
[29] Ansys Contact Technology Guide Section 6.1.4.1
[30] Marazana, G., Perry, I., Maillet, D., & Rael, S. (2004). Design optimization of spreader heat sink for power
electronics, International Journal of Thermal Sciences, 43 (1) 21 – 29.
[31] ISA Transactions, vol. 9. No2, PP 95 – 103 (1990).
[32] New material for extreme environment. (n. d). Retrieved January 2, 2014, from
[33] http://www.extremat.org/heat-sink-materials?Edition=en
[34] Thompson, M. K., 2007, “A multi-scale Iterative Resistance,” Thesis (Ph.D.) Massachusetts Institution of Technology, pp. 26 – 29.