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(57) Abstract: A micro-component useful as a heat exchanger, vaporizer, or chemical reaction chamber comprising a separator forming on opposite sides thereof adjacent and longitudinally extending micro-channels for laminar fluid flow, the separator being a middle element in a sealed enclosure having inlet and outlet opening transverse to the channels allowing the flow of fluid through the channels.

MULTI-PURPOSE MICROCHANNEL MICRO-COMPONENT

FIELD OF THE INVENTION

[0001] The present invention relates to a device, structure and assembly useful as a micro-component heat exchanger and micro-chamber for the promotion of chemical reactions. The invention further relates to micro-components useful in the sequential processing or reforming of reactants involved in the production of hydrogen gas used in fuel cells and the micro-chemical processing of reactants and products.

BACKGROUND AND SUMMARY OF THE INVENTION

[0002] In the prior art, micro-component heat exchangers and cooling mechanisms have been found useful in the fields of microprocessor design where heat generated in the operation of a microprocessor is dissipated by an ancillary mechanism that provides a coolant or otherwise withdraws heat energy created as a function of electrical circuit processing from the system. Examples of such devices are described in: United States Patent No. 5,987,893 showing a micro cooler having micro-channels through which a coolant flows. The micro cooler includes a plurality of thin layers of metal joined in an assembly by diffusion bonding; United States Patent No. 5,727,618 relating to a modular micro-channel heat exchanger for a heated region in a micro device such as a chip. A coolant enters the exchanger, absorbs heat and exits; United States Patent No. 5,453,641 describes V-shaped or tapered micro-channels formed in a substrate; United States Patent No. 5,002,123 also describes V-shaped micro-channels tapered in the

direction of flow of fluid through the channel; United States Patent No. 4,777,560 shows a heat sink formed of an integral element of thermally conductive material.

[0003] It is an object of the present invention to provide a micro-component heat exchanger assembly that facilitates the flow of gas phase and liquid phase fluids on either side of an intermediate separator or waveplate having micro-channels formed on opposite sides thereof such that energy transfer of gas phase fluids on the opposite sides of the separator is principally effected by diffusion and energy is conducted through the separator. It is a further object of the invention to provide a device in which the intermediate separator between alternate flows may include a catalyst to promote a chemical operation on the fluid passing through the device. It is yet another object to provide a micro-device having increased surface area between sections such that a micro-component reaction chamber is provided and that increased efficiency in the transfer of heat energy by diffusion is achieved.

[0004] The invention is described more fully in the following description of the preferred embodiment considered in view of the drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Figure 1A and Figure 1B are respectively cut away plan and cut away side views of the micro-channel device.

[0006] Figure 1C is a cross-sectional representation of a micro-channel device.

[0007] Figure 2A and Figure 2B show a cross-sectional detail views of the micro-channel assembly.

[0008] Figure 3A and Figure 3B are respectively plan and cross section views of the lower, or bottom, component of the micro-channel device assembly.

DETAILED DESCRIPTION OF THE INVENTION AND THE PREFERRED EMBODIMENT

[0009] In brief, the invention is a micro-component assembly useful as a heat exchanger or chemical reaction chamber comprising a thin zigzag, wave shaped or other alternately folded formed separator that forms adjacent and longitudinally extending micro-channels on opposite sides thereof for gas phase or liquid phase fluid flow. The separator is preferably a metal lamina formed in a zigzag cross-section and may comprise alternately directed folds or waves in a unitary member. In cross-section, the separator may be approximately sinusoidal in shape, bearing in mind that the separator is formed from a thin sheet material and is subject to variations in the forming / manufacturing process. In a laminated structure, the separator is a middle element in a sealed or laminated enclosure having longitudinally separate laterally extending inlet and outlet openings transverse to the channels allowing the flow of fluid through the channels.

[0010] In its variations, the device is a micro-component heat exchanger in which the separator forms adjacent and longitudinally extending micro-

channels for the flow of separate fluids between which heat is exchanged. As a micro-component reaction chamber the separator may include thereon a catalyst composition to promote a chemical reaction in the fluid flowing in the channels formed therein. In a multiple function application, separate endothermic and exothermic reactions may be promoted at the opposite surfaces of the micro-channels formed by the separator.

[0011] In its fabrication, one of an upper or lower section and two opposite side sections of a rectangular enclosure may be integrally formed from a "U" shaped channel section; the two additional side sections of the enclosure are formed from side plates.

[0012] As a micro-component heat exchanger or reaction chamber, the device is formed as a laminate including upper, lower and side members enclosing a middle sheet separator formed or stamped in a zigzag or wave shape that separates the device into two arrays of longitudinally separate side by side channel sections for the flow of separate fluids through respective sides of the device. The middle separator sheet may include, such as by a coating, a catalyst to promote a chemical reaction by a fluid passing therethrough or a surface treatment that increases surface area or enhances reactions. In this manner, the device is useful as a micro-component reaction chamber that provides increased surface area on which a reactant may react with, for example, a catalyst as the reagent passes through the micro-channel.

[0013] The device is shown in the drawings and includes a top sheet, bottom sheet and a middle sheet between the top and bottom sheets that separates the device into two adjacent channels for the flow of fluids. The middle sheet is preferably formed or stamped in a zigzag, folded, wave, or corrugated pattern to promote the longitudinal side-by-side flow of separate fluids on opposite sides thereof through the device. The middle sheet may be coated with a catalyst to promote a chemical reaction in a fluid passing therethrough, or chemically or otherwise treated to enhance the surface area with which the fluid interacts. When used as a micro-reaction chamber, the folded pattern, by itself, of the middle sheet with a catalyst coating thereon increases the available surface area for reagents to react with the catalyst.

[0014] With reference to Figure 1A, the device 1 is shown in plan view with perimeter sides 2, 3, 4, and 5 and upper plate section 6 and lower plate section 9 forming an enclosure for micro-channel separator 7 which is sandwiched between the upper and lower plates. Inlet and outlet openings 61 and 62 are shown formed into upper section 6. Figure 1B shows a side cross section depicting a "U" shaped channel member forming opposite sides 3 and 5 and the lower plate section 9. When such a "U" channel is used, separate end plates such as shown at 10 and 11 at sides 2 and 4 complete the perimeter enclosure of the device. The micro-channels are shown figuratively in Figure 1C in which an enclosure for the device is shown formed by sides 3, 5, 6 and 9 and the middle lamina is shown at 7 dividing the assembly into micro-channels A1, A2, A3 AN on one side and micro-channels B1, B2, B3 BN on the opposite side of the middle separator. A

first fluid flow is directed through an inlet and outlet on one side through micro-channels A1, A2, A3 AN; a second fluid flow is directed on the other side through an inlet and outlet to micro-channels B1, B2, B3 BN.

[0015] Figure 2A shows the middle sheet or separator 7 forming the alternating micro-channels 71, 72, 73, 74, 7n on the opposite sides of the folded sheet or waveplate. The micro-channels are formed in a wave or zigzag cross section pattern in the central section of a plate having side flanges 20 and 21 that overlap side edges 5 and 3 extending from the lower plate section 9 to form a "U" base member. The separator is an integrally formed folded array of a conductive material laminated between the upper and lower plates with brazed contact points sealing the separator between side edges 5 and 3 and shoulder flanges 20 and 21. The seal between the side edges and flanges separates fluid flow on the opposite sides of the separator. The entire assembly including side plates 10 and 11 and top plate 6 is preferably brazed together. Brazing is preferred over diffusion bonding of the components because brazing is effected at a lower temperature and brazing does not require the addition of pressure to bond adjacent member surfaces. (Brazing is the preferred method of bonding the components. Diffusion bonding which requires a higher temperature than brazing may be useful for devices having, in certain applications, different temperature and durability requirements.)

[0016] Figure 3A is a plan view of the "U" channel base member; Figure 3B shows the member in cross section. The lower plate section 9 also

includes separated inlet and outlet openings 91 and 92 leading to and from the array of micro-channels formed by the separator waveplate. In a completed assembly, the opposite surface areas of the separator 7 on the side facing the upper section 6 and on the side facing the lower section 9 allow the exchange of heat energy by conduction through the separator. Fluid flows from inlet 61 to outlet 62 on one side and from inlet 91 to outlet 92 on the opposite side of the device. Flow direction is arbitrarily determined by the use and intended application of the device. In the preferred embodiment, gas phase heat is exchanged between fluids and the separator by diffusion, rather than by convection. Heat is exchanged between the two fluids on the opposite sides by conduction through the separator. In conventional macro-scaled channeled heat exchangers, turbulent flow occurs through the channels and heat transfer is effected by convection with the separator wall and conduction through the separator wall to the second fluid. In the micro-channels of the present invention, laminar flow through the micro-channels occurs in both gas phase or liquid phase flow; in gas phase flow, heat transfer from the fluid to the separator is by diffusion; in liquid phase flow, heat transfer from the fluid to the separator is by conduction. In both instances, heat transfer through the separator is by conduction.

[0017] In an example, the device is formed of metal alloy; all components of the assembly are brazed together and tested under pressure, *inter alia*, to verify the seal separating the micro-channels on the opposite sides. The device must withstand high operating temperatures, such as in the order of 900° C. Dimensions are dependent on the reaction and heat transfer

requirements of a particular micro-component application. In general, length is determined to optimize pressure drop in laminar flow through the micro-channels with regard to residence time and heat transport required by an application. Width is determined by overall capacity requirements. A minimum thickness is an optimization objective, but is subject to mechanical durability considerations. For typical micro-processing applications, typical dimensions of the micro-devices include an overall thickness in the range of approximately 1.0 millimeters to approximately 20.0 millimeters, an overall length in the range of approximately 10.0 millimeters to approximately 300.0 millimeters, and an overall width in the range of approximately 10.0 millimeters to approximately 100.0 millimeters depending on application requirements. The middle separator or waveplate is formed from a metal alloy material of a thickness in the range of approximately 0.01 millimeters to approximately 1.0 millimeters and includes channel separations of in the range of approximately 0.01 millimeters to approximately 1.0 millimeters between adjacent peaks with nominal fold radii up to approximately 0.5 millimeters. In a wave shape, a radius for wave peaks and troughs in the range of approximately 0.005 millimeters approaches a minimum. Suitable materials for forming the middle waveplate separator include stainless steels and alloys thereof, nickel alloys such as Inconel, and steel metals that include chromium, nickel and other additives. In an example, an Inconel alloy, a category of low co-efficient of expansion steels with high nickel content that are stable at high temperatures, formed the separator. BNi-2 is a suitable

brazing material used to bond the separator to the sidewalls. BNi-2 is a combination of iron, boron, chromium and silicon with a balance of nickel.

[0018] In summary, the device is a micro-component useful as a heat exchanger or chemical reaction chamber comprising a separator forming on opposite sides thereof adjacent and longitudinally extending micro-channels for fluid flow. The separator may be a conductive middle element in a sealed enclosure having inlet and outlet openings transverse to the channels allowing the flow of fluid through the channels. The same assembly is useful for multiple purposes. A single design may be adapted to different applications: a heat exchanger, a reaction chamber and a vaporization chamber. The micro-channel device may be used to exchange heat between gases, between liquids, and between a gas and a liquid flowing on opposite sides of the micro-channels. As a reaction chamber the micro-channel walls of the separator may include a catalyst or promoter to induce a predetermined reaction in fluid flowing in the micro-channels in contact therewith. As a vaporization chamber, heat from a fluid flowing on one side transferred through the separator will promote a phase change in a fluid on the other side from an introduced liquid to an exiting gas.

[0019] Having described the invention in detail, those skilled in the art will appreciate that, given the present disclosure, modifications may be made to the invention without departing from the spirit of the inventive concept herein described. Therefore, it is not intended that the scope of the invention be limited to the specific and preferred embodiments illustrated and described.

Rather, it is intended that the scope of the invention be determined by the appended claims.

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WHAT IS CLAIMED IS:

[C-1] 1. A micro-component assembly comprising a separator forming at opposite sides thereof adjacent and longitudinally extending micro-channels for laminar fluid flow, the separator being a middle element enclosed by upper, lower and side sections of an enclosure, the upper and lower sections of the enclosure each including longitudinally spaced apart inlet and outlet openings transverse to a plurality of the micro-channels.

[C-2] 2. A micro-component heat exchanger comprising a conductive separator forming at opposite sides thereof adjacent and longitudinally extending micro-channels for the laminar flow of separate fluids between which heat is exchanged, the separator being a middle element enclosed by upper, lower and side sections of an enclosure, the upper and lower sections of the enclosure each including inlet and outlet openings transverse to the channels for the laminar flow of fluid through the micro-channels.

[C-3] 3. A micro-component reaction chamber comprising a middle separator forming at opposite sides thereof adjacent and longitudinally transverse micro-channels for the flow of a reactive fluid, the middle separator being sealed within upper, lower and side sections of an enclosure, the upper and lower sections of the enclosure each including inlet and outlet openings transverse to a plurality of the micro-channels for the flow of fluid through the

channels, the middle separator including thereon a catalyst composition to promote a chemical reaction in the fluid flowing therethrough.

[C-4] 4. Micro-component vaporization chamber comprising a waveplate separator forming at opposite sides thereof adjacent and longitudinally extending micro-channels for fluid flow, the separator being a middle element enclosed by upper, lower and side sections of an enclosure, the upper and lower sections of the enclosure each including inlet and outlet openings transverse to a plurality of the micro-channels, the micro-channels on the opposite sides being adapted, on one side, for the flow of a heated fluid through the micro-channels and, on the opposite side, for the flow of a liquid phase of a fluid to the inlet for the micro-channels and for the outlet from the micro-channels of a gas phase of the fluid.

[C-5] 5. The micro-component of claim 2 wherein heat is exchanged by diffusion between a gas phase fluid and the separator.

[C-6] 6. The micro-component of claim 4 wherein heat is exchanged by conduction between a liquid phase fluid and the separator.

[C-7] 7. The device of claim 1 or claim 2 or claim 3 or claim 4 in which one of the upper section or the lower section of the enclosure is formed from a longitudinally extending approximately "U" shaped channel.

[C-8] 8. The device of claim 7 in which side sections of the enclosure transverse to the "U" shaped channel are formed from side plates.

[C-9] 9. The device of claim 7 in which the separator includes at respective sides thereof a flanged end section that is bonded to upward extending edge ends of the "U" shaped channel.

[C-10] 10. The device of claim 9 in which the bond is a braised bond.

[C-11] 11. The device of claim 9 in which the bond is a diffusion bond.

[C-12] 12. The device of claim 1 or claim 2 or claim 3 or claim 4 in which the separator is formed in a zigzag pattern of alternately directed folds.

[C-13] 13. The device of claim 1 or claim 2 or claim 3 or claim 4 in which the separator is formed in a wave pattern that is approximately sinusoidal in shape.

[C-14] 14. The device of claim 1 or claim 2 or claim 3 or claim 4 having a thickness in the range of approximately 1.0 millimeters to approximately 20.0 millimeters, a length in the range of approximately 10.0 millimeters to approximately 100.0 millimeters, and a width in the range of approximately 10.0 millimeters to approximately 300.0 millimeters.

[C-15] 15. The device of claim 14 in which the separator is a waveplate is formed from a metal alloy.

[C-16] 16. The device of claim 15 in which the metal alloy is a stainless steel.

[C-17] 17. The device of claim 15 in which the metal alloy includes a nickel component.

[C-18] 18. The device of claim 15 in which the metal alloy includes a chromium component.

[C-19] 19. The device of claim 1 or claim 2 or claim 3 or claim 4 in which the separator comprises a material having a thickness in the range of approximately 0.01 millimeters to approximately 1.0 millimeters.

[C-20] 20. The device of claim 1 or claim 2 or claim 3 or claim 4 in which the separator comprises a shaped sheet in which separate channels formed by the sheet have a nominal width in the range of approximately 0.01 millimeters to approximately 1.0 millimeters.

[C-21] 21. The device of claim 1 or claim 2 or claim 3 or claim 4 in which the separator comprises a wave shaped folded sheet in which nominal

separations between the sides of the sheet forming adjacent folds are in the range of approximately 0.01 millimeters to approximately 1.0 millimeters.

[C-22] 22. The device of claim 21 with folds having nominal radii in the range of up to approximately 0.5 millimeters.

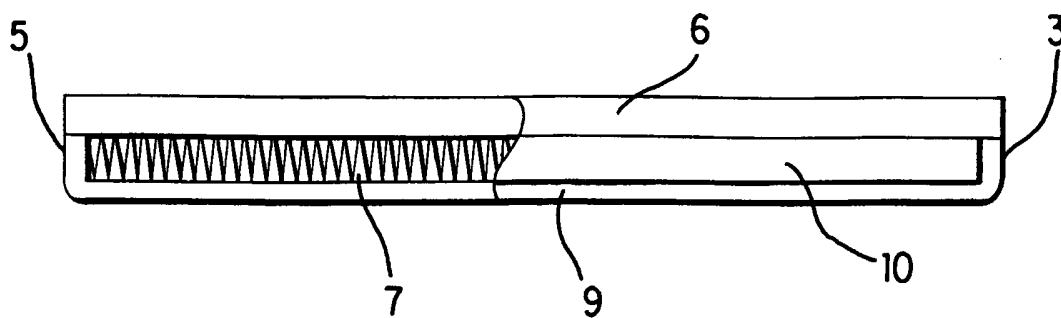


FIG. 1B

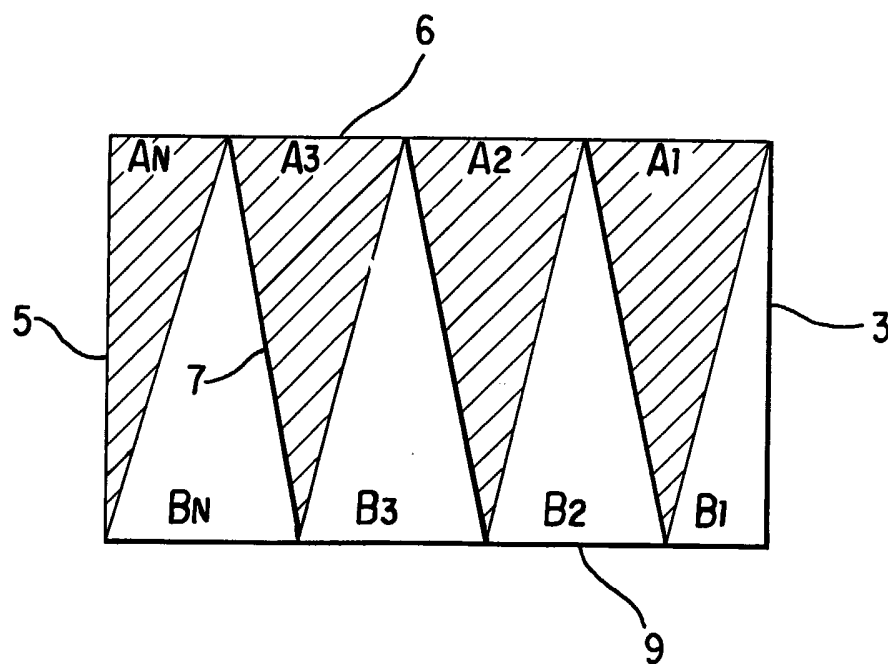
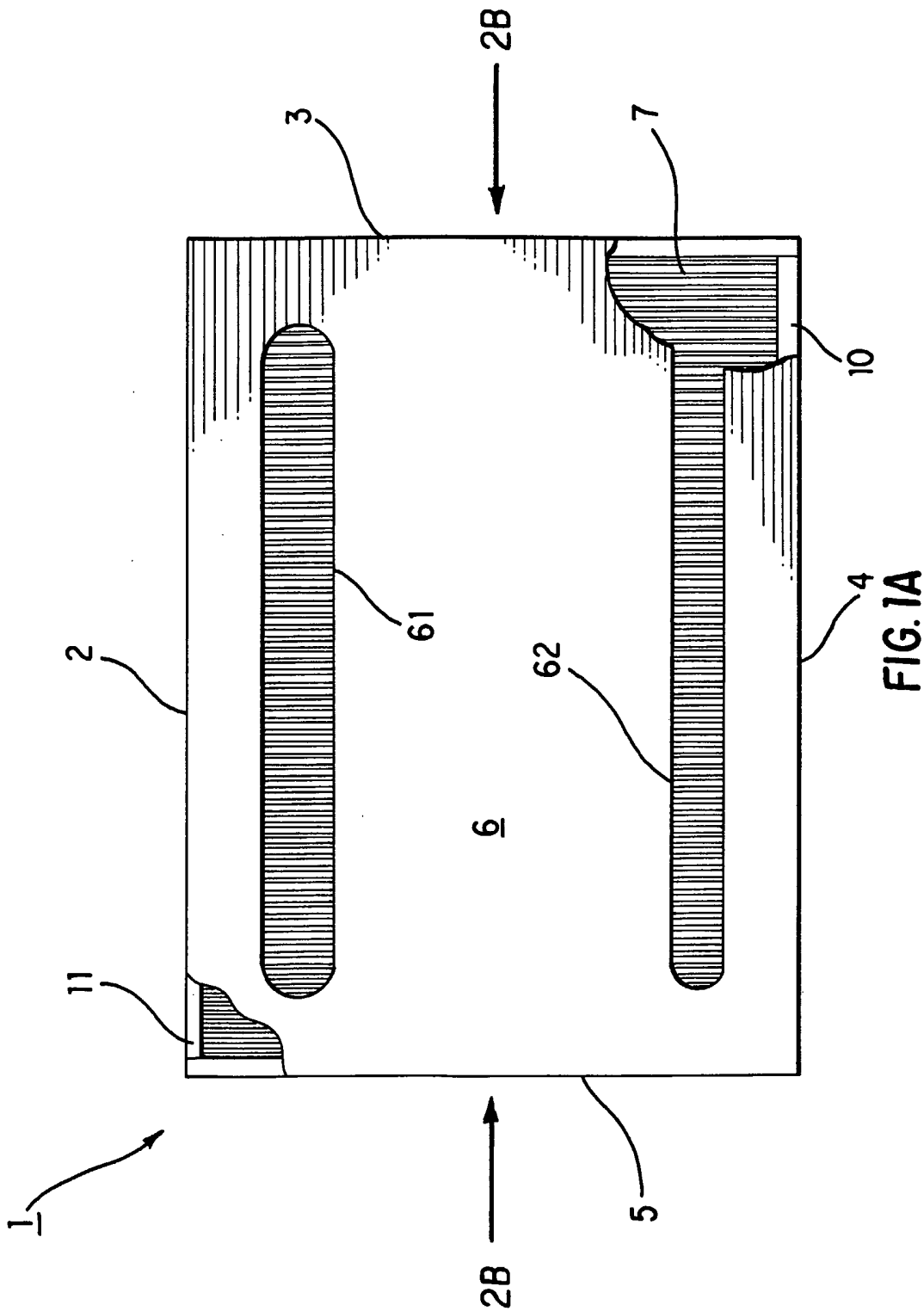


FIG. 1C



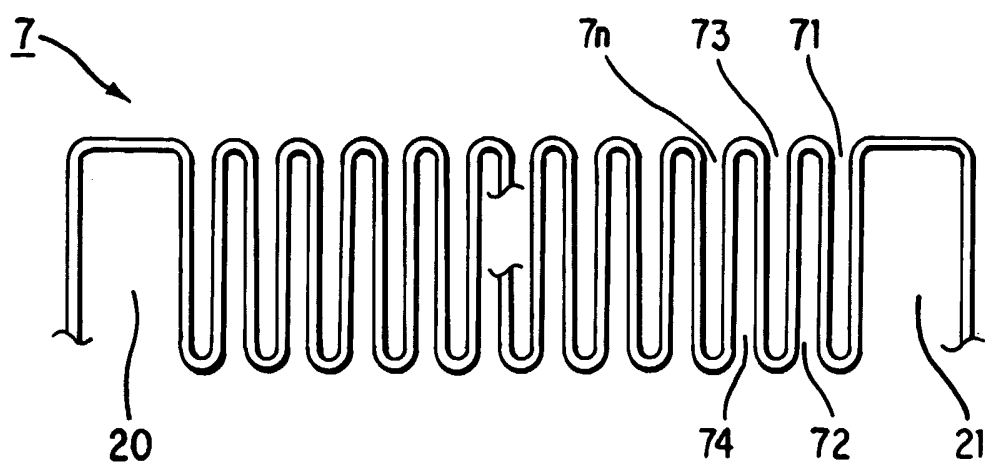


FIG. 2A

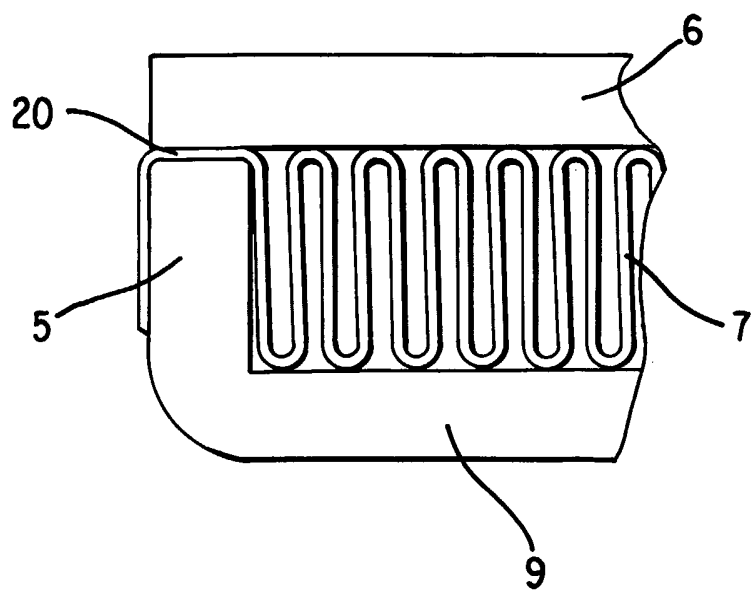


FIG. 2B

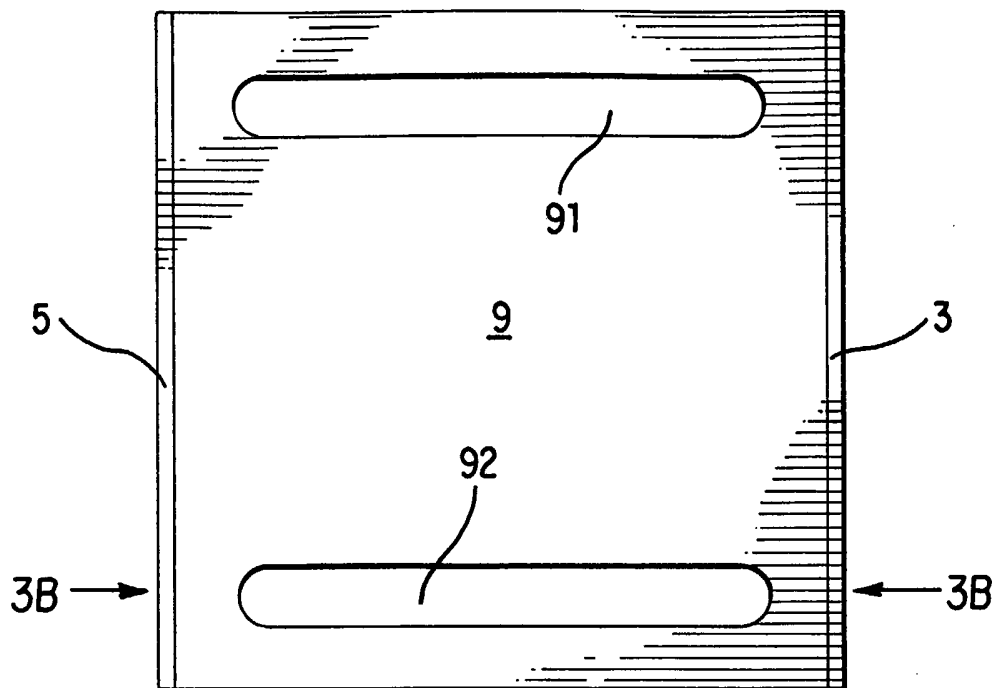


FIG. 3A

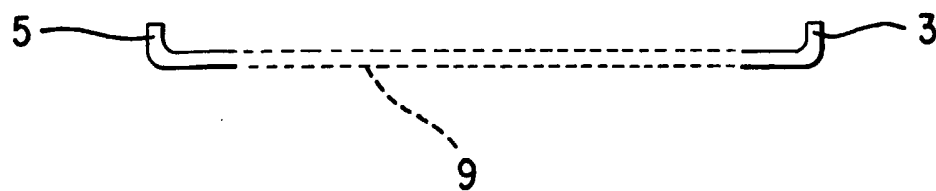


FIG. 3B