Electronic devices are becoming compact with enhanced performance. Therefore, it becomes a challenging task to provide the cooling solutions for these compact devices with high-density heat generation. Regarding this challenge, thin flat heat pipe can play a vital role. In the present study, experimental investigation of the thin flat heat pipe with a thickness of 1.0 mm has been performed. In this paper, different kinds of new fiber wick structures consisting of a combination of copper fine fibers and axial grooves are investigated. Thin heat pipe having these new wick structures showed highly improved thermal performance as compared with that having normal wick structures. The effect of length, thermal test mode, and bending on the thin heat pipe thermal performance has been studied. From the present study, it is found that maximum heat transfer capability of the present 1.0-mm-thin heat pipe is 11 W, with the thermal resistance of 0.6 °C/W. Bending has reasonable effect on the thermal performance of heat pipe. Besides, thermal performance of remote heat exchanger fabricated by using the developed thin heat pipe has been investigated. Twenty-five watts of heat can be transferred by using the present assembly.

1. Introduction

Recently, a number of cooling modules consisting of the thin heat pipes are used for cooling of compact electronic devices such as notebook PC. At present, thinner heat pipe with a minimum thickness of 2 mm is commonly used. With enhanced performance of electronic devices, heat generation and density factor are increasing. Therefore, the thin heat pipe, which has a thickness of less than 2 mm, cannot satisfy the thermal performance and makes it difficult for practical use. However, ultrathin heat pipe such as 1-mm-thick heat pipe has its role to play in resolving the limitation of thermal design in electronic devices dramatically. Owing to the growing demand of ultrathin heat pipes, in the present study the authors try to develop ultrathin 1-mm-thick heat pipes.

In practice, when we fabricated 1-mm-thick heat pipe using normal wick structure available from our mass-production product, maximum heat transfer, $Q_{\text{max}}$, was only around 5 W, and heat pipe thermal resistance was around 5°C/W. The performance was not sufficient enough for its practical use.

Because of the limitation of inner space for 1-mm heat pipe, it is necessary to miniaturize wick space and keep the vapor space as wide as possible to improve the thermal performance. Moreover, high-performance wick structure that possesses a good reflux performance is necessary to prevent the dry-out and increase the $Q_{\text{max}}$.

In this paper, the performance evaluation result of 1-mm heat pipe using different kinds of new wick structures is reported, that is small space and good reflux performance. Besides, the thermal performance evaluation result of 1-mm heat pipe remote heat exchange assembly is reported in this paper.

2. Heat pipe structure

Figure 1 shows the thin flat heat pipe made of copper pipe with original diameter of 5 mm.

The present thin heat pipe is straight shaped, which has a rectangular cross section of $1.0 \times 7.43$ mm and different heat transfer lengths of 100, 120, 150, 180, and 200 mm.

3. Wick structure

Our standard wick structure named “composite

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Fig. 1. One-millimeter-thick heat pipe.
“wick” is the combination of axial groove wick and copper fine fiber wick (Fig. 2).

Copper fine fiber and spring that we call “spiral” are inserted into the copper tube along with the axial groove. The spiral pushes the copper fine fiber to the inner wall of the tube. As a result, the outer side of spiral acts as liquid path and inner side of the spiral acts as vapor path. Axial groove wick can provide low liquid pressure drop, and fine fiber wick has higher capillary force; with the combination of these two features our composite heat pipe has very low thermal resistance and higher Q\textsubscript{max}.

However, when we fabricated 1-mm-thin heat pipe using this standard composite wick, the vapor path was blocked by spiral. Therefore, we could not get good thermal performance. To solve this issue, we designed the new wick structure for 1-mm heat pipe without using spiral.

Three kinds of wick structures are designed for 1-mm-thick heat pipe (Fig. 3).

1) Twist wick
   This wick is twist of copper fine fibers.

2) Wick in spiral
   This wick is spiral bundling of copper fine fibers.

3) End bundle wick
   This type of wick bundling is done only at both ends of copper fine fibers.

Twist wick and wick in spiral are designed while concentrating placement of wick in the central area of heat pipe. In these two types, we get vapor space at both sides of fine fiber wick. End bundle wick is similar to the above two wick structures, but it can set fine fiber wick widely in the width direction compared with the other two types.

4. Thermal test setup and procedure

Figure 4 shows the thermal test setup for the current thin flat heat pipe. Cartridge heater embedded in the copper block is used as the heat source; it has a cross-sectional area of 25 × 25 mm. Copper block consisting of water circulation path is used as the water cooling condenser. It has a cross-sectional area of 75 × 70 mm, and during the test, 40 mm of the heat pipe is placed on the top of the condenser block surface. For both the evaporator and condenser section, clamping devices are used to get rid of any air gap.

By using K-type thermocouple temperature on the heater surface \(T_h\), evaporator temperature \(T_e\), adiabatic temperature \(T_a\), and condenser temperature \(T_{c1}, T_{c2}\) are measured. The thermal test of the heat pipe was
performed in the horizontal mode with evaporator and condenser at the same level. And temperatures at all the points are recorded until the temperature at the evaporator becomes steady. All the thermal tests have been done with a fixed adiabatic temperature. In this paper, we mentioned this temperature as the operating temperature of the heat pipe. To find out the $Q_{\text{max}}$ of each heat pipe, heat input is increased by 1 W until dry-out occurs.

5. Results and discussion

In this present study, the authors have focused on determining the effect of the wick structures, heat pipe length, thermal test mode, and bending on the thermal performance of 1.0-mm-thin flat heat pipe. Evaluation of performance is done based on the heat pipe thermal resistance, $R_{hp}$, that is calculated by the following equation:

$$R_{hp} = R_{e-c} = (T_e - T_c)/Q \quad \cdots \cdots \cdots \quad (1)$$

Here, $Q$ is the heat flow rate applied to the heater block.

5a) Effect of wick structure

Figure 5 shows the thermal performance comparison data for the three types of wick structures mentioned previously. Only the horizontal test mode has been done under a fixed operating temperature of 60 °C. From the data it can be seen that for all the three types of wick structures $Q_{\text{max}}$ is same in the level of 11 W. But for the end bundle wick heat pipe thermal resistance is much lower compared with the other two types. This is due to the higher porosity level in the end bundle wick.

5b) Effect of length

Figure 6 shows the thermal performance of 1.0-mm-thin flat heat pipe with different lengths. Length is varied from 100 to 200 mm, and twist wick structure is used for these heat pipes. Test has been done at 60 °C operating temperature with horizontal test mode. It has been found that thermal performance heat pipe length has a large effect on its thermal performance. However, thermal resistance remains almost the same for all lengths of heat pipe.

5c) Effect of thermal test mode

The effect of three different thermal test modes has been studied in this paper: along with the horizontal mode 15° and 30° inclination mode (Fig. 7). One-millimeter heat pipe that is used for this test has the length of 130 mm. For the horizontal mode heater block and condenser block are in same horizontal plane. However, for the other two test modes heater block is in the plane 15° and 30° inclined to the plane of condenser block, acting as a top heat source. As a result of this test, it has been found that for 15° inclined test mode $Q_{\text{max}}$ is 9 W, which is same as that of horizontal mode. For 30° inclined test mode $Q_{\text{max}}$ reduces to 8 W.

5d) Effect of bending

Considering the practical application of 1.0-mm heat pipe in compact electronic devices, heat pipe with bended structure has been fabricated for this study. Along with the straight heat pipe, 135° one-bend, 135° two-bend, and 90° one-bend samples are fabricated.
The length of these heat pipes is 130 mm, as the wick structure end bundle wick is used. Figure 8 shows the bended heat pipe. From the test result (Fig.9), it can be seen that $Q_{\text{max}}$ decreases only 1 and 2 W for 135° one and two bends, respectively, compared with that of straight heat pipe. But for 90° bended sample $Q_{\text{max}}$ reduces to 5 W, and thermal resistance is very high. This is due to the higher vapor and liquid pressure drop in the bended section.

6. One-millimeter-thick heat pipe assembly

By using the above-mentioned 1.0-mm-thin heat pipe, in this study remote heat exchange heat pipe assembly was fabricated. This assembly consists of a copper plate, two heat pipes, fan assembly, and blower type DC fan. Copper plate, which is acting as the heat receiver from the heat sources, has a thickness of 0.3 mm. Heat pipe length is 112.5 mm. Total thickness of this assembly is 5.3 mm. DC fan is $45 \times 45 \times 5$ mm in size. This present thin heat pipe assembly is for multi heat source purpose. There are two heat sources named as heat source 1 and heat source 2. Figure 10 shows the present thin heat pipe assembly.

For the thermal performance, evaluation of the present assembly test has been done with a fixed 5-W heat input in heat source 1 and the heat input of heat source 2 is increased by 4 W starting from 8 W. DC fan is operated at input voltage of 5 V. Each point of temperature has been measured. Figure 11 shows the thermal test setup of the assembly. Performance evaluation is done based on the heat source 1 and heat source 2 thermal resistance defined as $R_1$ and $R_2$, respectively. $R_1$ and $R_2$ are calculated by the following equations.

$$R_1 = (T_{1}-T_{\text{hp_con3}})/Q_1 \quad \cdots \cdots \quad (2)$$

$$R_2 = (T_{2}-T_{\text{hp_con3}})/Q_2 \quad \cdots \cdots \quad (3)$$

Here, $Q_1$ and $Q_2$ are the applied heat input for heat source 1 and heat source 2, respectively.
Figure 12 shows the thermal performance of the present assembly. It can be seen that even after increasing $Q_2$ to 20 W no dry-out occurs for the present assembly. So, the present assembly can transfer 25 W of heat.

7. Conclusion

One-millimeter-thin heat pipe has been successfully developed. Experimental investigations for practical application of thin heat pipe have also been done. This study concludes as follows:

i) The new fiber wick structure provides sufficient capillary head, permeability, as well as enough vapor space for the circulation of working fluid inside the 1.0-mm-thin flat heat pipe.

ii) Maximum heat transfer capability for the present 1.0-mm-thin heat pipe is 11 W with a heat pipe thermal resistance of 0.6°C/W.

iii) Presently developed thin heat pipe is capable of working in a top heat source application, and sufficient thermal performance can be achieved for bended structure.

iv) One-millimeter heat pipe assembly can transfer 25 W of heat with a low thermal resistance.

On the basis of the above performance, it can be concluded that the presently fabricated thin flat heat pipe and the heat pipe assembly will find applications in the cooling of the compact electronic devices.

Reference