The impact of wick structure in LHP to remove waste heat from electronic component

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Abstract. Loop heat pipes (LHP) are used in many branches of industry, mainly for cooling of electrical elements and systems. The loop heat pipe is a vapour-liquid phase-change device that transfers heat from evaporator to condenser. One of the most important parts of the LHP is the porous wick structure. The wick structure provides capillary force to circulate the working fluid. To achieve good thermal performance of LHP, capillary wicks with high permeability and porosity and fine pore radius are expected. The aim of this work is to develop porous wick of sintered copper powder with different grain sizes. There were grain sizes with 50 and 100 μm. Then this porous wicks were used in LHP and there were performed a series of measurements impact of wick to remove waste heat from the insulated gate bipolar transistor (IGBT).

Keywords: loop heat pipe, wick, cooper, powder, porosity
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INTRODUCTION

The trend development of electronic components is miniaturization of the dimension. It leads to an increase waste heat. This heat is often leads to lower performance and failure of electronic components in case of insufficient cooling. In order to maintain appropriate working conditions, waste heat must be removed. One of possibility to remove waste heat is use loop heat pipe (LHP). LHPs are two-phase heat transfer devices that utilize the evaporation and condensation of a working fluid to remove heat, and the capillary forces developed in fine porous wicks to circulate the fluid. LHP consists of an evaporator with wick, a condenser, a compensation chamber, and liquid and vapor line (Figure 1). Only the evaporator and the compensation contain wicks; the rest of the loop is made of smooth wall tubing. The wick in the evaporator is made with fine pores for purpose of developing a capillary pressure to circulate fluid around the loop, while the wick in the compensation chamber is made with larger pores for purpose of managing fluid ingress and egress. The operating principle of the LHP is as follows. As heat is applied to the evaporator, liquid is vaporized and the menisci formed at the liquid/vapour interface in the evaporator wick develop capillary forces to push the vapour through the vapour line to the condenser. Vapour condenses in the condenser and the capillary forces continue to push liquid back to the evaporator. The waste heat from the heat source provides the driving force for the circulation of the working fluid and no external pumping power is required. The two - phase compensation chamber stores excess liquid and controls the operating temperature of the loop.

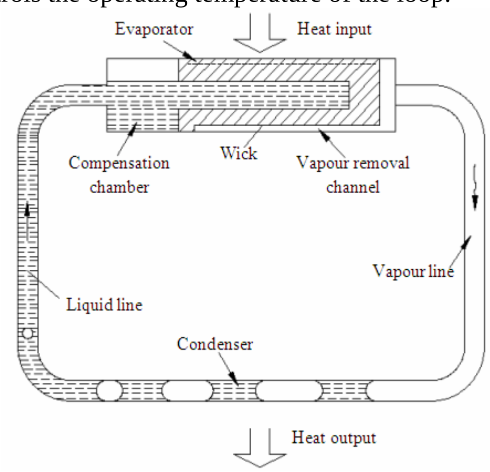


FIGURE 1. Schematic diagram of LHP.

In order for the loop to continue to function, the wick in the evaporator must develop a capillary pressure to overcome the total pressure drop in the loop. One of the advantages of a capillary loop is that the meniscus in the evaporator wick will automatically adjust its radius of curvature such that the resulting capillary pressure is equal to the total system pressure drop. The total pressure drop in the system is the sum of frictional pressure drops in the evaporator grooves, the vapour line, the condenser, the liquid line, and the evaporator wick, plus any static pressure drop due to gravity:

$$\Delta P_{total} = \Delta P_{groove} + \Delta P_{vap} + \Delta P_{con} + \Delta P_{liq} + \Delta P_w + \Delta P_g \quad (1)$$

The capillary pressure rise that the wick can develop is given by

$$\Delta P_{cap} = \frac{2\sigma.\cos\theta}{R}, \quad (2)$$

where, σ is the surface tension of the working fluid, R is the radius of curvature of the meniscus in the wick, and θ is the contact angle between the liquid and the wick. As the heat load to the evaporator increases, so will the mass flow rate and the total pressure drop in the system. In response, the radius of curvature of the meniscus decreases so as to provide a higher capillary pressure that matches the total system pressure drop. The radius of curvature will continue to decrease with increasing heat loads until it is equal to the pore radius of the wick, Rp. Under this condition, the wick has reached its maximum capillary pumping capability:

$$\Delta P_{cap,max} = \frac{2\sigma.\cos\theta}{R_p} \quad (3)$$

Further increase of the heat load will lead to vapour penetration through the wick and system deprime. Thus, under normal operation, the following condition must be satisfied at all times [1]:

$$\Delta P_{total} \leq \Delta P_{cap} \quad (4)$$

WICK STRUCTURE OF LHP

To achieve good thermal performance, capillary wicks with high permeability and porosity and fine pore radius are expected. These parameters depend mainly on the manufacturing process. The most frequently used wicks are made of sintered metal, like nickel, cooper, titanium, stainless steel or polymers (polyethylene, polypropylene, PTFE). [2].

According [3] the main parameters of wick are porosity, pore diameter and permeability. The optimal porosity of sintered wick is between 30- 75% regardless of the pore diameter. The sintered material porosity increases when the temperature or the forming pressure decrease. The optimal permeability is between 10^{-14} and 3.10^{-13} m^2. The pore diameters of these various porous materials are between 1 and 20 µm, except for copper, which has larger pore diameters (between 20 and 100 µm.

In [4] the optimal capillary wick was found to be sintered at 650 °C for 30 min. using direct loose sintering technique, with 90% nickel and 10% copper. The wick reaches the porosity of 70% and a mean pore diameter of 1.8 µm. In [1] were fabricated biporous nickel wicks. A porosity of 77,4% was achieved using cold pressure sintering method, at a temperature of 700°C, with a pore former content of 30% in volume.

2.1 Characterization of sintered structures

According above mentioned experiences with sintered structures for LHP we decide use for propose of wick structure copper powder. At first we do analysis of several sintered structures depending from grain size, sintering temperature and sintering time on porosity, pore size and strength. In electric furnace was sintered etalons from copper powders with grain sizes 50 and 100 µm at temperature 800 and 950 °C for time 30 and 90 minutes.

Porosity measuring

The porosity of a wick structure describes the fraction of void space in the material, where the void may contain working fluid. For the porosity measuring, the weight method was used. At First, the sample was weighed in dry state. Secondly, the sample was soaked with distilled water (ρ = 0.998 g·cm-3 at 20°C). The weight of absorbed water was estimated by the difference between both values, and then a deduction of the "empty space" (thus the total pore volume) and the porosity.

$$\varepsilon = \frac{M_{soaked\ sample} - M_{dry\ sample}}{V_{total} \cdot \rho_{distilled\ water}} \quad (5)$$

The results of porosity measuring are shown in table 1 and 2.

TABLE 1. Porosity of sintered structures with grain size 50 µm.

Grain size (µm)	50	50	50	50
Sintering temperature (°C)	800	800	950	950
Sintering time (min.)	30	90	30	90
Porosity (%)	55	54	52	50

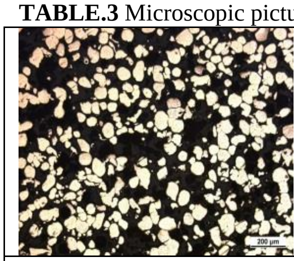
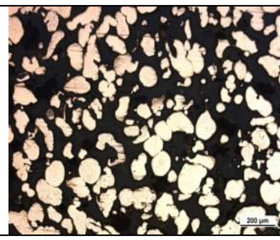
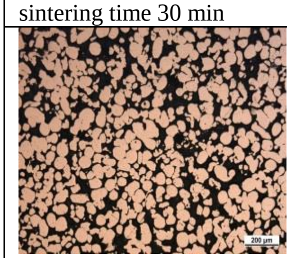
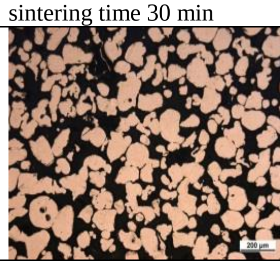
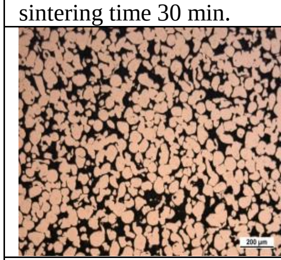
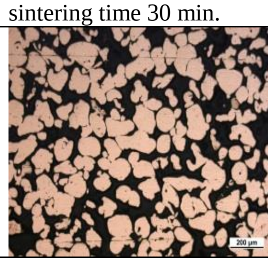
TABLE 2. Porosity of sintered structures with grain size 100 µm.

Grain size (µm)	100	100	100	100
Sintering temperature (°C)	800	800	950	950
Sintering time (min.)	30	90	30	90
Porosity (%)	58	56	55	52

Microscopic analysis of pore size

Investigation of etalons sintered structures by microscopic analysis shown, how influent sintered temperature and time pore size and ratio grain size to pore size of each structures. In table 3 are pictures created by 100 times zoom of porous structures sintered from copper powder grain size 50 and 100 μm. On first two pictures is seen, that the structures sintered at temperature 800 °C has two times bigger pore than powder grain. Comparison of etalons sintered at temperatures 800 and 950 °C is seen that the etalons sintered at temperature 800 °C has so much bigger pore size than at temperature 950 °C. It is meaning that pore sizes are so much width to create capillary action in structure. Comparison of etalons sintered at same temperature and various time intervals was observed, that the time of sintering at temperature nearest the melting temperature of sintering material is not decisive. And the last comparison of etalons at the same sintering temperature and time interval, observe that the grain size of sintered material has impact on pore size. According microscopic analysis of sintered structures, which clarify their shape and profile, can conclude that the main influencing factor of pore size is grain size, sintering temperature and not so much sintering time.

TABLE.3 Microscopic pictures of the sintered structures.

	
Grain size 50, sintering temperature 800 °C, sintering time 30 min	Grain size 100, sintering temperature 800 °C, sintering time 30 min
	
Grain size 50, sintering temperature 950 °C, sintering time 30 min.	Grain size 100, sintering temperature 950 °C, sintering time 30 min.
	
Grain size 50, sintering temperature 950 °C, sintering time 90 min.	Grain size 100, sintering temperature 950 °C, sintering time 90 min.

DESIGN OF LHP

From results porosity measurement and microscopic analysis two etalons were chosen for wick structure of LHP. The first structure was made with grain size 50 μm and sintered at temperature 950 °C for 30 minutes (figure 2.) The second structure was made with grain size 100 μm and sintered at temperature 950 °C for 30 minutes. The wick structures were sintered in send form (mold) manufactured according model of required shape in muffle furnace.

FIGURE 2. Sintered wick structure for LHP.

All parts of LHP (evaporator, compensation chamber, vapor and liquid line) were made from copper pipes. As a working fluid was used distilled water. In the evaporator was inserted sintered wick structure from copper powder. To avoid heat loss (it is also called heat leak) into the compensation chamber was inserted a brass flange with rubber seal between the evaporator and the compensation chamber. In the figure 3 is the model of design LHP and the main parameters of LHP design are in table 4.

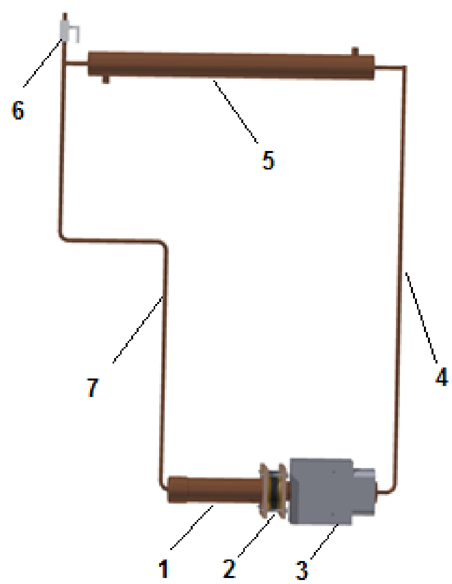


FIGURE 3. Model of design LHP: 1. compensation chamber, 2. rubber seal, 3. evaporator, 4. vapor line, 5. condenser, 6. filling valve, 7. liquid line.

TABLE 4. Main design parameters of the LHP.

LHP evaporator			
Total length (mm)	130	Length (mm)	110
Active length (mm)	86	**Charge mass**	
Outer/inner diameter (mm)	28/26	Distilled water	60%
Material	copper	**Vapor line**	
Saddle		Length (mm)	670
Size (length/ high/ wide)	118/89/ 40	Outer/inner diameter (mm)	6/4
Material	alumin a	**Liquid line**	
Sintered copper powder		Length (mm)	820
Number of vapor grooves	6	Outer/inner diameter (mm)	6/4
Porosity (%)	51	**Condenser**	
Outer/inner diameter (mm)	26/8	Length (mm)	420
Compensati on chamber		Outer/ inner diameter (mm)	6/4
Outer/inner diameter (mm)	35/33		

MEASUREMENT AND RESULTTS

The LHP with sintered wick structure was proposed to testing cooling of IGBT. On the evaporator of LHP was mounted the aluminum block with fixed Insulated gate bipolar transistor (IGBT). For better heat transport was applied thermal conductive paste on the connection between IGBT and aluminum block and between aluminum block and the evaporator [5]. The condenser of LHP was made as tube heat exchanger. The cooling circle of heat exchanger was regulated by the thermostat at constant temperature 20 °C. In the figure 4 is schema of the measuring unit.

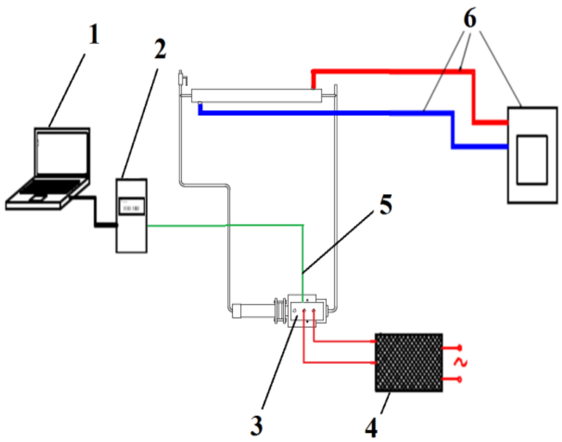


FIGURE 4. Schematic diagram of measuring device: 1-PC, 2- logger, 3-IGBT, 4- power supply voltage and current, 5- thermocouple, 6- thermostat.

To measure temperature of IGBT was under him inserted thermocouple. The maximum permissible temperature of IGBT is 100°C. Transistor was connected to DC power of source and it was gradually loaded by DC. Like this was performed measurement of impact two wick structures in LHP to heat remove from IGBT. First wick structure was sintered from 50 grain size copper powder at temperature 950°C for 30 minutes and second structure was sintered from 100 grain size copper powder at temperature 950 for 30 minutes. The results from measurement are shown on figure 5 and 6. In the pictures are seen that on start-up of LHP at input power 100 W the temperature of evaporator increase and only after time, when the LHP start operate the temperature of evaporator decrease and is stabilized. After first stabilization of the temperature was input power gradually increased for 50 W.

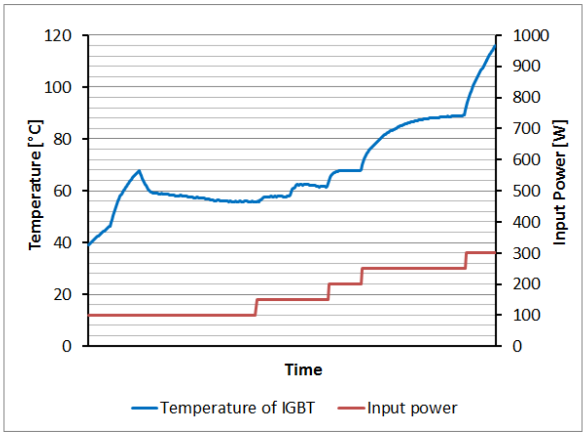


FIGURE 5. Measurement dependency of IGBT temperature from input power cooled by LHP with first variant of wick structure.

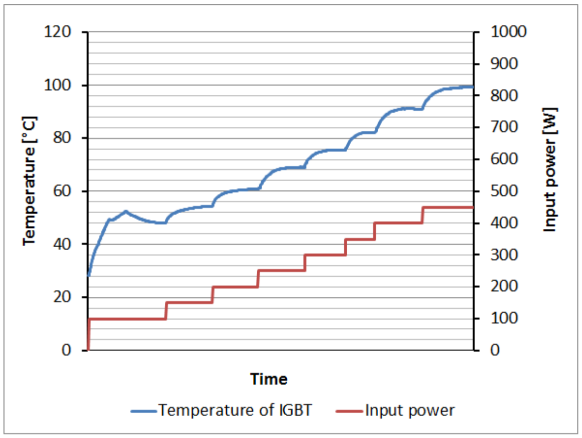


FIGURE 6. Measurement dependency of IGBT temperature from input power cooled by LHP with second variant of wick structure.

Comparison temperature course from increased input power of IGBT is seen that at load of up to 200 W were almost the same results of both LHP. Only if the higher amount of input power than 200 W was loaded in to IGBT it is seen that the LHP with first structure did not heat remove from IGBT and cooled at lower temperature under 100 °C. The LHP with second wick structure was able cooled the IGBT under 100 °C until input power 450 W.

CONCLUSION

According microscopic analysis of sintered structures, which clarify their shape and profile, can conclude that the main influencing factors of pore size are grain size, sintering temperature and not so much sintering time. Comparison Measurement comparison of dependency IGBT temperature from input power cooled by LHP with second variant of wick structure can conclude, however the both structures had the same porosity the better effect on heat removal from IGBT had porous structure with bigger pore size. The smallest pore size could cause the low capillary pressure in wick structure against total pressure in whole LHP system.

ACKNOWLEDGMENTS

This paper was created within the solution of project APVV-0577-10.

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