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COMPARATIVE EVALUATION OF VARIOUS HEAT SINKS MATERIALS IN ELECTRONIC EQUIPMENT

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Abstract

Most electronic components whose duties are attracted to maximum power efficiency required of a system to dissipate internal heat out of such components. MOSFETs, CMOS and special Processors, whose applications geared towards high voltages must have a system to effectively dissipate heat for maximum performance. Components with embedded heat sink have advantage and function effectively, the fact remain that the heat sink material is that which can dissipates heat during conduction of heat from the component. This paper considered various heat sink materials for proper heat transfer, radiation and dissipation. Aluminum, Copper, tungsten and Zinc were evaluated having various thermal conductivity and dissipation, and briefly heat-sink materials characteristics: weight, conductivity and quick thermal dissipation of heat from the heat-sink materials were discussed. And was observed that Aluminum heat sink material was more preferable during our evaluation and it was observed that the material is best for our modern day's high thermal components. Aluminum heat sink materials have a nomenclature of quick heat transfer, lighter in weight, Aluminum material is stability since thermal condition increases during high performance of the equipment, though some materials from the analysis have high conductivity but their weight and their radiation efficiency can affect the components which is firmly attached to it, considering new innovation in technology is revolving toward miniaturization of component sizes.

Keywords: Conductivity, dissipation, thermal, Heat sink, heat transfer.

1.0 Introduction

Most equipment used for higher signal efficiency, maximum power performance, Amplifier, high voltage systems, are designed with either external heat-sink or embedded type, this unique component role is essential to reduce the thermal condition of any component attached to it. Heat-sink materials are manufactured using various materials: copper, Zinc, Aluminum, tungsten, etc.

Existing systems designed have the capacity to withstand the internal temperature of the circuit, and their durability of the system is sustained, the efficiency of various systems are incorporating this essential factor. It is obvious that System thermal condition should be properly managed to adequately maintain stability of a functional system component. Conduction of internal heat from component is rapidly and must have an effective system to sustain the reaction. [3]

High voltage driven components actually needs high voltage supply to enable the system attain it high response performance and if such voltage is applied heat is conducted at a high thermal capacity, heat transfer and dissipation are required to overturn the thermal conductivity [1] in considering heat dissipation heat-sink materials are evaluated and a specific material is considered.

Experimental work conducted in the laboratory determined various thermal conductivity of materials, their failure rate and deficiency as heat increases in that material.

Heat conduction in a component is as a result of device performance and the enable power needed to drives the equipment to it maximum efficiency. Or a situation an equipment is used for a long duration without shutting it down for a while, to calm the internal temperature such device will conduct excess heat, there is one thing for device to conduct heat and other to radiate and dissipate it, if thermal system is not properly controlled, the equipment failure rate will be rapid.

Dissipation of internal temperature from the heat sink material and the component attached to heat sink is very key factor, because if a system is functioning maximally, conduction of heat is rapid, in such a system either the fans are provided to dissipate heat from the heat sink coupled with the ambient or atmospheric temperature penetrating through the vent hole perforated in the equipment chassis

2.0 Optimal Pin Fin Heat Sink under Natural Convection

[3] examined experimentally and numerically the heat transfer rate for two different pin fin heat sinks under natural convection. The first was flat and solid heated base, while, the other had a hole in its heated base. The influence of the base plate, fin height, holes diameter in the base plate and the heat sink porosity on the heat transfer performance was also studied. The heat sink made of aluminum and the heated element was fitted into a copper block while attached to the heat sink, from the experiment the results showed that the heat transfer coefficient for hallow heated base heat sink is higher than that of the unhallowed one due to greater acceleration and velocity in the circulation region. As the fin height, holes inside-outside diameter and input heat increases, the thermal performance increases. Finally, the hollow heat sink has a higher heat transfer co-efficient than the solid heat sink when its porosity is ≤ 0.262. Singh et al (2009), analyzed the thermal performance of a heat sink under natural convection by designing a model with ANSYS software. The ordinary circular pin fin with 32mm

length was used then the diameter of the pin was modified by an angle of expansion of 1 degree, 2 degrees and 3 degrees outward.

[3] Conducted simulation studies by using COMSOL metaphysics software to examine the thermal performance under forced convection for the heat sink designed in their previous research. Reynolds number (Re) range from 6468 to 45919 was studied and data obtained were compared with experimental data from other investigators. The results showed the highest heat transfer. All the perforated fin heat performance and pressure drop were compared with the corresponding solid fin under the same conditions. ANSYS 14 fluent software was used to design the system models. Heat flux of 5903 w/m2 was applied at the bottom of the base plate which has an area of (0.1 × 0.1) m2 and a thickness of 3mm, where the fins are mounted either in inline of staggered. Figure 5 shows the different perforations geometries used and their numbers. The results showed that all perforated fins had higher thermal performance than the solid fins, especially with a staggered arrangement.

3.0 Optimal Flat Fin Heat Sink under Force Convection

[16] numerically studied of the optimal fin designed to get a higher heat transfer rate for a heat sink under forced convection. First, triangular, rectangular and trapezoidal fins with constant volume were examined. The test section was made of aluminum plates with 190×110×1 mm dimensions. These plates were modified by making a circular and triangular notch at their centers with 20 % notch area. Experiments were carried under different heat flux values that ranged from 200 to 360 W and with various airflow rates. The results indicated that fins with circular notch have a heat transfer coefficient range from 10.34 to 10.55 W/m2 °C, compared to 10.08 to 10.29 for triangular notch and 9.6 to 9.76 for fin without a notch.

[1] Examined experimentally the thermal performance of a heat sink with hexagonal perforated fin under forced convection. The Nusselt number, heat transfer coefficient, thermal resistance, fin efficiency and fin effectiveness for a perforated fin were calculated and compared with the non-perforated fin. The results demonstrated that Nusselt number, heat transfer coefficient fin efficiency and fin effectiveness for a perforated fin are greater than those for non-perforated fin. Meanwhile, the thermal resistance and pressure drop for a perforated fin are smaller than solid one under the same conditions. There must be a firm contact between a component and the heatsink as seen in figure 1, for efficient conduction.

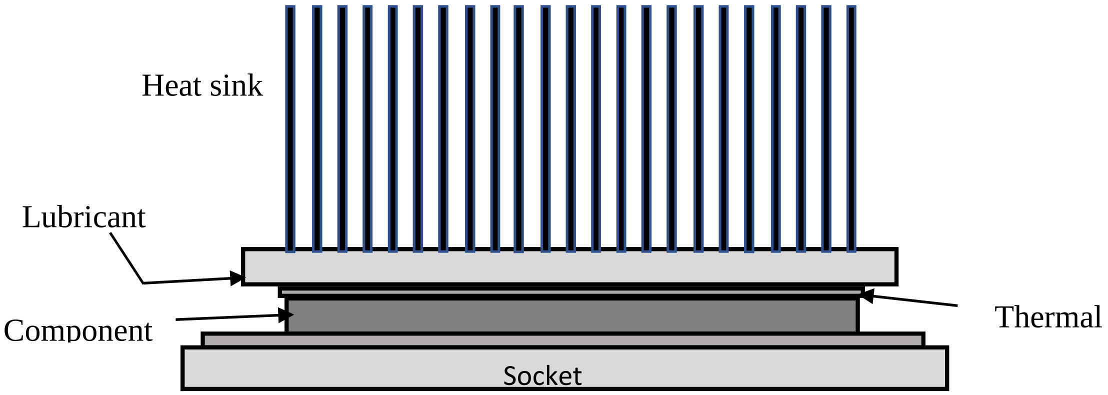

Figure 1 thermal interface between heat sink and component

4.0 Thermal analysis

All semiconductor devices are very sensitive to temperature variation, if the temperature of a component exceed a permissible limit, the component may be permanently damaged, there are two factor which determine the operating temperature of a component;

a. Surrounding temperature
b. Power dissipation of a component

Unless adequate cooling is provided or the component has a built-in-temperature compensation circuit, to prevent excessive current rise, the junction temperature will continue to increase until a maximum permissible temperature is reached, exceeded that, lead to permanent damage of component, or distortion the unstable condition which owing to rise in temperature is the thermal runaway.

Since high voltage component handle large current, they heat up during operation and such component is a temperature dependent device, the heat generated must be dissipated to the surrounding in order to keep the temperature within permissible limit.

We must first consider the concept of thermal resistance θ, which has units of degree Celsius per watt (OC/W). The temperature difference, $T_2 - T_1$, across an element with a thermal resistance θ is given by:

$$T_2 - T_1 = P\theta \tag{1}$$

Where P is the thermal power through the element. Temperature difference is the electrical analog of voltage, and power or heat flow is the electrical analog of current.

Manufacturers' data sheets for power device generally gives the maximum operating junction or device temperature $T_{j,max}$ and the thermal resistance from the case:

$\theta_{jc} = \theta_{dev-case.}$.

By definition the thermal resistance between the case and the heat-sink is $\theta_{case-\sin k}$,and between the heat sink and ambient is $\theta_{\sin k-amb}$

When a heat-sink is attached to the component, the temperature difference between the device and the ambient conditions can now be expressed as follows:

$$T_{dev-}T_{amb} = P_D(\theta_{dev-case} + \theta_{case-\sin k} + \theta_{\sin k-amb}) \tag{2}$$

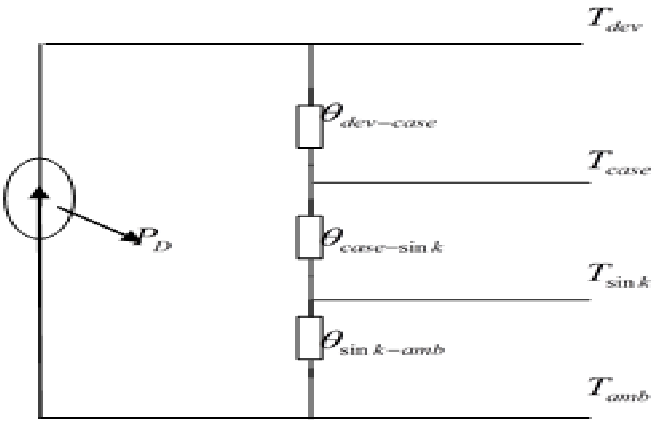

Figure 2: Electrical equivalent circuit for heat transfer (redrawn), where P_D is the power dissipation in the device.

Equation above may also be model by its equivalent electrical elements, the temperature difference across the elements, such as the case and heat sink, is the dissipated power (P_D) multiplied by the applied thermal resistance, which is $\theta_{case-sink}$ for the device.

If a heat-sink is not used: the temperature difference between the device and ambient is given as:

$$T_{dev-}T_{amb} = P_D(\theta_{dev-case} + \theta_{case-amb}) \quad (3)$$

Where $\theta_{case-amb}$ is the thermal resistance between the case and ambient temperature, The maximum power dissipation in a component, assuming a power MOSFET component is used for multi-functions in which the thermal resistance parameters are given below:

$\theta_{case-amb} = 1.75^{o}c/w.$

$\theta_{case-sin\,k} = 1^{o}c/w$

$\theta_{sin\,k-amb} = 5^{o}c/w,$

$\theta_{case-amb} = 50^{o}c/w.$

Let assume that ambient temperature is $T_{amb} = 30^{o}c$, and the maximum junction or device temperature is $Tdev^{o}{}_{j,max}$

When no heat-sink is used, the maximum device power dissipation is found to be

$$P_{D,\max} = \frac{T_{j,\max-}T_{amb}}{\theta_{dev-case} + \theta_{case-\sin k}} \quad (4)$$

Hence applying the values in equation (4) gives the results;

$$\frac{50 - 30}{1.75 + 50} = 2.32W$$

When a heat sink is used, the maximum device power dissipation is given as;

$$P_{D.max} \quad = \frac{Tamb_{j,max}}{\theta_{dev-case}+\theta_{case-sin\,k}+\theta_{sin\,k-amb}} \ (5)$$

Substituting from equation (5) result to;

$$\frac{50-30}{1.75-1+5} = 15.5W$$

The two results proved that the use of heat-sink allows more power to be dissipated in the device, while keeping the device temperature below its maximum limit.

The maximum safe power dissipation in a device is a function of the temperature difference between the junction and the case and the thermal resistance between the device and the case $\theta_{dev-case}$

Also expressed as:

$$P_{D.max} \quad = \frac{Tamb_{j,max}}{\theta_{dev-case}+\theta_{case-sin\,k}+\theta_{sin\,k-amb}} \ (6)$$

A plot of PD max versus Tcase is the power de-rating curve of the device in figure.3, which is corresponds to $T_{j,max}$, At this temperature ,no additional temperature rise in the device can be tolerated; therefore the allowed power dissipation must be zero, which implies a zero input signal.

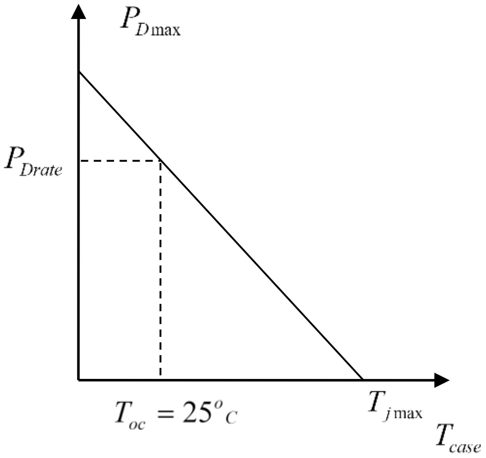

Figure 3. Power de-rating curve.

The rated power of a device is the power at which the device reached its maximum temperature, while the case temperature remains at room or ambient temperature, that is T_{case} =25°C. Maintaining the case at ambient temperature implies that the thermal resistance between the case and ambient is zero, or that an infinite heat sink is used. However, with nonzero values of $\theta_{case-sin\,k} and \theta_{sin\,k-amb}$, the case temperature rises above the ambient, and the maximum rated power of the device cannot be achieved. This effect can be seen examining the equivalent circuit model If the device temperature is at its maximum allowed value of $T_{dev} = T_{jmax}$, then as T_{case} increases, the temperature different across $\theta_{dev-case}$ decrease ,Which means that the power through the element must decrease

The actual maximum safe power dissipation in a device may be less than the rated value. This occurs when the case temperature cannot be held at the ambient temperature, due to the nonzero thermal resistance factors between the case and ambient.

Aluminum material advantages over other materials are as following:

a. Thermal conductivity: It represents the heat transferred per surface value and per second when a specific thermal gradient is applied. Its unit is Watt per meter per Kelvin (W/m/K)
b. Electric conductivity: It is the inverse of the electric resistivity. The conductivity is the capacity to let the electric current flow. It is the inverse of resistivity.

As seen in figure 1, material resistivity and conductivity help the companies to determine best heatsink for a particular device. Various materials are used for heat sink, but the potentials are the light weight of the material, fast dissipation of heat in such material and conductivity since heat have to be radiated fast as heat conduction is deposited in the component. Some material have high conductivity but are heavier while some cannot radiate heat easily. Good material must have this qualities, conduction, dissipation, light in weight and radiation. Aluminum material are most reliable for sustaining the life of components, are light, can dissipate heat fast, and radiate heat to the ambient temperature

Table 1: Materials resistivity and conductivity

S/N	*Material*	*Electric conductivity* (10^6 *S/m)*	*Electric resistivity (* 10^8 *Ω/m)*	*Thermal conductivity (W/m.K)*	*Melting or deterioration temperature (°C)*
1	*Silver*	*62.1*	*1.6*	*420*	*961*
2	*Copper*	*58.7*	*1.7*	*386*	*1083*
3	*Gold*	*44.2*	*2.3*	*317*	*1064*
4	*Aluminum*	*36.9*	*2.7*	*237*	*660*
5	*Molybdenum*	*18.7*	*5.34*	*138*	*2623*
6	*Zinc*	*16.6*	*6.0*	*116*	*419*
7	*Lithium*	*10.8*	*9.3*	*84.7*	*181*
8	*Brass*	*15.9*	*6.3*	*150*	*900*
9	*Nickel*	*14.3*	*7.0*	*91*	*1455*
10	*Steel*	*10.1*	*9.9*	*81*	*1528*
11	*Palladium*	*9.5*	*10.5*	*72*	*1555*
12	*Platinum*	*9.3*	*10.8*	*107*	*1772*
13	*Tungsten*	*8.9*	*11.12*	*174*	*3422*
14	*Tin*	*8.7*	*11.5*	*67*	*232*
15	*Bronze 67Cu33Sn*	*7.4*	*13.5*	*85*	*1040*
16	*Carbone steel*	*5.9*	*16.9*	*54*	*1400*
17	*Carbone*	*5.9*	*16.9*	*129*	*2500*
18	*Lead*	*4.7*	*21.9*	*85*	*327*
19	*Titanium*	*2.4*	*41.7*	*21*	*1668*
20	*Stainless steel 316LEN1.4404*	*1.32*	*76.0*	*15*	*1535*
21	*Stainless steel 304EN1.4301*	*1.37*	*73.0*	*16.3*	*1450*
22	*Stainless steel 310EN1.4841*	*1.28*	*78*	*14.2*	*2650*
23	*Mercury*	*1.1*	*90.9*	*8*	*-39*
24	*FeCrAl*	*0.74*	*134*	*16*	*+-1440*

Aluminum heat sink materials have an advantage in industrial needs based on its potentials and high performing equipment are associated with it, amplifiers and projector's equipment highly support such heat sink material,

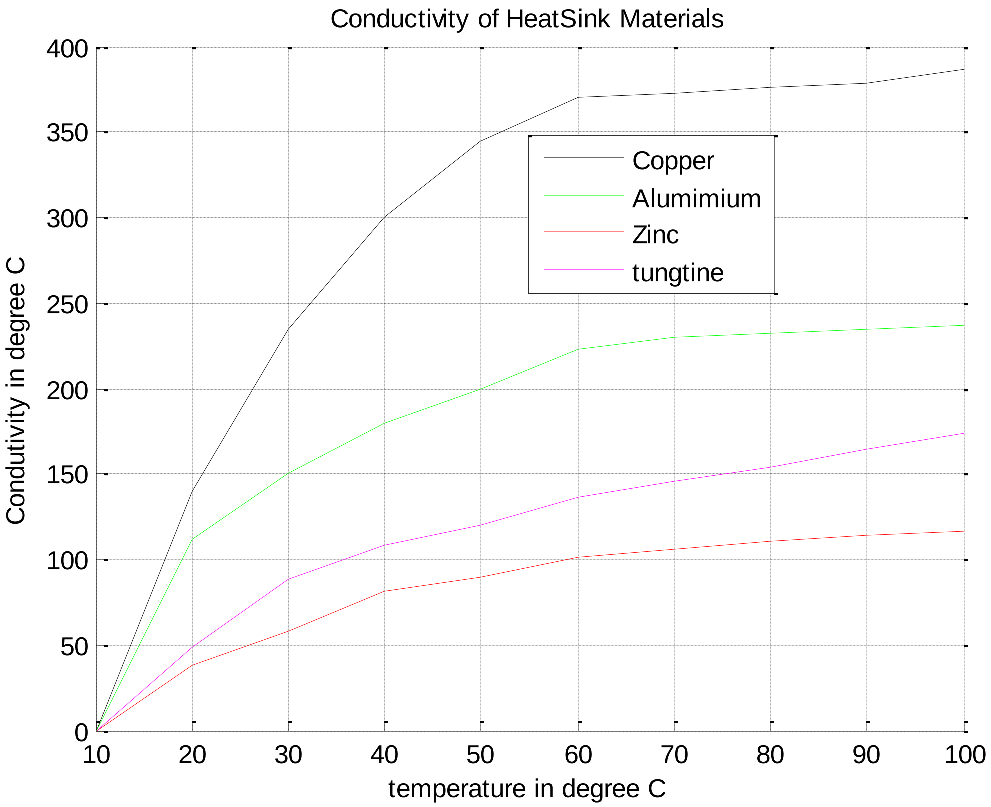

Fig. 4. Thermal conductivity of various materials

4.1 Zinc Material

Zinc die casting offers numerous advantages over aluminum extrusion in a number of heat sink applications. Die cast Zinc heatsink offer one piece construction, increased design flexibility, and lower cost, one of the biggest advantage is that heat dissipation fins can be incorporated into a frame, housing, or enclosure .casting the fins as part of the housing can greatly lower costs by reducing the number of components and eliminating assembly cost .Zinc is also stronger ,stiffer and tougher than extruder aluminum and also provides high impact strengths along with excellent ductility. They are easily ignored because of their lower thermal conductivity. Zinc alloy material limitation is lower thermal conductivity and Heavier in weight

4.2 Copper material

It is sometimes used as a heatsink as it is a good conductor of heat. This can be observed if you heat one end of a piece of copper; the other end will quickly reach the same temperature. Copper is used in many heating applications because it doesn't corrode and has a high melting point. The base material for a copper heatsink costs more than aluminum. The high cost may be justified by measuring the heatsinks overall performance, however. It can also be reduced by combining the copper with other materials. Those who use high performance processors or overclocked their computers generally value performance over cost. Weight is another drawback of a copper heatsink. A heatsink made of copper weighs more than an equal- sized one made from aluminum. CPU orientation should therefore be considered before choosing a heatsink

The copper heatsink is a popular thermal management option among computer customizers because of its capacity to absorb heat relatively quickly. This ability can also be a problem, however, as it tends to hold that heat for a long time. Another drawback is the higher cost compared to heatsinks made from other metals. This type of heatsink is also heavier than others. Copper heatsinks perform well at thermal management, especially when it comes to high end processors and over clocking. Limitation of copper alloy material**:** The base cost more than aluminum, Heavy in weight, basically for industrial facilities, Less ductile, It cannot be extruded**,** It holds heat for a long time

4.3 Aluminum Materials

Aluminum alloy has advantage as compared with other materials, even though aluminum extrusion or casting aluminum has many advantages: such as energy-saving, materials-saving, decoration, price, weight, and other aspects.

Aluminum alloy is equipped with high thermal conductivity, which are the decisive factors to maintain good thermal performance and the best medium of thermal energy conversion. It is characterized by less time, heating fast and high efficiency. Light and handy, easy processing are another two major features. The same specifications of the radiator, the weight of an aluminum alloy one is 1/3 of a steel one.

Note, Aluminum heat sink is the lightest among a variety of radiators. It is easy to handle and to install. At the same time, it is popular for the good thermal conductivity, heat dissipation, fast heating, high-strength metal heating. With the readiness of extrusion, it can be squeezed into various shapes of radiator, so it appears to be new, beautiful and decorative. Since aluminum anodizing is the best protective film after anodizing, so it is oxidation-proof and corrosion- proof, a reasonable price making it welcomed by mass working-class and aluminum profile supplier. Aluminum heat sink has good thermal conductivity, high pressure and high thermal strength of metal. The limitation of Aluminum alloy is mechanically soft structure.

5. Conclusions

Results shown that aluminum heat-sink material is reliable and is suitable for miniaturized electronic gadgets, is light, fast in conduction and dissipation, an equipment can drastically reduce the thermal effect during this operations. Some other heat-sink materials have various disadvantages: too heavy in weight, slow in dissipation of heat, which means that it retain heat and this can affect any component mounted on it, because conduction of heat from the component is rapid and radiation must be rapid also to transfer or dissipate heat to the ambient

Analysis also shown that system with embedded heat-sink perform better than those without heat sink, because when thermal resistance of any system increases the efficiency of that system is distorted. Heat-sinks are useful to sustain the lives of equipment, because the entire equipment live depends on it for sustainability, failure rate of various gadgets are traceable to thermal condition of equipment, this means that thermal conductivity must be properly manage in an equipment.

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