Trends in State-of-the-Art Heatsinks and Their Patent Technology

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ABSTRACT In recent years, the performance of electronic equipment improves year by year, while the equipment continues downsizing. As a result, there is a need for more efficient dissipation of heat generated by the electronic devices incorporated in the equipment. Heatsink plays an important role for such performance improvements, making it indispensable to use high-performance heatsinks suitable for each equipment so as to realize the design and performance required by customers. Accordingly, every heatsink manufacturer earnestly develops various heatsink technologies, thereby improving heatsinks through application of these technologies.

This paper presents technologies for heatsink performance upgrading placing emphasis on the patents owned by Furukawa Electric, together with explanatory description of the trends in state-of-the-art heatsink technologies.

1. INTRODUCTION

In recent years personal computers rapidly improve in performance. While this performance improvement owes much to the development of microprocessor unit (MPU) and graphics processor unit (GPU), it is known that such development provoked a rapid increase in heat generation density. As can be seen from Figure 1, the heat generation density of MPU and GPU has already surpassed that of electric hot plate, and is gradually approaching that of nuclear fusion reactor. Since the rapid increase in heat generation density accompanied by temperature rises begins to pose limitations on the performance of not only MPU and GPU but also that of electronic equipment itself, there is an urgent need for developing a new cooling technology that does not impede downsizing and performance upgrading of these equipment.

In the past decade, development of cooling devices and systems has made a rapid progress, centering on such areas as fan, various fins, graphite sheet, micro heatpipe (hereafter called μHP), vapor chamber and water-cooled system 1)~3). Cooling methods may be roughly classified into two types: passive methods using fan-less heatsinks; and active methods using fan-based heatsinks and power-driven cooling devices.

The passive devices include graphite sheet, μHP-based heatsink, and peraflex® —an advanced vapor chamber; and they have the advantage of maintaining silent operation of the equipment since no fans are used. These devices are mainly used in portable PCs having a heat generation rate of not more than 30 W, and in such applications, they are required to perform a function of efficiently diffusing heat over the entire equipment as well as to be low-profiled and lightweight. Whereas graphite sheet is superior in terms of lightweight, its thermal conductivity is at most twice that of copper, so that in case where a heat dissipation rate in excess of 5 W is required, a hybrid device gains superiority whereby the 1-mm thick heatpipe having an equivalent thermal conductivity of as much as some tens to some hundreds times that of copper is combined with a metal sheet. It is expected that peraflex, an advanced vapor chamber with a thickness of about 0.6 mm, will be widely used in future when the heat rate continues to increase while the thickness is strictly restricted.

The active heatsink system refers to a combination of fan and heatsink mentioned above, and fins to be mounted behind the fan play an important role since the system

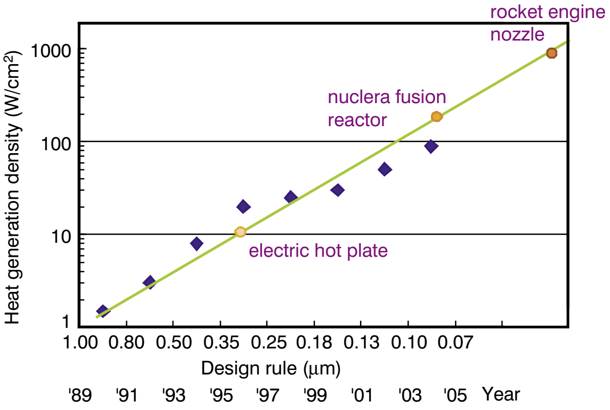

Figure 1 **Changes in heat generation density of MPU depending on design rule.**

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is based on forced air cooling. Most of the heatsinks currently in use can be classified into this category. Since it is anticipated that the heat generation rate of personal computers continues to increase while the equipment are still required to be low in height, light in weight, small in size as well as low in noise, efforts must be made for these active heatsinks that constitute the mainstream to improve themselves to meet these requirements. In this context, design optimization of active heatsinks has become a differentiation technology in the sphere of personal computers.

Water-cooled system for notebook PCs is based on a concept of using a pump to circulate working fluid all over the equipment thereby dissipating heat, and its heat dissipating rate (i.e. typically around 30 W) is higher than that of the above-mentioned fan-less heatsinks that dissipate heat solely from the keyboard. But it is disadvantageous in terms of long-term reliability —such that it has a moving part like fan, its piping is rather long, and the fluid decreases due to permeation through the piping— and cost, so that it is anticipated that the system has limited applications in the immediate future.

Optimally designed heatsinks obviously incorporate a variety of technologies and patents. Accordingly, this paper predicts technology development of the heatsink of the next generation in accordance with the segmentation of height reduction, weight reduction and size reduction.

2. HEIGHT REDUCTION TECHNOLOGY

In notebook PCs, performance upgrading and height reduction are progressing in parallel.

While at first fans were mounted in the shape of a box independently on the heat-diffusion plate and the like, gradually the casing for small fans was integrated in its lower portion with the heat-diffusion plate. Moreover, there have been many changes including: the material for fan casing has been changed from resin to metal to improve thermal performance; the air intake of the fan from single-sided to double-sided to increase the airflow rate, together with the shape from a box to a half cylinder with a lower flow resistance; and the air exhaust hole from single-sided to double-sided.

Heat-diffusion plates initially used aluminum in the form of die-casts and the like for its advantages in cost and weight, but recently, copper begins to be used for performance improvement.

Fins were integrally formed by die-casting at the beginning, but afterward manufacturing technologies such as the caterpillar fin technology whereby combined fins are continuously fabricated were developed to enable narrow-pitched fabrication together with the stacked fin technology, and currently products using these technologies are emerging as the mainstream.

μHPs that were primarily ϕ3 mm in size have grown to ϕ6 mm as the heat rate and the heat density increased, and they are mostly flattened to approximately 3 mm for application. Recently, a heatsink using 1-mm thick heatpipe has reached the level of practical application along with a vapor chamber shown in Figure 2 that incorporates heat-diffusion plate and μHP. The heatsink based on 1-mm thick μHP has achieved a thermal resistance of 1 K/W or less with a thickness of 10 mm including the fins.

Figure 2 Appearance of vapor chamber.

Whereas bonding of μHP with fin and heat-diffusion plate has been carried out by using adhesives or additional covering materials in the beginning, recently many heatsinks are either directly soldered so as to reduce thermal resistance or mechanically bonded by caulking.

The company-owned patents that contribute to the height reduction technology will be described below.

2.1 μHP

(1) Japanese Patent 3408033

This patent features prescribing the thickness of the oxide layer inside a μHP, which is essential for assuring long-term reliability. Referring to the recent trends in the technologies of other companies in the same business, it is inferred that this patent would be extensively used.

(2) Japanese Patents 1942645, 3045491 and 3035772

These patents become necessary for practical application of thin heatpipes having a thickness of less than 2 mm, describing a structure in which wire and the like is gathered to a part of the pipe cross-section, securing passages for the working fluid and the vapor separately.

(3) Japanese Patent 3403307

It is crucial for vapor chambers, since they directly cool MPUs and the like in close contact, to maintain flatness of the contact surface as well as to prevent dryout even in case of high heat density. These problems have been overcome by a supporting post shown in Figure 3 connecting the top and bottom sides of the device, and this technology has been incorporated in realizing a vapor chamber by Furukawa Electric for the world's first practical application.

2.2 Bonding Method and Relative Position of Components

(1) Japanese Patent 3454761

To realize an ideal low-profiled heatsink, it is essential that the heatsink has a structure such that a free space is provided above the air intake of the fan, fins are mounted in the way of the fan exhaust, and μHPs are bonded —using soldering and the like to effect low thermal resistance bonding— on the upper part of the fins at a loca-

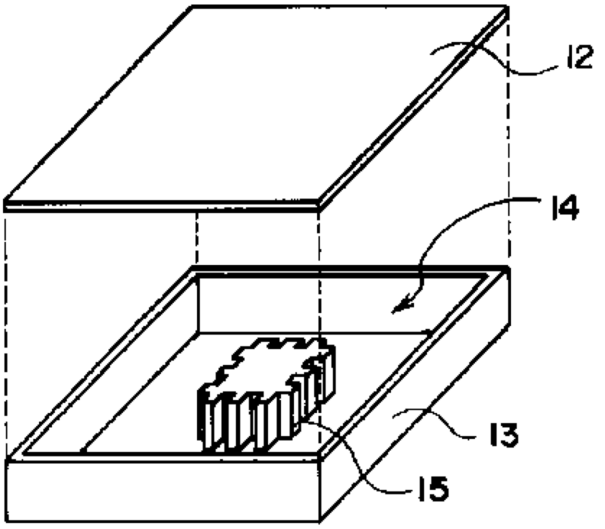

Figure 3 Schematic of internal structure of vapor chamber, with a supporting post numbered 15.

tion higher than the air intake. The patent discloses, as shown in Figure 4, bonding position of the μHP relative to each constituting components aiming at obtaining an ideal structure for heatsinks. While this patent discloses an ideal position of the μHP relative to the heat-diffusion plate, another patent has been filed that features a structure in which a part of the heat-dissipating section is located higher than the air inlet of the fan.

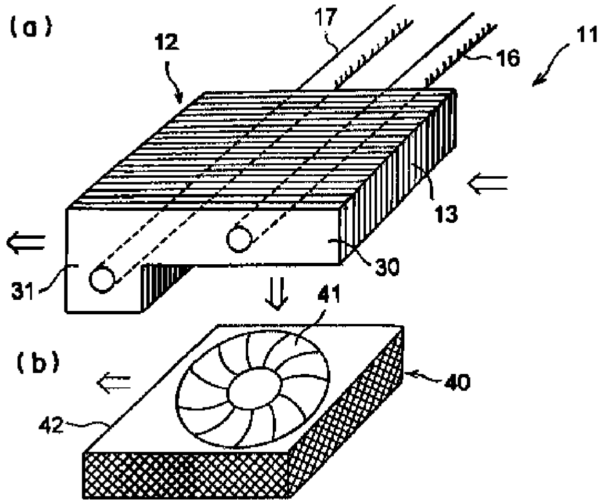

Figure 4 Ideal positions of heatsink components relative to each other.

(2) Japanese Patents 3413151 and 3413152

Depending on the location of MPU, it is occasionally impossible to secure a relative position with μHP as described in the Clause (1). In such cases, as disclosed in this patent, the μHP is mechanically fitted into the fins so as to enlarge fin area under the limitation of free space thus achieving a low-profiled, high-performance heatsink. See Figure 5.

(3) Japanese Patent 3273505

This patent features a heatsink structure whereby fins and μHPs are mounted on a heat-diffusion plate as shown in Figure 6.

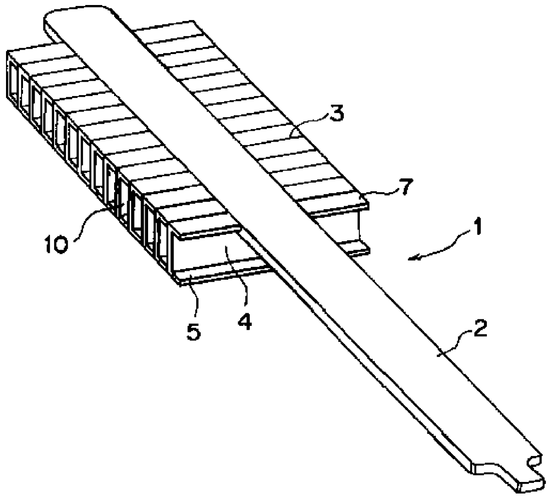

Figure 5 Example of mechanical fitting of μHP into fin.

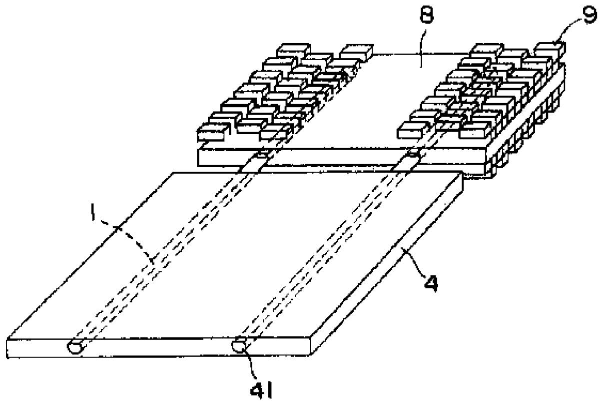

Figure 6 Schematic of heat-diffusion plate with heatpipe and fin.

As described above, a variety of technologies are incorporated into low-profiled heatsinks, and they are disclosed in the form of patents.

3. WEIGHT REDUCTION TECHNOLOGY

Those heatsinks presented in Figures 4 through 6 are low-profiled heatsinks with excellent thermal performance. But since they are mainly made of copper, problems arise about the cost and weight. To solve these problems, development of new heatsinks is under way, in which all the materials except for μHPs are changed to aluminum without degrading the thermal performance. It has been confirmed, through various developmental studies, that the aluminum heatsink shown in Figure 7 can achieve weight reduction without sacrificing its thermal performance.

The use of caulking can firmly fix the heat-receiving block and the μHP, resulting in, although somewhat depending on the caulking conditions and the structure, a lower thermal resistance than soldering. However, despite the fact that caulking itself is rather easy to carry out, care must be taken to use right dimensions and structures for caulking so as to avoid the possibilities of defective caulking such as buckling of μHP and gapping between the block and the μHP. Aluminum heatsinks manufactured by

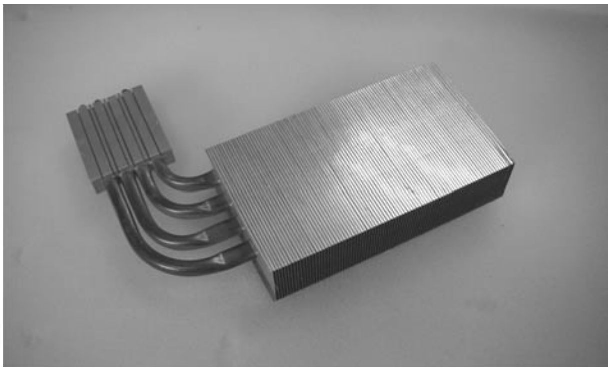

Figure 7 Heatsink with aluminum fin and aluminum heat-receiving block.

good caulking can reduce the cost as well as weight by 20~40 % compared with the copper heatsinks described in Chapter 2.

On the other hand, bonding of μHP and fins can yield, by press fitting the μHP into each fin, a thermal resistance equivalent to that of soldering. Since each fin is small in size, fin efficiency shows little difference notwithstanding whether copper or aluminum is used as the material, resulting in no appreciable difference in thermal performance.

Japanese patents 3268734, 3010181 and 3438944 have supported the realization of this heatsink, disclosing various caulking methods and structures that contribute to performance improvement.

4. SIZE REDUCTION TECHNOLOGY

Whereas in Chapters 2 and 3 the height and weight reduction technologies for notebook PCs were described, in this Chapter 4 downsizing technology incorporated with weight reduction technology for desktop PCs will be presented. Generally speaking desktop PCs afford ample space, so that it is a normal practice to mount just above the MPU a combination of fin array —e.g. extruded fin with copper insertions, soldered copper fins and Crimped fin® — and fan, as shown in Figure 8.

Recently, heat generation rate of GPUs has rapidly increased as well as MPU necessitating heatsinks with fan for GPUs, so that noise caused by the fan is drawing attention as a problem. This has resulted in a need for greater heatsinks, but since simple size increase would not improve thermal performance notwithstanding weight increase, tower-type heatsink incorporating μHP has been put into practical use. In this heatsink, technologies disclosed in Japanese patents 2685918 and 3106428 have been applied to realize a lightweight, compact heatsink. See Figure 9.

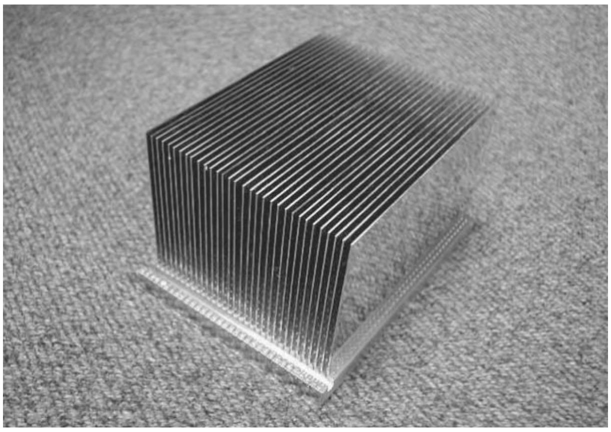

Figure 8 Heatsink for desktop PC.

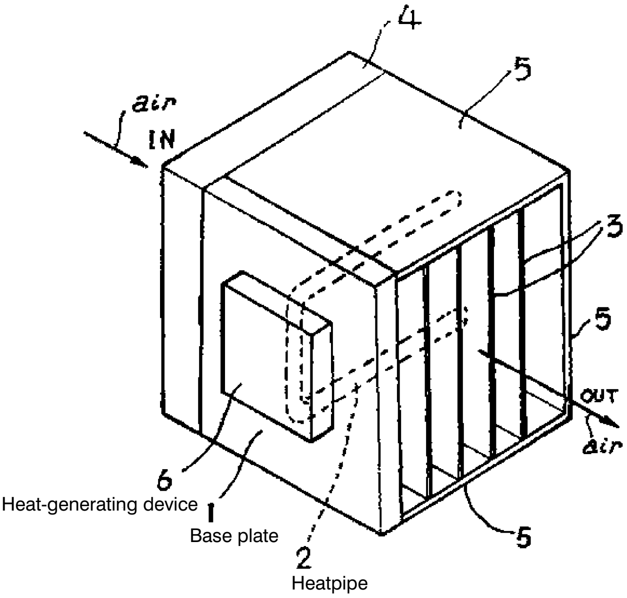

Figure 9 Schematic of tower-type heatsink.

5. CONCLUSION

This paper has presented state-of-the-art heatsinks and their technologies, which may be summarized as follows.

(1) Thin heatpipe to realize low-profiled heatsinks
(2) Caulking techniques to reduce thermal resistance
(3) Aluminum heatsink contributing to the weight reduction of heatsinks
(4) Tower-type heatsink to realize space-saving heatsinks

We intend to evolve these achievements further toward practical application of high-performance heatsinks that are lower-profiled, lighter and more compact.

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