(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
30 September 2010 (30.09.2010)

PCT

(10) International Publication Number
WO 2010/110790 A1

(51) International Patent Classification:
H05K 7/20 (2006.01) *H01L 23/34* (2006.01)
G06F 1/20 (2006.01)

(21) International Application Number:
PCT/US2009/038255

(22) International Filing Date:
25 March 2009 (25.03.2009)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant *(for all designated States except US)*: **HEWLETT-PACKARD DEVELOPMENT COMPANY, L.P.** [US/US]; 11445 Compaq Center Drive W., Houston, TX 77070 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **BRATKOVSKI, Alexandre, M.** [US/US]; 1501 Page Mill Rd., Palo Alto, CA 94304-1100 (US). **OSIPOV, Viatcheslav** [RU/US]; 785 Carole Ct., East Palo Alto, CA 94303-1692 (US). **BURWARD-HOY, Graeme, W.** [NZ/US]; 13703 South Court, Palo Alto, CA 94306 (US). **KIYAMA, Lennie, K.** [US/US]; 1501 Page Mill Rd., Palo Alto, CA 94304-1100 (US).

(74) Agents: **COLLINS, David, W.** et al.; Hewlett-packard Company, Intellectual Property Administration, Mail Stop 35, P.O. Box 272400, Fort Collins, CO 80527-2400 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to the identity of the inventor (Rule 4.17(i))*

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

— *with international search report (Art. 21(3))*

(54) Title: GRID HEAT SINK

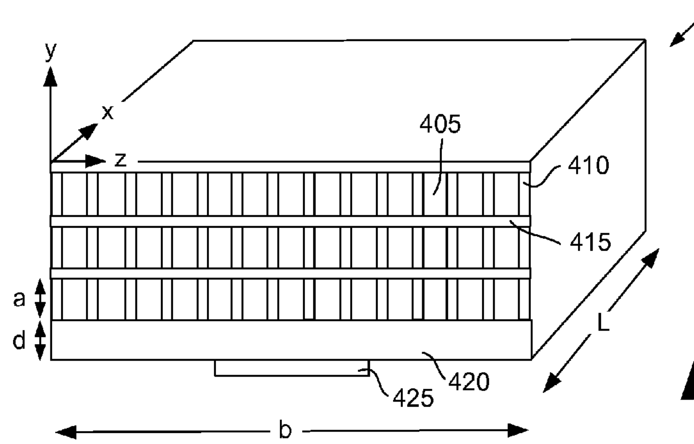

Fig. 4

(57) **Abstract**: A grid heat sink (400) includes a base (420), a plurality of intersecting fins (410, 415), and a plurality of channels (405) formed by the intersecting fins. Each of the channels (405) accepts cooling air (1605) at an input side of the grid heat sink (400) and directs the cooling air (1605) to an exit at an output side of said grid heat sink (400).

WO 2010/110790 A1

GRID HEAT SINK

BACKGROUND

[0001] As an electronic component operates, the electron flow within the component generates heat. If this heat is not removed, the electronic component may overheat, causing malfunction or damage to the component. The heat generated by the electronic component can be dissipated in a number of ways, including using a heat sink which absorbs and dissipates the heat via direct air convection.

[0002] Improvements in integrated circuit design and fabrication techniques are allowing IC manufacturers to produce smaller IC devices and other electronic components which operate at increasingly faster speeds and which perform an increasingly higher number of operations. As the operating speed of an electronic component increases, so too does the heat generated by these components. Further, computer components are being more densely packaged. These factors contribute to the desire for a heat sink which has more thermal and volumetric efficiency in removing heat from these electronic components.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] The accompanying drawings illustrate various embodiments of the principles described herein and are a part of the specification. The illustrated embodiments are merely examples and do not limit the scope of the claims.

[0004] Fig. 1 is a perspective view of an illustrative heat sink, according to one embodiment of principles described herein.

[0005] Fig. 2 is a perspective view of an illustrative heat sink, according to one embodiment of principles described herein.

[0006] Figs. 3A and 3B are diagrams of an illustrative cooling system, according to one embodiment of principles described herein.

[0007] Fig. 4 is a perspective view of an illustrative grid heat sink according to one embodiment of principles described herein.

[0008] Fig. 5A is an illustrative diagram of a temperature profile within a finned heat sink, according to one embodiment of principles described herein.

[0009] Fig. 5B is an illustrative diagram of a temperature profile within a grid heat sink, according to one embodiment of principles described herein.

[0010] Fig. 6A is an illustrative graph of heat removal as a function of air flux, according to one embodiment of principles described herein.

[0011] Fig. 6B is an illustrative graph of a difference between heat sink surface temperature and air exit temperature as a function of air flux, according to one embodiment of principles described herein.

[0012] Fig. 7 is a front view of an illustrative grid heat sink, according to one embodiment of principles described herein.

[0013] Fig. 8 is a front view of an illustrative grid heat sink, according to one embodiment of principles described herein.

[0014] Fig. 9 is a front view of an illustrative grid heat sink, according to one embodiment of principles described herein.

[0015] Fig. 10 is a cross-sectional view of an illustrative grid heat sink, according to one embodiment of principles described herein.

[0016] Fig. 11 is a front view of an illustrative grid heat sink, according to one illustrative embodiment of principles described herein.

[0017] Fig. 12 is a front view of an illustrative grid heat sink, according to one embodiment of principles described herein.

[0018] Figs. 13A-D show illustrative steps in forming a grid heat sink from a continuous sheet of thermally conductive material, according to one embodiment of principles described herein.

[0019] Fig. 14 is a cross-sectional view of an illustrative grid heat sink formed with a continuous sheet of thermally conductive material, according to one embodiment of principles described herein.

[0020] Fig. 15 is a cross-sectional view of an illustrative grid heat sink formed with a continuous sheet of thermally conductive material, according to one embodiment of principles described herein.

[0021] Fig. 16 is a diagram of an illustrative cooling system which incorporates a grid heat sink, according to one embodiment of principles described herein.

[0022] Fig. 17 is a diagram of an illustrative cooling system which incorporates a grid heat sink, according to one embodiment of principles described herein.

[0023] Fig. 18 is a diagram of an illustrative cooling system incorporated into a blade server, according to one embodiment of principles described herein.

[0024] Fig. 19 is a diagram of an illustrative computer rack containing a number of blade servers, according to one embodiment of principles described herein.

[0025] Throughout the drawings, identical reference numbers designate similar, but not necessarily identical, elements.

DETAILED DESCRIPTION

[0026] As an electronic component operates, the electron flow within the component generates heat. If this heat is not removed the electronic component may overheat, causing malfunction or damage to the component. The heat generated by the electronic component can be dissipated in a number of ways, including using a heat sink which absorbs and dissipates the heat via direct air convection.

[0027] Improvements in integrated circuit design and fabrication techniques are allowing IC manufacturers to produce smaller IC devices and other electronic components which operate at increasingly faster speeds and which perform an increasingly higher number of operations. As the operating speed of an electronic component increases, so too does the heat generated by these components.

[0028] Additionally, computer components are being more densely packaged which can demand more thermal and volumetric efficiency in the heat removal systems. For example, the shrinking sizes and increased functionality of modern electronic devices can result in much more restricted volumes for heat removal systems. In some computing architectures, such as arrays of blade servers, these volume restricted computing devices may be placed in close proximity to each other.

[0029] In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present systems and methods. It will be apparent, however, to one skilled in the art that the present apparatus, systems and methods may be practiced without these specific details. Reference in the specification to “an embodiment,” “an example” or similar language means that a particular feature, structure, or characteristic described in connection with the embodiment or example is included in at least that one embodiment, but not necessarily in other embodiments. The various instances of the phrase “in one embodiment” or similar phrases in various places in the specification are not necessarily all referring to the same embodiment.

[0030] Fig. 1 is a perspective view of an illustrative heat sink (100) which is in thermal contact with underlying computer chip (115). The heat sink (100) includes a base (110) and a number of vertical fins (105). Air passes through the vertical fins (105) and removes heat from the heat sink (100). The air may be moved by natural convention or forced convection. Natural convention utilizes the buoyancy forces of hot air to lift the heated air away from the fins and draw cool air into the heat sink to replace it. In forced convection cooling systems, a fan or other device creates a pressure difference or moving air flow which is channeled through the fins. Natural conventions systems typically have much lower cooling capacities than forced convention cooling systems.

[0031] Fig. 2 is an illustrative diagram of heat sink (100) through which an air flow (200) passes. According to one illustrative embodiment, the heat sink (100) includes a base (110) with a thickness “d”. The heat sink (100) has a number of vertical fins (105) and an overall width “b” and length “L.” The air flow (200) passes through the fins (105) parallel to the plane of the base.

[0032] Fig. 3A is an illustrative diagram of a forced air cooling system (300) which includes a fan (305). The heat from the chip (115) is transferred into the base (110) which distributes the heat into the vertical fins (105). The fan (305) may blow air stream directly into the vertical fins (105) in a process called impingement cooling. Alternatively, the fan (305) may create suction by removing air between the fins and blowing it out the top of the fan. A suction cooling system has inherent limitations in the amount of pressure differential which can be generated by the fan or blower.

[0033] Fig. 3B is an illustrative diagram of impingement cooling by the fan (305). Cooling air (310) is forced from above the fan (305) into the heat sink (100). A number of inefficiencies can arise in this configuration. First, the distribution of the air over the heat sink surfaces is not uniform. For example, the fan blade velocities are highest at the perimeter of the fan. Consequently, higher pressures and air flow are generated at the perimeter of the fan. In the center of the fan, much lower air flow may occur. The air flow may recirculate beneath the fan. Consequently, the center of the heat sink may not be effectively cooled.

[0034] Additionally, heated air may be recirculated. For example, air from the heat sink may escape upwards, curve around the housing of the fan (305) and be sucked back into the fan (305). This recirculation may be avoided by having a taller duct which encloses the fan. However, a taller duct makes the already tall cooling assembly even taller. Further, even if the heated air is not recirculated, air which prematurely exits the heat sink is not utilized to its full capacity and reduces the overall cooling efficiency of the heat sink for a given air flow rate.

[0035] The amount of cooling provided by a heat sink depends on a number of factors. These factors may include: the temperature difference between the cooling air and the surface of the heat sink, the volume of air forced through the heat sink, and the surface area of the heat sink.

[0036] Fig. 4 is a perspective view of one illustrative embodiment of a grid heat sink (400) which has significantly greater surface area than similarly sized finned heat sink (300). According to one illustrative embodiment, the grid heat sink (400) includes base (420) with a number of vertical fins (410). Horizontal fins (415) intersect the vertical fins (410) to form a grid with a number of channels (405). The channels may have a variety of geometries including, but not limited to, square, rectangle, hexagonal, or other geometries. In some illustrative embodiments, the channels may extend through the heat sink and maintain a fairly constant cross-section. In other illustrative embodiments, cross sections of the channels (405) may vary from channel to channel or vary along the length of an individual channel.

[0037] Fig. 5A is a cross-sectional diagram of a finned heat sink (100) which shows the temperature profile (500) in a space between the fins. For purposes of illustration, only one segment of the finned heat sink (100) is shown and the entire view has been rotated to so that the vertical fins (105) are horizontal. The temperature profile has three segments, a first segment labeled T_m which represents the temperature through the conductive base (110). Surface temperature, T_s, represents the temperature of the surface of the heat sink at a given point. $T(x)$ represents the air temperature profile through the open space between the fins (105).

[0038] A heat flux, Q, moves from the underlying chip into the base. This raises the temperature of the base (110). As shown in Fig. 5A, there is slight decline in temperature profile T_m as the heat flux moves through the relatively high thermal conductivity base material. The air flow interacts with the surface of the heat sink (100) at the surface temperature (T_s). The temperature profile, $T(x)$, through the air flow is illustrated as declining along the length of the profile. The measurement locations used to generate the temperature profile $T(x)$ are made along the centerline of the (505) of the heat sink segment. The height of the temperature profile is higher or lower than the centerline (505) to show the relative temperature differences through the temperature profile. Ideally, the air temperature would be equal to the surface temperature T_s. This would result in a higher thermal efficiency of the heat sink in removing heat from the underlying chip. For laminar air flows, the air layers which travel near the surface of the heat sink are closer to the surface temperature $\boldsymbol{T_s}$, while layers that are farther away from the surface may be at much lower temperatures. For higher air flux rates, a turbulent flow may develop. In a turbulent flow, a much higher amount of mixing occurs in the air, which results in a more uniform temperature distribution and more efficient heat transfer away from the heat sink.

[0039] Fig. 5B is a diagram of an illustrative section of a grid heat sink (400). As described above, a temperature flux $\boldsymbol{Q}$ enters the base (420) and is conducted up the primary fins (410) and into the cross fins (415). As an air flux passes through the grid heat sink (400), a temperature profile forms. The temperatures are measured along the centerline (510). Through the thickness $\boldsymbol{d}$ of the base (420) there is slight decline in temperature. The additional surface area provided by the cross fins (415) creates channels (405) with a characteristic dimension $\boldsymbol{a}$ and additional surface area. The temperature profile $\boldsymbol{T(x)}$ shows less severe declines and generates higher thermal efficiencies in removing heat from the chip because there is a more uniform heating of the cooling air. Further, the enclosed channel prevents the premature escape and recirculation problems of the air flow.

[0040] The grid heat sink allows for a much larger amount of heat removal for the same size of heat sink and the same air flow rate, or the same heat removal for a smaller coolant flow. Consequently, for a given system a grid heat sink may be smaller, thereby reducing the overall volume of the system. Additionally or alternatively, the increased thermal performance may allow for lower operating temperatures of the heat generating component. The heat removal of various heat sinks as a function of air flux can be estimated using Eq. 1.

$$W(j) = 0.023 m A b \rho C \frac{v(j)L(j)}{(d+a)} \left(\frac{\rho d v(j)}{\mu} \right)^{-0.2} \left[1 - \exp\left(\frac{-L_o}{L(j)} \right) \right] (\Theta - T) \qquad \text{Eq. 1}$$

Where:

W = heat removed from system in Watts

j = volume flow rate of air through the system

v = velocity of air
ρ = density of air
C = specific heat of air
μ = Newtonian viscosity of air
b = width of heat sink
L = length of heat sink
d = thickness of heat sink base
a = dimension of channel
θ = exit temperature of air
T = surface temperature of heat sink
$m = 2$ for the fin cooling system and $m \approx 4$ for the grid system

[0041] Fig. 6A is an illustrative graph of the heat removed for a fin system and a grid system as estimated by Eq. 1. The vertical axis represents heat removed in units of Watts from the heat sink by the passage of cooling air. The horizontal axis is air flux through the heat sink in cubic meters per second. The dashed line represents the heat removed in a grid system and the dash-dot line represents the heat removed from a fin system. As can be seen from the graph, a grid system with comparable size and mass removes significantly more heat than a fin system. For example, at 0.0075 cubic meters of air per second, the fin system removed approximately 45 Watts of heat. The grid system removed approximately 85 Watts of heat.

[0042] A measure of the thermal efficiency of the heat sink is the difference between the exit temperature of the air (θ) and the surface temperature of the heat sink (T). Ideally, the exit air temperature (θ) would be equal to the surface temperature of the heat sink (T). When the exit air temperature equals the surface temperature of the heat sink, the air has absorbed all of the heat possible. To accomplish this level of thermal efficiency is often impractical because the size of the heat sink becomes infinitely larger. However, when comparing two heat sinks of similar size, the thermal efficiency can provide a measure of the efficiency of the heat sink designs.

[0043] The difference (***ΔT***) between the exit air temperature (***θ***) and the surface temperature of the heat sink (***T***) can be estimated using the Eq. 2, shown below.

$$\Delta T \equiv (\Theta - T) = W\left[AbL(j)\frac{mh(j)}{d+a}\left[1-\exp\left(-\frac{L_o}{L(j)}\right)\right](\Theta - T)\right]^{-1} \qquad \text{Eq. 2}$$

[0044] Fig. 6B shows an illustrative graph of the results of Eq. 2 for a grid system and a fin system of comparable size. The horizontal axis represents the air flow rate through the heat sinks in cubic meters per second. The temperature difference in degrees Celsius is shown along the vertical axis, with lower temperature differences at the bottom of the axis and higher temperature differences shown proportionally higher on the axis.

[0045] The temperature difference between the exit air and the heat sink surface for the grid system is shown as a dotted line. The temperature difference for the fin system is shown as a dot-dashed line. As can be seen from the curves on the chart, the temperature differences become smaller for higher volume flow rates. There are a number of factors which could produce this result including increased turbulence in higher velocity flows. In general, turbulent flows are more efficient in transporting heat away from a surface than more ordered flows. Consequently as turbulence increases, the efficiency of the heat sink can increase.

[0046] The grid system has lower temperature differences than the fin system for all flow rates shown in Fig. 6B. For example, at a flow rate of 0.0075 cubic meters per second, the temperature difference for the fin system is approximately 6.5 degrees Celsius and the temperature difference for the grid system is approximately 3 degrees Celsius. Consequently, for a given flux of air through the heat sink, the grid system can be more efficient than the fin system in removing heat.

[0047] The grid heat sink could have a variety of configurations and geometries. Fig. 7 shows a grid heat sink (700) which is in thermal contact with an underlying chip (725). The grid heat sink (700) includes a base (720) which distributes heat to the various vertical fins (710). These primary vertical fins (710) serve as conduction paths to the overlying structures. According to one illustrative embodiment, a number of cross fins (715) intersect the primary vertical fins (710) and provide additional surface area and structural support for the heat sink (700). As discussed above, the intersecting fins create a number of channels (730). Air flow is directed through the channels to provide the desired cooling of the heat sink (700) and underlying chip (725). These channels may have a substantially uniform cross-section through the length of the heat sink (700). Additionally or alternatively, there may be various disruptions in the channels, such as surface roughness, offsets of the channel cross-section, etc. These obstructions may generate additional focused cooling by direct impingement of the flow on the obstruction or may serve to create additional turbulent flow within the channel to improve heat transfer. In some embodiments, the cross section of the channels may increase toward the exit to allow for expansion of the air flow. The volume and temperature of the expanding air flow are physically related such that an expansion of the volume of the air flow results in a lower temperature within the air flow. Consequently, altering the cross-section of the channel may be used to make adjustments to the temperature of the air.

[0048] Fig. 8 is a diagram of an illustrative heat sink (800) which has tapered primary fins (810). As discussed above, the primary fins (810) serve as a conduction path for the majority of the heat which is dissipated in the rest of the structure. By making the base of the primary fins (810) thicker at the base where there is a greater amount of heat flux, the heat sink temperature can be more uniform.

[0049] According to one embodiment, the cross fins (815) may be significantly thinner than the primary fins (810). The cross fins (815) need only conduct a relatively small amount of heat from the adjoining primary fins through the cross fin area. Consequently, the cross fins could be relatively thin with little performance degradation. Increasing the thickness of the fins results in a reduction of the cross area of the air channels (830). A quantitative trade off between fin geometry and air flow can be performed for specific designs, heat loads, and fan combinations.

[0050] Further, the cross-section of the channels (830) may vary along through the height of the heat sink (820). For example, if high volume flow rates are desired near the base (820) of the heat sink (800), the cross sectional area of the channels at the base could be increased. Alternatively, if high surface areas are desired at the base, a plurality of smaller channels could be formed near the base (820).

[0051] According to one illustrative embodiment, the grid heat sink may be formed by joining a number of stacked tubes. The tubes may be made from a thermally conductive material such as metal and joined using any number of techniques. For example, the tubes may be joined using welding, soldering, adhesive, or other techniques. The tubes may have various cross-sectional geometries which may vary from tube to tube and/or along the length of the individual tubes.

[0052] Fig. 9 is a diagram of one illustrative embodiment of a grid heat sink (900). The grid heat sink (900) includes a number of radial primary fins (910) which extend from a base (920). The base (920) is in direct thermal contact with a chip (925). The heat flux into the base (920) is concentrated in the center of the base directly over the chip (925). The radial primary fins arms (910) connected to the center of the base (920) to more directly conduct the heat from the base (920). A number of curved cross fins (915) intersect the radial primary fins (910) to form a number of channels (930). The channels (930) can be of any suitable geometry including triangular, rectangular, wedge shaped, or any other suitable geometry.

[0053] Fig. 10 is a cross-sectional diagram of an illustrative heat sink (1000) which includes a number of primary fins (1010) which extend from a base (1020). The base (1020) is in thermal contact with an underlying chip (1025). The cross fins (1015) extend from the primary fins (1010) but do not intersect the adjacent primary fins. The result is a number of open channels (1030) between the primary fins. The extension of the cross fins (1015) into the open channels (1030) create a high surface area within the channels. In some embodiments, higher pressure fluid flow may be applied to one portion of a heat sink than other portions of the heat sink. For example, in the embodiment shown in Fig. 10, a higher pressure fluid flow may be applied to the lower portion of the open channel (1030) near the base. This could result in a two dimensional fluid flow, with a portion of the fluid passing axially down the open channel and a portion of the fluid passing through the serpentine upper portion of the channel to exit through the top of the heat sink (1000).

[0054] According to one illustrative embodiment, the grid heat sink may also have a number of external fins (1035) which extend beyond the interior grid structure to provide additional cooling by external force or free convention.

[0055] Fig. 11 is a diagram of an illustrative heat sink (1100) which includes a base (1120) which is in thermal contact with an underlying chip (1125). A number of primary fins (1110) extend upward from the base (1120). The primary fins (1110) and base (1120) can be formed using metal extrusion processes. The channels (1145) can be created by inserting bent sheet metal forms (1115, 1130, 1135) into the spaces between the primary fins (1110). The shape of the sheet metal form determines the size, number and geometry of the resulting channels (1145). For example, a first form (1115) has relatively large channels. The second form (1130) creates smaller and more numerous channels. Consequently the second form (1130) creates more surface area within the heat sink (1100). A third form (1135) creates smaller channels closer to the base (1120) and larger channels near the lid (1140).

[0056] The sheet metal forms (1115, 1130, 1135) may be thermally and structurally joined to the primary fins (1110) in a number of ways, including, but not limited to welding, soldering, adhesives, or spring forces. For example, the lid (1140) could compress the sheet metal forms between the primary fins (1110) and produce appropriate thermal contact between the forms (1115, 1130, 1135) and the primary fins (1110) and base (1120).

[0057] Fig. 12 is an illustrative diagram of a heat sink (1200) which incorporates a continuous thermally conductive sheet (1215) which is bent to form channels (1230). The conductive sheet (1215) is placed over the primary fins (1210) and contacts the base (1220). A cover (1205) encloses upper portion of the heat sink (1200) and forms some of the surfaces of the channels (1230).

[0058] Figs. 13A-13D are illustrations which show steps in forming a grid heat sink (1300) from a continuous sheet of conductive material (1305). According to one illustrative embodiment, two bends (1315, 1310) are made in the sheet (1305) to create a U shaped geometry as shown in Fig. 13A. Fig. 13B illustrates additional bends (1325, 1320) being made in the sheet to form a first channel (1330). As shown in Fig. 13C, this process is repeated to form a column which includes two additional channels (1335, 1340). Fig. 13D illustrates the formation of additional columns to form a grid which is attached to a base (1345). As discussed above, a variety of methods may be used to attach the grid to the base or make internal joints in the grid. The resulting grid heat sink (1300) is formed from a continuous sheet of conductive material (1305) and a base (1345). The type, thickness, and other properties of the conductive material (1305) can be altered according to the specific design needs.

[0059] Fig. 14 is a diagram of an alternative geometry for forming a grid heat sink (1400) from a continuous sheet of thermally conductive material (1410). According to one illustrative embodiment, the thermally conductive material (1410) is bent and joined at various contact points (1415) to form channels (1405). The entire grid structure is joined to a base structure (1415).

[0060] Fig. 15 is a diagram of an alternative geometry for forming a grid heat sink (1500) from a continuous sheet of thermally conductive material (1510). According to one illustrative embodiment, the thermally conductive material (1510) is bent and joined to form relatively open channels (1505). The entire grid structure is joined to a base structure (1515).

[0061] Fig. 16 is a diagram of an illustrative cooling system (1600) for a chip (1615). The air flow (1605) is directed through two ducted fans (1620), into a manifold (1620), and then through a grid heat sink (1625). The grid heat sink (1625) is thermally connected to the chip (1615) and conducts heat away from the chip (1615). The air flow (1605) removes the heat from the grid heat sink (1625) by convective heat transfer. In this illustrative embodiment, the ducted fans (1610) are used to create a high air pressure in the manifold (1620) which forces the air through the channels in the grid heat sink (1625). This approach may have a number of advantages for over suction systems where the fan creates low pressure to suck air through a heat sink. The suction action of the fan is limited in the pressure differential which can be generated. A suction fan system can not produce a pressure any lower than zero. Consequently, the maximum pressure differential which can be produced by a suction fan system is equal to the supply pressure, which is typically atmospheric pressure. In contrast, fan systems which create high pressure at the inlet to force air through a heat sink do not have a similar limitation in the maximum pressure which can be generated. Rather, pressure systems are limited only by the mechanics of the cooling system, such as the design of the fans, the available power, the physical strength of the fans, manifold and grid heat sink, etc. Consequently, a pressure system could produce several atmospheres of pressure to drive the air flow through the grid heat sink. This could be particularly advantageous when very small channels are used in the grid heat sink.

[0062] Fig. 17 shows an illustrative embodiment of the a cooling system (1700) which includes a blower fan (1710) which attached to a manifold (1720) which directs the air flow through a grid heat sink (1725). The grid heat sink (1725) is used to cool an underlying chip (1715).

[0063] Fig. 18 is a side view of an illustrative cooling system (1700) within a blade server (1800) which is represented by a dotted outline. Blade servers (1800) are very compact computers which may have one or more central processor units (CPUs) (1805). The grid heat sink (1725) is thermally connected to the CPU (1805). An air flow (1810) is generated by the fan (1710). The air flow (1810) through openings in the left of the blade server (1800) and enters the fan (1710) where it is compressed and ejected into the manifold (1720). The manifold (1720) directs the air flow (1810) through the grid heat sink (1725). The air flow (1810) is then vented out of the right of the blade server (1800).

[0064] The compact design, low profile and thermal efficiency may make the grid cooling system particularly suitable for applications which have geometric constraints. Fig. 19 is front view of an illustrative rack (1900) of blade servers (1800). The rack (1900) contains 16 blade servers (1800), each of which may have multiple processors. The front of each of the blade servers (1800) has a number of openings through cooling air is drawn. After passing over the various components within the blade server (1800), the heated air is vented out the back of the rack. A variety of fan configurations can be used. According to one illustrative embodiment, one larger fan or array of fans supply pressurized air for multiple grid heat sinks.

[0065] In sum, a grid heat sink provides increased thermal and volumetric efficiency when compared to fin heat sinks. The channels formed by the primary fins and cross fins provide additional surface area and prevent the premature exit and recirculation of cooling air. Consequently, grid heat sinks may be particularly desirable for more compact systems which have concentrated heat sources.

[0066] The preceding description has been presented only to illustrate and describe embodiments and examples of the principles described. This description is not intended to be exhaustive or to limit these principles to any precise form disclosed. Many modifications and variations are possible in light of the above teaching.

CLAIMS

WHAT IS CLAIMED IS:

1. A grid heat sink (400) comprising:

a base (420);

a plurality of intersecting fins (410, 415);

a plurality of channels formed by said intersecting fins (405), each of said channels being configured to accept cooling air (1605) at an input side of said grid heat sink (400) and channel said cooling air (1605) to an exit at an output side of said grid heat sink (400).

2. The grid heat sink according to claim 1, in which said intersecting fins (415, 420) comprise primary fins (410) and cross fins (415); said primary fins (410) being directly connected to said base (420) and extending away from said base (420); said cross fins (415) intersecting said primary fins (410).

3. The grid heat sink according to claim 1, in which said primary fins (410) and cross fins (415) are constructed from a continuous sheet of thermally conductive material (1305).

4. The grid heat sink according to claim 3, further comprising welded joints, said welded joints joining a first section of said continuous sheet of thermally conductive material (1305) to a second section of said continuous sheet of thermally conductive material (1305).

5. The grid heat sink according to claim 1, in which said grid heat sink (1100) comprises:

an extruded base (1120) with integral primary fins (1110); and

a sheet metal cross fins (1115).

6. The grid heat sink according any of the above claims, in which each of said plurality of channels (405) is enclosed on four sides by said intersecting fins (410, 415), each of said channels (405) being mutually parallel to each other and being parallel to said base (420).

7. The grid heat sink according to any of the above claims, in which cooling air (1605) entering a first channel does not mix with cooling air (1605) entering a second channel until said cooling air (1605) exits said grid heat sink (400).

8. The grid heat sink according to any of the above claims, further comprising a top plate (1140), said top plate (1140) being configured to join distal ends of said primary fins (1110).

9. The grid heat sink according to any of the above claims, further comprising a blower fan (1610, 1710), said blower fan (1610, 1710) being configured to pressurize said cooling air (1605) and direct said pressurized cooling air (1605) into said channels.

10. The grid heat sink of according to any of the above claims, wherein said channels (405) have varying cross-sectional geometries.

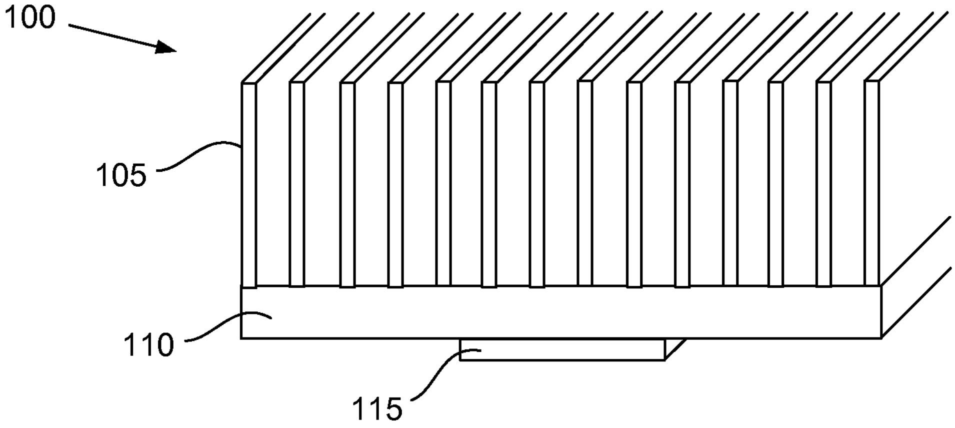

Fig. 1

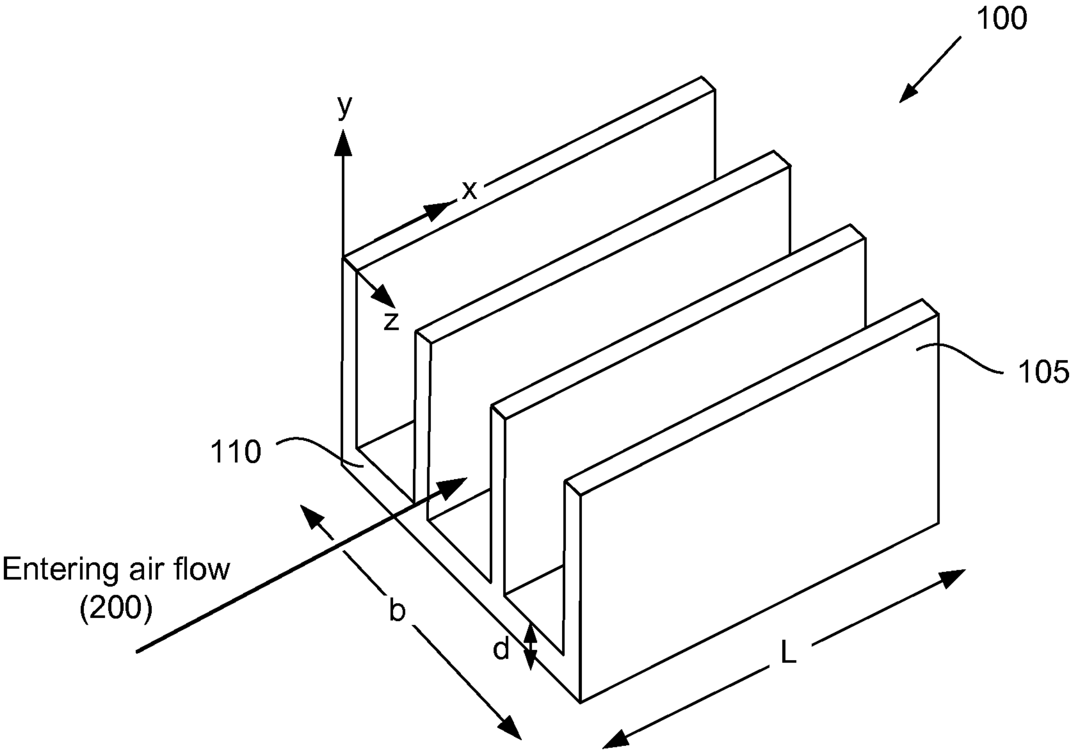

Fig. 2

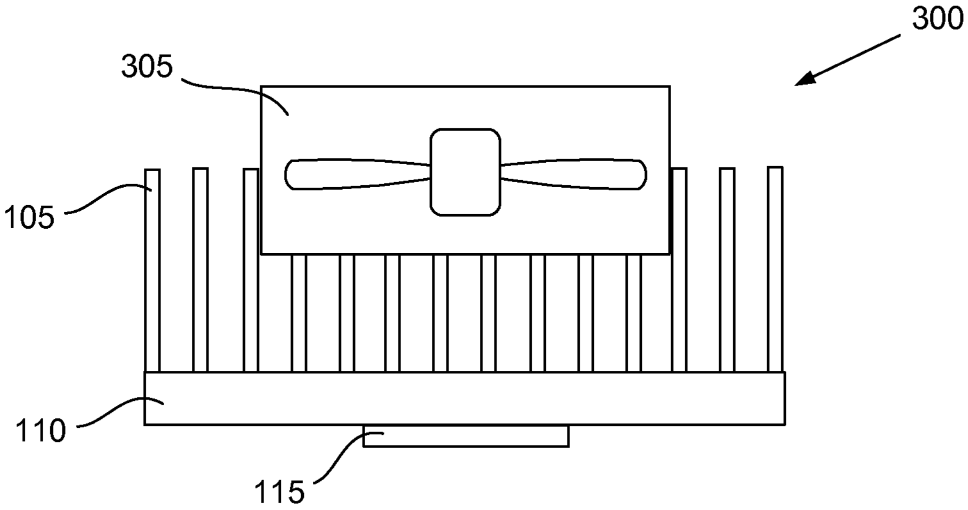

Fig. 3A

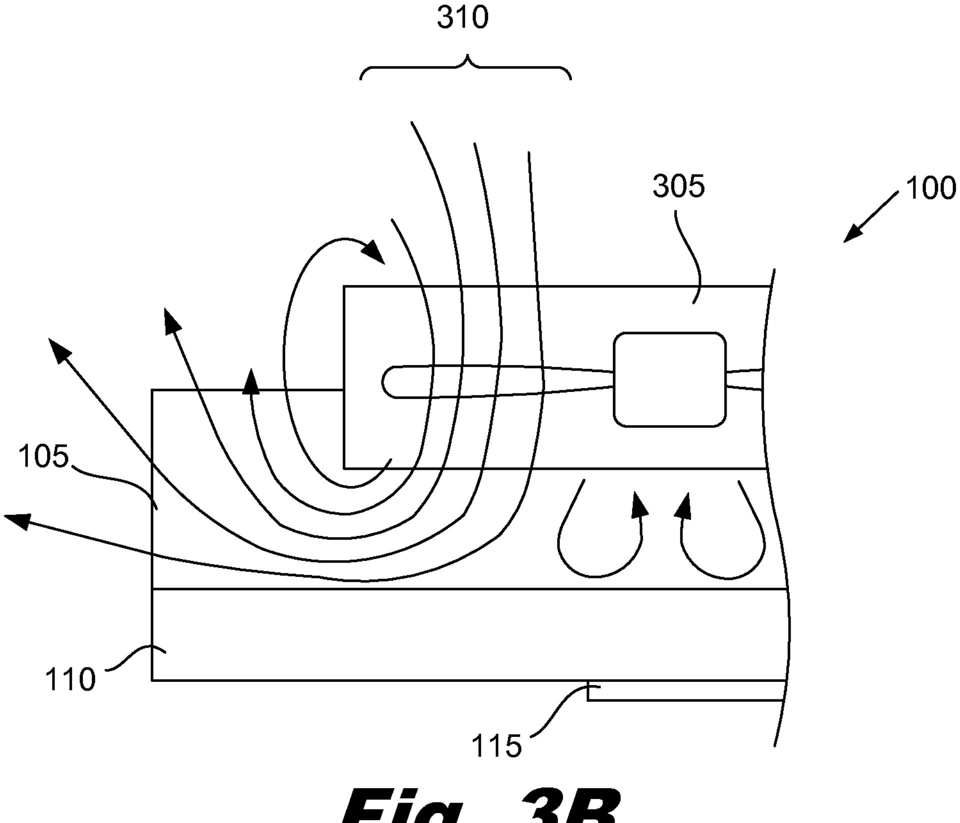

Fig. 3B

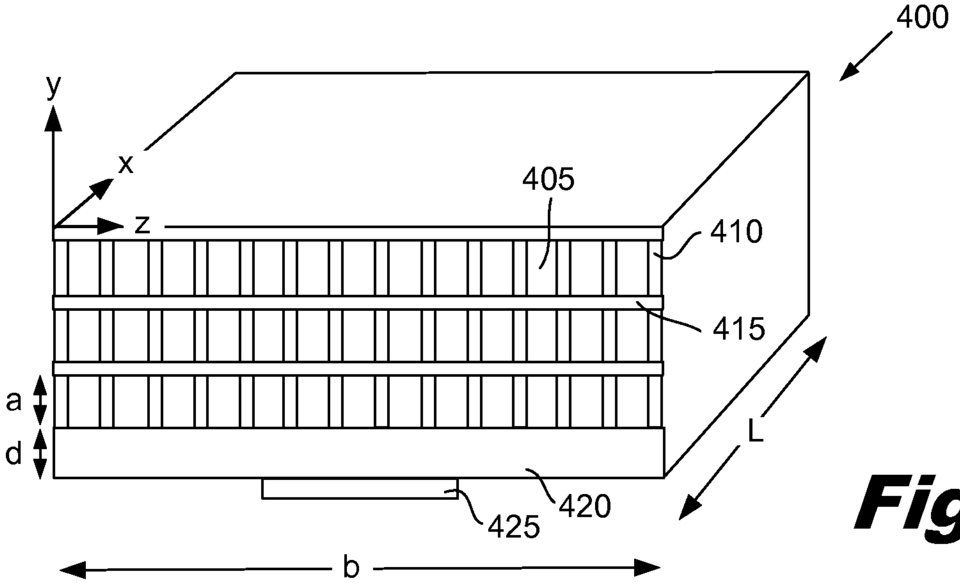

Fig. 4

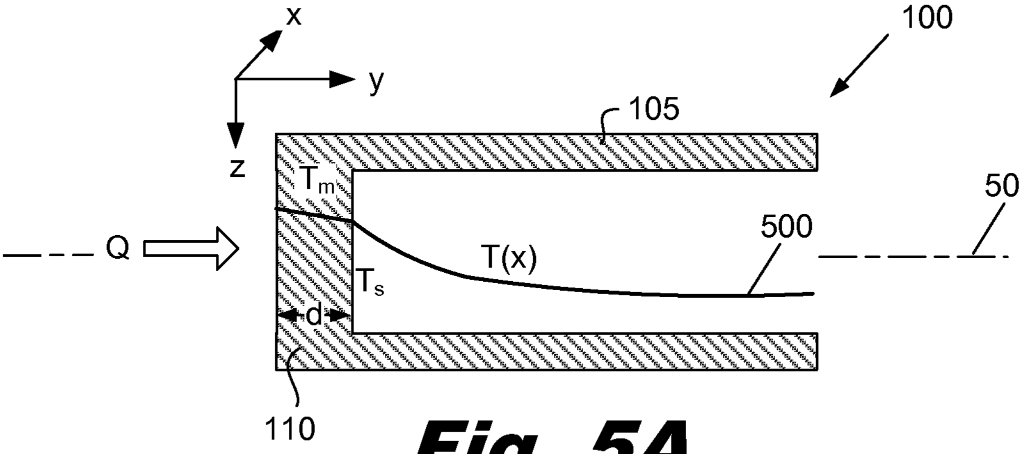

Fig. 5A

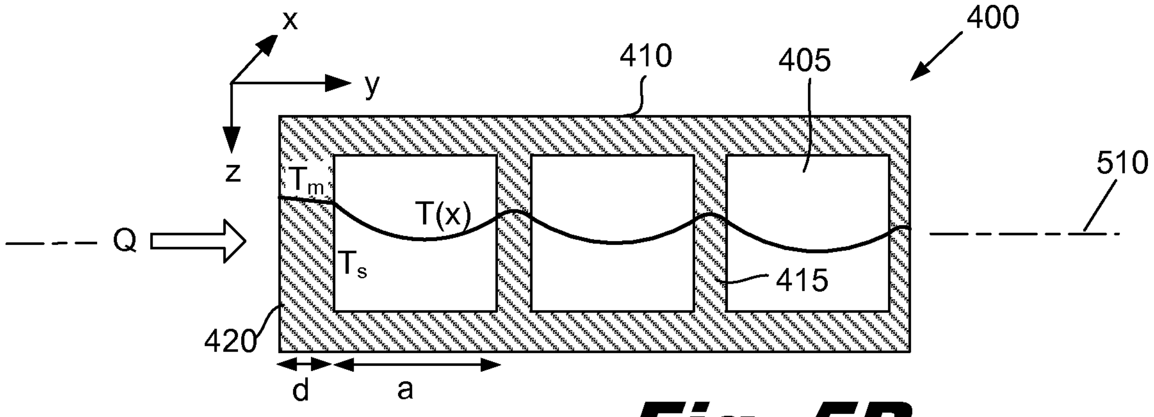

Fig. 5B

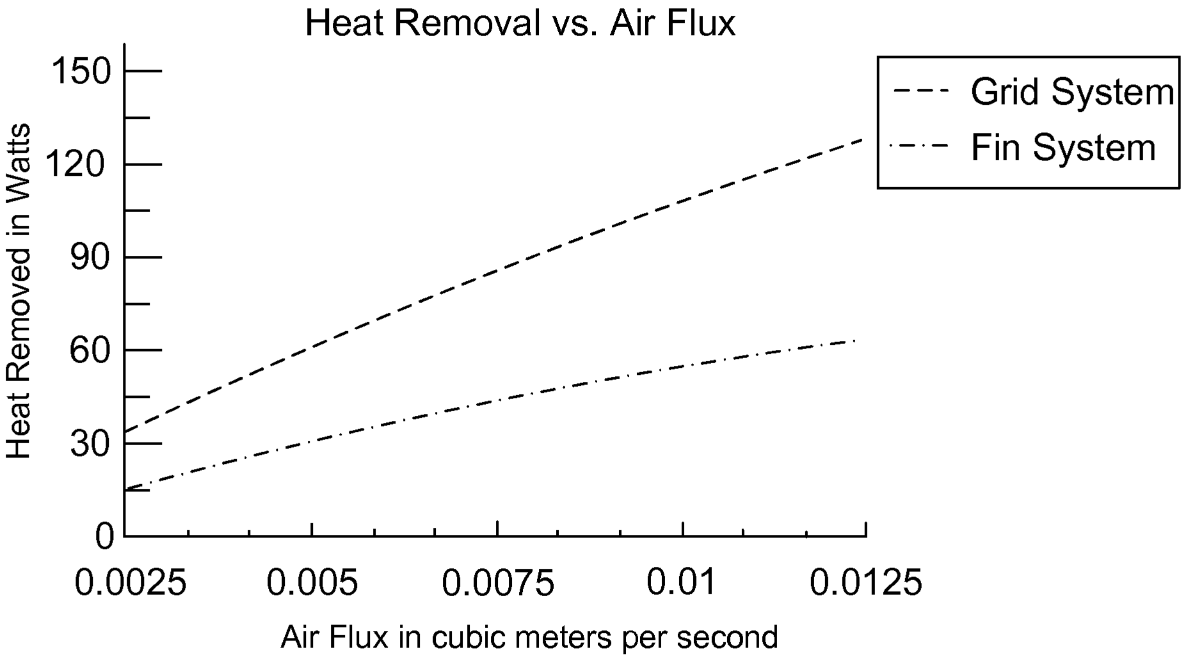
Heat Removal vs. Air Flux
Heat Removed in Watts
150
120
90
60
30
0
0.0025
0.005
0.0075
0.01
0.0125
Air Flux in cubic meters per second
Grid System
Fin System

Fig. 6A

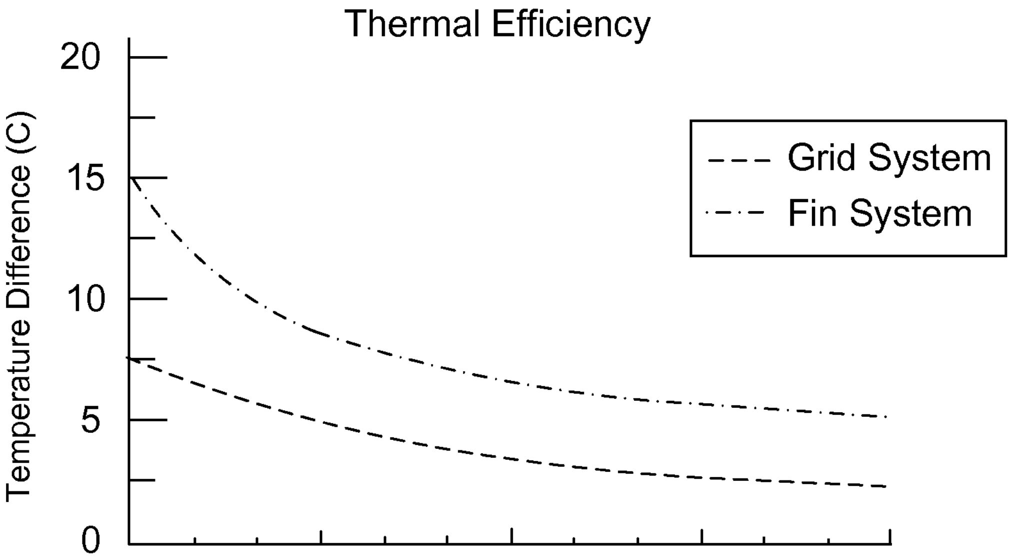
Thermal Efficiency
Temperature Difference (C)
20
15
10
5
0
0.0025
0.005
0.0075
0.01
0.0125
Air Flux in cubic meters per second
Grid System
Fin System

Fig. 6B

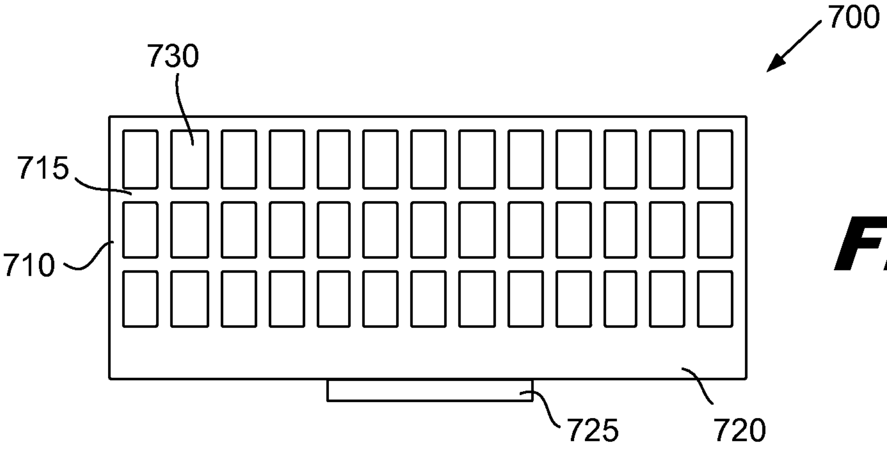

Fig. 7

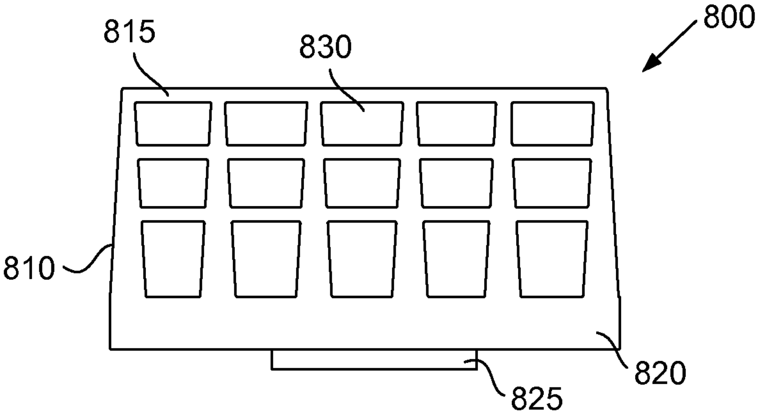

Fig. 8

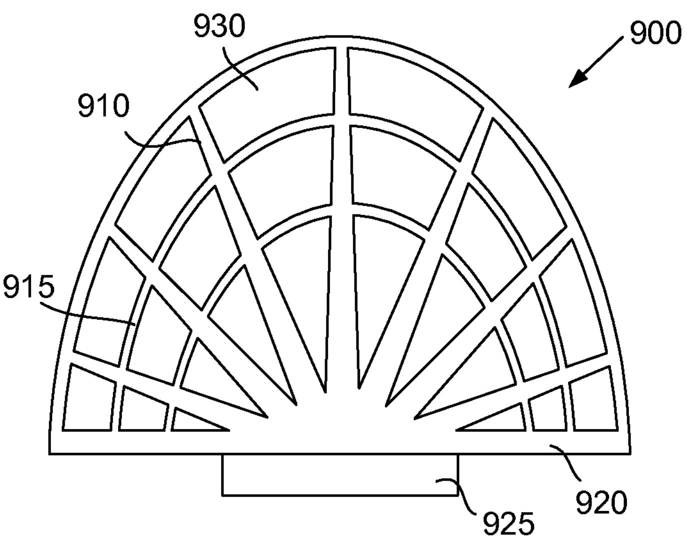

Fig. 9

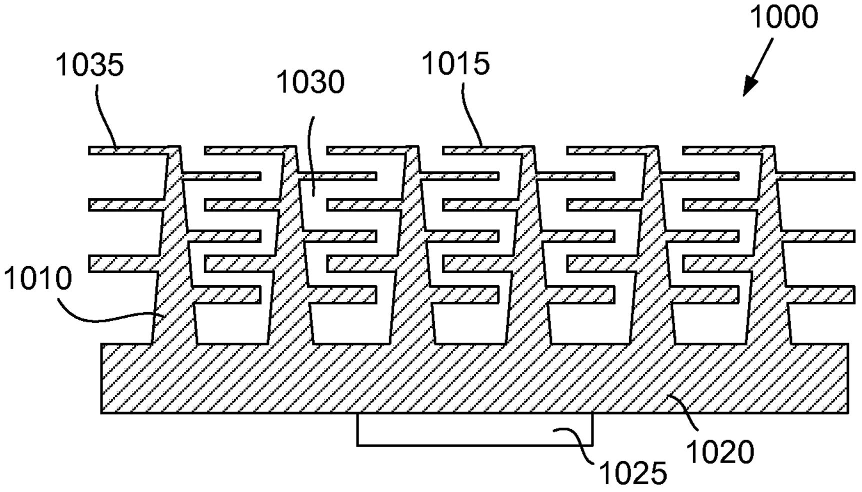

Fig. 10

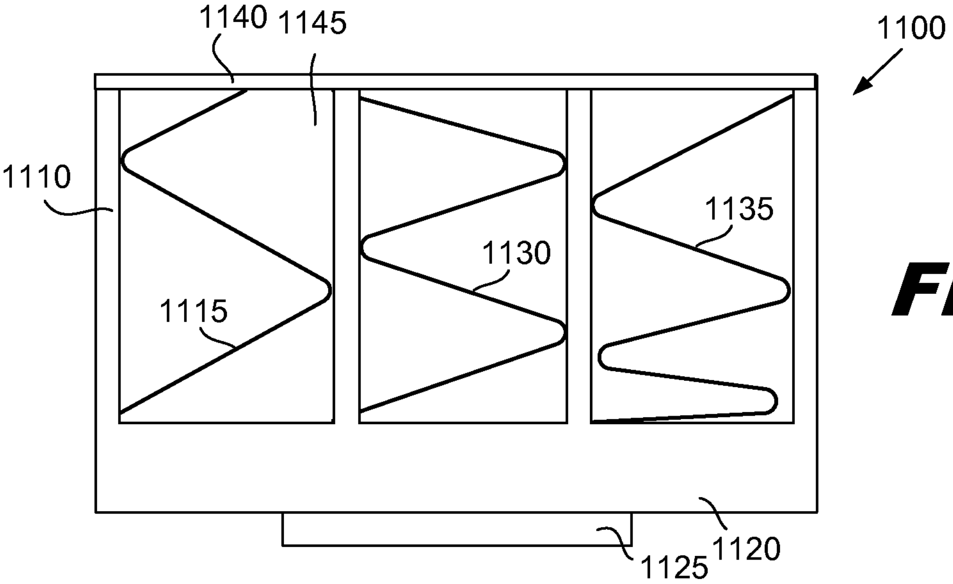

Fig. 11

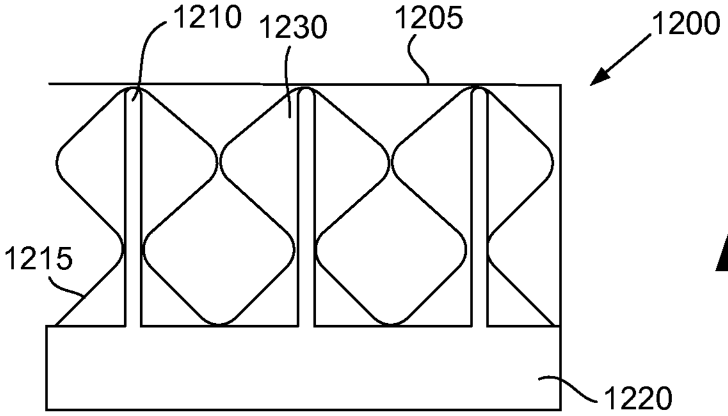

Fig. 12

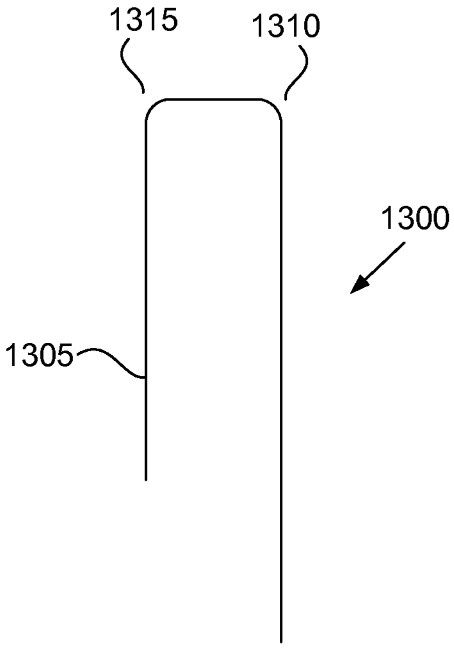

Fig. 13A

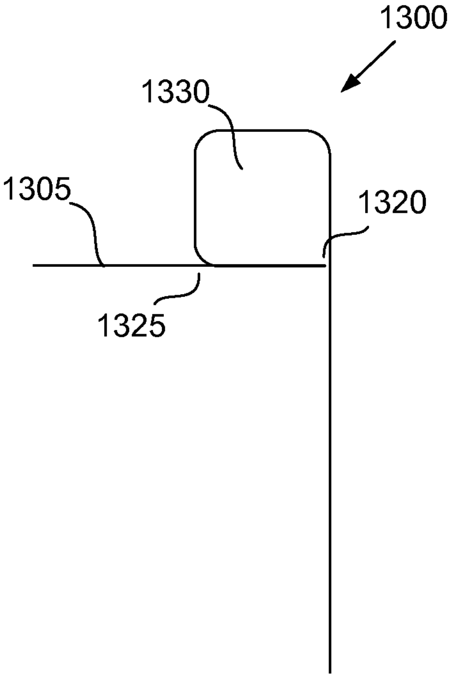

Fig. 13B

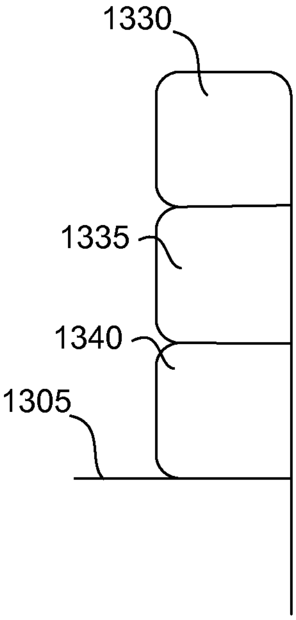

Fig. 13C

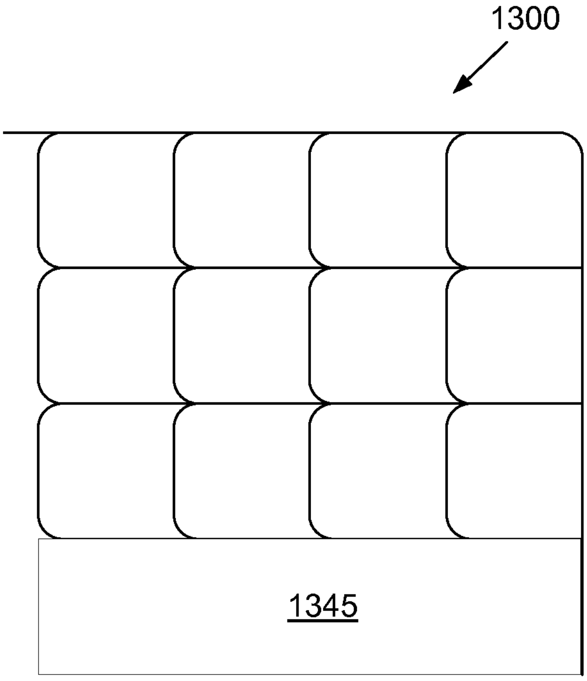

Fig. 13D

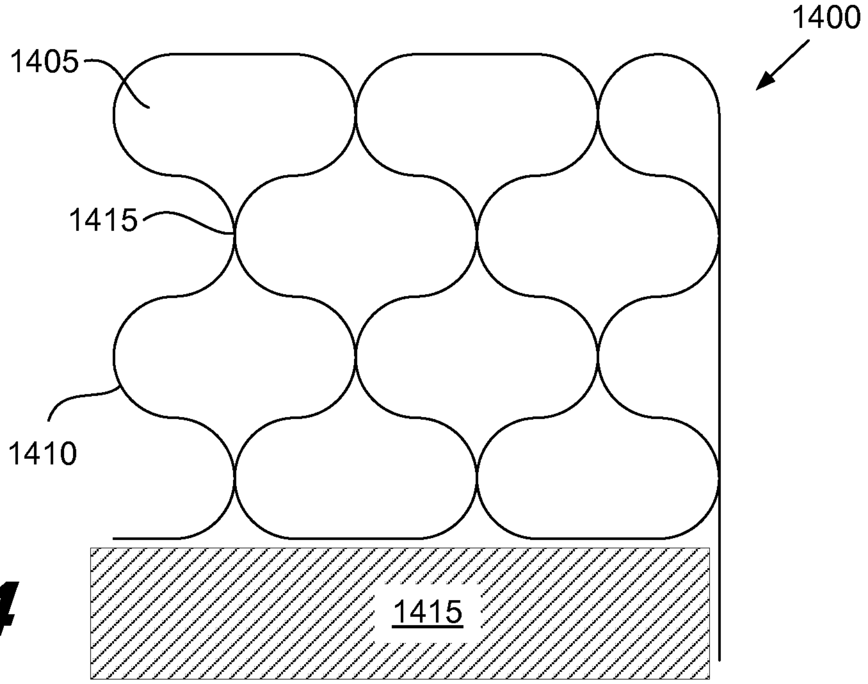

Fig. 14

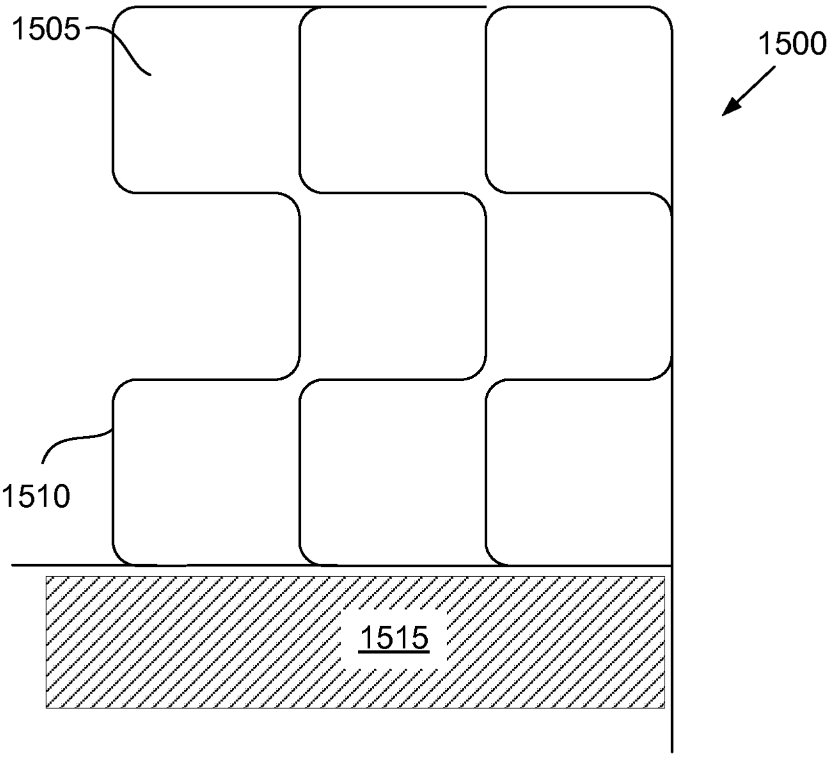

Fig. 15

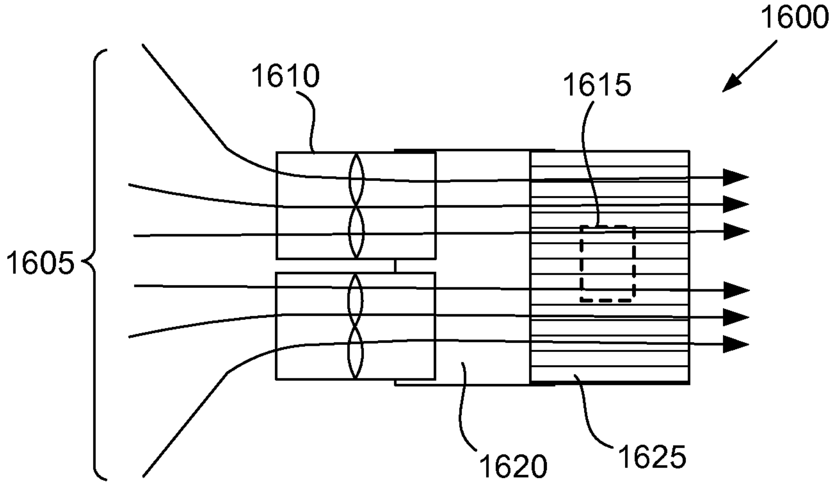

Fig. 16

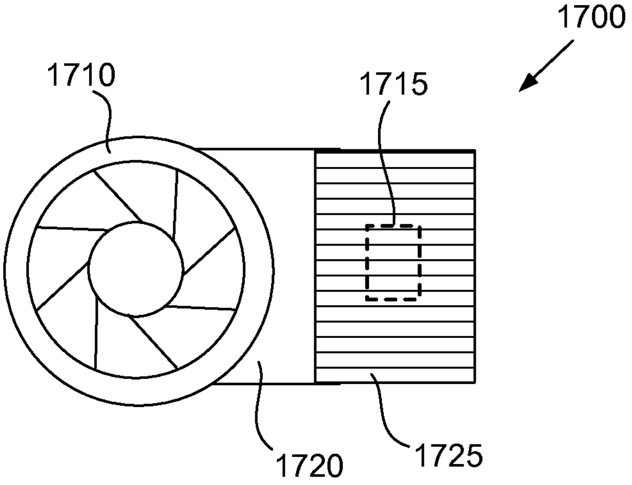

Fig. 17

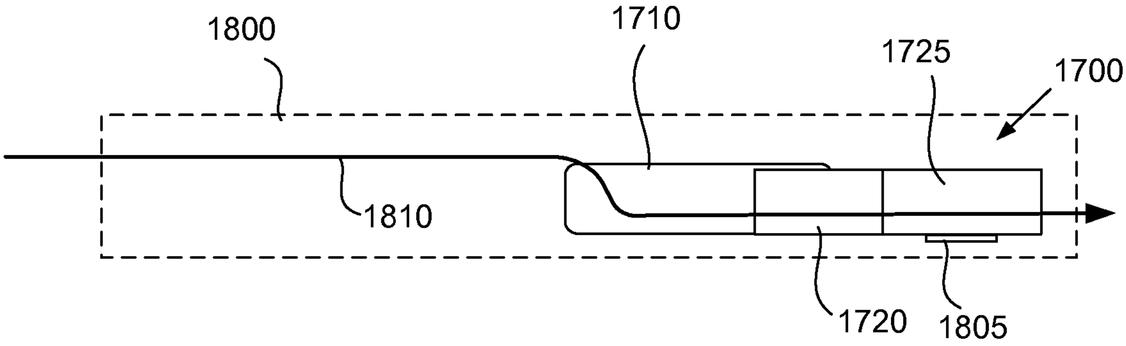

Fig. 18

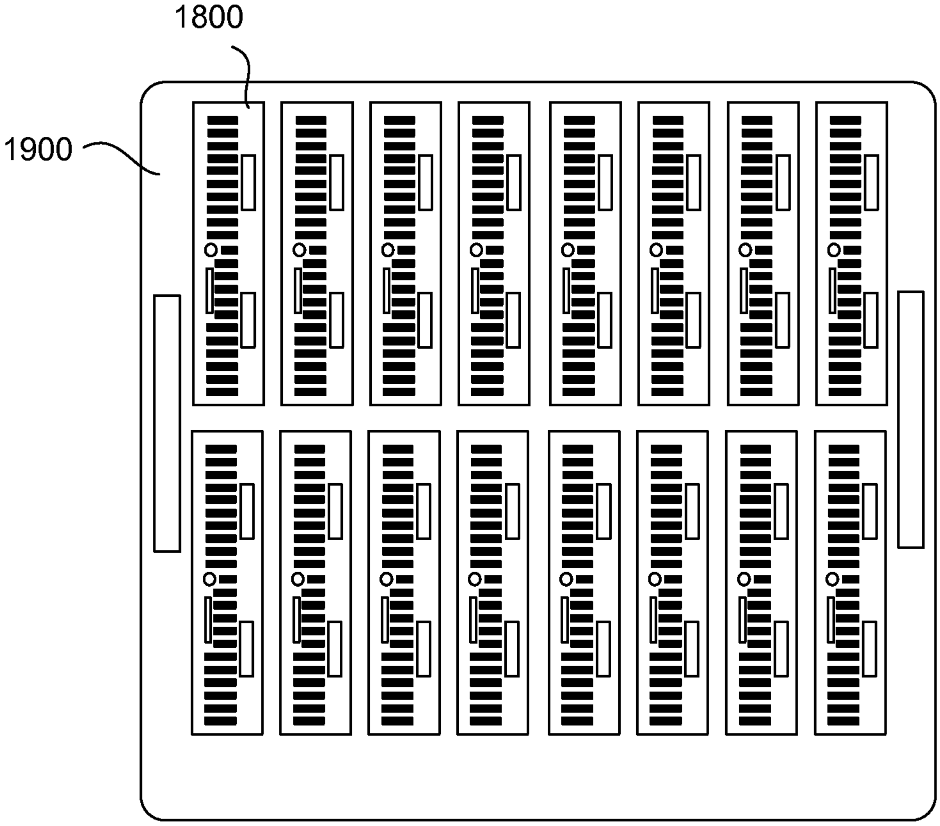

Fig. 19

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2009/038255

A. CLASSIFICATION OF SUBJECT MATTER

H05K 7/20(2006.01)i, G06F 1/20(2006.01)i, H01L 23/34(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: B22D 17/00, H05K 7/20

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean Utility models and applications for Utility models since 1975
Japanese Utility models and applications for Utility modesl since 1975

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) &keywords: heat, sink, fin, grid

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6,516,867 B1 (YASUHIRO OOTORI) 11 February 2003 See column 5, line 53 - column 6, line 11 and figure 7 column 7, line 39 - line 49 and figure 8	1, 2, 6-10
Y	US 6,085,830 A (KOICHI MASHIKO et al.) 11 July 2000 See column 10, line 66 - column 11, line18 and figure 14	1
Y	KR 10-0159134 B1 (PFU Limited) 15 December 1998 See the whole document	1, 2, 6-10
A	US 2005/0281000 A1 (RICHARD C. CHU) 22 December 2005 See the whole document	1-10

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 23 DECEMBER 2009 (23.12.2009)	Date of mailing of the international search report **28 DECEMBER 2009 (28.12.2009)**
Name and mailing address of the ISA/KR Korean Intellectual Property Office Government Complex-Daejeon, 139 Seonsa-ro, Seo-gu, Daejeon 302-701, Republic of Korea Facsimile No. 82-42-472-7140	Authorized officer KOH, Jong Wook Telephone No. 82-42-481-5677

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 06516867 B1	11.02.2003	AU 6872800 A	17.04.2001
		AU 2000-68728 A1	06.09.2000
		BR 0007214 A	31.07.2001
		CA 2350199 A1	22.03.2001
		CN 1321335 A	07.11.2001
		CN 1162898 C	18.08.2004
		CN 1321335 A0	07.11.2001
		EP 1133791 A1	19.09.2001
		JP 3350900 B2	25.11.2002
		JP 2001-085579 A	30.03.2001
		JP 03-350900 B2	20.09.2002
		KR 10-2001-0080979 A	25.08.2001
		NZ 511320 A	20.12.2002
		TW 462902 B	11.11.2001
		TW 462902 A	11.11.2001
		US 2002-0050333 A1	02.05.2002
		WO 2001-020657 A1	22.03.2001
US 06085830 A	11.07.2000	JP 11-083361 A	26.03.1999
		JP 11-083360 A	26.03.1999
		JP 11-067990 A	09.03.1999
		JP 03-889129 B2	07.03.2007
		JP 03-908349 B2	25.04.2007
		JP 10-263779 A	06.10.1998
		JP 10-319156 A	04.12.1998
		US 06253829 B1	03.07.2001
KR 10-0159134 B1	15.12.1998	EP 1056132 B1	29.10.2003
		EP 0614330 A1	07.09.1994
		EP 0614330 B1	21.02.2001
		EP 1056129 A2	29.11.2000
		EP 1056129 A3	30.01.2002
		EP 1056130 A2	29.11.2000
		EP 1056130 A3	30.01.2002
		EP 1056130 B1	29.10.2003
		EP 1056131 A2	29.11.2000
		EP 1056131 A3	30.01.2002
		EP 1056132 A2	29.11.2000
		EP 1056132 A3	30.01.2002
		EP 0614330 A4	06.09.1995
		JP 2586778 Y2	09.12.1998
		JP 2744566 B2	28.04.1998
		JP 2796038 B2	10.09.1998
		JP 2804690 B2	30.09.1998
		JP 2806745 B2	30.09.1998
		JP 2806746 B2	30.09.1998
		JP 02-586778 Y2	02.10.1998
		JP 02-744566 B2	06.02.1998
		JP 02-796038 B2	26.06.1998

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2009/038255

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		JP 02-804690 B2	17.07.1998
		JP 02-806745 B2	24.07.1998
		JP 02-806746 B2	24.07.1998
		JP 06-045392 U	14.06.1994
		JP 06-104586 A	15.04.1994
		JP 06-244575 A	02.09.1994
		JP 06-314759 A	08.11.1994
		JP 07-030025 A	31.01.1995
		JP 07-074295 A	17.03.1995
		US 05583316 A	10.12.1996
		US 05756931 A	26.05.1998
		US 05760333 A	02.06.1998
		US 06011216 A	04.01.2000
		US 06140571 A	31.10.2000
		US 06143977 A	07.11.2000
		US 06166904 A	26.12.2000
		US 06208894 B1	27.03.2001
		US 06315721 B2	13.11.2001
		US 2001-0001125 A1	10.05.2001
		WO 1994-004013 A1	17.02.1994
US 2005-281000 A1	22.12.2005	US 07085135 B2	01.08.2006