



US 20140151012A1

(19) **United States**

(12) **Patent Application Publication**  
**Salamon**

(10) **Pub. No.: US 2014/0151012 A1**

(43) **Pub. Date: Jun. 5, 2014**

(54) **HEAT SINK WITH STAGGERED HEAT EXCHANGE ELEMENTS**

**Publication Classification**

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(51) **Int. Cl.**  
**F28F 5/00** (2006.01)

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(52) **U.S. Cl.**  
CPC ..... **F28F 5/00** (2013.01)  
USPC ..... **165/185**

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(57) **ABSTRACT**

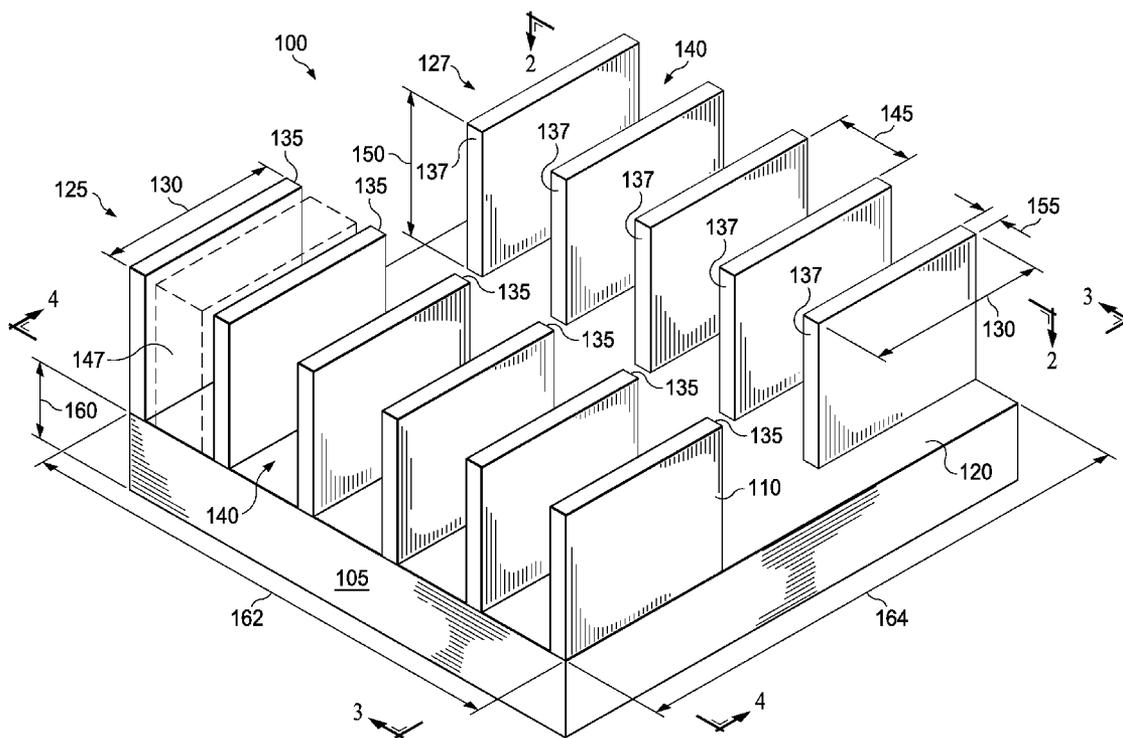
A heat sink comprising a base, a first row of metal fins and a second row of wedge-shaped vortex generators. The first row of metal fins can be connected to and raised above a surface of the base, long dimensions of the metal fins being substantially parallel to each other and to the surface. The second row of wedge-shaped vortex generators can be connected to and raised above the base, each of the wedge-shaped vortex generators having a long dimension that is substantially parallel to the long dimensions of others of the wedge-shaped vortex generators and to the surface. The first and second rows can be substantially opposed to each other such that first ends of the metal fins are staggered with respect to first ends of the wedge-shaped vortex generators.

(21) Appl. No.: **14/176,979**

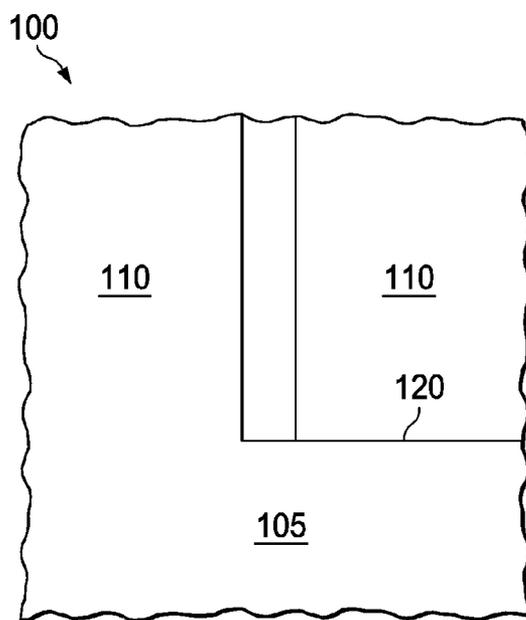
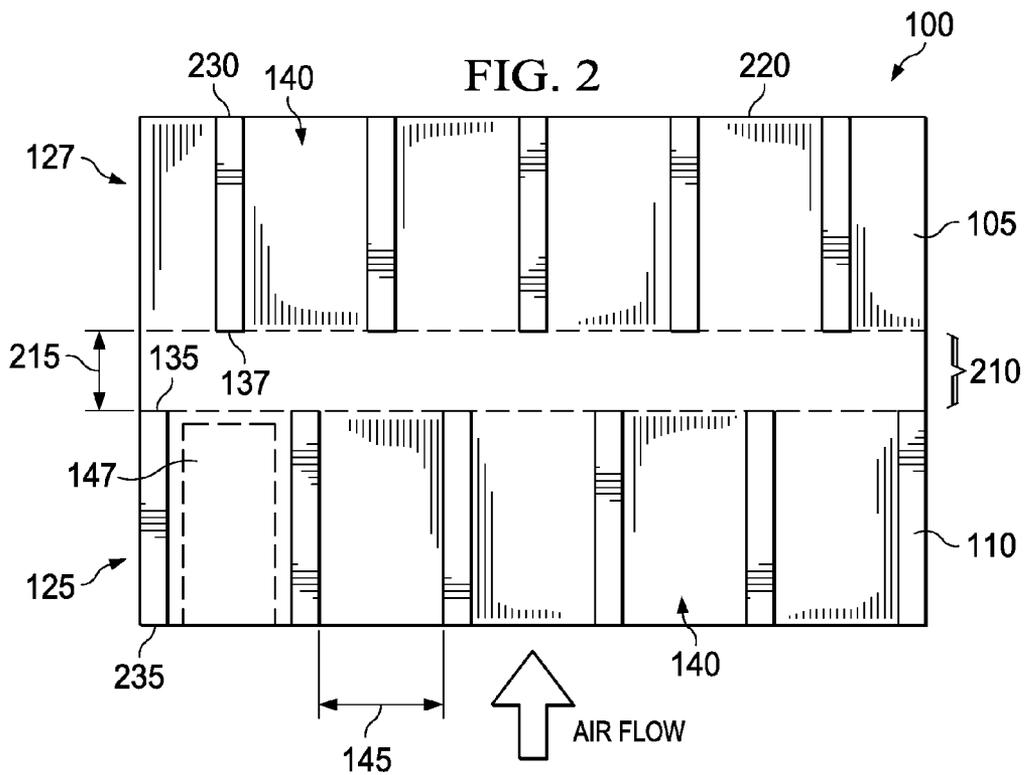
(22) Filed: **Feb. 10, 2014**

**Related U.S. Application Data**

(63) Continuation of application No. 12/835,405, filed on Jul. 13, 2010, now abandoned.







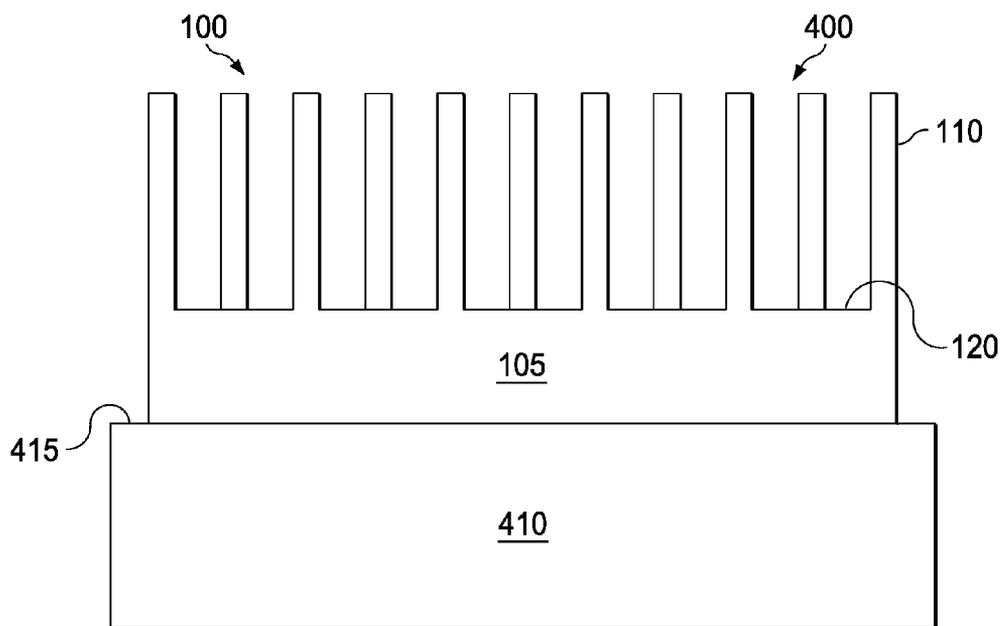


FIG. 4

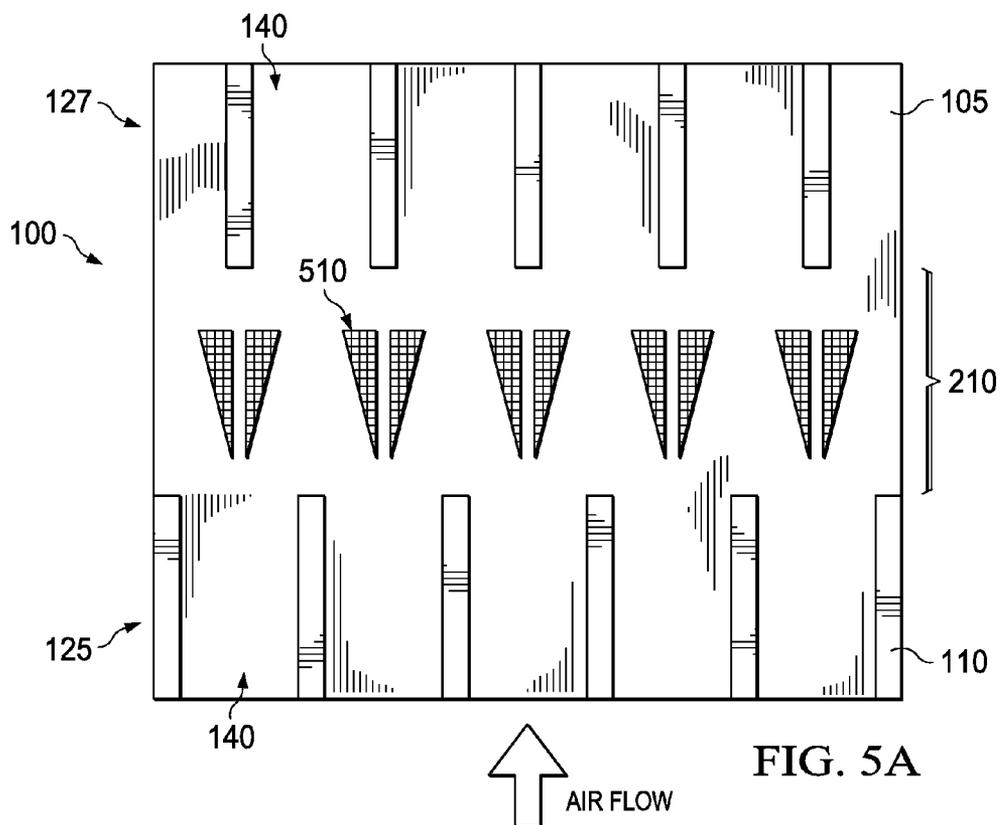
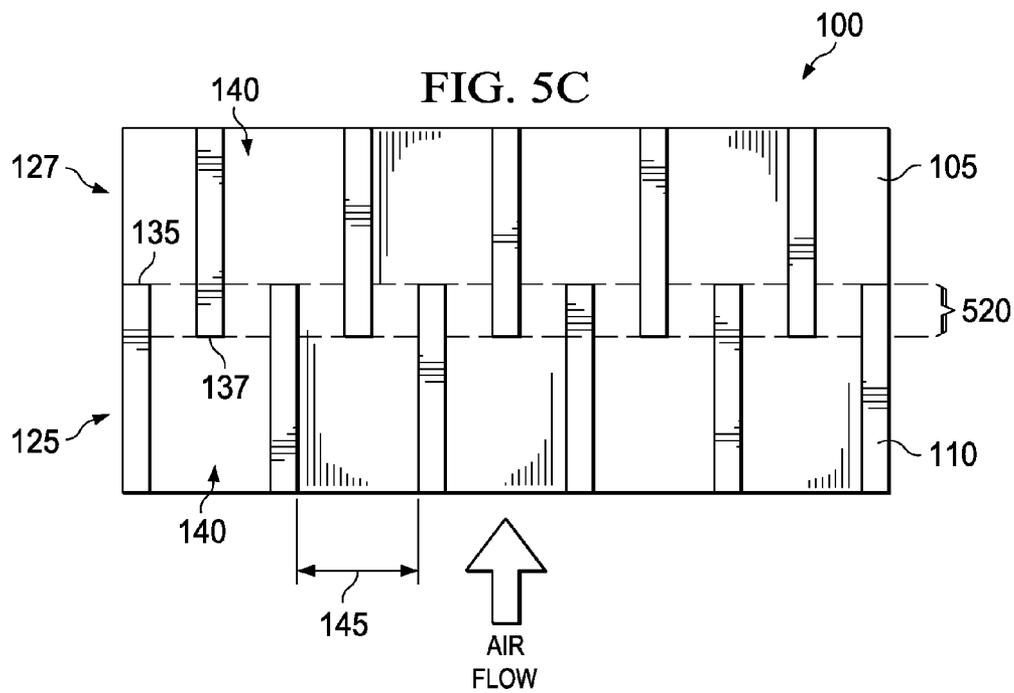
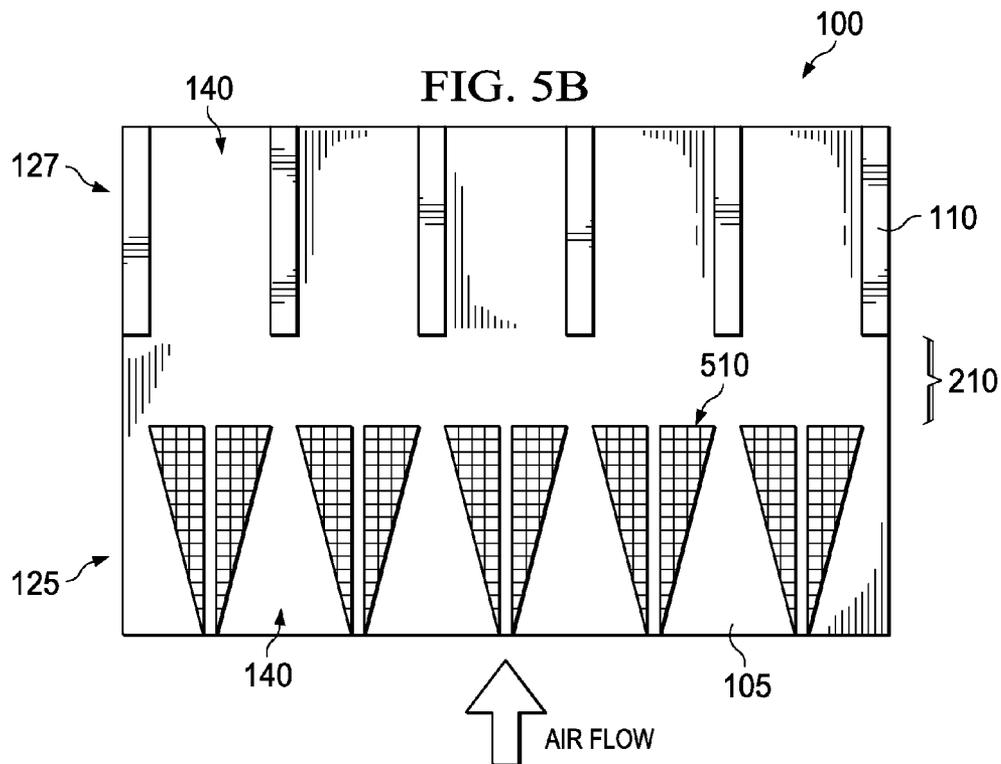
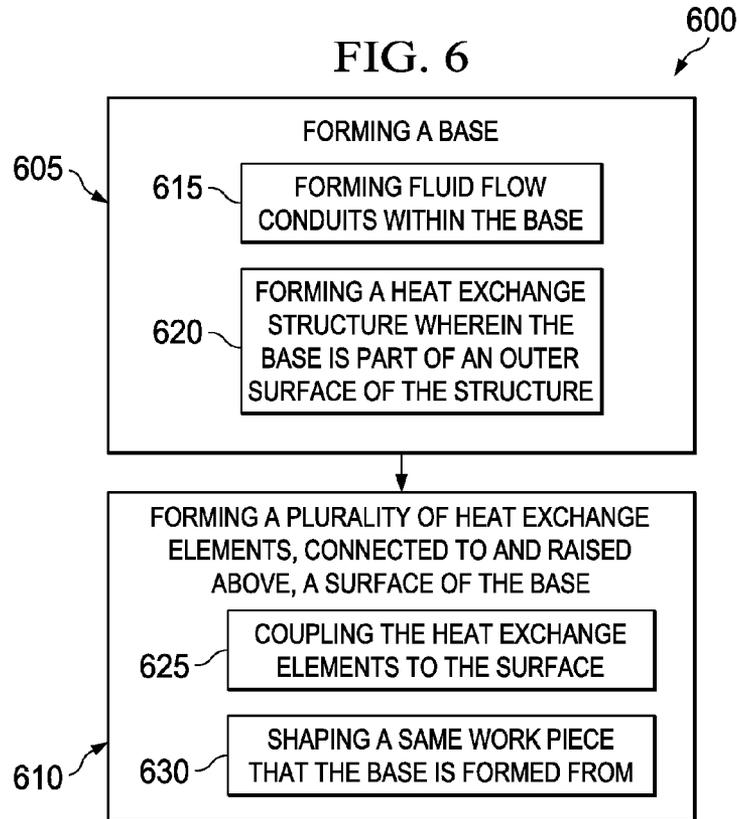
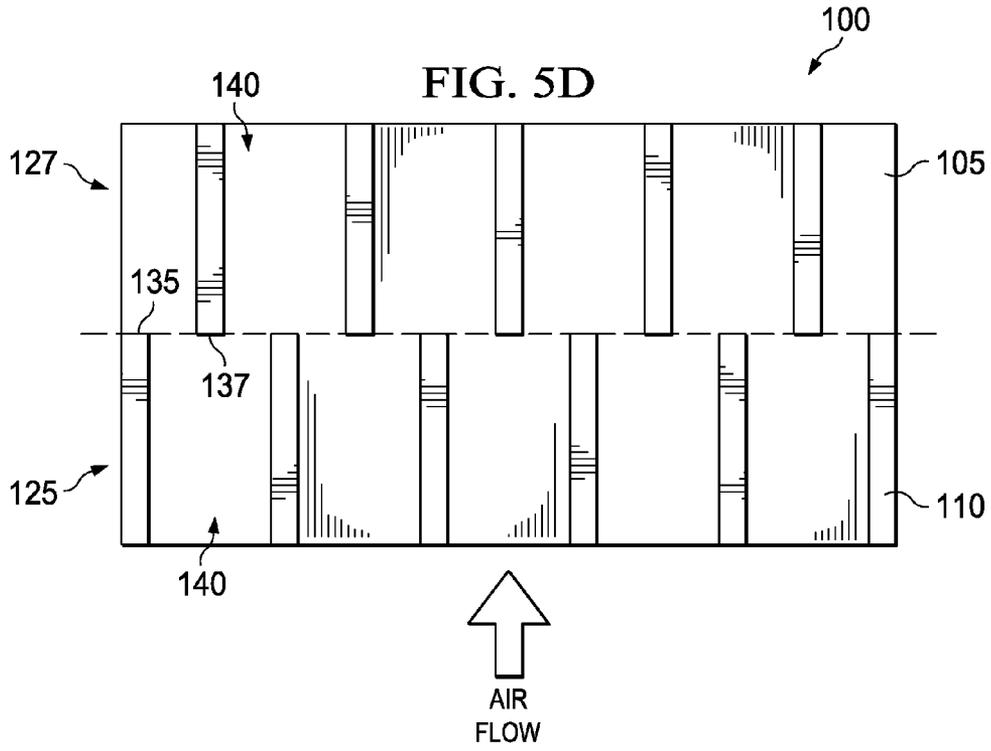
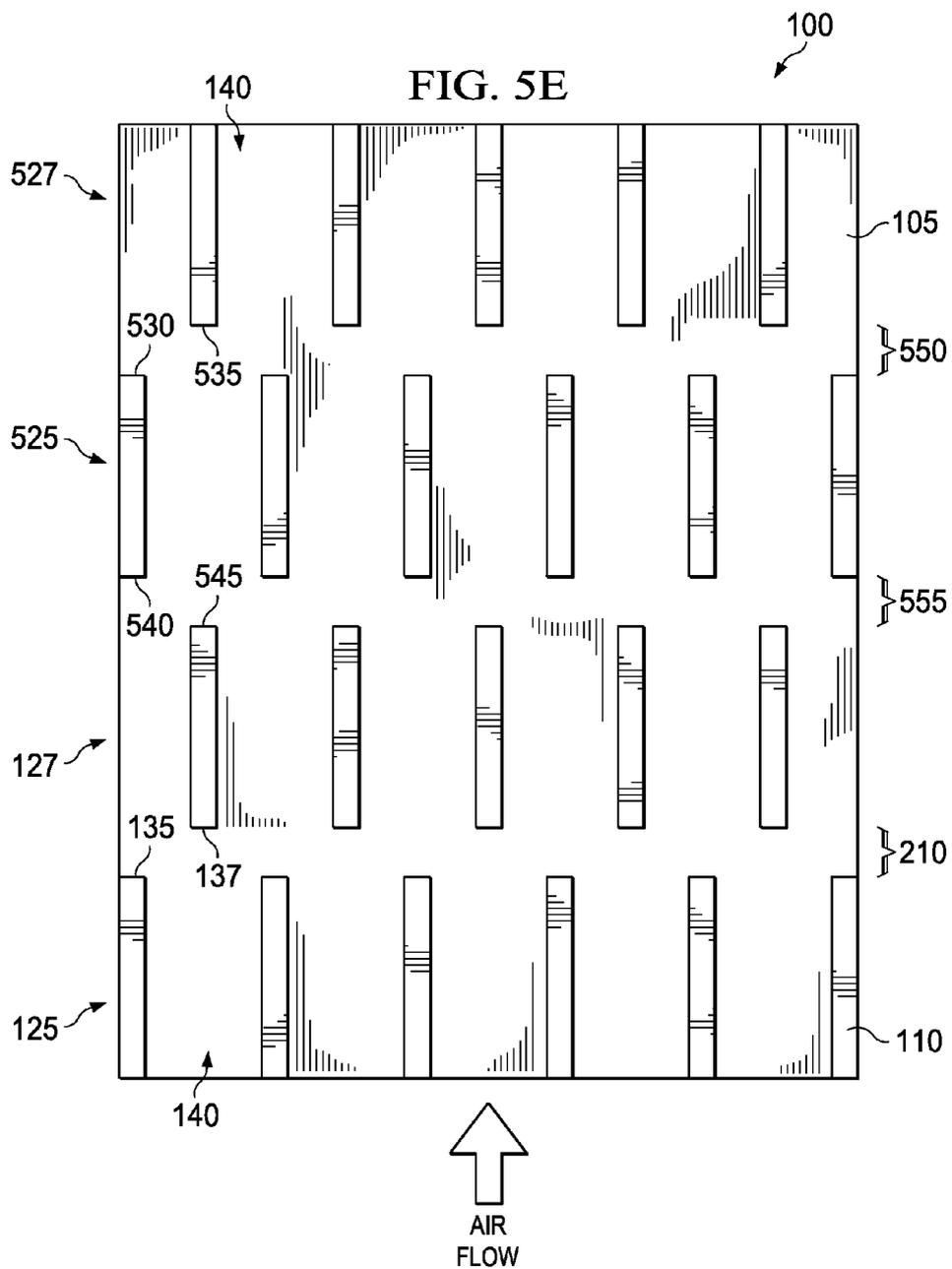


FIG. 5A







## HEAT SINK WITH STAGGERED HEAT EXCHANGE ELEMENTS

### CROSS-REFERENCE

[0001] This application is a continuation application of U.S. patent application Ser. No. 12/835,405, filed on Jul. 13, 2010 to Salamon, entitled "HEAT SINK WITH STAGGERED HEAT EXCHANGE ELEMENTS", commonly assigned with the present application, and is fully incorporated herein by reference in its entirety.

### TECHNICAL FIELD OF THE INVENTION

[0002] The present disclosure is directed, in general, to a heat sink and methods of manufacture thereof.

### BACKGROUND OF THE INVENTION

[0003] This section introduces aspects that may be helpful to facilitating a better understanding of the inventions. Accordingly, the statements of this section are to be read in this light. The statements of this section are not to be understood as admissions about what is in the prior art or what is not in the prior art.

[0004] Heat sinks are commonly used to increase the heat transfer area of an electronic device to decrease the thermal resistance between the device and cooling medium, e.g., air. There is a growing trend, however, for electronic devices to dissipate so much power that traditional heat sink designs are inadequate to sufficiently cool the device. Improved heat transfer efficiency from electronic devices would help extend the lifetime of such devices.

### SUMMARY OF THE INVENTION

[0005] One embodiment is a heat sink comprising a base, a first row of metal fins and a second row of wedge-shaped vortex generators. The first row of metal fins can be connected to and raised above a surface of the base, long dimensions of the metal fins can be substantially parallel to each other and to the surface. The second row of wedge-shaped vortex generators can be connected to and raised above the base, each of the wedge-shaped vortex generators can have a long dimension that can be substantially parallel to the long dimensions of others of the wedge-shaped vortex generators and to the surface. The first and second rows can be substantially opposed to each other such that first ends of the metal fins are staggered with respect to first ends of the wedge-shaped vortex generators.

[0006] Some embodiments of the heat sink further comprise a third row of metal fins connected to and raised above the surface of the base, long dimensions of the metal fins of the third row can be substantially parallel to each other and to the surface, wherein the third and second rows can be substantially opposed to each other. In some such embodiments, first ends of the metal fins of the third row can be aligned with respect to second ends of the wedge-shaped vortex generators. In some such embodiments, a relatively narrower end of each one of the wedge-shaped vortex generators can be located closer to the first row than a relatively broader end of the each one of the wedge-shaped vortex generators. In some such embodiments, first ends of the metal fins of the third row can be aligned with respect to second ends of the wedge-shaped vortex generators. In some such embodiments, a relatively broader end of each one of the wedge-shaped vortex generators can be located closer to the first row than a rela-

tively narrower end of the each one of the wedge-shaped vortex generators. In some such embodiments, the metal fins of the first row can be substantially parallel to the metal fins of the third row.

[0007] In some embodiments of the heat sink, a relatively broader end of each one of the wedge-shaped vortex generators can be located closer to the first row than a relatively narrower end of the each one of the wedge-shaped vortex generators. In some embodiments of the heat sink, a relatively narrower end of each one of the wedge-shaped vortex generators can be located closer to the first row than a relatively broader end of the each one of the wedge-shaped vortex generators. In some embodiments of the heat sink, the wedge-shaped vortex generators can be metal element. In some embodiments of the heat sink, the base can be a metal base. In some embodiments of the heat sink, the wedge-shaped vortex generators can be metal elements.

### BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The embodiments of the disclosure are best understood from the following detailed description, when read with the accompanying FIGURES. Some features in the figures may be described as "vertical" or "horizontal" for convenience in referring to those features. Such descriptions do not limit the orientation of such features with respect to the natural horizon or gravity. Various features may not be drawn to scale and may be arbitrarily increased or reduced in size for clarity of discussion. Reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

[0009] FIG. 1 presents a perspective view of an example embodiment of the heat sink of the disclosure;

[0010] FIG. 2 presents a plan view of the heat sink along view line 2-2 shown in FIG. 1;

[0011] FIG. 3 presents a sectional view of the heat sink along view line 3-3 shown in FIG. 1;

[0012] FIG. 4 presents a sectional view of the heat sink along view line 4-4 shown in FIG. 1;

[0013] FIGS. 5A-5E present plan views of alternative embodiments of the heat sink of the disclosure, analogous to the view presented in FIG. 2; and

[0014] FIG. 6 presents a flow diagram of selected steps in an example method of manufacturing a heat sink of the disclosure, e.g., such as presented in FIGS. 1A-5E.

### DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[0015] The description and drawings merely illustrate the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangements that, although not explicitly described or shown herein, embody the principles of the invention and are included within its scope. Furthermore, all examples recited herein are principally intended expressly to be only for pedagogical purposes to aid the reader in understanding the principles of the invention and the concepts contributed by the inventor(s) to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions. Moreover, all statements herein reciting principles, aspects, and embodiments of the invention, as well as specific examples thereof, are intended to encompass equivalents thereof. Additionally, the term, "or," as used herein, refers to a non-exclusive or, unless otherwise indicated. Also, the vari-

ous embodiments described herein are not necessarily mutually exclusive, as some embodiments can be combined with one or more other embodiments to form new embodiments.

[0016] Embodiments of the disclosure benefit from the recognition that thermal boundary layers develop along the surfaces of a heat sink. Consequently, efficient heat transfer from the heat sink to the surrounding air can be deterred because the primary means of heat transfer from the slow air flowing in the boundary layer at the surface and the faster moving cold air in the space farther away from the surface is diffusion.

[0017] The embodiments described herein improve heat transfer efficiency by: i) increasing the turbulence (or mixing) of air located in the channels between the heat exchange elements of a heat sink; and ii) placing structures in a staggered fashion so as to ensure cooler air in the middle of channels contacts heat exchange elements directly. For instance, increased air turbulence helps mix the hotter air next to the heat exchange elements with the cooler air in the middle of channels, and thereby improve heat transfer. The increased contact of cold air with heat exchange elements, achieved by staggering the heat exchange elements in different rows as described herein, are believed in some cases to be capable of improving the cooling factor of a heat sink by up to about three times as compared to an analogous heat sink designs but without the staggered elements.

[0018] One embodiment of the disclosure is a heat sink. FIG. 1 presents a perspective view of one example embodiment of the heat sink of the disclosure. FIG. 2 presents a plan view of the heat sink along view line 2-2 shown in FIG. 1. FIG. 3 presents a sectional view of the heat sink along view line 3-3 shown in FIG. 1. FIG. 4 presents a sectional view of the heat sink along view line 4-4 shown in FIG. 1. FIGS. 5A-5C present plan views of alternative embodiments of the heat sink of the disclosure analogous to the view presented in FIG. 2.

[0019] Turning to FIG. 1, the heat sink 100 comprises a base 105 and a plurality of heat exchange elements 110. The heat exchange elements 110 are connected to and raised above, a surface 120 of the base 105. There is first row 125 of the heat exchange elements 110 and a second row of the heat exchange elements 110. Each of the heat exchange elements 110 of the first row 125 have a long dimension 130 that is substantially parallel to the long dimension 130 of other heat exchange elements 110 of the first row 125, and, also substantially parallel to the surface 120 of the base 105. Each of the heat exchange elements 110 of the second row 127 have the long dimension 130 that is substantially parallel to the long dimension 130 of other heat exchange elements 110 of the second row 127, and, also substantially parallel to the surface 120 of the base 105. The first row 125 and the second row 127 are substantially opposed to each other such that one set of ends 135 of the heat exchange elements 110 of the first row 125 are staggered with respect to one set of ends 137 of the heat exchange elements 110 of the second row 127.

[0020] The term staggered as used herein means that the ends 137 of the heat exchange elements 110 of the second row 127 are substantially offset from the ends 135 of the heat exchange elements 110 of the first row 125. For instance, consider two adjacent the heat exchange elements 110 in either of the rows 125, 127. The adjacent the heat exchange elements 110 define a channel 140, with a channel width 145, in-between the adjacent the two heat exchange elements 110. The ends 137 of elements 110 in the second row 127 are considered to be staggered with respect to ends 135 of elements

110 in the first row 125 when the ends 137 are aligned with a central space 147 (e.g., a middle 80 percent, more preferably a middle 40 percent, and even more preferably, a middle 20 percent of the space 147; FIGS. 1-2) of the one of the channels 140 located between the ends 135 of elements 110 in the first row 125.

[0021] In some embodiment, the height 150 of an element 110 might be longer than the long dimension 130 which, e.g., can correspond to a horizontal length of the element 110. However, the horizontal length, which is substantially parallel to the base surface, is still the long dimension 130 in the plane of the base's surface 120, e.g., because it is at least longer than the thickness 155 of the element 130 and because the height 150 dimension is perpendicular to the base's surface 120.

[0022] Heat sink designs featuring heat exchange elements with parallel long dimensions, such as disclosed herein, can provide superior heat removal as compared to certain heat sink designs using a two-dimension array pin- or pillar-shaped heat exchange elements for configurations where the air flow is predominantly parallel to the base and the long dimension of the heat exchange elements described in the invention. In contrast, pin- or pillar-shaped heat exchange elements can provide superior heat removal as compared to certain heat sink designs described in this invention when the flow is predominantly parallel to the heat sink base and also orthogonal to the long dimension of the heat exchange elements, and also when the flow is predominantly orthogonal to the heat sink base. The invention described herein is of interest to the case where the flow is predominantly parallel to the heat sink base and the long dimension of the heat exchange elements.

[0023] For many of the example embodiments presented herein, such as in FIGS. 1-4, the heat exchange elements 110 are depicted as being rectangular-shaped planar fins. In some embodiments such a heat exchange element 110 design can be desirable, e.g., because such structures can be relatively simple and inexpensive to manufacture, or, because the air flow characteristics around such structures are relatively easy to simulate via computer modeling. In other embodiments, however, it may be advantageous for the heat exchange elements 110 to have other shapes. Examples of other heat exchange element designs are presented in patent application Ser. Nos. 12/165,063; 12/165,193; and 12/165,225, all of which are incorporated by reference herein in their entirety. Non-limiting example designs include: bent or curved fins, fins that include flow diverters, monolithic structurally complex designs, or active heat sink designs.

[0024] As illustrated in FIG. 2, in some embodiments, the set of ends 135 of the heat exchange elements 110 of the first row 125 are separated from the set of ends 137 of the heat exchange elements 110 of the second row 127 by a gap 210. Including such an inter-row gap 210 can help reduce the overall pressure drop of air passing around the elements 110, since the airflow field will tend to rearrange when air goes through the gap 210 from one row 125 to the other row 127. Additionally, the gap 210 can also help the thermal boundary layer, which can develop next to the elements 110, to renormalize.

[0025] To facilitate such advantages, in some embodiments, a length 215 of the gap 210 between the set of ends 135 of elements 110 of the first row 125 and the set of ends 137 of elements 110 of the second row 127 can be up to about five times a channel width 125 between adjacent ones of elements

**110.** In some preferred embodiments, the gap **210** extends to an outer perimeter **220** of the base **105**. In some preferred embodiments, the gap **220** is substantially centrally located over the base **105** (e.g., such as when the elements **110** of the first row **125** and the second row **127** all have the same long dimension **130** length).

**[0026]** In some embodiments, there are additional structures that can be located in the gap **210** to facilitate increase air flow turbulence around the elements **110**. For instance, as shown in FIG. 5A. The heat sink **100** can further including one or more vortex enhancers **510** located in the gap **210**. The vortex enhancers **510** can be configured to direct air flow from channels **140** within the first row **125** of heat exchange elements **110** to channels **140** within the second row **127** of heat exchange elements **110**. Of course, in still other embodiments, such as shown in FIG. 5B, one or more of the elements **100** (e.g., the entire first row **125** of elements **110** can itself be designed as vortex enhancers. One skilled in the art would understand that the vortex enhancers can create vortices that are spatially and temporally varying and which enhance mixing of the cold air in the channel's middle and the hot air at the heat sink's surfaces. Example vortex enhancer designs (also known as vortex generators) are presented in the above-incorporated U.S. patent application Ser. No. 12/165,225.

**[0027]** In some embodiments, however there is no gap between the ends **135**, **137** of the elements **110** of the opposing rows **125**, **127**, such as discussed above in the context of FIG. 2. For instance, as illustrated in FIG. 5C, the set of ends **135**, **137** of the heat exchange elements of the first row **125** partially overlap with the set of ends **137** of the heat exchange elements **110** of the second row **127**. In some embodiments, as illustrated in FIG. 5C, a length **520** of the overlap between the set of ends **135** of the elements **110** of first row **125** with the set of ends **137** of elements **110** of the second row **127** is up to about five times a channel width **145** between adjacent ones of the heat exchange elements **110**.

**[0028]** In yet other embodiments, such as shown in FIG. 5D there is neither a gap nor an overlap between the ends **135**, **137** of the elements **110** of the opposing rows **125**, **127**. For instance, the ends **135**, **137** of the elements **110** from the opposing rows **125**, **127** can be substantially aligned with each other.

**[0029]** Some embodiments of the heat sink can include additional rows of heat exchange elements. For instance, as shown in FIG. 5E, the heat sink **100** can further including one or more additional rows **525**, **527** of the heat exchange elements **110**. Analogous to that discussed in the context of FIGS. 1 and 2, above, a set of ends **530** of the heat exchange elements **110** of the additional row **525**, are staggered with respect to a set of ends **535** of an opposing different additional row **527**.

**[0030]** Or, a set of ends **540** of the heat exchange elements **110** of the additional row **525** are staggered with respect to a second set of ends **545** of the first row or the second row (e.g., second ends **545** of the elements of the second row **127**, as depicted in FIG. 5E). As also illustrated in FIG. 5E, the set of ends **530**, **535** in the additional rows **525**, **527** can be separated by a gap **550** between the row **525**, **527**. Or, there can be a gap **555** between one or more of the additional rows **525** and one of the first and second rows (e.g., there is a gap **555**, between the set of second ends **540** of the elements **110** of the additional row **525** and the set of second ends **545** of the elements **110** of the second row **127**. In still other embodiments, however, the set of ends **535**, **537** of the elements of the

additional rows **525**, **527** can have overlap or be aligned, similar to that described in the context of in FIGS. 5C and 5D regarding example embodiments of the first and second rows **125**, **127**.

**[0031]** In some preferred embodiments, as also illustrated in FIG. 5E, the channels **140** in the additional rows **525**, **527** are oriented substantially parallel with each other and with the channels **140** of the first and second rows **125**, **127**. Such configuration helps avoid air pressure drops which can decrease the heat sink's cooling performance. In other embodiments, however non-parallel channel orientations between rows could be used.

**[0032]** In some embodiments of the heat sink **100**, as illustrated in FIG. 2, second ends **230**, **235** of the heat exchange elements **110** of the rows **125**, **127** can substantially extend to the outer perimeter **220** of the base **105**. However, in other embodiments, one or both of the second ends **230**, **235** may not extend to the perimeter **220**.

**[0033]** In some embodiments of the heat sink **100**, as illustrated in FIG. 2, lengths of the long dimensions **130** of the heat exchange elements **110** of the first row **125** are substantially equal to each other (e.g., within 10 percent). Similarly, the lengths of the long dimensions **130** of the heat exchange elements **110** of the second row **127** can be substantially equal to each other, and in some cases, to lengths of the long dimensions **130** of the elements of the first row **125**. However, in other embodiments, the long dimension **130** of the elements **110** in the first or second row **125**, **127** may not be the same length within a row **125** (or row **127**) or between different rows **125**, **127**.

**[0034]** As illustrated in FIG. 3 and FIG. 4, in some embodiments of the heat sink **100**, the heat exchanger elements **110** are continuously connected to the base **105**. That is, the elements **110** and the base **105** are formed from the same work piece of starting material (e.g., aluminum and copper and their alloys, or steel, brass or silver). For instance, the starting material can be a piece of metal which is shaped or machined, as further discussed below, to define the elements **110** and base **105**. In other embodiments, however the elements **110** can be separately made and then coupled, as further discussed below, to the base **110**.

**[0035]** One skilled in the art would be familiar with the appropriate size and spacing of elements **110** to use for particular cooling applications. For instance, in certain micro-electronic applications, the elements **110** can have lengths **130** and heights **150** up to about 200 mm and thicknesses up to about 2 mm, with the height-to-length aspect ratio ranging from about 1:1 to 20:1, height-to-thickness aspect ratios ranging about from 1:1 to 500:1, and the channel width **145** ranging from about 1 to 20 mm. Proportionally greater sizes and spacing could be used in larger-scale cooling applications.

**[0036]** As further illustrated in FIG. 4, another embodiment of the disclosure is an apparatus **400**. The apparatus **400** comprises a heat sink **100**, such as any of the embodiments of heat sinks **100** discussed in the context of FIGS. 1-5E. The apparatus **400** also comprises a structure **410** configured to produce heat. The heat sink **100** is coupled to the device **410**. One skilled in the art would be familiar with the means to couple a heat sink to a structure so as to achieve efficient heat transfer.

**[0037]** For instance, in some embodiments the apparatus **400** can be an electrical device, and the heat generating structure **410** includes an integrated circuit, or, in other cases, a

power supply of the electrical device. In some embodiments, the apparatus 400 can a heat exchanger and the heat generating structure 410 is a pipe that carries a heated fluid therein (e.g., water, air, refrigerant). For instance, a plurality of heat sinks 100 can be thermally coupled to a heat pipe structure 410 that is configured to circulate fluid from another device that generates heat, e.g., a motor or electrical power supply (not shown). In other embodiments, however, heat pipes could be incorporated within the base 105. Although the base 105 and structure 410 are depicted as having a planar interface 415, in other cases, the interface 415 could be non-planar (e.g., such as when the structure 410 is the wall of a cylindrical pipe).

[0038] Another embodiment of the disclosure is a method of manufacturing a heat sink. FIG. 6 presents a flow diagram of selected steps in an example method 600 of manufacturing a heat sink 100 of the disclosure, such as any of the embodiments of heat sinks 100 discussed in the context of FIGS. 1-5E.

[0039] With continuing reference to FIGS. 1-5E throughout, the method comprises a step 605 of forming a base 105, and a step 610 of forming a plurality of heat exchange elements 110, connected to and raised above, a surface 120 of the base 105. The elements 110 can be configured in any of the manners discussed herein.

[0040] In some embodiments, forming the base 105 in step 605 includes machining a thin sheet of metal to the appropriate dimensions. E.g., for some electronic cooling applications, the base's thickness 160 (FIG. 1) may be on the order of about 1 to 10 mm. E.g., for some micro-electronic cooling applications the length 162 and width 164 can be on the order of 10 to 300 mm.

[0041] In some cases, forming the base (step 605) can include a step 615 of forming fluid flow conduits (e.g., pipes or chambers) within the base 105. During the heat sink's operation fluid can be circulated through the conduits to facilitate cooling.

[0042] In some cases, forming the base (step 605) includes a step 620 of forming a heat exchange structure (e.g., a structure 410 such as discussed in the context of FIG. 4) wherein the base 105 is part of an outer surface of the heat exchange structure.

[0043] In some embodiments, forming the plurality of elements 110, connected to and raised above, the base's surface 120 in step 610, includes a step 625 of coupling the heat exchange elements 110 to the surface 120.

[0044] The coupling step 625 can include coupling individual elements 110, or preformed rows 125, 127 of the elements 110, to the surface 120. For instance the preformed rows can comprise a metal sheet which is folded to form the elements 110, and then the folded sheet can be coupled to the base 120. Non-limiting examples of coupling methods include epoxy bond, brazing, soldering, welding or various combinations thereof.

[0045] In other embodiments, the forming step 610 can include a step 630 of shaping a same work piece that the base 105 is formed from. As a non-limiting example, a single metal sheet work piece can be shaped by skiving, machining, bending or stamping, the sheet to form the elements 110. As another non-limiting example, a molten work piece can be shaped by extrusion or die casting, or, extrusion or die casting followed by post-extrusion machining, to form the elements 110.

[0046] Although the embodiments have been described in detail, those of ordinary skill in the art should understand that they could make various changes, substitutions and alterations herein without departing from the scope of the disclosure.

What is claimed is:

1. A heat sink, comprising:

a base; and

a first row of metal fins connected to and raised above a surface of said base, long dimensions of said metal fins being substantially parallel to each other and to said surface;

a second row of wedge-shaped vortex generators connected to and raised above said base, each of said wedge-shaped vortex generators having a long dimension that is substantially parallel to the long dimensions of others of the wedge-shaped vortex generators and to said surface; and

wherein said first and second rows are substantially opposed to each other such that first ends of said metal fins are staggered with respect to first ends of said wedge-shaped vortex generators.

2. The heat sink of claim 1, further comprising:

a third row of metal fins connected to and raised above the surface of said base, long dimensions of said metal fins of the third row being substantially parallel to each other and to said surface; and

wherein said third and second rows are substantially opposed to each other.

3. The heat sink of claim 2, wherein first ends of said metal fins of the third row are aligned with respect to second ends of said wedge-shaped vortex generators.

4. The heat sink of claim 2, wherein a relatively narrower end of each one of the wedge-shaped vortex generators is located closer to the first row than a relatively broader end of the each one of the wedge-shaped vortex generators.

5. The heat sink of claim 4, wherein first ends of said metal fins of the third row are aligned with respect to second ends of said wedge-shaped vortex generators.

6. The heat sink of claim 1, wherein a relatively broader end of each one of the wedge-shaped vortex generators is located closer to the first row than a relatively narrower end of the each one of the wedge-shaped vortex generators.

7. The heat sink of claim 1, wherein a relatively narrower end of each one of the wedge-shaped vortex generators is located closer to the first row than a relatively broader end of the each one of the wedge-shaped vortex generators.

8. The heat sink of claim 2, wherein a relatively broader end of each one of the wedge-shaped vortex generators is located closer to the first row than a relatively narrower end of the each one of the wedge-shaped vortex generators.

9. The heat sink of claim 1, wherein the wedge-shaped vortex generators are metal elements.

10. The heat sink of claim 9, wherein the base is a metal base.

11. The heat sink of claim 2, wherein the wedge-shaped vortex generators are metal elements.

12. The heat sink of claim 11, wherein the base is a metal base.

13. The heat sink of claim 2, wherein the metal fins of the first row are substantially parallel to the metal fins of the third row.