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A Review: Advances in Heat sink Cooling Systems

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Abstract: *The ever rising transistor densities and switching speeds in microprocessors have been accompanied a dramatic increase in the system heat flux and power dissipation. In this context the rising IC densities combined with even more stringent performance and reliability requirement have made thermal management issues ever more prominent in the design of sophisticated microelectronic systems. So in order to achieve a high degree power dissipation extruded heat sinks, a number of research works have been done in last two decades. It is observed that components of modern portable electronic devices with increasing heat loads with decrease in the space available for heat dissipation. The increasing heat load of the device needs to be removed for maintaining the efficient performance of the device. The exponential increase in thermal load in air cooling devices requires the thermal management system to be optimized to attain the highest performance in the given space. In the present paper a review report on comprehensive description for thermal conditions for cooling purpose within the heat sink for electronic devices has been summarized. This paper is about review of current and advancement of Heat sink cooling technologies. There are various technologies discussed here like Air cooling, Piezofans Jet Impingement phase change material, nano lighting,etc. This paper is about brief review about heat sink and its cooling techniques*

Keywords: *Heat sink, Cooling*

1. INTRODUCTION

Nowadays in the present world, there is a great demand for the electronic devices which are compact in size, occupying less space in system etc. This in turn poses a serious challenge in cooling the electronic devices due to the increase in heat generation coupled with the limited heat removal surface area. Thermal issues exist over a wide range of power dissipation levels from handheld devices that dissipate a few Watts to high-performance microprocessors dissipating over 100W. The engineers came up with some solutions like Heat sinks, forced air cooling (fans), heat pipes which are traditional cooling methods. But still they have some drawbacks, such as the heat sinks needs to have smooth and flat surface for better heat dissipation, which costs more for fabrication; forced air cooling (fan) requires more space in the system; heat pipes are hollow metal tubes which contains thermal liquid in it, which has got the chances of damaging the system. To overcome these drawbacks, synthetic jet can be potentially used for cooling applications. The local heat transfer characteristics of impingement of a synthetic air jet are studied in this work

2 CONDUCTION AND HEAT SPREADING

In all cooling applications, heat from the device heat sources, must first travel via thermal conduction to the surfaces exposed to the cooling fluid before it can be rejected to the coolant. For example, as shown in Figure 1, heat must be conducted from the chip to the lid to the heat sink before it can be rejected to the flowing air. As can be seen thermal interface materials (TIMs) may be used to facilitate thermal conduction from the chip to the lid and from the lid to the heat sink. In many cases heat spreaders in the form of a flat plate with good thermal conductivity may be placed between the chip and lid to facilitate spreading of the heat from the chip to the lid or heat sink. Vapor chambers are also used to spread heat from a concentrated chip or module heat source to a larger heat sink.

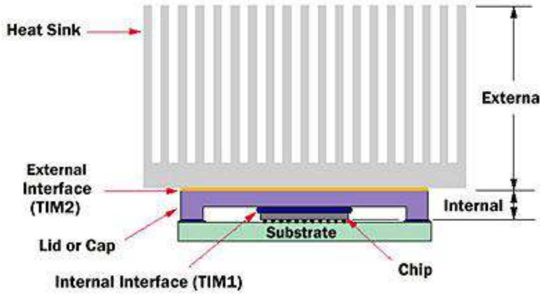

Figure 1. Chip package with thermal conduction path to heat sink via TIMs.

Figure 1. Chip package with thermal conduction path to heat sink via TIMs.For high-power applications, the interface thermal resistance becomes an important issue. Direct soldering (e.g., reflow soldering) is often difficult, certainly when copper is used because of the large CTE mismatch between Cu and Si. However, a few promising materials are entering the market. Even more interesting is a nanostructured foil, which utilizes a very fast exothermic reaction to create a soldered connection virtually at room temperature [3]. Extensive long-term reliability studies are in progress [4]. Heat spreading is a very effective way of mitigating the need for sophisticated high-heat flux cooling options. Of course, to be effective the benefits of decreasing the heat flux density by increasing the area

should outweigh the penalty of adding another layer that the heat must be conducted across. By applying heat spreaders cooling methods such as loop heat pipes and low-flow liquid cooling may be augmented to accommodate higher heat flux applications.

3 AIR COOLING

It is generally acknowledged that traditional air-cooling techniques are about to reach their limit for cooling of high-power applications. With standard fans a maximum heat transfer coefficient of maybe 150 W/m^2K can be reached with acceptable noise levels, which is about 1 W/cm2 for a 60°C temperature difference. Using 'macrojet' impingement, theoretically we may reach 900 W/m^2K, but with unacceptable noise levels. Non-standard fans/dedicated heat sink combinations for CPU cooling are expected to have a maximum of about 50 W/cm^2, which is a factor of 10 higher than expected 15 years ago. However, some new initiatives have emerged to extend the useful range of air-cooling such as piezo fans, 'synthetic' jet cooling and 'nanolightning'.

Fig 2 Air Cooling

4 PIEZO FANS

Piezoelectric fans are low power, small, relatively low noise, solid-state devices that recently emerged as viable thermal management solutions for a variety of portable electronics applications including laptop computers and cellular phones. Piezoelectric fans utilize piezoceramic patches bonded onto thin, low frequency flexible blades to drive the fan at its resonance frequency. The resonating low frequency blade creates a streaming airflow directed at electronics components. A group at Purdue reports up to a 100% enhancement over natural convection heat transfer [7].

5 'SYNTHETIC' JET COOLING

Synthetic jet is a relatively new technique which synthesizes stagnant air to form a jet resulted from periodic oscillations of a diaphragm in a cavity. Synthetic jet actuator is composed of a closed cavity with one end covered by electromagnetic actuator and a circular orifice at other end. Usually the jet is formed due to the entrainment of the vortex pairs which are rotating in opposite direction and formed at the edges of the orifice. They have promising application in various fields such as jet vectoring, electronics cooling, and boundary layer separation. In present work the synthetic jet is driven by acoustic speaker for the impingement of jet on the heated surface. The temperature distribution across the heated surface is measured with the help of infrared thermal camera

An approach using periodic microjets coined 'synthetic jets' has initially been studied by Georgia Institute of Technology and is being commercialized by Innovative Fluidics. Due to the pulsating nature of the flow, synthetic jets introduce a stronger entrainment than conventional-steady jets of the same Reynolds number and more vigorous mixing between the wall boundary layers and the rest of the flow. One of the test set-ups is shown in Figure 3. A synthetic jet entrains cool air from ambient, impinges on the top hot surface and circulates the heated air back to the ambient through the edges of the plate. A radial counter current flow is created in the gap between the plates with hot air dispersed along the top and ambient air entrained along the bottom surface. The idea was further explored by the development of flow actuators using MEMS technology [8].

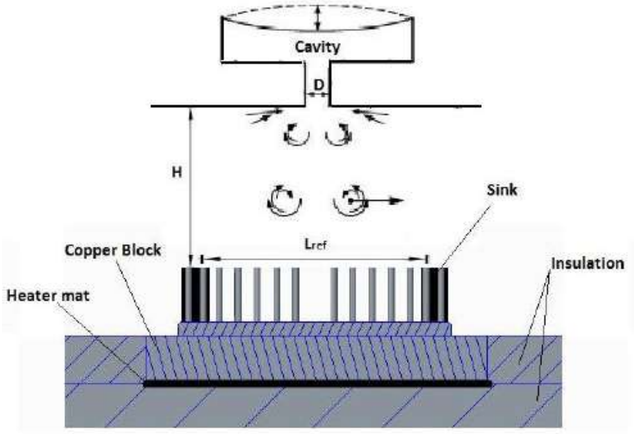

Figure 3. Flow dynamics of normal jet impingement with an oscillating diaphragm.

6 NANOLIGHTNING

An interesting new approach to increasing the heat transfer coefficient called 'nanolightning' is being pursued by researchers from Purdue . It is based on 'micro-scale ion-driven airflow' using very high electric fields created by nanotubes. As shown in Figure 4, the ionized air molecules are moved by another electric field, thereby inducing secondary airflow [9]. Cooling a heat flux level of 40 W/cm^2 has been reported. The technology is being commercialized through a start-up company (Thorrn).

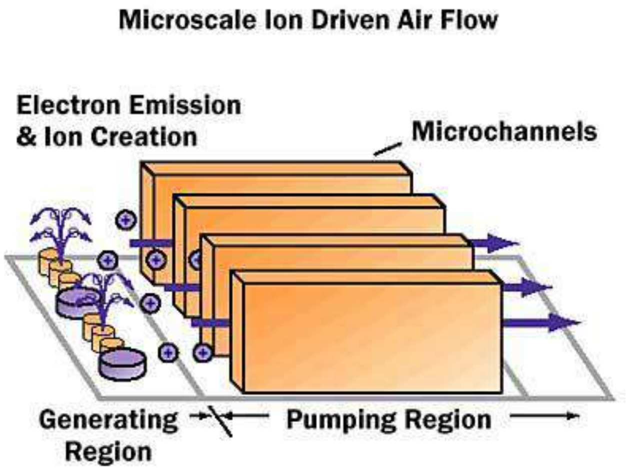

Figure 4. 'Nanolightning' sketch.

7 HEAT PIPES

Heat pipes provide an indirect and passive means of applying liquid cooling. They are sealed and vacuum pumped vessels that are partially filled with a liquid. The internal walls of the pipes are lined with a porous medium (the wick) that acts as a passive capillary pump. When heat is applied to one side of the pipe the liquid starts vaporating. A pressure gradient exists causing the vapor to flow to the cooler regions. The vapor condenses at the cooler regions and is transported back by the wick structure, thereby closing the loop. Heat pipes provide an enhanced means of transporting heat (e.g., under many circumstances much better than copper) from a source to a heat sink where it can be rejected to the cooling medium by natural or forced convection. The effective thermal conductivity of a heat pipe can range from 50,000 to 200,000 W/mK [11], but is often much lower in practice due to additional interface resistances. The performance of heat pipes scales from 10 W/cm^2 to over 300 W/cm^2. A simple water-copper heat pipe will on average have a heat transfer capacity of 100 W/cm^2. An example of a typical application of a heat pipe for an electronics cooling application is given in Figure 5.

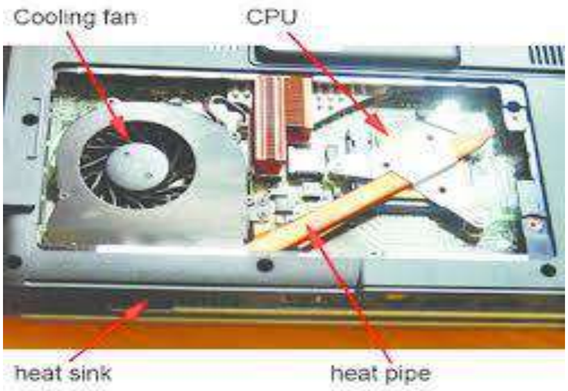

Figure 5. Examples of heat pipes used in a notebook application

Although there is virtually no limit to the size of a heat pipe, the effectiveness of a heat pipe decreases with decreasing lengths. For heat pipes with a length less than about 1 cm the performance of a solid piece of metal (e.g., copper) is often comparable. They are very effective as efficient heat conductors to transport heat to locations were more area is available. 2D heat spreaders (otherwise known as vapor chambers) based on the heat pipe principle can achieve much higher effective thermal conductivities than copper. For example, a thin planar heat spreader has been developed that is claimed to have a thermal performance greater than diamond [12].

8 IMMERSION COOLING

Direct liquid or immersion cooling is a well-established method for accommodating high heat flux backed by over thirty years of university and industrial research. With natural convection two-phase flow, generally termed nucleate pool boiling, the critical heat flux using FC-72 is in the range of 5 to 20 W/cm^2. However, much higher heat fluxes up to 100 W/cm^2 can be accommodated with surface enhancement of the heat source. Figure 13 illustrates a device submerged in a pool of dielectric liquid. The heat dissipated in the device produces vapor bubbles that are driven by buoyancy forces into the upper region of the container, where the vapor condenses and drips back into the liquid pool. One of the disadvantages of this technique is the need for a liquid compatible with the device. Most often, water cannot be used because of its chemical and electrical characteristics.

9 LIQUID JET IMPINGEMENT

Wang et al. [38] claim a cooling of 90 W/cm^2 with a 100°C temperature rise using a flow rate of only 8 ml/min. Researchers at Georgia Institute of Technology studied a closed loop impingement jet [39]. Cooling of almost 180 W/cm2 has been realized using water, using a flow of 0.3 l/min at 300 kPa. The micropump used 7 W to drive it.At this point it is difficult to say which one is better, micro channels or micro jets. Micro channels are easier to fabricate and implement but the temperature no uniformity is larger and the nucleation is more difficult to control. Microjets achieve better cooling uniformity but more fabrication steps are required and an initial pressure is necessary to form the jet

10 SPRAY COOLING

In recent years spray cooling has received increasing attention as a means of supporting higher heat flux in electronic cooling applications. Spray cooling breaks up the liquid into fine droplets that impinge individually on the heated wall. Cooling of the surface is achieved through a combination of thermal conduction through the liquid in contact with the surface and evaporation at the liquid-vapor interface. The droplet impingement both enhances the spatial uniformity of heat removal and delays the liquid separation on the wall during vigorous boiling.Spray evaporative cooling with a Fluorinert™ coolant is used to maintain junction temperatures of ASICs on MCMs in the CRAY SV2 system between 70 and 85°C for heat fluxes from 15 to 55 W/cm^2 [41]. In addition to the CRAY cooling application, spray cooling has gained a foothold in the military sector providing for improved thermal management, dense system packaging, and reduced weight [42]. A research group at UCLA discussed chip-level spray cooling for an RF power amplifier and measured a maximum heat flux of over 160 W/cm^2 [43]. Isothermal Systems Research manufactures SprayCool products [44].Spray cooling and jet impingement are often considered competing options for electronic cooling. In general, sprays reduce flow rate requirements but require a higher nozzle pressure drop.

11 PHASE CHANGE MATERIALS AND HEAT ACCUMULATORS

Phase change materials are successfully used as heat-storing materials for air conditioning, cool boxes, efficient fire-retarding powders, as functional materials for self-heating insoles for boots and many other industrial applications. Their use for electronics thermal management is limited to applications where time-dependent phenomena play a role. For example, reference [65] discusses the use of phase change materials as compared to copper for use in a power semiconductor unit.Chemical heat accumulators should also be mentioned. For example, the use of composite materials based on granulated open-porous matrix filled with a hygroscopic substance can be seen as a new approach to accumulate heat [66]. The advantage is a significant increase in the heat that can be stored as compared to sensible heat and latent heat. For example, for a 100°C temperature rise copper absorbs 40 kJ/kg. Evaporation of water is associated with an absorption of 2260 kJ/kg. The enthalpy of a reversible chemical reaction can reach a value of 7000 kJ/kg. A principal advantage of reversible chemical reactions for heat accumulation is their ability to store the accumulated energy for a long time, if the reaction is controlled by the presence of either a catalyst or a reagent. Hence, the major applications are in the field of summer-winter heat storage for buildings, etc. Chemical heat accumulators could potentially be used for outdoor electronic applications when a night-day rhythm is present.

12 CONCLUSIONS

A number of approaches show interesting industrial potential for the cooling of high-power electronics. This prospect is attested to by the number of small companies that are entering the market. For example, there are now companies engaged in the development and commercialization of microchannels, spray cooling, synthetic jets, thin film Peltier elements. For heat flux densities up to and maybe even beyond 50 W/cm^2 air-cooling may remain the cooling option of choice. For heat fluxes over 100 W/cm^2, some form of liquid-cooling appears to be the most viable option. Several papers have demonstrated solutions that may be industrially feasible for application in the range between 500 and 1000 W/cm^2. Considering the range of efforts underway to extend conventional cooling technologies, as well as develop new ones, the future seems bright for accommodating high-heat flux applications.

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