Necessity of Electronics Cooling and Availability of Suitable Cooling Techniques

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Abstract- *In view of the present trend of continual increase in both packaging and power densities in modern day's electronic components, the search for the suitable cooling techniques, depending on the applications, motivated the investigators all over the world. As the conventional air cooling technique is no longer adequate for the high heat flux applications, the search for alternative forms of cooling have captured much attention in recent years to circumvent the problems of high thermal resistance associated with the system hardware. Keeping it in mind, the present article describes about the heat generation from the facilities to the chip, road map of the high performance chip and various causes of the failure of the chip. In addition, it also illustrates on the thermal issues associated with the electronic package assembly, thermal management challenges along with the several cooling techniques practices which include both active as well as passive cooling techniques.*

Keywords- Heat Flux, Cooling Technique, Thermal Management, Electronic Device, Chip.

I. INTRODUCTION

Discoveries in many of today's cutting-edge technologies are getting more and more dependent upon the power to safely dissipate the enormous amounts of heat from very small areas. High heat flux ranges are currently encountered in high performing supercomputers, advanced military avionics, electric vehicles and power devices. Ultra high heat fluxes are encountered in various high-energy devices, magnetrons which are used for short-pulses, radars and lasers, fusion reactors and synchrotron sources which delivers high brilliance X-ray beams. The design and production of chips with high-gate densities has improved the performance of electronic components. The increased heat dissipation per unit area is required to maintain the devices well below the allowable operating temperature. Heat is a normal spin-off of any electronic device which depends on the model of a particular device.

Some electronic devices with very vital thermal managements are listed below.

(a) Microprocessors used in various computers.
(b) Power semiconductor modules used in different industries such as, automotive, aerospace and naval or space explorations.
(c) High power laser diodes.
(d) High power RF modules.
(e) High luminous LEDs with consistent colour scale.
(f) High power lasers and RF weapons with extreme temperature build up.

II. HEAT GENERATION: FROM FACILITIES TO CHIP

In the last few years, the cooling of electronic devices and its thermal management have played a great role in bringing about a harmonious adaptation in the increase of power while maintaining components' temperature at the requirement level to satisfy the performance and reliability of the electronic devices. Due to the increase in the function of the device, the size of the device increases from interconnects to server farm making more heat generation rate as shown in undermentioned figure 1. The heightened heat flux at all the points from chip to system to facilities pose major cooling challenges.

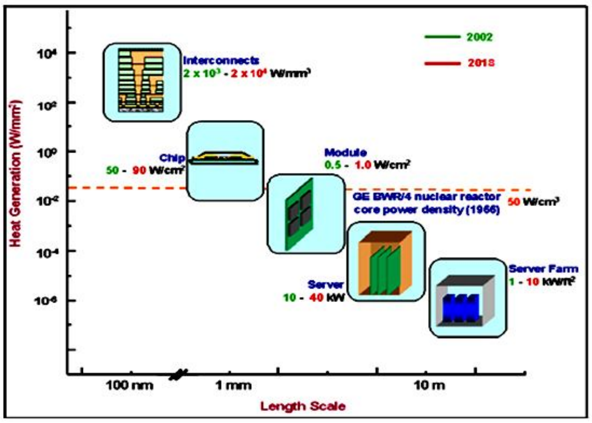

Figure 1. Chronological evolution of electronic devices.

III. ROAD MAP OF HIGH PERFORMANCE CHIP

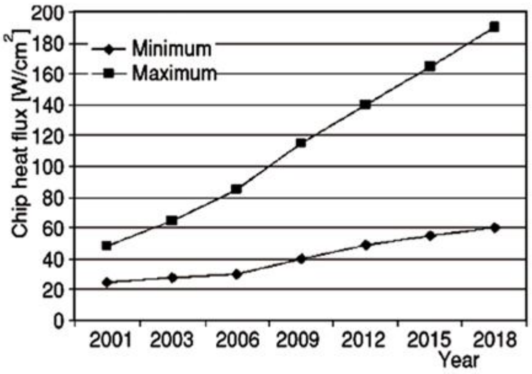

Figure 2. High performance chip heat flux trends.

The semiconductor industries are aiming keen attempt throughout the years to reduce thesize of the electronic devices. With the increase amount of power dissipations and reductions inthe size, the increase in power density is awaited to promote over the next few yearsas shown in figure 2. The increase in power density indicates that the thermal management solution play a crucial role in determining the future semiconductor device technology.

IV. FAILURE OF THE CHIP

From the present researches it is observed that for each 2°C temperature rise, the dependability of a silicon chip will be diminished to 10 %. As illustrated in figure 3, the possibility of the main causes of the failure of the electronic chips are due to the rise in temperature (55 %), vibrations (20 %), humidity of air (19 %) and the dust in the environment (6 %). Therefore, it is a great challenge for the packaging engineers to move out heat from the electronic chip very efficaciously.

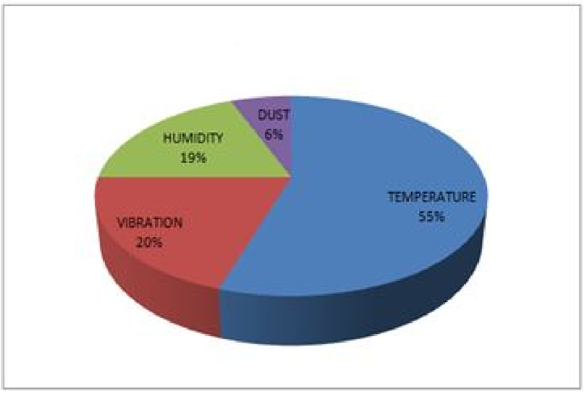

Figure 3. Major causes of the failure of chip in percentage.

V. THERMAL ISSUES IN ELECTRONIC PACKAGE ASSEMBLY

(a) The simplest semiconductor device is a transistor having two junctions and a diode.
(b) Junction is the specified band between two different regions of a semiconductor (p-type or n-type semiconductor).
(c) Junctions are the sites of heat generations, due to flow of electrons.
(d) The junction temperature is limited to 125°C for the silicon made devices for the safe operation.
(e) The lower junctions' temperatures are preferable for reliability.
(f) In typical applications, numerous electronic components, some less than 1µm in sizes, are made from a silicon wafer into the chips.
(g) Heat is generated when current flows through a resistance i.e. $Q = I^2R$.
(h) When transistor was first introduced, it was known as "heatless" device as compared to the vacuum tubes.
(i) However, when such transistors are densely packed (1000's or millions) in a small volume, heat removal is a challenge.
(j) Heat fluxes in electronic devices can range from 1 W/cm^2 to quite more than 100 W/cm^2.

VI. THERMAL MANAGEMENT CHALLENGES

Following are the thermal management challenges in electronic items.

(a) Decreased form factor.
(b) All time growing power density.
(c) Abrasive environment.
(d) Product miniaturization.
(e) Decreasing product cost.
(f) Reliability and performance constraints.
(g) Meeting rigorous standards.
(h) Growth of advanced technology and materials.
(i) Increasing consumers' requirements and needs.

VII. COOLING TECHNIQUES

Thermal cooling techniques are categorized into two types such as active cooling techniques and passive cooling techniques.

A. Active cooling techniques

Active cooling is mechanically assisted cooling. It offers outstanding cooling capacity. It allows temperature control that can be attained below the ambient temperature. In most of the cases, the active cooling technique eliminates the uses of cooling fans. For example, air or liquid jet impingement, forced liquid convection, spray cooling, thermoelectric coolers and refrigeration systems. Figure 4 illustrates the mechanism of thermoelectric cooling which is a very unique active cooling technique.

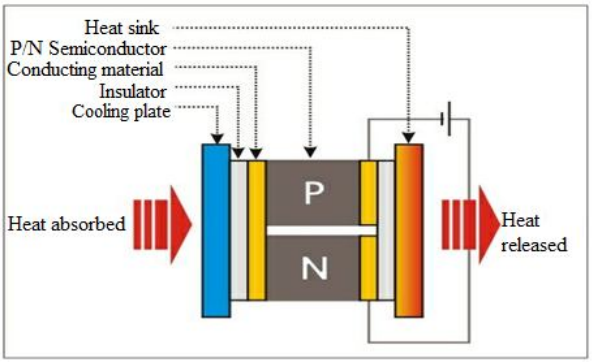

Figure 4. Thermoelectric architecture for cooling of electronic device.

In thermoelectric cooling the Peltier effect is used to produce heat flux between the junctions of the two different materials. According to Jean Peltier theory when a DC current is applied between two dissimilar conductors, a circuit is completed which allows for continuous transfer of heat between the two conductor junctions. The thermoelectric cooler (other also known as Peltier cooler) is a solid-state participating heat pump which carries heat from one side of the device to the other side of the device, with the use of electric energy, depending on the direction of the flow of the current.

The performance of thermoelectric cooler depends on the factors like the temperatures of the cold and hot sides, thermal and electrical conductivities of the materials of which devices are made, contact resistances between the thermoelectric devices and heat source or heat sink and the heat sink's thermal resistance. Applications of thermoelectric cooling befall in food industries, medical equipment, laser devices, production of semiconductor integrated micro chips and industrial electronics and telecommunications.

In other words, the point-wise and systematic descriptions about the factors seriously affecting the performance of thermoelectric coolersare follows.

(a) Temperatures of the cold and hot sides.
(b) Thermal and electrical conductivities of the materials of which devices are made.
(c) Contact resistances between the thermoelectric devices and heat source or heat sink.
(d) Heat sink's thermal resistance.

The thermoelectric cooling is advantageous because of factors like lightweight, absence of moving parts hence noiseless and maintenance free, suitability for manufacturing in very small sizes which is very ideal for microelectronics, heating or cooling practice by changing the directions of current flows, very accurate temperature control and wide operating temperature ranges, operations in any orientations with zero gravity, environmental friendly due to absence of refrigerants like harmful CFCs and hence environmental and safety benefit together with fast and dynamic response. However, some disadvantages of using thermoelectric coolers are high cost and low energy involvements.

In other words, the point-wise and systematic descriptions about some of the advantages offered by the thermoelectric cooling are listed below.

(a) It has no moving parts.
(b) It is light weight.
(c) Suitable for manufacturing in very small sizes. So ideal for microelectronics.
(d) Maintenance free.
(e) Reduced and low-noise operations of cooling fans, while providing larger cooling power.
(f) Heating or cooling practice by changing the directions of current flows.
(g) Wide operating temperature ranges.
(h) Very accurate temperature control (to within 0.1° C).
(i) Operations in any orientations with zero gravity and high G- level.
(j) Environmental friendly because of absence of refrigerants like harmful CFCs. So environmental and safety benefit.
(k) Quite fast and dynamic response.

In other words, the point-wise and systematic descriptions aboutsome of the disadvantages of using a thermoelectric coolers are the involvements of the followings.

(a) Very high cost
(b) Quite low energy

In addition, the point-wise and systematic descriptions about some of the applications of thermoelectric cooling are as follows.

(a) Food industries.
(b) Medical equipment.

(c) Laser devices.
(d) Production of semiconductor integrated micro chips.
(e) Industrial electronics and telecommunications.

B.Passive cooling techniques

The passive cooling systems are not assisted by mechanical devices. This technique includes applying very good heat spreaders and heat sink to the electronic packages. For a module on the spatial limitations, passive cooling proficiency are more practical than active cooling. Some passive cooling techniques are use of natural convection with air/liquid, high thermal conductivity substrates, heat sinks, thermosyphons, phase change materials (PCMs). A typical case of passive cooling by means of heat sink is illustrated in figure 5, which is basically used for cooling of electronic chip in semiconductor industry.

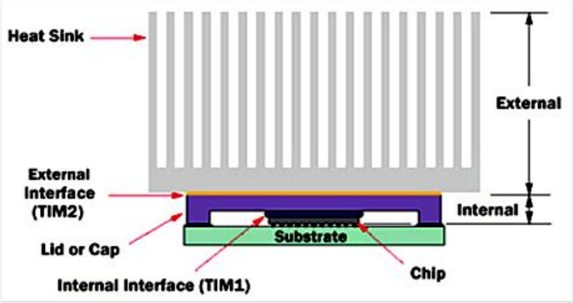

Figure 5. Structure of the heat sink.

In electronics industries heat sinks are passive heat exchangers that can cool a device by dissipating heat into the surroundings. It functions by efficiently transferring thermal energy from the higher temperature devices to the lower temperature fluid mediums. Fluid mediums can be water, air, oil or refrigerants. The heat sink consists of a base with one or more flat surfaces and align of combs or fins like protrusions that increase the surface area of the heat sink which is in contact with air and hence increases the rate of heat dissipation.

Furthermore, the point-wise and systematic descriptions about some of the applications of heat sinks are mentioned below.

(a) Cooling electronic devices like microprocessors.
(b) Refrigeration.
(c) Heat engines.

VIII.CONCLUSION

Owing to the current development along with the constant intensification in both packaging and power densities in the present day electronic gadgets, the quest for the appropriate cooling methods, subject to the uses, stimulated the researchers around the globe. For instance, the traditional air cooling method is not enough for the high heat flux uses, the pursuit for different arrangements of cooling have apprehended considerable focus in present times to surpass the glitches of high thermal resistance related to the electronic devices. Bearing this cognizance, the current article demonstrates on the heat generation from the facilities to the chip, road map of the high performance chip in addition to different reasons of the failure of the chip. Furthermore, it also exemplifies the thermal issues related to the electronic package assembly, the thermal management challenges together with the various cooling methods or procedures which contain both active and passive cooling methods with superior cooling behaviors.

IX. ACKNOWLEDGMENT

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