Development of High-Performance Heatsink “Crimped fin®”

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ABSTRACT As the heat generation of CPUs steadily increases with some bumps and detours in recent years, there is an urgent requirement for the thermal performance of heatsinks. Since the requirement includes many conditions with respect to the volume, cost and environmental issues as well as noise reduction, it is often difficult to use high-performance heatsinks of remote type or Peltier devices, thus resulting in the use of a heatsink of conventional type. This paper discusses the advantages and limitations of the so-called Crimped fin® heatsink that belongs to the conventional type of heatsink, in which copper or aluminum heat-dissipating fins are mechanically bonded onto a base plate of either copper or aluminum. A brief description of the development and some application examples of Crimped fin® heatsinks of new configuration will also be included.

1. INTRODUCTION

The heat generation rate of CPUs shows, while being influenced by the surrounding circumstances such as the market and the technology innovation of peripheral equipment, the tendency toward a steady increase. Accordingly, today it is required to dissipate some tens watts —sometimes in excess of 100 W— of heat from a high-performance CPU to fully exploit its performance. It is expected that the power consumption of CPUs might decrease in future as the semiconductor design rule becomes finer, but on the other hand, the density of heat generation will surely increase. In either case, there arises a need for high-performance heatsinks. In addition, these heatsinks are required not only to have satisfactory thermal performance but also to meet many conditions with respect to the volume, cost, environmental issues and noise reduction. Due to the constraints on the volume and cost especially, it is virtually impossible, in most cases rather than in many cases, to use high technologies such as heatpipe-based remote heatsinks or vapor chambers, but to resort to the use of conventional heatsinks. It can be said that the heatsink of Crimped Fin type to be discussed here would be the optimum selection to reach a possible solution under the above-mentioned conditions, because this type provides the highest degree of freedom in designing among those heatsinks that consist of metals solely.

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2. FEATURES OF CRIMPED FIN HEATSINK

2.1 Positioning of Crimped Fin Heatsink

Crimped Fin heatsink is a heatsink in which copper or aluminum heat-dissipating fins are mechanically bonded onto a base plate of copper or aluminum, thereby being provided with high performance because the fins can be densely arranged. The heatsink has been developed to deal with thermal solutions where integral heatsinks made of aluminum extrusions conventionally in use are not applicable.

The aluminum extrusion-based integral heatsink is manufactured by extruding an aluminum extrusion to the shape of the heatsink itself and cutting it to a specified length, thus featuring the lowest manufacturing cost. Due to the geometrical constraints of the extrusion dies, however, the heatsink has a fin configuration limitation of 0.5 mm in fin thickness and 2.3 mm in fin pitch. To increase the heat transfer area, we have no choice but to manufacture the base plate and the fin separately, then bonding them by some means.

The bonding methods come in two ways, namely brazing including soldering and mechanical bonding like crimping. The Crimped Fin heatsink is manufactured by a mechanical method such that the base plate is grooved, fins are inserted into the grooves and are fixed by mechanically deforming both sides of the grooves.

In other words, the Crimped Fin heatsink is one of the alternatives to substitute the aluminum extrusion-based integral heatsink. Compared with this heatsink, the Crimped Fin heatsink is obviously superior in terms of

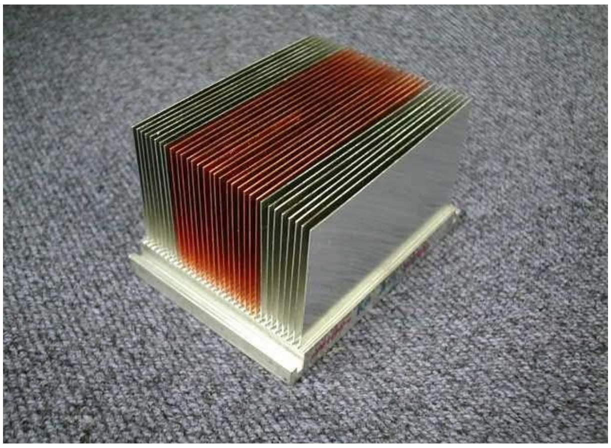

Photo 1 Crimped Fin heatsink with copper base plate and hybrid copper and aluminum fins.

thermal performance. Compared with soldered heatsinks, on the other hand, it is almost comparable in thermal performance, but has the following advantages.

(1) Crimped Fin heatsink uses simple tooling and a pressing machine to bond the fins so that it is low in production costs, while the soldered heatsink is sure to increase in cost by the amount corresponding to the soldering material. With respect to the production time, in addition, soldering is more time-consuming than mechanical pressing thus building up cost elements.

(2) Although they are equivalent with each other in terms of thermal performance, the individual difference in the thermal performance of the Crimped Fin heatsink is smaller than that of the soldered heatsink, because the former is uniformly press worked mechanically. Soldering process is more likely to fluctuate due to the unevenness of solder and the fixing method at the time of loading to the soldering furnace.

(3) Ordinary lead-tin solder is becoming difficult to use due to the environmental regulations. Many kinds of lead-free solders are now available, but they are all expensive. The Crimped Fin heatsink is completely free from environmental impacts.

(4) Soldering of aluminum-to-aluminum and aluminum-to-copper is technically difficult. Plating of aluminum makes the material as easy to be processed as copper, but plating is expensive. In contrast to this, Crimped Fin heatsinks can use any combination of copper and aluminum. Not only different materials for the base plate and the fin, but also a hybrid of materials, e.g. copper fins and aluminum fins can be used like the one shown in Photo 1. Consequently, design can be optimized in response to the required performance.

For these reasons the Crimped Fin heatsink has sufficient justification for existence at this time, when heatsinks are required to address the new problems of environmental regulations and noise as well as increasing heat generation by CPUs, and they are applicable to many uses accordingly.

2.2 Heat-Dissipation Performance

Figure 1 shows the performance curves of the Crimped Fin heatsink. Basically the thermal performance of a heatsink is represented by thermal resistance R_{ca} which is defined as the difference between CPU temperature T_c and ambient temperature T_{amb} divided by the heat generation rate of CPU Q. Following the same definition, the Figure shows the airflow dependence of the thermal resistance for Crimped Fin heatsink in comparison to those of aluminum-extruded heatsink and solder-bonded heatsink.

All the heatsinks have the same volume by dimensions of 65 mm (W) x 90 mm (L) x 50 mm (H), and the fins are all 0.4 mm in thickness with a pitch of 1.9 mm except for the aluminum extruded heatsink, fins of which are —due to the fact that such a small pitch can not be realized— 2.8 mm in pitch, 0.6 mm in thickness and 47 mm in height.

In the Figure, the Crimped Fin heatsinks (plotted by △, ◇ and ×) are obviously higher in performance than the aluminum extruded heatsink (plotted by ●), still they are slightly superior to the solder-bonded heatsink (plotted by ■). Specifically, the measurements of the solder-bonded heatsink and the Crimped Fin heatsink (plotted by ×) have been obtained using the models that are entirely identical in the fin material (aluminum), base plate material (copper), fin pitch, fin thickness and base plate size. If it is assumed that they are identical in the configuration and material and that they have sound bonding, they should have equivalent thermal performance because basically they can be considered as a metal block. The only difference to be noted is that, however, the solder-bonded heatsink compared here uses fins of folded type, so that, even though the fins have the same surface area in the design drawings, they might be slightly curved causing non-uniform airflows. That is to say, the reason why the Crimped Fin heatsink slightly outperforms the solder-

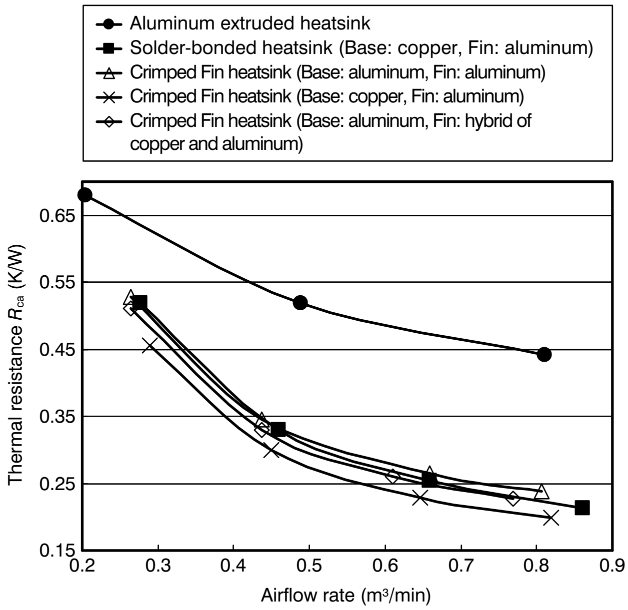

Figure 1 Thermal performance of Crimped Fin heatsink in comparison to other heatsinks.

bonded heatsink can be attributed to the difference in the straightness of the fins.

It is also possible for the Crimped Fin heatsink, as mentioned before, to select a design such that not aluminum but copper is used for the base plate, and copper is used for a part of the fin array adjusting the copper fin counts, thereby making an attempt to render an achievement of required performance compatible with cost reduction. The hybrid-fin heatsink (plotted by ◇) in the Figure has been designed based on such a concept.

2.3 Stability of Thermal Performance

Table 1 shows the results of confirmation of thermal performance stability of the Crimped Fin heatsink, whereby the thermal resistance of three types of heatsinks, i.e. two Crimped Fin heatsinks and one solder-bonded heatsink, were measured using eight samples per heatsink and their individual differences were compared. It can be seen from the standard deviation over eight samples that the Crimped Fin heatsink is very much smaller in the individual difference than the solder-bonded heatsink. When it is claimed that industrial products such as heatsinks should be evaluated with respect not to mean value but to guaranteed value, comparisons should be made using the mean + 3σ.

In the previous Section it was described that if the heatsinks have the same configuration and material as well as sound bonding, they should have the same performance independently of the bonding method. Referring to this description together with such a fluctuation factor mentioned here, it may be concluded that the Crimped Fin heatsink offers better performance than the solder-bonded heatsink of the same configuration.

Table 1 Stability of thermal performance.

Material	Base	Copper	Aluminum	Copper
	Fin	Aluminum	Aluminum	Aluminum
Bonding method		Solder bonding	Crimping	Crimping
Number of sample		8	8	8
Thermal resistance R_{ca} (K/W)	Mean	0.325	0.338	0.296
	Standard deviation σ	0.0105	0.0048	0.0042
	Mean + 3σ	0.357	0.355	0.309

2.4 Comparison of Various Types of Heatsinks

Table 2 compares the Crimped Fin heatsink with other types of heatsinks. Whereas each heatsink has its own advantages and disadvantages, the Crimped Fin heatsink is seen to offer a wide range of optimum solutions.

3. LIMITATIONS OF CRIMPED FIN HEATSINK

3.1 Vertical Airflow and Horizontal Airflow

CPUs are generally cooled using a heatsink and a fan, and the cooling methods come in two types, i.e. the one in which the fan is directly mounted on the heatsink effecting vertical airflow as shown in Figure 2, and the other in which the fan is arranged on the side of the heatsink effecting horizontal airflow as shown in Figure 3. The former is mainly adopted in desktop PCs and the latter in servers.

The vertical airflow is adopted in cases where the heatsink has to be accommodated together with the fan in a vacant space just above the CPU, but its cooling efficiency is inferior to that of the horizontal airflow. This is largely because the fan is located near the heatsink fins with its

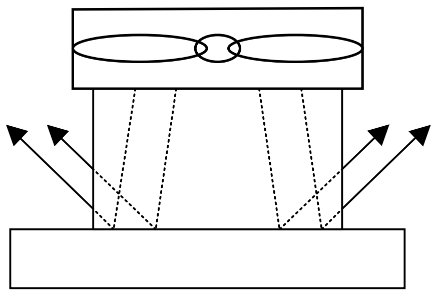

Figure 2 Heatsink with vertical airflow.

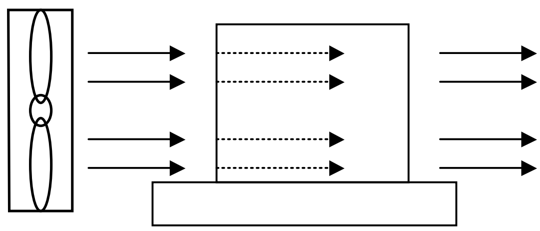

Figure 3 Heatsink with horizontal airflow.

Table 2 Comparison of various types of heatsinks.

		Crimped Fin heatsink		Aluminum extruded heatsink		Solder-bonded heatsink	
Design flexibility	Fin pitch and height	No limitations	○	Manufacturing limitations are posed on the height/width ratio	×	No limitations	○
	Fin and base material	Either copper or aluminum can be used in any configuration	○	Only aluminum can be used	×	Changing the material for a part of fin array is difficult	△
Manufacturing process		Simple	○	Most simple	◎	Complex, involving soldering in furnace	×
Cost		Low	○	Low	○	High	×
Reliability		No problem	○	No problem	○	Zinc solder is weak against high-temperature and high-humidity	×
Environmental issues		No problem	○	No problem	○	Lead solder is environmentally hazardous	×
Thermal performance			○	Thermal resistance is higher than the other two	×		○

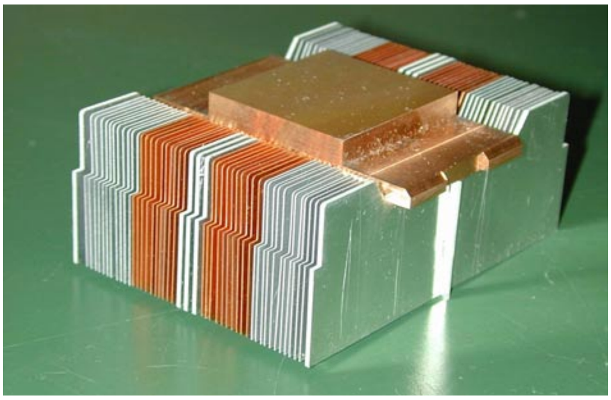

Photo 2 Heatsink with a base plate smaller than the fin area.

shaft bearing facing the center portion of the heatsink, rendering this portion potentially windless. Another reason may be that the airflow bounces from the base plate to go through horizontally causing accumulation and drift of airflows, so that a uniform airflow becomes difficult to be realized.

Accordingly it can be said that, no matter how densely the fins are bonded on the base plate, an appreciable portion of the heat transfer area does not contribute to improve the thermal performance. All heatsinks of vertical airflow type have such a drawback, whether they belong to aluminum extruded heatsink, solder-bonded heatsink or Crimped Fin heatsink. To solve this problem various designs have been proposed to increase the downward airflow rate that bypasses the base plate, e.g. reducing the shaft bearing area of the fan, reducing the area of the base plate, or removing a part of the base plate as shown in Photo 2, but none of them have achieved substantial improvements.

3.2 Aluminum Extruded Heatsink with Pressure-Inserted Copper Block

Thus a new extruded heatsink based on a radical change of idea has appeared in the market, in which, as shown in Photo 3, an aluminum cylinder extrusion provided with radial fins is extruded, and a copper cylinder is pressure-inserted into the hollow core of the aluminum extrusion to make the whole structure a heatsink. This is called aluminum-extruded heatsink with pressure-inserted copper block (hereinafter called AECIH). It may be well to say that this is an optimum solution to the heatsinks provided with a top-mounted fan, because this structure can realize the following advantages that cannot be achieved by the Crimped Fin heatsink.

(1) When viewed from the fan, the shaft bearing corresponds to the copper cylinder as to the position, and the airflow faces toward the entire fin array.
(2) Since there is no base plate beneath the fin array, the airflow goes straight downward without generating accumulation and drift that constitute the disadvantages of vertical airflow, resulting in airflows comparable to horizontal airflow.
(3) It is possible to bend the fin to the same direction as the airflow or to the opposite direction, allowing fin configuration to be designed to adapt to the flow vector from the fan.

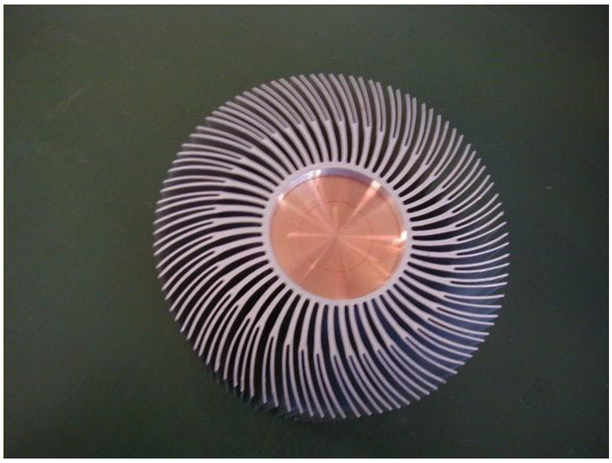

Photo 3 Aluminum extruded heatsink with pressure-inserted copper block (AECIH).

(4) Since the fin array is manufactured by extrusion of aluminum, it is low in cost.

Owing to the advantages of the items (1) through (3) specifically, the AECIH is superior in terms of thermal performance to the Crimped Fin heatsink, which ought to have a larger heat transfer area due to its densely packed fin array. Thus it was found out that among the heatsinks with a top-mounted fan the AECIH is the most advantageous, and, accordingly, the use of the Crimped Fin heatsink was beginning to be limited to the horizontal airflow heatsinks.

However, from another point of view it may be said that, because the Crimped Fin heatsink is denser in the fin arrangement per se, it would achieve better performance if it is possible to use fin crimping to form a structure equivalent to AECIH. It was against such a background that the authors embarked on the development of a Crimped Fin heatsink of new configuration.

4. DEVELOPMENT OF CRIMPED FIN HEATSINK OF NEW CONFIGURATION

Basically, fin-crimping technique involves bonding of two plane materials perpendicularly intersecting, so that it is difficult to form a structure whereby fins are radially arranged around a cylinder. More specifically, in this technique rectangular fins are inserted into the parallel grooves provided on the coplanar surface of a base plate, and the gap area between each fin is pressed in the direction perpendicular to the base plate, thereby fixing the fins by mechanical deformation as shown in Figure 4. If the base plate is curved, therefore, crimping the fin becomes virtually impossible.

The authors contemplated combining the two structural images of a cylinder block with radiating fins and of perpendicularly intersecting planes by fin crimping, and finally arrived at an idea of adopting a polygon prism to form a structure with radially arranged fins using the crimping technique. It was thought that not triangular or pentangular prisms having odd number of sides but regular polygon prism having even number of sides would allow fin

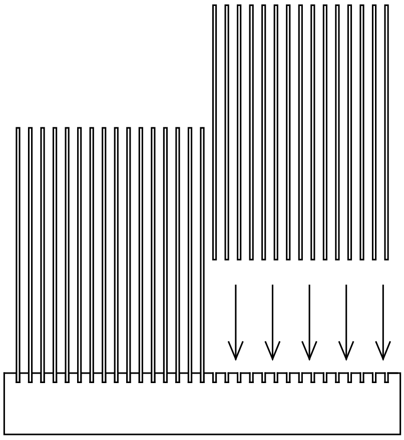

Figure 4 Manufacturing method for Crimped Fin heatsink.

crimping as usual, based on mechanical pressing utilizing two opposite sides; and further, that it was possible to form equally-spaced radial fins by bending the fins after crimping.

To obtain radial fins approximating a circular shape, square prism is insufficient, so that polygon prisms higher than hexagon in rank are required. Octagonal or decagonal prism is obviously better for its circularity, but either would involve complicated mechanical processing. It was therefore decided to use hexagonal prism.

As shown in Figure 5, the manufacturing process for the hexagonal Crimped Fin heatsink includes three repetitions of both-sides crimping followed by bending of the crimped fins.

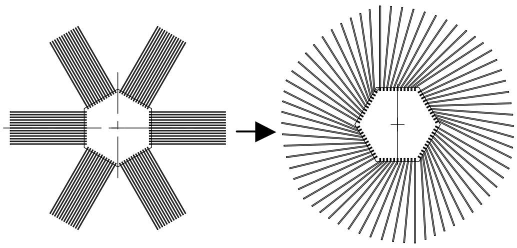

Figure 5 Manufacturing method for hexagonal Crimped Fin heatsink.

5. PERFORMANCE OF CRIMPED FIN HEATSINK OF NEW CONFIGURATION

Table 3 shows the performance of four prototypes of the hexagonal Crimped Fin heatsink with different fin thickness, fin pitch, etc. All the prototypes have been designed under the constraints of ϕ90 mm x 35 mm (H) in volume, and 350 gram in mass. The prototype heatsinks completely utilize one of the advantages of the Crimped Fin heatsink, i.e. suitable mixing of copper and aluminum fins is permitted to adjust the weight.

Although the prototypes fulfill the specifications of the new Crimped Fin heatsink such as the airflow as efficient as that of AECIH together with the densely arranged fins specific to fin crimping, the first and second prototypes were inferior to AECIH by 0.015 K/W with respect to the thermal performance. The reason for such results, despite the fact that copper fins are employed in place of aluminum fins, is that the crimped fins are thinner than the extruded fins unsatisfactorily counterbalancing the difference in the thermal conductivity between copper and aluminum, resulting in a temperature difference between the fin base and the fin end; in other words, insufficient fin efficiency. But even so, increasing fin thickness means simulating the advantages of the AECIH, eventually reducing the advantages of the Crimped Fin heatsink.

Accordingly we decided to improve the thermal performance by way of increasing the heat transfer area to such a degree that fully compensates the poor fin efficiency, i.e. densification of the fin array. It is a geometrical truth that radial fins tend to have coarse pitch at the outer circumference no matter how densely they are arranged at the inner circumference. Probably in consideration of this, in the case of AECIH also each fin is made to branch at its end. The method we took was such that two fins were inserted into each groove, and they were spread out after crimping to form a V-shape, thereby increasing the densities of fins at the outer circumference. The prototype-3 manufactured in this way was the first to be comparable with the AECIH in terms of thermal performance.

Table 3 Structure and performance of hexagonal Crimped Fin heatsink prototypes, illustrating the development process.

	AECIH	Prototype-1	Prototype-2	Prototype-3	Prototype-4
					
Fin pitch		1.3 mm	1.1 mm	1.3 mm	1.3 mm
Fin thickness	1.0 mm / 0.6 mm	0.4 mm	0.3 mm	0.2 mm	0.2 mm
Fin count	52 at base, 104 at end	Copper: 36 Aluminum: 30	Copper: 54 Aluminum: 24	Copper: 72 Aluminum: 60	Copper: 60 Aluminum: 132
Extended heat transfer area (cm^2)	1740	1370	1620	2740	3150
Thermal resistance R_{ca} (K/W)	0.265	0.280	0.275	0.265	0.250

An alternative way to increase the heat transfer area involves increasing the surface area per fin. In the case of AECIH fins are bent from the radial direction to the copper core center with an additional offset at the midpoint, realizing an elongation of the fin length within a fixed circle so as to increase the heat transfer area accordingly. The Crimped Fin heatsink was in turn provided with a flexing point at an intermediate point of the fins, in addition to the existing one, to have ultimately a greater bending angle. The prototype-4 obtained in this way was identified to have an increased heat transfer area, outperforming the AECIH in terms of thermal performance.

Meanwhile, the data shown in Table 3 were gathered under the conditions of: the fins are bent in the opposite direction to fan rotation; the thermal resistance was measured using identical fans; and the revolution was set to a noise level of 45 dB.

The hexagonal Crimped Fin heatsink has been optimized with respect to the fin thickness and the heat transfer area, and its hexagonal core has been enlarged with a view to adapting it to various CPU areas, finally arriving at a structure shown in Photo 4, and it was confirmed that this structure exhibits the best thermal performance meeting the prerequisite conditions of volume and weight limitations.

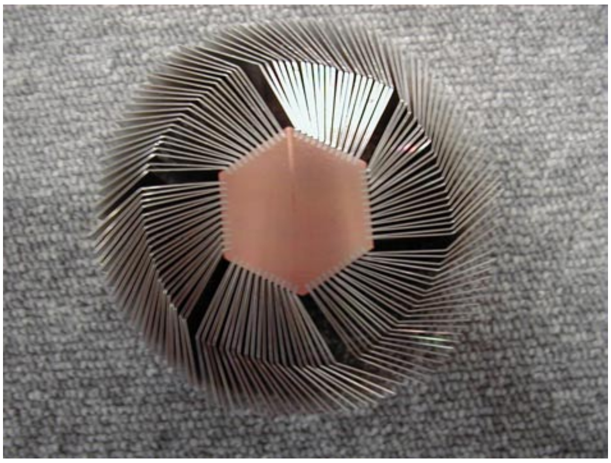

Photo 4 Hexagonal Crimped Fin heatsink with optimized configuration.

The hexagonal Crimped Fin heatsink thus optimized has a heat transfer area of 2850 cm^2 using 132 fins of 0.3-mm thickness, where copper fin is not used for the sake of weight adjustment. Yet it has a thermal resistance of 0.246 K/W, better than that of AECIH (i.e. 0.265 K/W) by about 0.02 K/W.

Changes in the thermal resistance as a function of heat transfer area of the five prototypes of the hexagonal Crimped Fin heatsink mentioned above is shown in Figure 6, whereby fin thickness is taken as a parameter. Although parameters such as the difference of material — i.e. copper or aluminum, the size of the center block, etc. are not included, the Figure is thought to provide a guideline to the design of hexagonal Crimped Fin heatsinks in case of different conditions.

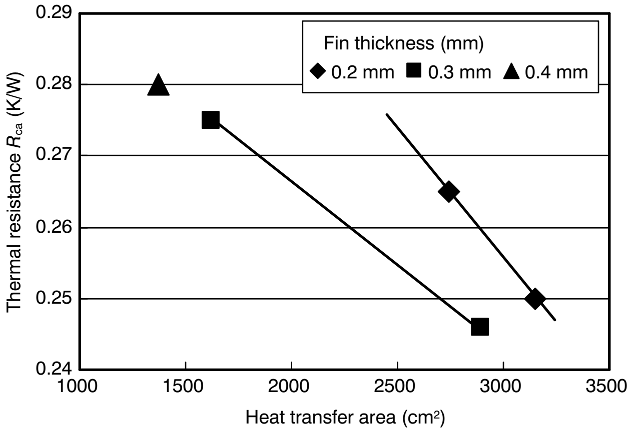

Figure 6 Relationship between thermal resistance and heat transfer area of hexagonal Crimped Fin heatsink with fin thickness as a parameter.

6. CONCLUSION

Whereas the Crimped Fin heatsink has superior characteristics in terms of thermal performance, reliability and environment-friendliness, it was found structurally difficult for the heatsink to deal with those applications whereby it was used with a top-mounted fan. In this paper, it has been reported that the new Crimped Fin heatsink has been realized by taking full advantage of techniques such as both-sides crimping and two-fin insertion, and that the new heatsink can meet the requirements involved with such applications.