HEAT PIPES IN ELECTRONIC PACKAGING

by

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NOMENCLATURE

Q_{in}	Input power
K_P	Thermal conductivity of pipe
K_W	Effective thermal conductivity of wick structure
K_l	Thermal conductivity of working fluid
K_{wick}	Thermal conductivity of wick material
NE_e	Number of element at evaporator section
NE_a	Number of element at adiabatic section
NE_c	Number of element at condenser section
L_e	Length of evaporator section
L_a	Length of adiabatic section
L_c	Length of condenser section
E_{Le}	Element length at evaporator section
E_{La}	Element length at adiabatic section
E_{Lc}	Element length at condenser section
A_P	Cross sectional area of pipe
A_W	Cross sectional area of wick structure
A_{epi}	Pipe wall – wick structure contact area at evaporator section
A_{ev}	Wick structure – vapour contact area at evaporator section
A_{apo}	Outside surface area of pipe wall at adiabatic section
A_{api}	Pipe wall – wick structure contact area at adiabatic section
A_{av}	Wick structure – vapour contact area at adiabatic section
A_{cpo}	Outside surface area of pipe wall at condenser section

A_{cpi}	Pipe wall – wick structure contact area at condenser section
A_{cv}	Wick structure – vapour contact area at condenser section
H_{ewp}	Heat transfer coefficient between pipe wall and wick structure at evaporator section
H_{ewv}	Heat transfer coefficient between wick structure and vapour at evaporator section
H_{apo}	Heat transfer coefficient between pipe wall and ambient at adiabatic section
H_{awp}	Heat transfer coefficient between pipe wall and wick structure at adiabatic section
H_{awv}	Heat transfer coefficient between wick structure and vapour at adiabatic section
H_{cpo}	Heat transfer coefficient between pipe wall and cooling fluid at condenser section
H_{cwp}	Heat transfer coefficient between pipe wall and wick structure at condenser section
H_{cwv}	Heat transfer coefficient between wick structure and wick structure and condenser section
C_{P_P}	Specific heat of pipe
C_{P_W}	Specific heat pf wick structure
C_{P_V}	Specific heat of vapour
$\dot{m}$	Vapour mass flow rate
L	Latent heat of vaporisation
ρ_P	Density of pipe
ρ_W	Density of wick structure
ρ_V	Density of vapour
T_P	Temperature of pipe wall
T_W	Temperature of wick structure

T_V	Temperature of vapour
T_∞	Ambient temperature
T_f	Cooling water temperature

Greek Notations

ε	Wick porosity

PAIP HABA DALAM PEMBUNGKUSAN ELEKTRONIK

ABSTRAK

Industri electronik berkembang ke arah qualiti dan kelajuan computational yang tinggi. Keadaan ini menyebabkan peningkatan dalam flux haba. Sehubungan itu, para jurutera menghadapi satu cabaran baru untuk menangani masalah dalam pembungkusan chip. Berbanding dengan kesemua keadah penyejukan, paip haba merupakan pilihan yang lebih baik kerana efficiensi dan reliabiliti yang tinggi. Oleh itu, penyelidikan yang lebih lanjut perlu dilakukan dengan menggunakan parameter yang berlainan untuk memahami prinsipal paip haba. Bahagian pertama penyelidikan meliputi fabrikasi pelbagai saiz paip haba dan pemanasan dilakukan dengan beberapa keamatan yang berlainan. Melalui cara ini, penyebaran haba sepanjang paip of paip haba boleh diperolehi. Selain itu, kajian dilakukan dengan menambahkan bilangan punca haba dan mengenalpasti penyebaran suhu sepanjang paip tersebut. Kajian menunjukan bahawa, suhu maksimum bagi sistem meningkat apabila keamatan suhu meningkat dan purata perbezaan suhu bagi kesemua kes adalah ± 7°C. keputusan yang diperoleh masih dalam julat yang boleh diterima bagi paip haba. Bahagian kedua meliputi keadah Finite Element digunakan dan sejurusnya dikembangkan melalui MATLAB 6.0 untuk menjana sistem model haba analisis yang mempunyai ciri-ciri sama seperti dalam experiment. Model jangkaan ini digunakan untuk membuat perbandingan dan menentusahkan keputusan experiment. Analisis menunjukkan perbezaan diantara kedua-dua model experiment dan analisis

sangat minimal iaitu ± 4°C. ini membuktikan ujikaji melalui experiment dijalankan dengan betul dan perkembangan lanjut perlu dilakukan untuk penggunaan masa hadapan. Bahagian akhir dalam penyelidikan ini adalah mengenai penggunaan paip haba dalam pembebasan haba oleh telefon bimbit. Dalam isu telefon bimbit, paip haba mikro digunakan untuk memindahkan haba dari kawasan penjana ke kawasan persekitaran. ANAYS digunakan untuk simulasi haba yang bertindakbalas ke atas 'heat spreader'. Beberapa parameter dipilih dan kajian dilakukan untuk optimasi penyebaran haba dipersekitaran 'heat spreader'. Sumilasi dijalankan berpandukan empat parameter yang berlainan iaitu bilangan paip haba, jarak diantara setiap paip haba, bilangan penjana haba dan kadar penjana haba. Kajian ini membolehkan maklumat mengenai penyebaran haba di dalam telefon bimbit diperoleh dan boleh dikaji pada masa hadapan. Keadah ini membantu untuk mendapatkan kadar penyebaran haba yeng lebih baik dalam produk electronik bimbit.

HEAT PIPES IN ELECTRONIC PACKAGING

ABSTRACT

The electronic industry is developing towards higher quality and computational speed. It has led to the increase in chip heat fluxes. Therefore, the challenge has come for the engineers to overcome the problem in chip packaging. Among all the cooling methods, heat pipe is a better selection because of its high efficiency and reliability. Therefore, further studies have been carried out to understand the behavior of heat pipe with different parameter. The first part of the research consists of fabrication of various sizes of heat pipes and applies variable heat input. Therefore it's characteristic and the heat dissipation of heat pipe along a certain length can be obtained. More over, studies are done by increasing number of heat sources and to identify its temperature distribution along the heat pipe. The research shows that, then maximum temperature increases when heat input increases and average temperature drop for all entire case is ± 7°C. This result is in an acceptable range for well designed heat pipe. Secondly, Finite Element Method is developed through MATLAB 6.0 and to simulate the predicted thermal model which has the similar features with the experiment. This predicted thermal model is later used to compare and verify with the experimental results. The analysis done shows that the variation between both experimental values and predicted values are very minimal and it is around ± 4°C. Thus, this strongly proves that the experiment is correctly done and further enhancement can be done for future application. Final part of the research is about application of heat pipes in power dissipation of cellular phones. In the case of cellular phone, micro heat pipe is used to transfer heat from heat spreader to casing and antenna. ANSYS is used to simulate the heat dissipation on the heat spreader. Several parameters have been studied to obtain the optimal heat dissipation along the heat spreader. The simulation is based on four different parameters, which are number of heat pipes, spacing between heat pipes, numbers of heat sources and heat generation rate. With parametric study, more information on heat dissipation along heat spreader of cellular phone can be gained. This method helps in achieving better power dissipation in portable electronic products.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Electronic industry has taken a new revolution as we venture into the era. Most of the electronic components from microprocessor to high-end power converter generates and rejects heat for their optimum and reliable operation. Moreover, the continuous increase in the system power and the shrinkage of portables devices present increasing challenges in thermal management at the component level and system level. Other than that many of today's electronic devices require cooling beyond the capability of standard metallic heat sinks. Effective cooling of electronic components is crucial for successful functioning and high reliability of modern electronic devices. The heat generated in these electronic devices must be dissipated. Heat pipe which was introduced by Gaugler in 1942 as a cooling strategy for electronic equipment present a promising alternative compared to traditional cooling schemes. The main concept of a heat pipe involves passive two-phase heat transfer device that can transfer large quantity of heat with minimum temperature drop. This method offers the possibility of high local heat removal rates with ability to dissipate heat uniformly.

Heat pipe is currently being studied for a variety of applications, covering almost the entire spectrum of temperatures encountered in heat transfer processes. Heat pipes are used in wide range of products like air-conditioners, refrigerators, heat exchangers, transistors and capacitors. Heat pipes are also used in laptops to reduce the working temperature for better performance. Their application in the field of cryogenics is very significant, especially in the development of space technology. Heat pipes are commercially available since the mid 1960's. Electronic industry has just embraced heat pipe as reliable and cost-effective solution for high-end cooling application.

Heat pipe is a very efficient heat conductor. It is also referred to as a superconductor. A typical heat pipe consists of a vessel in which its inner walls are lined with a wick structure. The vessel is first vacuumed, then charged with a working fluid, and hermetically sealed. When the heat pipe is heated at one end, the working fluid evaporates from liquid to vapour (phase change). The vapour travels through the hollow core to the other end of the heat pipe at sonic speed, where a condenser removes heat energy. Here, the vapour condenses back to liquid and releases heat at the same time. The liquid then travels back to the original end via wick by capillary action. The energy required to change phase from liquid to gas is called the latent heat of evaporation. In electronic cooling applications, it is important to maintain junction temperatures below 125-150 °C. In this case, copper/water heat pipes are typically used.

Sim (2001) quoted in his work that, as the demand for smaller and more powerful electronics devices continuously increases, it creates an opening to optimize the demand in thermal management at component and system level. If the temperature constrain is not fulfilled, the electronic devices will not work at its best. Because of that reason, thermal management is given a lot of importance in electronic packaging.

1.2 Fundamental Working Principles of Heat Pipes

Figure 1.1 shows that, a typical heat pipe consist of three main sections, which include an evaporator section, an adiabatic section, and a condenser section. Heat added at the evaporator section vaporises the working fluid, which is in equilibrium with its own vapour. This creates a pressure difference between evaporator section and condenser section, which drives the vapour through the adiabatic section. At the condenser section, heat is removed by condensation and is ultimately dissipated through an external heat sink. The capillary effect of the wick structure will force the flow of the liquid from condenser to evaporator section.

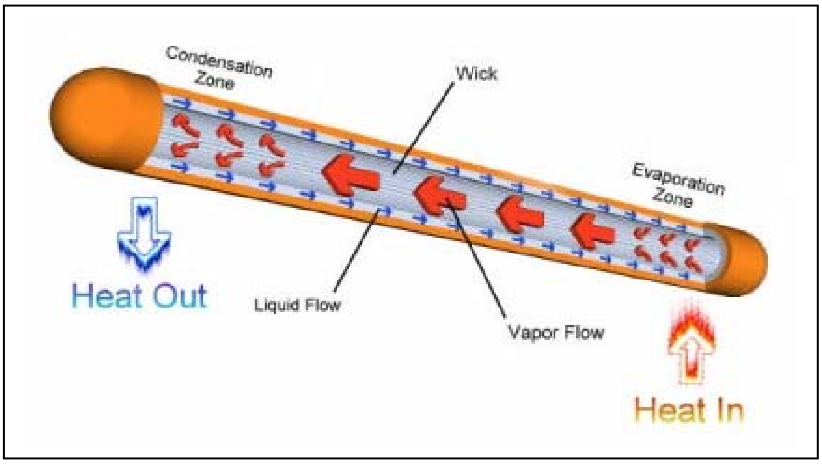


Figure 1.1 Heat pipe Construction and Operation.

Heat pipe operates on a closed two-phase cycle and utilizes the latent heat of vaporization to transfer heat with a very small temperature gradient. Heat pipe consists of three main parts, which are the vessel, wick structure and working fluid. The vessel or a container is normally constructed from glass, ceramics or metal. Wherelse wick structure is constructed from woven fibreglass, sintered metal powders, screen, wire meshes, or grooves. Finally, typical working fluid used varies vary from nitrogen or helium for low temperature heat pipes to lithium, potassium or sodium for high temperature. In order to fabricate a working heat pipes, all three parts are given important consideration to the material type, thermo physical properties and compatibility. Working principles of heat pipe can be represented in a block diagram as shown in figure 1.2.

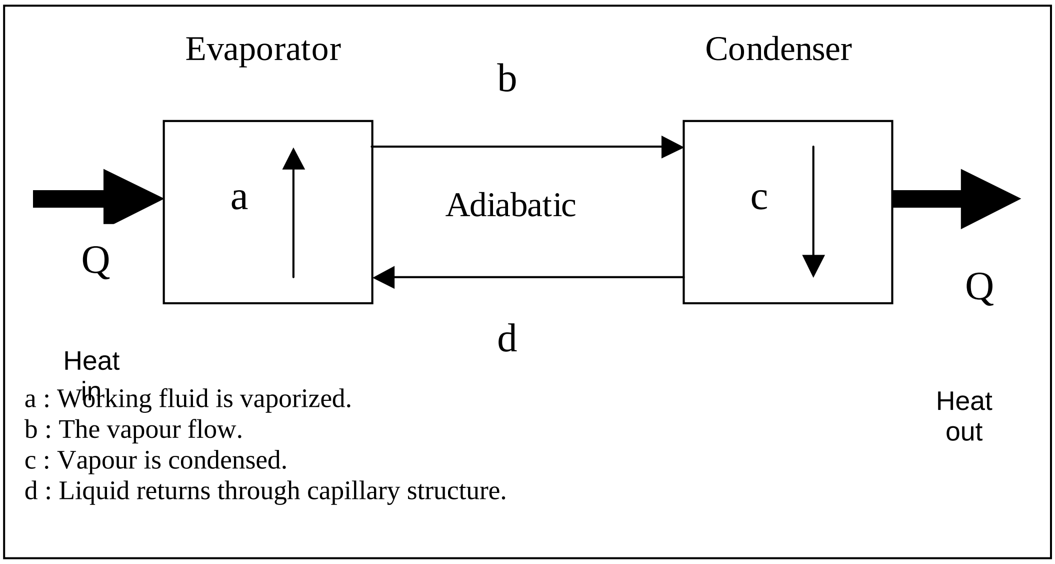


Figure 1.2: Block Diagram of a heat pipe.

Heat pipe is capable of creating its own capillary pressure at the evaporator end. This would cause a continuous flow of liquid in the wick and replenish the liquid at the evaporator zone. Heat flow through evaporator section and condenser section assumed to be adiabatic. Due to this reason, the vapour experiences a negligible temperature drop. Generally heat pipes exhibit thermal characteristics that are even better than a solid conductor of the same dimension.

As for wick structure, the working fluid travels from the condenser section to the evaporator section. The working fluid should be evenly distributed over the evaporator section. In order to provide a proper flow path with low flow resistance, an open porous structure with high permeability is desirable. This is to ensure that the working fluid returns from the condenser to the evaporator**.**

1.3 Heat Pipe Design

There are many factors to consider when heat pipe is designed. Compatibility of materials, operating temperature range, length and diameter of heat pipe, power limitation, heat transport limitation of the heat pipe, thermal resistance, effect of bending and flattening of the heat pipe and operating orientation are given high importance. However, the design issues are reduced to certain major considerations by limiting the selection to copper/water heat pipes for cooling electronics.

The main consideration is the amount of power the heat pipe is capable of carrying. Another aspect is the temperature range that the particular working fluid can operate. This working fluid needs a compatible vessel material to prevent corrosion or any chemical reaction. Table 1.1 illustrates the typical characteristics of heat pipe (www.enertron.com).

Table 1.1: The Typical Characteristics of Heat Pipe.

Temperature Range (°C)	Working Fluid	Vessel Material	Measured axial[8] heat flux (kW/cm²)	Measured surface[8] heat flux (W/ cm²)
-200 to -80	Liquid Nitrogen	Stainless Steel	0.067 @ -163°C	1.01 @ -163°C
-70 to +60	Liquid Ammonia	Nickel, Aluminum, Stainless Steel	0.295	2.95
-45 to +120	Methanol	Copper, Nickel, Stainless Steel	0.45 @ 100°C[X]	75.5 @ 100°C
+5 to +230	Water	Copper, Nickel	0.67 @ 200°C	146@ 170°C
+190 to +550	Mercury* +0.02% Magnesium +0.001%	Stainless Steel	25.1 @ 360°C*	181 @ 750°C
+400 to +800	Potassium*	Nickel, Stainless Steel	5.6 @ 750°C	181 @ 750°C
+500 to +900	Sodium*	Nickel, Stainless Steel	9.3 @ 850°C	224 @ 760°C
+900 to +1,500	Lithium*	Niobium +1% Zirconium	2.0 @ 1250°C	207 @ 1250°C
1,500 + 2,000	Silver*	Tantalum +5% Tungsten	4.1	413

[8]Varies with temperature
[X]Using threaded artery wick
*Tested at Los Alamos Scientific Laboratory
*Measured value based on reaching the sonic limit of mercury in the heat pipe
Reference of "Heat Transfer", 5th Edition, JP Holman, McGraw-Hill

1.4 Limitations on Heat Transport Capacity

Heat pipe performance and operation are strongly dependent on shape, working fluid and wick structure. Certain heat pipes can be designed to carry a few watts or several kilowatts, depending on the application. The effective thermal conductivity of the heat pipe will be significantly reduced if heat pipe is driven beyond its capacity. Therefore, it is important to assure that the heat pipe is designed to transport the required heat load safely.

But during steady state operation, the maximum heat transport capability of a heat pipe is governed by several limitations, which must be clearly known when designing a heat pipe. There are five primary heat pipe transport limitations;

1.4.1 Viscous

Viscous force will prevent vapour flow in the heat pipe. This causes the heat pipe to operate below the recommended operating temperature. The potential solution is to increase the heat pipe operating temperature or operate with an alternative working fluid.

1.4.2 Sonic

Vapour will reach sonic velocity when exiting the heat pipe evaporator resulting at a constant heat pipe transport power and large temperature gradient. The main reason is the power and the temperature combination. In other words, the heat pipe is due operating at low temperature with too much of power. This is a normal problem during a start-up. The potential solution for this limitation is to create large temperature gradient so that heat pipe system will carry adequate power as it warns up.

1.4.3 Entrainment/Flooding

This is where high velocity vapour flow prevents condensate vapour from returning to evaporator. The main reason is due to low operating temperature or high power input that the heat pipe is operating. To overcome this, the vapour space diameter or the operating temperature is increased.

1.4.4 Capillary

It is the combination of gravitational, liquid and vapour flow and pressure drops exceeding the capillary pumping head of the heat pipe wick structure. The main cause is the heat pipe input power exceeds the design heat transport capacity of the heat pipe. The problem can be resolved by modifying the heat pipe wick structure design or reduce the power input.

1.4.5 Boiling

It is described as a film boiling in a heat pipe evaporator that typically initiates at 5-10 W/cm^2 for screen wick and 20-30 W/cm^2 for power metal wicks. This is caused by high radial heat flux. It will lead towards film boiling resulting in heat pipe dry-out and large thermal resistances. The potential solution is to use a wick with a higher heat capacity or spread out the heat load.

1.5 Advantages of Heat Pipes

There are a lot of advantages in the application of heat pipe compare to other cooling devices. These several characteristics of heat pipe that make them useful in a wide variety of applications were identified by Eastman (1968). Firstly, the heat transfer capacity of a heat pipe may be several orders of magnitude greater than even the best solid conductors because it operates on a closed two-phase cycle. These characteristics may result in a relatively small thermal resistance and allows physical separation of the evaporator and condenser without high penalty in overall temperature drop.

Moreover, the increase in the heat flux in the evaporator may increase the rate at which the working fluid is vaporized, without significant increase in the operating temperature. Thus, the heat pipe can operate as a nearly isothermal device, adjusting and maintaining a relatively constant source temperature.

Another advantage of heat pipe is that both the evaporator and condenser operate independently. It needs only common liquid and vapour stream. Because of this, the area where heat is added can differ in size and shape from the area over which heat is rejected, provided the rate at which the liquid is vaporized does not exceed the rate at which it is condensed. In this case, heat fluxes generated over relativity small areas can dissipate over larger areas with reduced heat fluxes. This characteristic is useful in the thermal control of electronic components. Because it allows the high fluxes generated at the component level to be reduced and allows convection to be used to dissipate the heat. Finally, its thermal responds time is less than other heat transfer device such as solid conductors. The main reason is the closed two-phase cycle.

1.6 Effective Thermal Resistance

As discussed previously, heat pipe requires a very small temperature difference because of the usage of the latent heat of vaporization. This will cause the effective thermal conductivity to be few times greater then the best solid conductors. Figure 1.2 shows the comparison of the heat pipe and solid conductors.

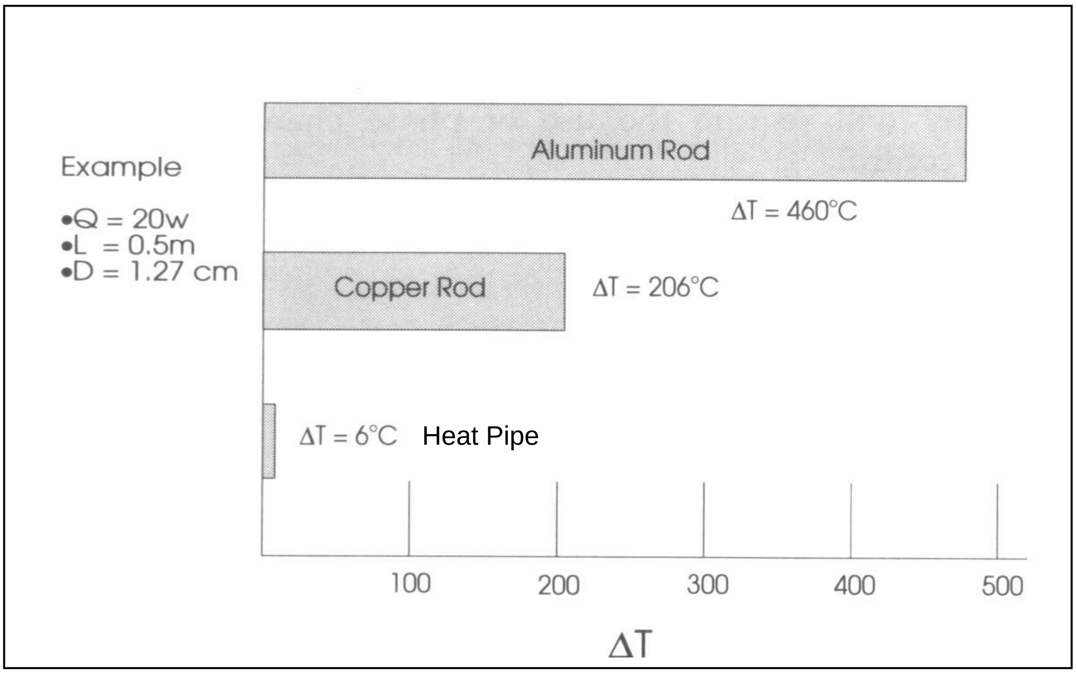


Figure 1.3: Comparison of heat pipe and solid conductors.

1.7 Heat Pipe analysis in Portable Device

Portable electronic devices like cellular phones increasingly offer more electronic features. The operating conditions of cellular phone along with high powered components present enormous challenge to the cooling system. To overcome this, heat spreader is used to dissipate heat in cellular phones. One large heat spreader is perceived to be more efficient compared to several smaller ones. Heat pipes can further enhance the heat dissipation by transporting the heat away from the source. Higher efficiency is achieved when a heat spreader is incoperated with a heat pipe having good contact between them. Keypad can be used as a heat spreader, which dissipates heat to the environment. This approach is used to reduce hot spots on cellular phones.

Basically, heat spreader is a thin planar heat pipe whose thickness can be as low as 500 microns. It can be used to replace the outer shell of portable electronic device. Figure 1.4 shows a perspective view of a thick heat spreader attached to the heat pipes of a portable device skin. This heat spreader device is used for uniform heat dissipation from multiple heat sources to the outer skin, eliminating the need for additional heat sinks and fans.

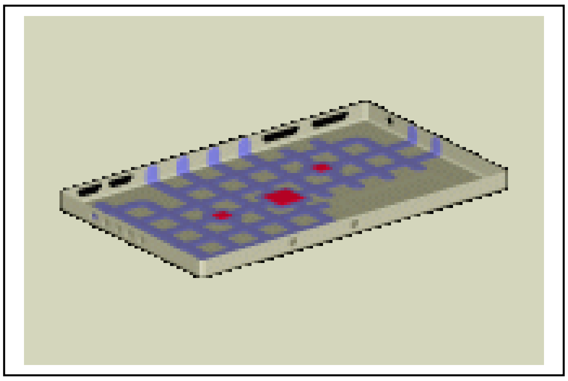


Figure 1.4: Heat spreader in a portable device shell.

Sim (2001) has developed a method to determine heat dissipation profile using FEM model to predict the pipe wall and vapour temperature distribution. This method lead to the simplified heat pipe design and determination of hot spots for arbitrary location of heat source on electronic devices.

Heat pipes seemed to be a popular method of cooling in current electronic packages. A lot of experimental data were generated and gathered by researchers to have a better understanding of the working principals and its future applications in thermal management. Numerical investigations have been conducted in a big scale by researchers to compare with the available experimental results. This topic is worth pursuing since extensive research had been done to improve the current results and it still has a lot to explore to maximize its potential.

CHAPTER 2

Literature Survey

Extensive research had been done in exploring the application and horizon of the heat pipe in current research. Studies show that the usage of heat pipe will be expanding in coming years. Current papers published are focusing on multiple orientations of heat pipe applications and its performances in electronic packaging industry. The literature reviews presented in this chapter covers the scope of steady state, transient state and studies on flat plate heat pipes.

Heat pipes have been widely used in military applications, which have high reliability standards. Test data collected on field heat pipes applied to electronic cooling shows the mean time between failure values is in excess of 120000 hours. According to Xie and Aghazadeh(1998) properly manufactured copper/water heat pipe can reasonably be expected to operate for 30 years.

Babin and Peterson (1990) carried out an experimental investigation of a cylindrical bellows heat pipe. Three-heat pipe is constructed. The heat input to the evaporator occurs axially through the end face, while heat rejection occurs radially in the condenser. For the three heat pipes, the boiling limit occurs over most of the operating temperature range tested. For a 2054 cm long condenser and a 45° tilt angle, an axial heat flux of 200 W/cm^2 is obtained with a temperature drop of 65°C between the evaporator and the condenser resulting in a thermal resistance of 0.7K/W. The axial heat flux is the heat transfer rate divided by the cross sectional area of a heat pipe. Normally, it is higher than the radial heat flux, defined as the heat transfer rate divides by the heat transfer area at the evaporator. One of the main advantages of the concept is insensitivity to vibrations. Another advantage is the inherent flexibility of the bellows structure compensates any misalignment between the component and the heat pipe evaporator. Thus, the contact resistance between component and evaporator is reduced.

Adami and Yimer (1990) reported the results from an experimental investigation of a copper flat plate heat pipe, 305 mm long, 152 mm wide and 19 mm thick. The capillary structure is a 100 mesh copper screen. Water is used as working fluid. The heat pipe operation is stable within a temperature range of 35°C to 95°C. With forced convective cooling, a maximum heat transfer rate of 110W is obtained with an axial temperature drop of 10°C.

Experimental investigations of the transient respond of a water heat pipe were carried out by El-Genk and Lian (1993). Experiments were performed to investigate the transient response of a water heat pipe to step changes in input power at different cooling rates. The copper heat pipe employs a double-layered, mesh copper screen wick and its evaporator section was uniformly heated while the condenser was convectively cooled. The time constants of the vapour temperature and the effective power, for both heat up and cool down transients, were determined as functions of the electric power input and the water mass flow rate in the cooling jacket of the condenser section. Both the vapour and the wall temperatures were measured at ten axial locations along the heat pipe. Results on transient studies shows that the vapour temperature and wall temperature was almost uniform along the heat pipe. It also reported that the time constant for the vapour temperature and the effective power depend on their steady-state values and their rate of changes at the beginning of the transient state.

Said and Akash (1999) carried out an experimental performance on a heat pipe. According to their research, heat transmitted through a heat pipe is based on phase change, it can be pointed out using a heat pipe with similar dimensions of a solid pipe, and thus large amount of heat transfer can be obtained. Their application is wide and has been used for heat recovery in hot exhaust gas system (energy conversion) and for use in domestic and industrial application.

Result obtained show that in steady state condition, temperature is always higher for a wickless heat pipe compared to the wick for a given tilt angle measured from the horizontal axis. For the entire tilt angle given, it shows that the wickless heat pipe reaches steady-state evaporator temperature condition faster then the heat pipe with wick structure. Furthermore it also shows that the temperature gradient is higher for a heat pipe with no wick structure. They also discovered that, drawing heat from evaporator section is faster in heat pipe with wick structure than without wick structure.

According to their results, it is better to have the condenser as close as possible to the steady state temperature. When the wick is used, the best performance occurred when the heat pipe is positioned at an angle of 90°C, by which its steady-state temperature reaches about 150°C. It also shows that the heat pipe with wick structure starts with a slow temperature gradient in the first 20 to 30 minutes before it accelerates at high temperature gradient of around 4.0°C/min. Moreover, the overall heat transfer coefficient for the conditions is evaluated for all six cases. It shows that the performances of the heat pipe are improved when wick is used.

Tan et al(2000) carried out an analytical approach to study liquid flow in an isotropic wick structure of a flat plate heat pipe with multiple heat sources. In this study, the heat sources have been modelled as point sources using Dirac-Delta function to describe the heat distribution. The study has been extended to locate the position of the multiple heat sources for optimum heat pipe performance. The optimum performance of the heat pipe is accomplished when the minimum pressure drop is attained cross the wick structure. By using Dirac-Delta function, the distribution function can be developed to express distribution of any number of point heat sources on the heat pipe surface. The simplified analytical model employing point source is capable of predicting qualitatively the pressure and velocity distribution in a two-dimensional flat plate heat pipe. This analytical method is particularly suitable for locating heat source positions for optimum heat pipe performance. They concluded that this analysis is very suitable if the Printed Circuit Board (PCB) with different capacity of heat sources are presented on a design.

Sim (2001) studied on heat pipes and its applications in electronics packaging. Finite Element Method (FEM) was used to study the performance of a cylindrical heat pipes. In steady state analysis, wall and vapour temperature distribution is obtained by using Gauss elimination method. The maximum heat transport capacity of a heat pipe as well as the effect of cooling load at the condenser section was analysed. This analysis used to provide a solution for cooling of PCB or thermal management at system level. Based on the studies in single heat source-cooling scheme, the length of the evaporator, adiabatic and condenser are chosen. Each section are divided into number of elements. The comparison made between prediction models with the numerical and the experimental results of the vapour and pipe wall temperature distribution along the heat pipe. The prediction models of both vapour and wall temperature agreed well with the numerical and experimental results.

Faghri and Buchko (1991) carried out the experimental and the numerical analysis for the circular heat pipes operating at low temperature. They concluded that the maximum head load on heat pipe varies greatly with the locations of the local heat fluxes. They did an analytical evaluation on the liquid pressure and the velocity distribution. The heat source locations on the heat pipe are important for an optimum heat pipe performance. According to their studies, the most appropriate location to place the source for efficient dissipation is determined using this analytical method. The simplified analytical model is capable of predicting the pressure and velocity distribution qualitatively in a two-dimensional heat pipe model. At these optimised locations, minimal liquid pressure drop is achieved across the wick structure in the heat pipe as compared to the other heat source locations.

Mazuik et al(2001) studied experimentally the performance of a heat pipe. They used flat miniature pipe with copper sintered powder wick structure with water. The main idea was to make sure that the conventional heat pipe technologies are put to practical use in large quantities. The high fluxes typical for the electronic equipment had to use effective heat pipe with high heat transfer capabilities at any inclination. Therefore, miniature heat pipes are used with improved wick structure due to its suitable operation at high heating mode typical for most portable device. The studies were done by comparing the experimental with the developed software results.

Namba et al(2000) carried out studies on heat pipe for electronic devices and evaluation of their thermal performances. The study includes the performances of miniature heat pipe developed for cooling of notebook computer thermal system. Experiments for the miniature heat pipe were conducted on their thermal properties and reliability. As a result of the tests, maximum heat transfer rate and reliability of the miniature heat-pipe developed were obtained and it was indicated that the miniature heat-pipe could be applied to electronic equipment cooling. These evaluations testing of the cooling system using this miniature heat-pipe have clarified its effectiveness. Thus, proving the cooling system using miniature heat-pipe was extremely effective for cooling notebook computer.

Seok et al(2002) improved the thermal performance of miniature heat pipe for notebook cooling. A miniature heat pipe (MHP) with woven wire wick was used for cooling a notebook computer. The cross-sectional area of the pipe is reduced by about 30% of the original, when the diameter of the MHP is pressed from 4 to 2 mm for packaging in a notebook computer. In the present study, a test of the MHP has been performed in order to review the thermal performance by varying pressed thickness, total length of MHP, wall thickness, heat flux and inclination angle. New wick types were considered for overcoming low heat transfer limits, which occur when the MHP is pressed to a thin plate. Through a performance test, the limiting thickness of pressing is shown to be within the range of 2 to 2.5 mm.

When the wall thickness of 0.4 mm is reduced to 0.25 mm for minimizing conductive thermal resistance through the wall of heat pipe, the heat transfer limit and thermal resistance of the MHP were improved by about 10%. While the thermal resistance of the MHP with central wick type is lower than that of the MHP with circular oven wire wick, the thermal resistance of the MHP with composite wick of woven/straight wire is higher than that of the MHP with circular woven wire wick. From the performance test conducted on the MHP cooling modules with woven wicks, it was observed that the T_{jc} (junction temperature of the processor) satisfies a demand condition of being between 0°C and 100°C^{0}C. This shows the stability of the MHP as a cooling system of notebook computers.

Sung et al(2002) conducted analytical and experimental investigations on the operational characteristics and the thermal optimization of a miniature heat pipe with a grooved wick structure. A mathematical model for heat and mass transfer in a miniature heat pipe with a grooved wick structure is developed and solved analytically to yield the maximum heat transport rate and the overall thermal resistance under steady-state conditions. The effects of the liquid–vapor interfacial shear stress, the contact angle, and the amount of initial liquid charge have been considered in the proposed model. In particular, a novel method called a modified Shah method is suggested and this method is an essential feature of the proposed model. In order to verify the model, experiments for measuring the maximum heat transport rate and the overall thermal resistance were conducted. The analytical results for the maximum heat transport rate and the total thermal resistance based on the proposed model were shown to be in close agreement with the experimental results. From the proposed model, numerical optimization was performed to enhance the thermal performance of the miniature heat pipe. It was estimated that the maximum heat transport rate of 3 mm and 4 mm outer diameter heat pipes can be enhanced up to 48% and 73%, respectively, when the groove wick structure was optimized from the existing configurations. Similarly, the total thermal resistance of these heat pipes can be reduced by 7% and 11%, respectively, as a result of optimization.

Lin et al(2002) did further studies on miniature heat pipes. High performance miniature heat pipes were developed for the cooling of high heat flux electronics using new capillary structures made of a folded copper sheet fin.

Using the folded sheet fin, capillary flow channels with fully and partially opened grooves are made by electric-discharge-machining technique. It is easy to form the capillary grooves as dense as desired through the present fabrication techniques. Heat pipes with two different capillary structures and different fill amounts were tested in the horizontal orientation. Activating different numbers of chip resistors simulates three heating modes of the evaporator. The heat pipe with partially opened groove wick performed better than that with fully opened groove wick. The condenser heat transfer coefficient was higher by 120% or greater in the case of the former wick type compared to the latter at an operating temperature of 110°C. Heat fluxes higher than 140 W/cm^2 are achieved using concentrated heating modes.

Jones et al(2003) studied on micro heat pipes in low temperature Co-fire Ceramic (LTCC) Substrates. With projected power densities above 100 W/cm^2 for devices, new methods for thermal management from the heat generation at the die to heat removal to the ambient must be addressed. By integrating micro heat pipes directly within the ceramic substrate, effective thermal conductivity for spreading heat in both radial and axial directions was achieved. New materials and processes were developed to fabricate the unique components required to handle high thermal loads. Enhanced thermal technique used to minimize the thermal impedance through the ceramic in the evaporator and condenser sections were developed, increasing the effective thermal conductivity from 2.63 W/m°C to near 250 W/m°C. The use of an organic insert fabricated into the desired complex shape using rapid prototyping methods, coupled with the viscoelastic flow of the low temperature co-fire ceramic (LTCC) during lamination, allowed complex shapes to be developed while ensuring uniform green tape density during lamination prior to tape firing. Large cavities, three-dimensional fine structures and porous wicks for capillary 3-D flow were utilized to fabricate the heat pipes. Heat pipes and spreaders, using water as the working fluid, have been shown to be successfully operated with power densities in excess of 300 W/cm^2.

Sahin and Kalyon (2005) investigated the surface temperature along pipes. They used insulation to maintain uniform surface temperature along the pipes. An analytical solution was obtained for the insulation thickness variation over a pipe to maintain a uniform outer surface temperature. A high temperature fluid is considered to be flowing through the pipe. The amount of the insulation material is assumed to be finite. Heat transfer from the outer surface of the pipe is through convection and radiation. The results of the solution shows that insulation thickness was found to be independent from the outer surface convective and radiative heat transfer coefficients. In addition, the solution was found to be very close to linear variation, which was very easy to implement in practice. For high velocity fluid flow problems and low thermal conductivity insulation material applications the insulation thickness may be applied uniformly over the pipe as the variation of the outer surface temperature will be insignificant.

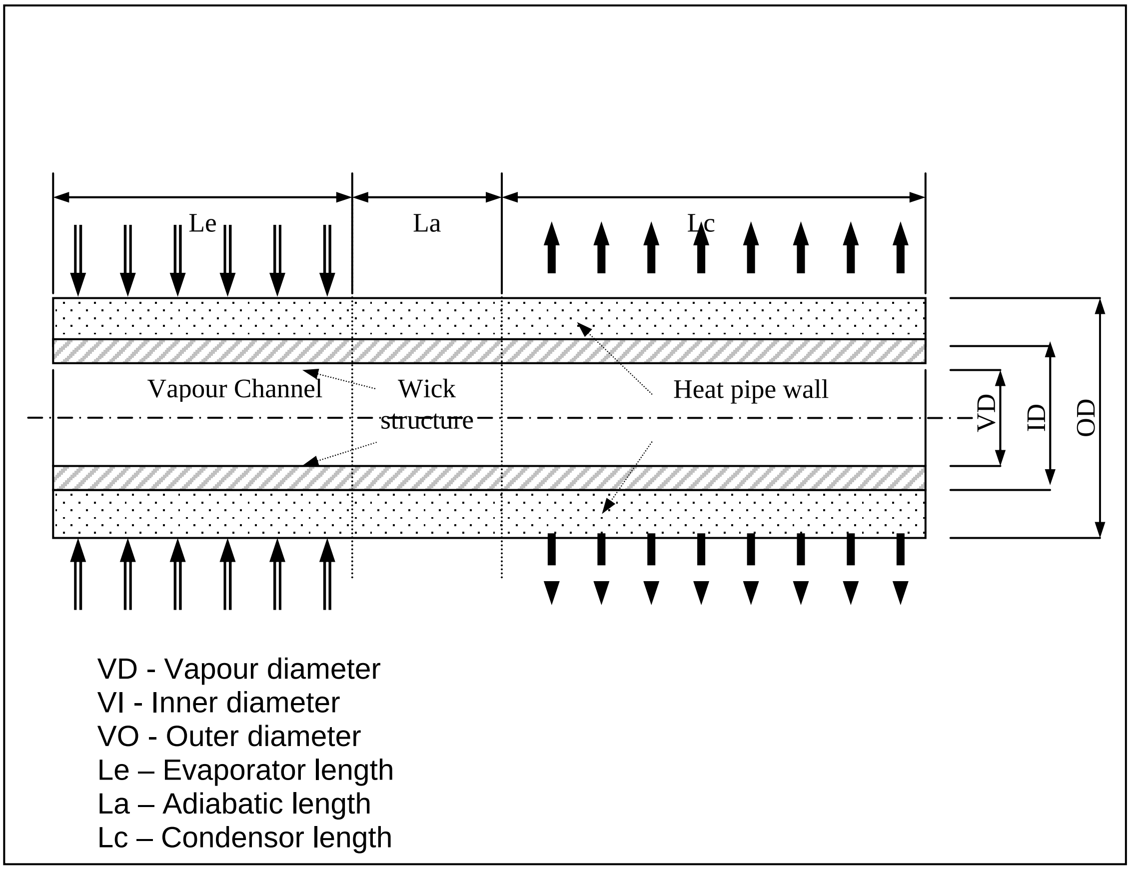
CHAPTER 3

METHODOLOGY

The main issue in any electronic packaging system is the cooling in the system. There are two main concerns with these cooling situations. Fan is an alternative cooling system but it consumes a lot power and low reliability. Hence heat pipe is used to replace fans. Heat pipe works independently and no power consumption. In addition, heat pipe is very well known for its high heat transfer rate. Heat pipe is capable of transferring a large quantity of heat with small temperature gradient at both ends. This is the characteristic that makes heat pipe an ideal solution for maintaining the junction temperature range of electronic components at an acceptable level.

This section consists mainly of three important parts. First is the solution using Finite Element Method (FEM) to solve the mathematical equations. The second part is the heat pipe development and fabrication and experimental set up. The final part of this chapter focuses on parametric studies on the application of heat pipe in cellular phone.

In the analytical part, the most important parameter is the temperature distribution along the heat pipe. This is essential to analyse the performance of the heat pipe and to determine the junction temperature. All these studies are done by solving the governing heat transfer equation. In order to solve these complex mathematical expressions, FEM is used to analyse steady state. Figure 3.1 shows schematic drawing of a heat pipe.



The Figure 3.1: Schematic drawing of a heat pipe.

3.1 Steady State analysis

In order to do some studies in heat pipes, certain assumption had to be made. This had to be done to derive the governing heat transfer equation for evaporator, adiabatic and condenser section. In steady state condition, the vapour and liquid flow are steady, laminar and incompressible. It is assumed that vaporization and condensation process to be uniform. The wick structure is also assumed to be isentropic and saturated with the working fluid. This analysis are adapted from Sim (2001) and developed accordingly for this study. This analysis is important because the result is later compared with the results obtained experimentally.