Evolution of the Heatsink Technology

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ABSTRACT The environment around heatsinks is increasing in severity day by day. It is known that the heat generated by electronic devices continues to increase, while the casing is becoming more compact. Moreover, there is an urgent requirement for addressing environmental issues including weight reduction and elimination of environmentally hazardous substances. This paper presents the manufacturing technologies for heatsinks that have been developed in response to such requirements together with the heatpipe products using such technologies.

1. INTRODUCTION

Recently, the heat generated by the devices in electronic equipment unprecedentedly increases in density. These electronic devices include: the integrated circuits such as central processing unit (CPU) for the so-called information-oriented home appliances like personal computers together with graphic processor unit (GPU); and the semiconductor power devices represented by insulated gate bipolar transistor (IGBT) for electric railways 1). It is said that the heat generation density of these high heat-generating devices is reaching a level corresponding to that of nuclear reactors, so that it is virtually impossible to dissipate such a heat rate on an individual component basis. Accordingly, there is a need for heat dissipation using high-performance heatsinks that can efficiently diffuse heat.

On the other hand, downsizing and weight reduction of the equipment that use these semiconductor devices are being promoted, and, as the result, the vacant space available to heat-dissipating devices such as heatsinks is becoming much reduced. An urgent need for developing high-performance heatsinks arises from this reason also.

Moreover, solder widely used for manufacturing heatsinks is required to be lead-free, because the RoHS Directive (Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment) requires that, as a general rule, electrical and electronic equipment marketed in Europe should be lead-free by July 1, 2006.

In view of these requirements, Furukawa Electric has been developing various high-performance heatsinks based on heatpipe as well as various bonding methods without using brazing metals such as solder, thereby responding to the market needs.

2. EVOLUTION PROCESS OF HEATPIPE TECHNOLOGY

Here let us describe the trends in heatsinks focusing on those for personal computers.

At first, the heat generation rate itself of CPUs was small and hence the heat density was low necessitating no heatsinks, and conventionally the heat was dissipated into the printed circuit board, taking advantage of the CPU package made of plastics, through the socket. Then, as CPUs upgraded in integration scale and the design rule for circuit patterns improved in preciseness together with the increasing clock frequency, the heat generation rate continued to upsurge. Consequently, a need for cooling using heatsinks arose, and heatsinks based on extrusions and die-castings were employed for desktop PCs. Later on, as the heat generation rate of CPUs increased higher, these blower-less air-cooling devices were found to be insufficient, so that forced air-cooling using a motor-driven fan was introduced, and this cooling method continues to be used up until now experiencing many improvements 2), 3).

On the other hand, with respect to notebook PCs, the heat was at first diffused over the entire casing using its aluminum sheet metal to be naturally dissipated into the air. In the meantime, in 1993, heatpipe was combined with the casing to improve the heat-diffusing performance, and further, motor-driven fan was introduced thus achieving performance improvements year by year. As it is now some CPUs generate a heat rate of more than 100 W, and those developed for notebook PCs in excess of 30 W. Moreover, the heat generation rate of other devices such as GPU now exceeds 10 W, producing a tendency toward increased temperature within the casing.

As described above, the heatsinks of today are used in many crucial places where extremely high performance is required. Accordingly, it is essential for heatsinks to maximize the fin efficiency by adopting heatpipes that outper-

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form diamond having the highest thermal conductivity among solids.

3. NEW REQUIREMENTS FOR HEATSINKS

Thus heatsinks are required to have high thermal performance as well as other advantageous characteristics.

For notebook PC application, for example, there is an increasing need for lightweight heatsinks. The objective of weight reduction is portability enhancement of course, but it should be noted here that recently there is a tendency to install larger LCDs accompanied by increased product weight. A significant weight reduction of heatsinks is therefore required to suppress the weight increase in comparison to previous models and to compensate for the increase in weight due to other components.

There is also an intense need for profile reduction. As mentioned earlier, the surface area of PC is growing in size due to the increased LCD size, so that it is desirable to have a low-profiled casing so as to suppress volume increase. Since heatsinks are also required to be low-profiled, it is a normal practice to use a remote heatsink system, whereby the heat is absorbed by a heatpipe, transferred to a fin array at the end of the casing, and the array is cooled using a fan.

Moreover, there is an increasing need for dealing with environmental issues, including: elimination of lead in compliance with the RoHS Directive; improvement in recyclability; and elimination of environmentally hazardous substances. It is essential to meet these requirements that are related with the disposal and recycle of products as well as to improve the performance and user-friendliness of products. To this end, it is crucial for manufacturers to have advanced design competence in addition to processing capability.

4. SOLUTIONS TO WEIGHT REDUCTION

Main measures for weight reduction include:

(1) To use lightweight materials
(2) To reduce the number of constituting members
(3) To devise a suitable configuration

It is required that the material for heatsinks has superior thermal conductivity. Copper has an excellent thermal conductivity of about 400 W/m·K, but its specific gravity is 8.96 g/cm^3 , so that, if copper is used in an entirety of a heatsink for desktop PC, it would weigh as much as 1 kg because heatsinks have grown in weight in proportion to the heat dissipation rate thus making them the heaviest among the desktop PC components. Thus, although a metal plate is used for reinforcement, it is becoming difficult for the circuit board on which a heatsink is mounted to maintain its configuration, resulting in a potential trouble of poor thermal contact with the heat-generating devices.

Accordingly, aluminum and its alloys with a specific gravity of 2.7 g/cm^3 (i.e. one third of copper) are preferred, despite the fact that their thermal conductivity is 240 W/m·K, much lower than copper. These physical parameters suggest that even if an aluminum member twice as thick as a copper member is used to obtain an equivalent heat transfer rate, the heatsink would be lighter by about 30 %, and further weight reduction can be obtained depending on design optimization.

Aluminum heatsinks have long before been adopted for ease of fabrication using casting and extrusion, but their adoption has been limited to such areas where high-performance operation is not necessary, because products with thin and narrow-pitched fins can not be realized and because their thermal conductivity is poor. In order to fabricate high-performance heatsinks of aluminum, it is necessary to use thin sheets of pure aluminum for the fins so as to increase the surface area per volume. While the heatsinks using a thin sheet are formed by means of press working, the thinner the sheet, the more skill and advanced techniques the process needs. At present, our process can manufacture heatsinks with 0.2-mm thick fins, thereby contributing to weight reduction and performance enhancement.

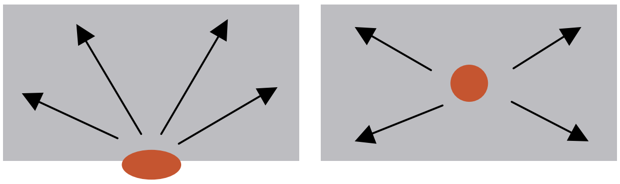
The use of heatpipes also significantly contributes to weight reduction, since they are provided with a thermal conductivity of as high as about 10,000 W/m·K regardless of their extremely small apparent specific gravity, i.e. approximately 2 g/cm^3 for a heatpipe of 6-mm in diameter. Suitable configuration of such a heatpipe enables much weight reduction while achieving considerable performance improvements. For example, it has been possible to reduce the weight by about half as well as to achieve a significant cost reduction while considerably improving the thermal performance by adopting a structural design, such that a 4-mm thick copper sheet has been replaced by a flattened heatpipe 2-mm high sandwiched between two 1-mm thick copper sheets. This example demonstrates the overwhelming effects of heatpipes when they are optimally designed.

5. SOLUTIONS TO PROFILE REDUCTION

As mentioned earlier, there is an intense need for profile reduction in the field of notebook PCs especially. For this reason, it is difficult to install cooling fins just above a heat generating device, so that normally the heat is transferred to be dissipated to the end of the casing where fins are installed with a fan, and it became essential to use a heatpipe in transferring the heat.

It has been a normal practice to bond a heatpipe on to the end of a fin using solder and the like. With this bonding method, however, heat has to be transferred from one end to the other of a fin, making inefficient use of the fin. In contrast, when the heatpipe is bonded to the center of the fin, not only the entire circumference of the heatpipe can be used to transfer the heat to the fin, but also the distance to any end of the fin is shortened, and the fin efficiency is improved. Based on this idea, stacked fin heatsink has been developed to be put into practical application. See Figure 1.

What is more, the height of fins has been reduced as



a) When bonded to fin ends, temperature difference occurs lowering the fin efficiency.

b) When heat source is at fin center, the fin efficiency improves.

Figure 1 **Effect of center bonding in stacked fin heatsinks.**

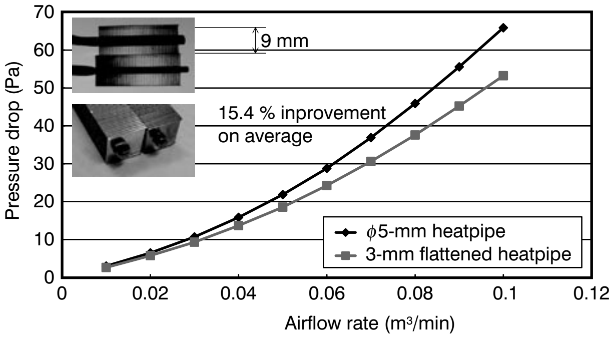


Figure 2 **Effect of flattened heatpipe with stacked fins on pressure drop reduction.**

the casing becomes low-profiled, and it was found that the influence of heatpipe itself on the airflow (i.e. pressure drop) can not be neglected. Accordingly, the technology of stacked fin heatsink using flattened heatpipe has been developed. As shown in Figure 2, this technology has made it possible to obtain higher airflow rates using an identical fan, achieving an improvement in the overall performance of fins combined with a fan.

Moreover, another example of particularly high-performance heatsink has been demonstrated, in which a fan casing is combined with a heatsink, and a heatpipe is installed there thus making those sections other than the heatsink share the cooling function.

6. SOLUTIONS TO ENVIRONMENT-FRIENDLINESS

While most heatsinks commercially available at present use solder for bonding each part, there is an urgent need to eliminate the use of lead contained in the conventional solder, because the lead can leach due to acid rain after the products are wasted, contaminating the soil and water sources. Accordingly, Furukawa Electric always uses a lead-free solder to replace conventional solders used in manufacturing heatsinks.

Not only the company uses lead-free solder, but also it has developed various bonding methods eliminating the use of solder itself, such as the stacked fin technology mentioned above and the crimped fin manufacturing technology.

Using the stacked fin technology, after fins are burred a heatpipe is press-fitted there to mechanically bond the fins. Thus, manufacturing capabilities of high-precision die machining as well as process management are required to bond the thin fins without damaging therely achieving a sufficient mechanical strength. In particular, the stacked fin heatsink with flattened heatpipe that has recently been brought to practical application necessitated more advanced techniques, and considerable efforts were made to establish the manufacturing technology realizing a satisfactory degree of heat transfer. See Figure 3.

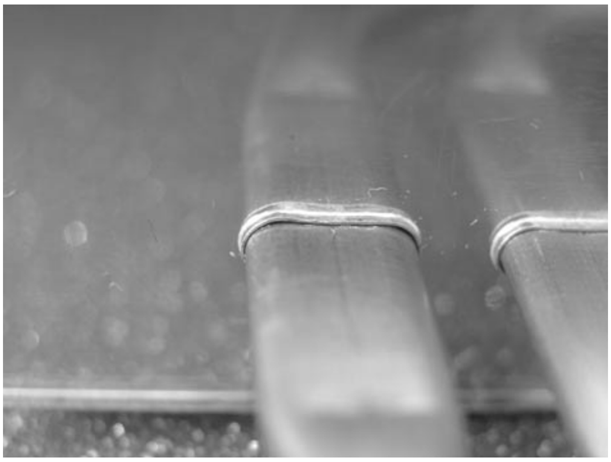


Figure 3 **Photograph of stacked fin heatsink with flattened heatpipe.**

By means of the crimped fin technology, on the other hand, after fins are inserted into the grooves cut in the base plate, a blade is used to stamp the base plate in the portion between the fins, and the fins are crimped by the deformed portions from the both sides to be securely fastened. Because the fin crimping makes use of the plastic deformation of metals in this way, it offers many advantages in that the thermal conductivity between the fin and the base plate is superior since brazing materials such as solder or adhesives do not exist in the bonding interface, and that it enables bonding of such combinations as aluminum-to-aluminum where solder poorly works in addition to copper-to-aluminum where any brazing filler metals work insufficiently. Moreover, the caulking technique has been developed for bonding heatpipes on to metal blocks such as die-casts for heat-receiving blocks, making it possible to manufacture heatsinks on a solderless basis.

These solder-less bonding techniques contribute to enhance environment-friendliness. First, since they are based on plastic deformation of metals to fasten the parts, they increase the ease of disassembly, e.g. in the case of crimped fins, the fins easily disengage by bending the base plate to form a fan shape. Second, since no adhesives are used, hence any generation of toxic gases when the parts are remelted. Lastly, Ni-plating for soldering aluminum materials is not necessary, reducing environmental impacts.

7. LATEST THERMAL SOLUTIONS

Let us introduce some examples.

Figure 4 shows a heatsink developed for a portable PC often called a desk-notebook PC. The desk-notebook PC has a high-performance, high-heat generating CPU normally used for desktop PCs on board its compact casing for notebook PCs, so that the PC has a strict limitation on free space. Accordingly, in this product, four flattened heatpipes 6 mm in diameter are used because it is known that plural, flattened, small-diameter heatpipes are more advantageous than a large-diameter heatpipe of high heat transfer rate to suppress the pressure drop in a low-profiled free space. The heatpipes are bonded to the center of a stacked fin array comprising lightweight aluminum fins, and aluminum is also used for the heat-receiving block thus reducing the weight.

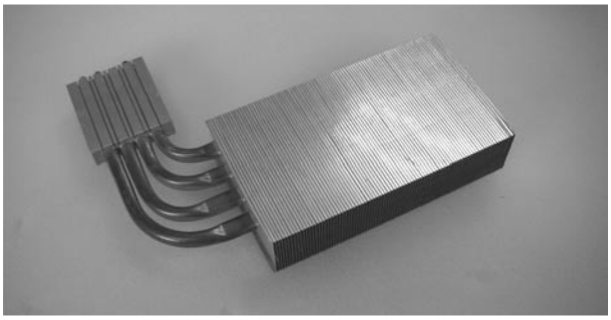


Figure 4 Heatsink for desk-notebook PC.

In this case, shortening the distance between the heat-receiving surface and the fin array would reduce the thermal resistance thereby improving the performance, but it is also important to distribute the heat rate as evenly as possible among the four heatpipes. Therefore, careful designing is needed to obtain the optimum solution to the overall configuration. Meanwhile the product uses caulking to fasten the heatpipe with heat-receiving block, without using solder or Ni-plating.

By adopting such a configuration, it was possible to reduce the weight by about 60 % in comparison to a heatsink that uses copper for the fin and heat-receiving block. These two heatsinks were compared for the performance using a setup such that a sample heatsink was put in a wind tunnel, a heat rate of 80 W was input to the heater block provided with thermocouples, and the temperature on the heatsink was measured as the airflow rate was changed. It was confirmed from the experimental results shown in Figure 5 that, since the design was optimized in terms of the relative position of the fin and heatpipe as well as the fin pitch, the aluminum heatsink has performance equivalent to that of the copper heatsink.

More specifically, it was demonstrated that the heatsink has a thermal resistance of 0.25 K/W at an airflow rate of 0.3 m^3/min, which indicates that under the conditions of input heat rate of 120 W and ambient temperature of 40°C, the CPU temperature is suppressed to 70°C. This confirms that the heatsink can sufficiently meet the performance requirements of high-performance CPU of the next generation. It was further confirmed that the heatsink does not change in the thermal resistance at a heat input of 150 W, exhibiting a sufficient heat transfer rate.

Next an example is introduced where a high-performance heatsink was used to achieve a reduction of power consumption.

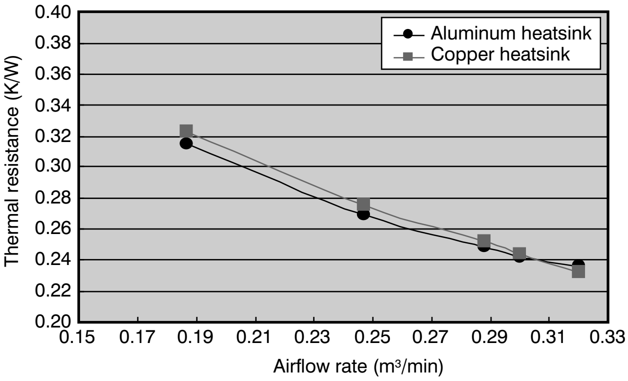


Figure 5 Thermal performance of aluminum and copper heatsinks for desk-notebook PCs.

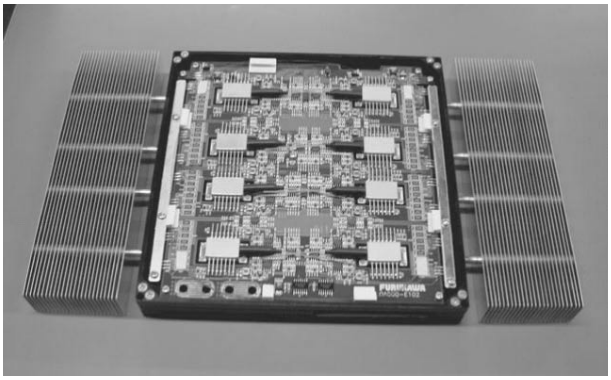


Figure 6 Photograph of Raman amplifier HPU-1001.

Figure 6 shows a Raman amplifier for optical communications 4), 5). In the casing, eight high-power laser diode modules (hereafter called LDM) each with a maximum heat generation rate of 15 W are used to attain a total heat generation rate of 120 W. Each LDM has a built-in Peltier cooler, which, in order to hold the temperature of the laser diode included in the LDM constant, cools the diode and in turn dissipate the heat into the heatsink. The ability of the Peltier cooler is proportional to the electric power supplied, and as the performance of the heatsink deteriorates and as the LDM temperature rises, much power is consumed accordingly to lower the LDM temperature to maintain a constant value, and this raises a need for an efficient heatsink.

Meanwhile, the casing of this Raman amplifier has to be low in profile to be accommodated in a rack, making it impossible to install a heatsink with fins of sufficiently large area just in the back of the LDM. It has been therefore decided to adopt a design such that the heat generated by the LDMs is individually transferred using a heatpipe to the casing side face, where eight units of stacked fin arrays are installed to effect, notwithstanding the low-profile casing, efficient heat dissipation. As a result, it was possible to suppress the temperature increase of the LDM much lower than using bulk heatsinks of solid aluminum extrusion that occupy an equivalent volume. This reduced the load on the Peltier cooler built in the LDM eventually resulting in a reduction of 30 % in the total power consumption as shown in Figure 7.

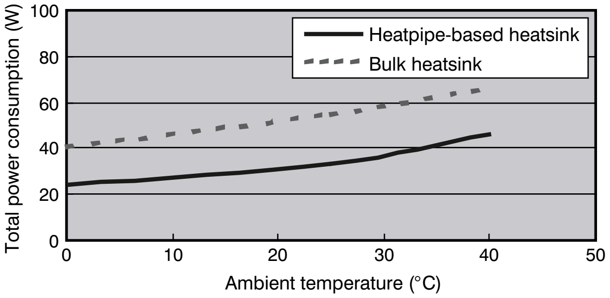


Figure 7 **Comparison of LDM power consumption between two types of heatsinks.**

8. THERMAL SOLUTIONS IN THE FUTURE

Thus it is thought that the heatsinks in the future would be required to make efficient use of heatpipes besides aluminum fins, thereby simultaneously achieving weight reduction and performance improvement. In addition, ease of recycling should be taken into consideration in designing so as to address environmental issues.

Furthermore, it would be necessary to actively adopt high-performance heatsinks in consideration of the fact that the use of these efficient devices reduces the load on other active components such as Peltier coolers and fans, eventually resulting in reduction of power consumption.

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