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CN-A- 1 158 549
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DESCRIPTION

Description

Field of the Invention

[0001] This invention relates to microchannel-based heat exchangers, including microchannel-based evaporators used to cool heat sources with high heat fluxes such as electronic devices.

Background of the Invention

[0002] Fluid heat exchangers are used to remove waste heat from high-heat flux heat sources (typically in excess of 5 watts/cm², and often substantially higher) by accepting and dissipating thermal energy therefrom. Examples of such high-heat flux heat sources include microelectronics, such as microprocessors and memory devices, solid-state light emitting diodes (LEDs) and lasers, insulated-gate bipolar transistor (IGBT) devices, such as power supplies, photovoltaic cells, radioactive thermal generators and fuel rods, and internal combustion engines.

[0003] The fluid heat exchangers dissipate heat by thermally conducting the heat into internal passages of the exchanger, through which a coolant fluid flows, absorbing the heat conducted across the walls of the exchanger, and then transporting the fluid outside the exchanger, where the heat is rejected to an external heat sink. While the coolant fluid flowing through the exchanger may be a gas, it is generally preferable to use a liquid, as liquids have higher heat capacities and heat transfer coefficients than gases. The liquid may remain in a single phase, or the liquid may partially or completely evaporate within the internal passages of the exchanger.

[0004] The flow of coolant liquid fed to the fluid heat exchanger may be driven by a pump, or by natural convection due to density differences and/or elevation between the incoming and exiting fluid (e.g. thermosyphons), or by capillary action in the internal passages of the exchanger, or by a combination of these mechanisms.

[0005] Evaporator-type exchangers rely on the boiling mode, and have the advantages of higher heat transfer coefficients (better heat transfer) per unit of fluid flow rate of the coolant fluid. They also require much less coolant flow, as the majority of the heat is absorbed through via the latent heat of vaporization of the boiling fluid, rather than the sensible heat (heat capacity) of a single-phase liquid or gas.

[0006] It is well known that the thermal performance and efficiency of fluid heat exchangers can be greatly enhanced if the internal passages are comprised of microchannels, i.e. channels having cross-sections with a smallest dimension of less than 1000 microns, and more typically, in the range of 50 - 500 microns.

[0007] US9310135 discloses a heat exchanger provided by assembling a plurality of individual plates having opposed faces, wherein flow channels are machined through those opposed faces, and the plates are interconnected with intervening shim plates. End plates are connected to an assembly of such plates and intermediate plates, to form a preform, which is then machined to a desired cross section. The resulting structure has a plurality of passages therethrough in one direction, and a second plurality of passages therethrough in a second direction, the passages fluidly isolated from one another. The resulting structure is configurable to a specific geometry of a flow passage, and enables heat exchange between fluids passing through the different flow channels

Summary of the Invention

[0008] In one general aspect, the invention features a microchannel heat exchanger according to claim 1.

[0009] In preferred embodiments, the thermally conductive sheets can further define access channel openings at each end of the lanes, which when stacked create access channels for the microchannels. The sheets can define a more dense packing of cross ribs in at least one inlet end of the heat exchanger to reduce the open cross-section at the inlet end of the lanes. The aspect ratio of the microchannels can be above 4: 1. The aspect ratio of the microchannels can be above 8: 1. The apparatus can further include thermally conductive separator sheets located between groups of the thermally conductive sheets to form a multilayer heat exchanger. The sheets can be made of at least one conductive metal. The sheets can be made of sinterable thermally conductive ceramics. The sheets can be bonded or fused. The microchannels can have a hydraulic diameter of below 500 microns. The microchannels can have a hydraulic diameter of below 200 microns. The base can be a base plate that is thicker than each of the sheets and the cover can include access channels in communication with the microchannels. The base can be thermally conductive yet electrically insulating. The heat exchanger can be constructed for boiling or evaporating fluid service, with the heat exchanger further including flow restrictors at the inlet ends of the microchannels. The flow restrictors can be formed by alternately closing an end of the first slot in a lane of slots with cross-ribs that are wider than the bulk of the cross-ribs between slots, with the alternating closed-ended lanes of slots being staggered with respect to the lanes of slots above or below, in alternating layers of slotted sheets, such that, when the sheets are stacked and bonded together, the cross-section of the parallel channels that are formed have a checkerboard pattern across the inlets of the plurality of channels, which serve as integral flow restrictors covering substantially 50% of a cross-sectional area of the main channels.

[0010] Systems according to the invention can help to suppress Ledinegg effects and thereby allow heat exchangers to work with two-phase systems. By providing inlet restrictions, microchannel evaporators according to the invention can avoid flow instabilities, due to the Ledinegg effect, whereby boiling within multiple (parallel) microchannels might otherwise be non-uniform and due to the interaction of varying pressure drop as boiling develops in the various channels, resulting in periodic backflow into the inlet header or manifold. This can help to achieve stabilized and substantially uniform boiling flows and thereby result in improved and more stable thermal performance when cooling high-flux heat sources.

Brief Description of the Drawing

[0011]

Fig. 1 is a plan view of a first type of grooved sheet for inclusion in a grooved laminate structure that can be used to implement a microchannel heat exchanger;

Fig. 2 is a plan view of a portion of the first type of grooved sheet of Fig. 1 shown in rectangle 2 on Fig. 1;

Fig. 3 is a plan view of a portion of a second type of grooved sheet for inclusion in the grooved laminate structure;

Fig. 4 is a plan view of a separator sheet for inclusion in the grooved laminate structure;

Fig. 5 is a perspective cutaway of the laminate structure formed by alternating first and second sheet types as shown Figs. 1-4 in an orientation shown by arrow 5 in Figs. 2 and 3;

Fig. 6 is a more detailed cutaway view of the grooved laminate structure of Fig. 5;

Fig. 7 is a second perspective cutaway of the laminate structure of Fig. 5 showing flow paths through the structure of Fig. 5 in an orientation shown by arrow 7 in Figs. 2 and 3;

Fig. 8 is an exploded view of the laminated sheets for assembly into a grooved laminate core using the grooved laminated structure presented in Figs. 1-7;

Fig. 9 is an exploded perspective view of a portion of a microchannel heat exchanger using the laminated core of Fig. 8; and

Fig 10 is a cross-sectional view of the grooved laminate structure of Fig. 5, taken through a plane that defines flow restrictors in the grooved laminate structure.

Detailed Description of an Illustrative Embodiment

[0012] A microchannel heat exchanger can be assembled using a grooved laminated structure made up of a plurality of thermally conductive sheets. One such sheet of a first type 40 is shown in Fig. 1. It includes common cut-out areas 42 that are separated lines 44 of slots 46 that define the microchannels.

[0013] More specifically, the sheet of the first type 40 includes a plurality of lines 44 of multiple slots 46, with the slots in a given line being separated by thin wall that functions as a cross-rib 48. These lines span between the common cut-out areas connected to the slots at either end of each line of slots. The common cut-out areas align with each other to form input and output manifolds when sheets are stacked.

[0014] Referring also to Figs. 2 and 3, alternating two or more types of sheets allows the microchannels to be defined in three-dimensions. In particular, the laminated core structure is assembled by alternating slotted-and-ribbed sheets having the cross-ribs staggered with respect to each other when the sheets are stacked so that each line of slots forms a continuous but serpentine flow path (see also Figs. 5-7).

[0015] Referring to Fig. 4, thermally conductive un-slotted separator sheets 60 having cut-out areas 62 that align with the common cut-out areas of the slotted-and-ribbed sheets can also be used on the top and bottom of the core and/or to separate layers of microchannels.

[0016] Referring to Fig. 8, stacking sets of the alternating slotted-and-ribbed-sheets, flanked by un-slotted separator sheets allows the formation of a core structure that includes one or more layers each having a plurality of microchannels with interspersed cross-ribs that intermittently partially interrupt the flow path with providing lateral strengthening of the channel walls. The number of alternating slotted-and-ribbed-sheets in each layer, along with the sheet thickness and slot width, determines the channel depth : width aspect ratio of the channel layers. The layered stacked sheets are preferably bonded to ensure that all the sheets are in thermally conductive communication with each other.

[0017] Referring to Fig. 9, the resulting sub-assembly can then be bonded to a base plate 74 to ensure that the base plate is in thermally conductive communication with the microchannel layers, and a cover 78 can be placed and sealed on top of the resulting assembly of microchannel layers 76 bonded to the base plate, thereby forming a complete microchannel heat exchanger assembly 70.

[0018] Referring to Fig. 10, the input sides of the microchannels preferably include flow restrictors where the exchanger is used in boiling or evaporative service. These restrictors can be built into the laminate structure by providing extra cross-ribs 82 at the inputs of the microchannels.

[0019] The laminated structures described above enable microchannel heat exchangers having one or more layers of microchannels with hydraulic diameters of less than 500 microns, with the microchannels having arbitrarily high depth : width aspect ratios and with thin walls.

The channels have internal cross-ribs connecting the channel's walls, and provide mechanical strength to the channel walls and way of breaking up the fluid stream lines to improve heat transfer. The thermally conductive sheet and base plate materials are preferably, but not limited to, metals and their alloys; non-metallic elements, thermally conductive carbon allotropes, or thermally conductive ceramics. Bonding of the sheets can be by any convenient means that ensure high thermal conduction between the sheets and the base plate.

[0020] Multiple layers of microchannels are formed by inserting, between stacks of slotted-and-ribbed sheets, additional thermally conductive un-slotted separator sheets having cut-out areas that align with the common cut-out areas of the slotted-and-ribbed sheets. The microchannels of any layer the may have the same or different depth: width aspect ratio and hydraulic diameter compared to the microchannels in the other layers.

[0021] The depth: width aspect ratio of the resulting microchannels can be at least 2:1, and preferably between 4:1 and 15: 1. The walls between the resulting microchannels can be less than 200 microns and preferably between 40 and 100 microns thick. The base plate and microchannel walls can be fabricated from materials having thermal conductivities in excess of 100 W/m-K. The hydraulic diameter of the resulting microchannels can be less than 500 microns, and preferably between 50 and 200 microns.

[0022] The liquid inlet channels can be provided with flow restrictors, to prevent backflow or two-phase flow instabilities. These inlet restrictions are provided by closing-off the inlet-side ends of the slots (e.g. by adding additional cross-ribs) of alternate sheets in the stacks of slotted-and-ribbed sheets, thereby reducing the open cross-sectional area of the inlets to the channels relative to the main channel cross-section beyond the closed portions. Preferably, the length of the closed-off (restriction) portions of the microchannels is at least 1 mm.

[0023] The various components of the microchannel heat exchanger (e.g. microchannel stacks, base plate, and over plate) can be bonded or fused, so that the exchanger is hermetically sealed (with the exception of the fluid inlet and outlet ports that communicate with the manifolds), so that the exchanger can hold elevated internal pressures. Bonding or fusing may be accomplished by any convenient means.

[0024] The various components of the microchannel heat exchanger (e.g. microchannel stacks, base plate, and over plate) can also be held together by mechanical means, with suitable seals between components, so that the exchanger can hold elevated internal pressures.

[0025] In another embodiment, the bottom base of the layer of the microchannel exchanger is made from or is coated with a thermally conductive yet electrically insulating ceramic or dielectric solid, such as aluminum nitride, silicon carbide, beryllium oxide, diamond film, and the like. The microchannel exchanger then serves as the substrate for (heat generating) electronic components, which are mounted on, and in thermal contact with, the electrically insulating but thermally conductive underside surface of the exchanger.

Methods of Manufacture

[0026] The various components of the microchannel heat exchanger, e.g. the thermally conductive base, the microchannel layers, manifolds, covers, fluid inlet and outlet ports, the slotted-and-ribbed sheets, etc. may be fabricated by any convenient means consistent with the final assembly of the heat exchangers. Such means may include, but are not limited to, the following methods and combinations thereof:

- Subtractive manufacturing techniques such as mechanical machining, milling, etching, punching, photochemical machining, laser ablation or micromachining, electrical discharge machining (EDM), ultrasonic machining, water-jet cutting, etc.
- Mechanical deformation of material, e.g. by skiving, "plowing", stamping, coining, extrusion, etc.
- Laminating and bonding of patterned sheets, to form 3-dimensional structures with internal features and passages. The sheets may have repeating areas of the patterns, so that after bonding, the bonded assemblies may be cut or diced into individual microchannel exchangers or exchanger sub-assemblies.
- Additive manufacturing techniques (3-D printing) as selective laser sintering, direct metal laser sintering, selective laser melting, stereo-lithography, fused deposition modeling, etc.
- Bonding or fusing techniques such diffusion bonding, brazing, soldering, welding, sintering, etc.
- Mechanical assembly techniques such as bolts, studs, clamps, adhesives, and the like, using seals, as appropriate, such as gaskets, O-rings, caulks, etc.

[0027] Embodiments according to the invention can be developed for a variety of different cooling configurations and applied to a variety of different cooling tasks. For example, they can be implemented in connection with the teachings of published PCT application no. WO2009/085307, filed December 26, 2008 and published US application no. US-2009-0229794, filed on November 10, 2008.

[0028] The present invention has now been described in connection with a number of specific embodiments thereof. However, numerous modifications which are contemplated as falling within the scope of the present invention should now be apparent to those skilled in the art. Therefore, it is intended that the scope of the present invention be limited only by the scope of the claims appended hereto. In addition, the order of presentation of the claims should not be construed to limit the scope of any particular term in the claims.

REFERENCES CITED IN THE DESCRIPTION

Cited references

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- [US9310135B \[0007\]](#)
- [WO2009085307A \[0027\]](#)
- [US20090229794A \[0027\]](#)

Patentkrav**1.** Mikrokanalvarmeveksler (70), omfattende:

5 en afdækning (78) med en første adgangskanal og en anden adgangskanal,
en termisk ledende bund (74),
en flerhed af termisk ledende plader (40) mellem afdækningen (78) og
bunden (74), der hver definerer en række side-om-side baner (44) anbragt
på linje med en flowretning, hvor banerne (44) hver inkluderer en flerhed
af slidser (46) anbragt på linje, der definerer mikrokanalsegmenter, der
10 strækker sig langs flowretningen og er adskilt af tværribber (48), der
strækker sig på tværs af banerne (44),
hvor pladerne (40) yderligere definerer fælles udskæringsområder (42) i
forbindelse med banerne (44) ved hver ende af banerne (44),
hvor pladerne (40) er stablet i en retning vinkelret på flowretningen mellem
15 bunden (74) og afdækningen (78) for at få i det mindste nogle af ribberne
(48) til at være forskudt fra hinanden langs flowretningen i tilstødende
plader (40) og derved at tillade mikrokanalsegmenterne i den samme bane
(44) i tilstødende plader (40) at være i forbindelse med hinanden langs
flowretningen for at definere en flerhed af tilstødende flerplademikrokanaler
20 i varmeveksleren (70), der hver strækker sig mellem
udskæringsområderne (42) langs flowretningen, og
hvor pladerne (40) er stablet mellem bunden (74) og afdækningen (78),
således at de fælles udskæringsområder (42) danner mindst en
indgangsmanifold og mindst en udgangsmanifold, der er anbragt på linje
25 med henholdsvis den første adgangskanal og den anden adgangskanal på
afdækningen (78).

2. Apparatet ifølge krav 1, hvor de termisk ledende plader (40) yderligere
definerer adgangskanalåbninger ved hver ende af banerne (44), som, når de er
30 stablet, danner adgangskanaler til mikrokanalerne.

3. Apparatet ifølge krav 1, hvor pladerne (40) definerer en mere tæt pakning af
tværribber (48) i mindst en indløbsende af varmeveksleren (70) for at reducere
det åbne tværsnit ved indløbsenden af banerne (44) i forhold til et tværsnit af en

del af banerne (44) mellem indløbs- og udløbsenderne af banerne (44).

4. Apparatet ifølge krav 1, hvor sideforholdet mellem mikrokanalerne er over 4:1.

5 **5.** Apparatet ifølge krav 1, hvor sideforholdet mellem mikrokanalerne er over 8:1.

6. Apparatet ifølge krav 1, der yderligere inkluderer termisk ledende separatorplader (60) placeret mellem grupper af de termisk ledende plader (40) for at danne en flerlagsvarmeveksler (70).

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7. Apparatet ifølge krav 1, hvor pladerne (40) er fremstillet af mindst et termisk ledende metal.

8. Apparatet ifølge krav 1, hvor pladerne (40) er fremstillet af sintrerbar termisk
15 ledende keramik.

9. Apparatet ifølge krav 1, hvor pladerne (40) er sammenklæbet eller sammensmeltet.

20 **10.** Apparatet ifølge krav 1, hvor mikrokanalerne har en hydraulisk diameter på under 500 mikrometer.

11. Apparatet ifølge krav 1, hvor mikrokanalerne har en hydraulisk diameter på under 200 mikrometer.

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12. Apparatet ifølge krav 1, hvor bunden er en bundplade (74), der er tykkere end hver af pladerne (40).

13. Apparatet ifølge krav 1, hvor bunden (74) er termisk ledende, men alligevel
30 elektrisk isolerende.

14. Apparatet ifølge krav 1, hvor varmeveksleren (70) er konstrueret til drift med kogning eller fordampning af fluid, og hvor varmeveksleren (70) yderligere inkluderer flowbegrænsere ved indløbsenderne af mikrokanalerne.

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15. Apparatet ifølge krav 14, hvor flowbegrænserne er dannet ved at lukke en indgangsende af hver anden bane (44) i hver af pladerne (40) med en tværribbe (48), hvor de lukkede baner (44) af slidser (46) er forskudt i forhold til hinanden i tilstødende plader (40), når pladerne (40) er stablet og sammenklæbet for at

5 danne et skakternet mønster på tværs af indløbene af flerheden af kanaler.

DRAWINGS

Drawing

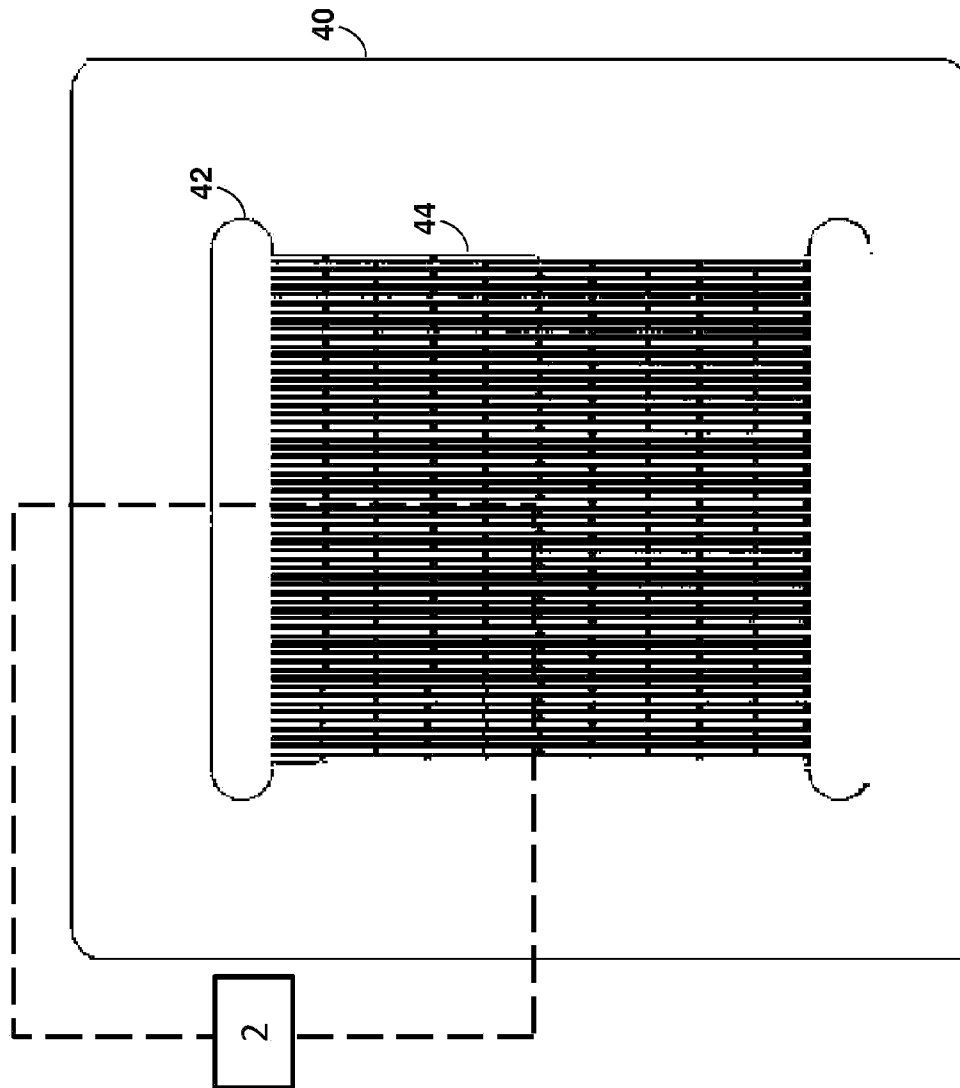
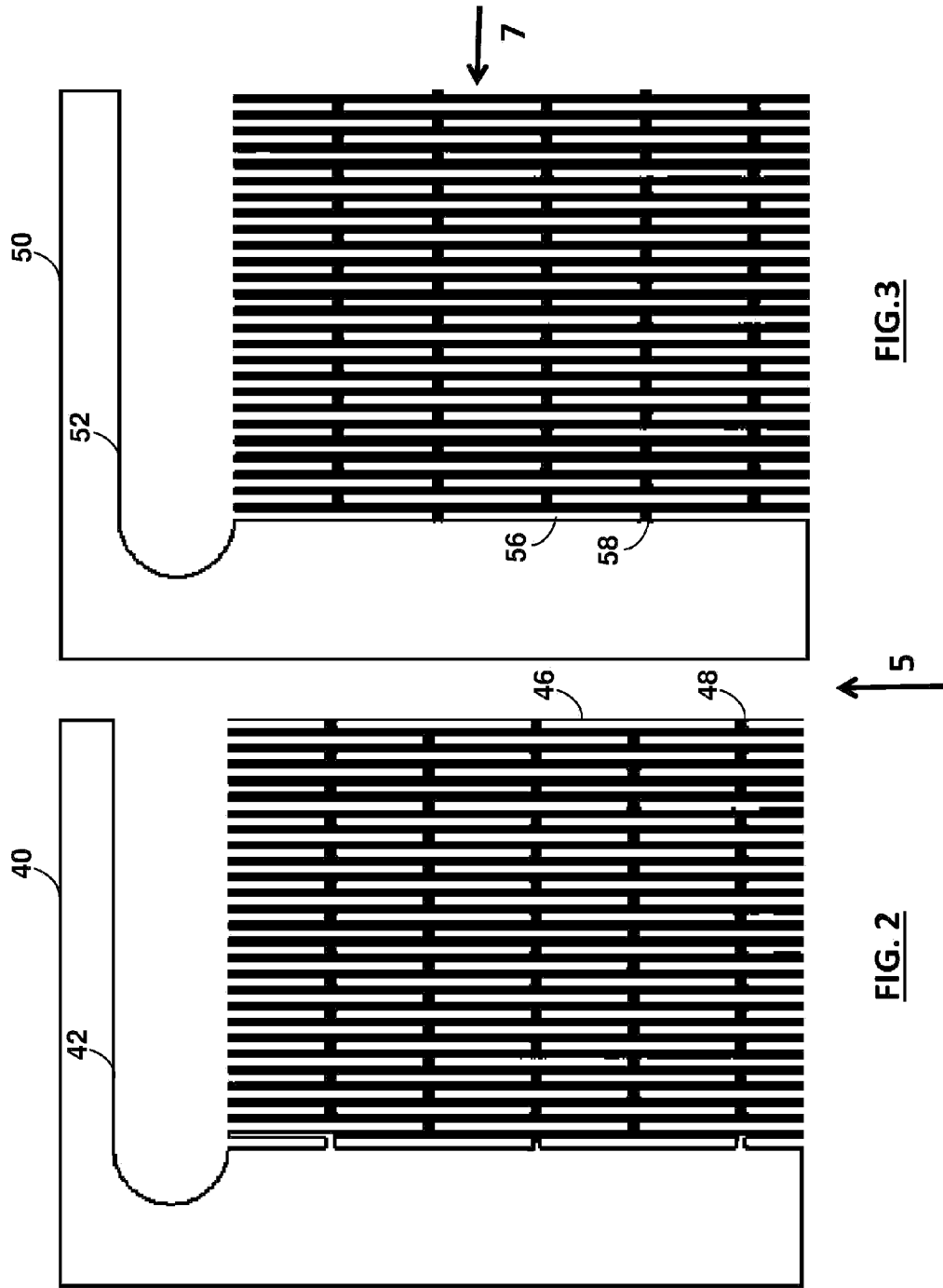


FIG. 1



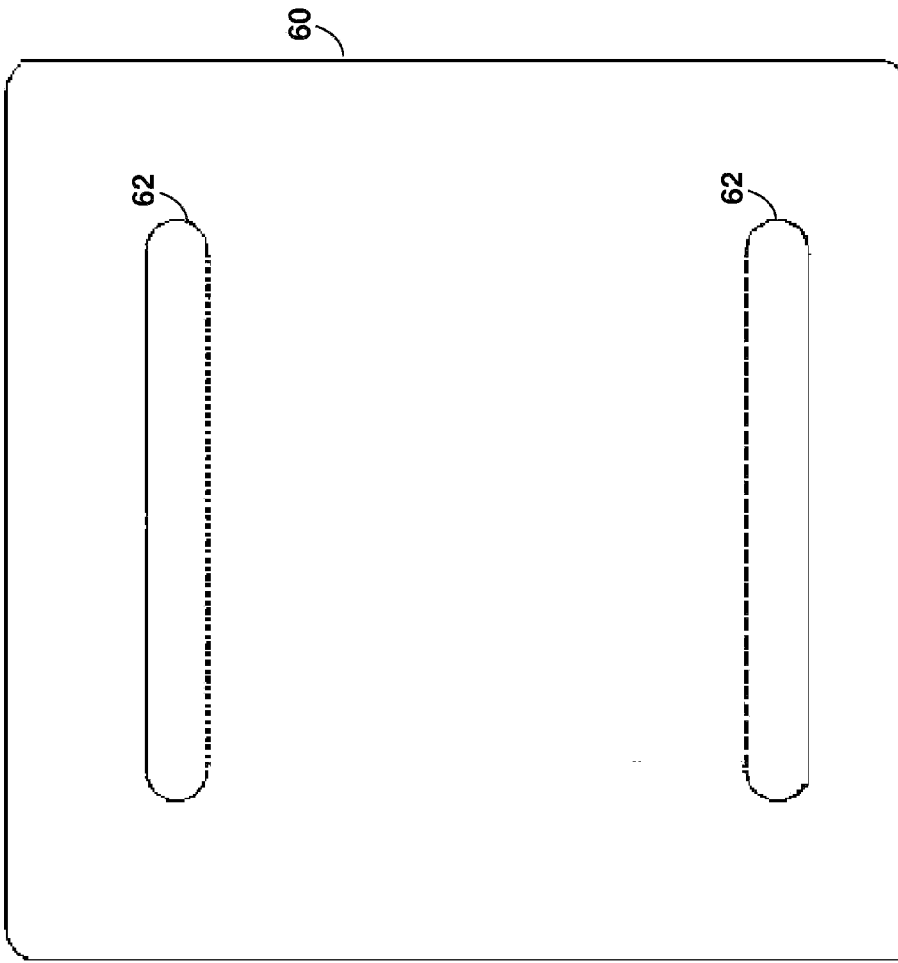


FIG. 4

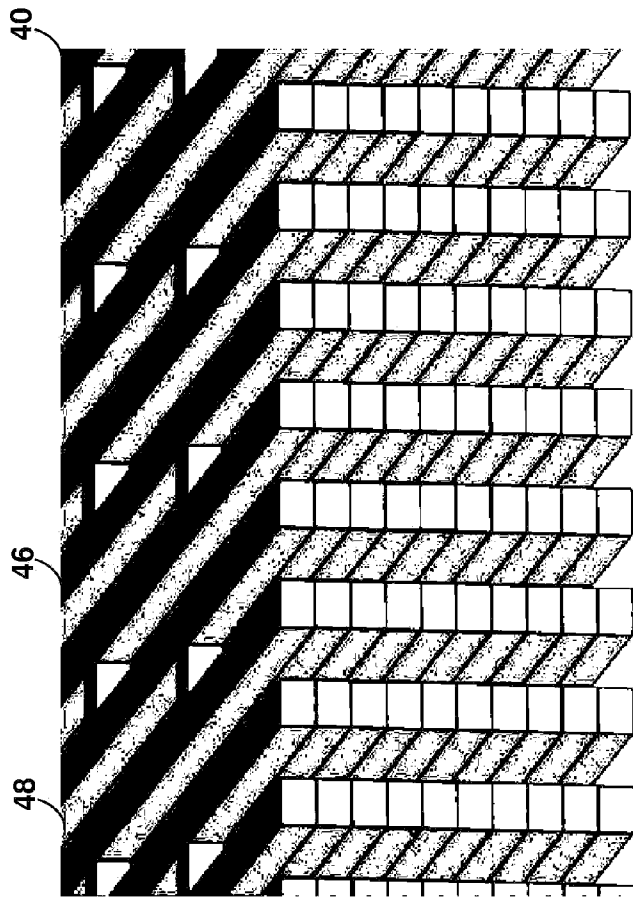


FIG. 6

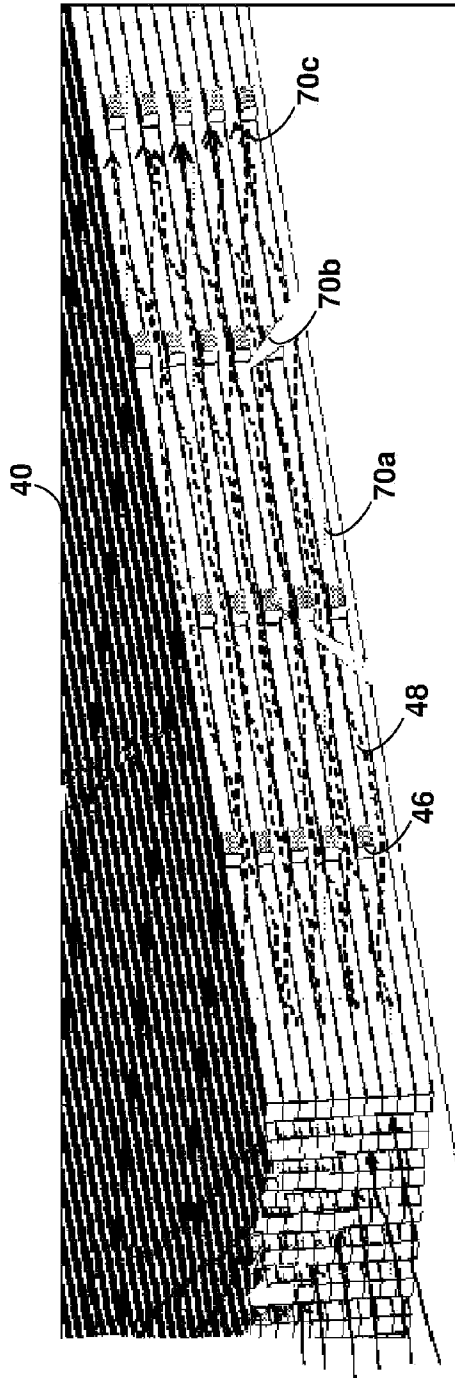


FIG. 7

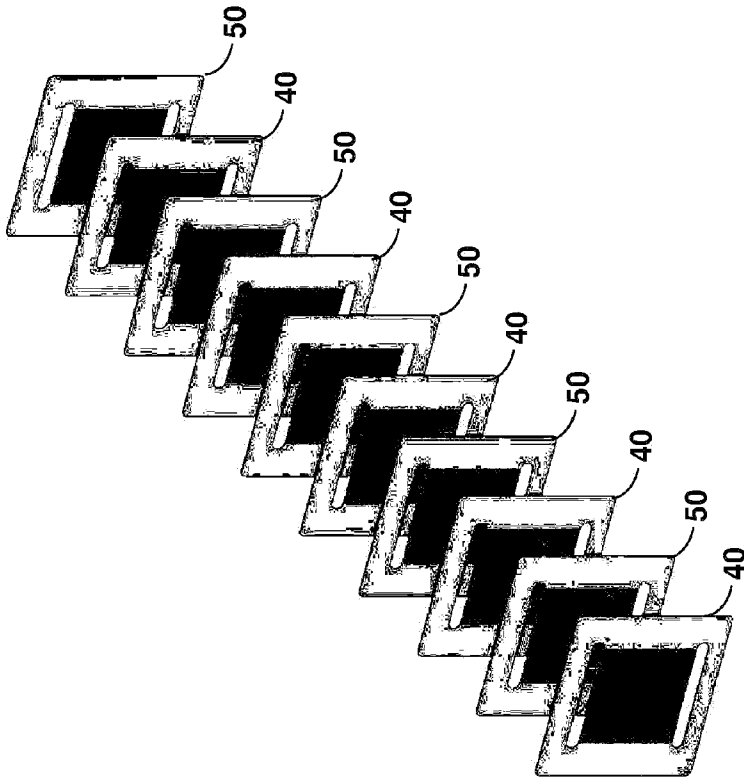


FIG. 8

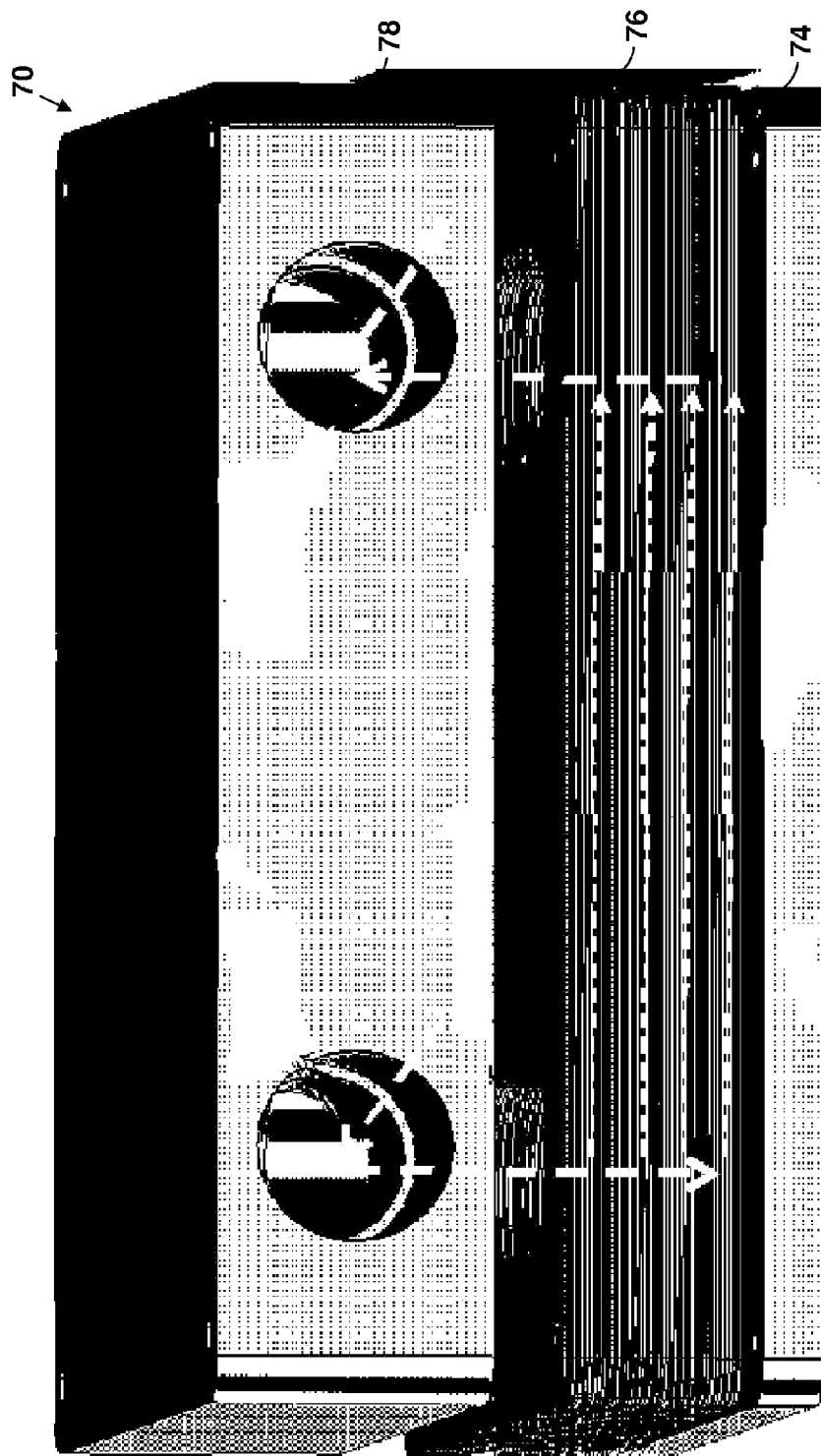


FIG. 9

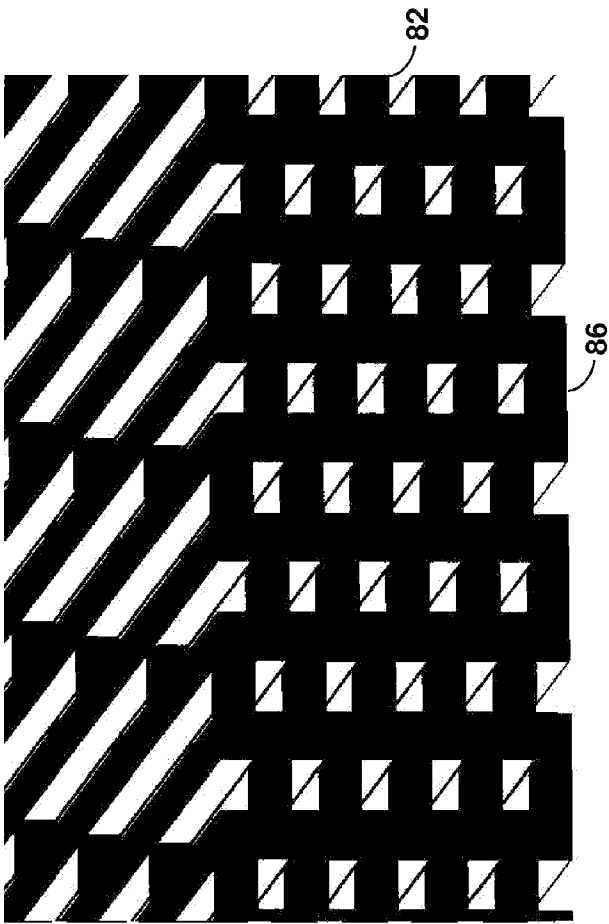


FIG. 10