US 20100163211A1

(19) **United States**

(12) **Patent Application Publication**

(10) **Pub. No.: US 2010/0163211 A1**

(43) **Pub. Date: Jul. 1, 2010**

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(54) **HEAT EXCHANGER ASSEMBLY**

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(21) Appl. No.: **12/317,859**

(22) Filed: **Dec. 30, 2008**

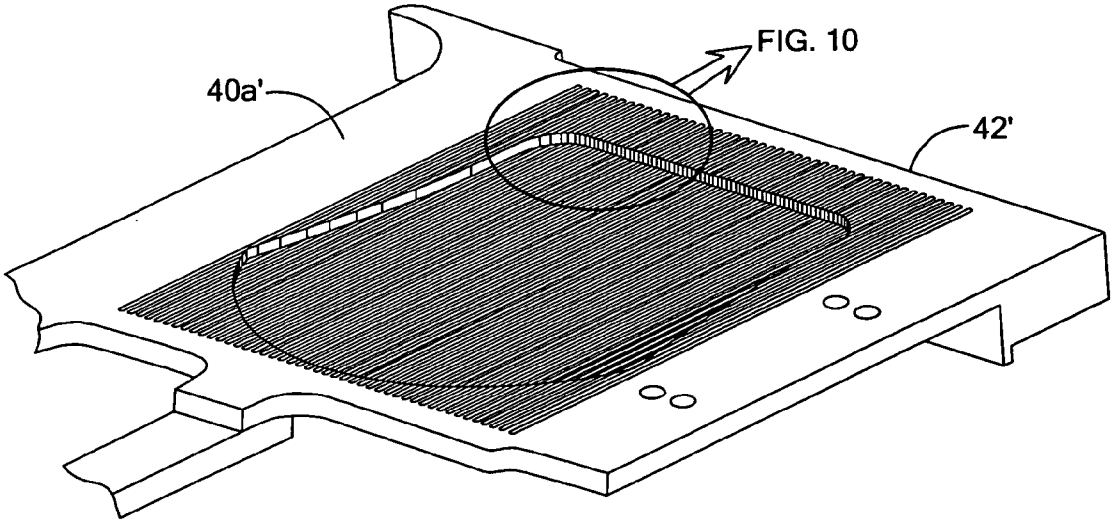
Publication Classification

(51) **Int. Cl.**
F28D 15/00 (2006.01)
B21D 53/02 (2006.01)

(52) **U.S. Cl.** **165/104.26**; 29/890.032

(57) **ABSTRACT**

An improved heat exchanger assembly and method. First and second plates made of a predetermined thermally conductive material are configured when mated to form a hermetically sealed vapor chamber. A wick made of the same predetermined thermally conductive material resides in the vapor chamber forming a gas chamber.



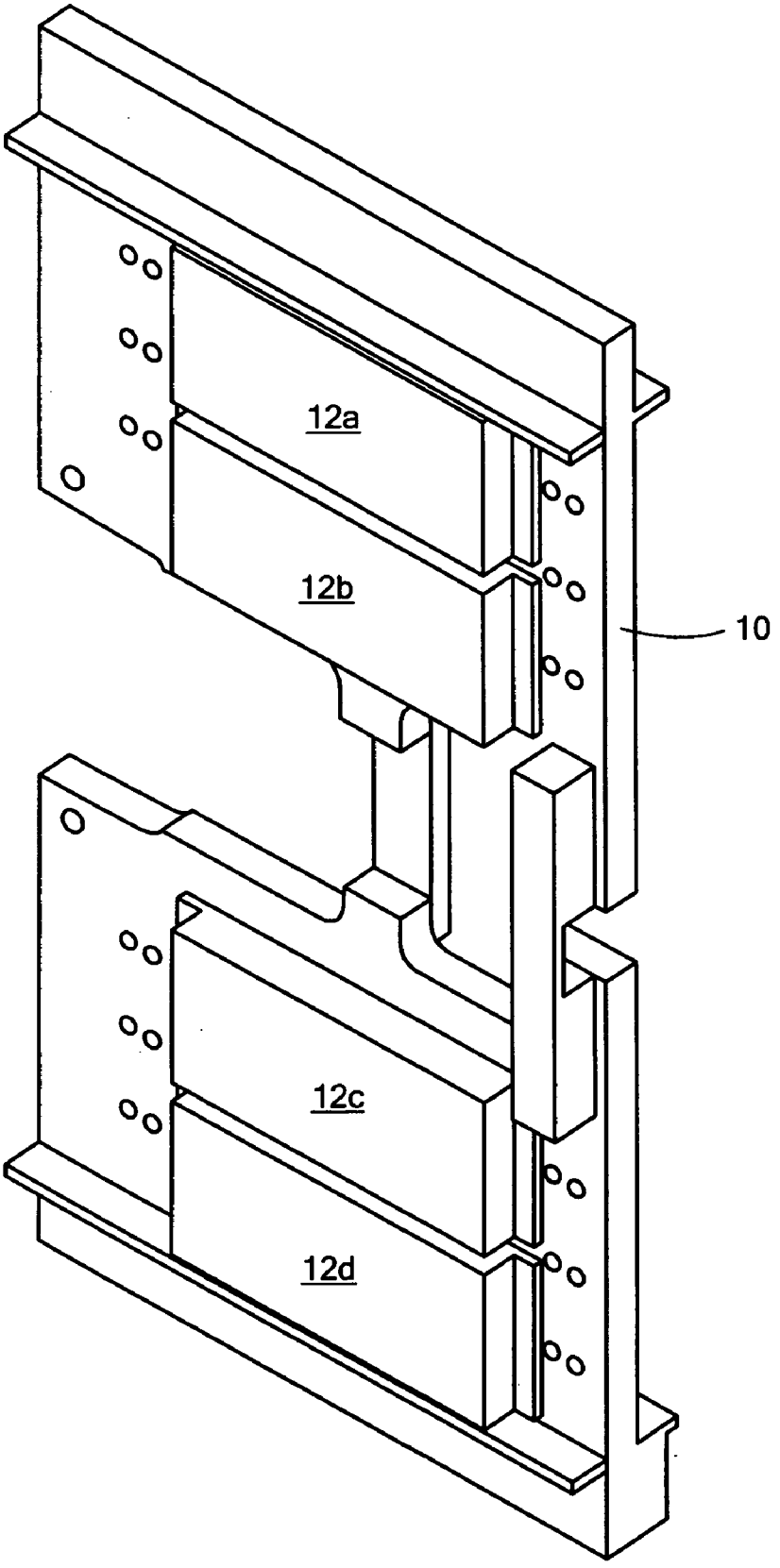


FIG. 1

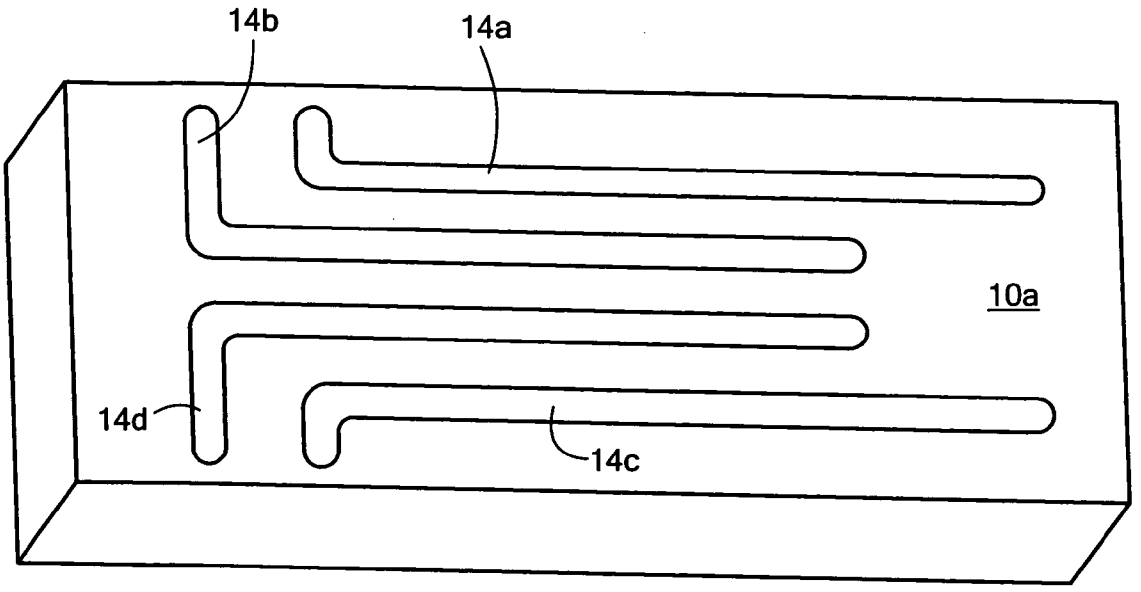


FIG. 2

PRIOR ART

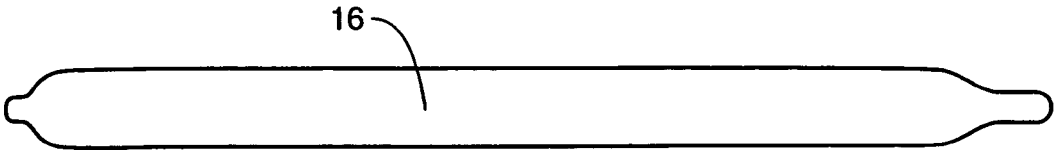


FIG. 3

PRIOR ART

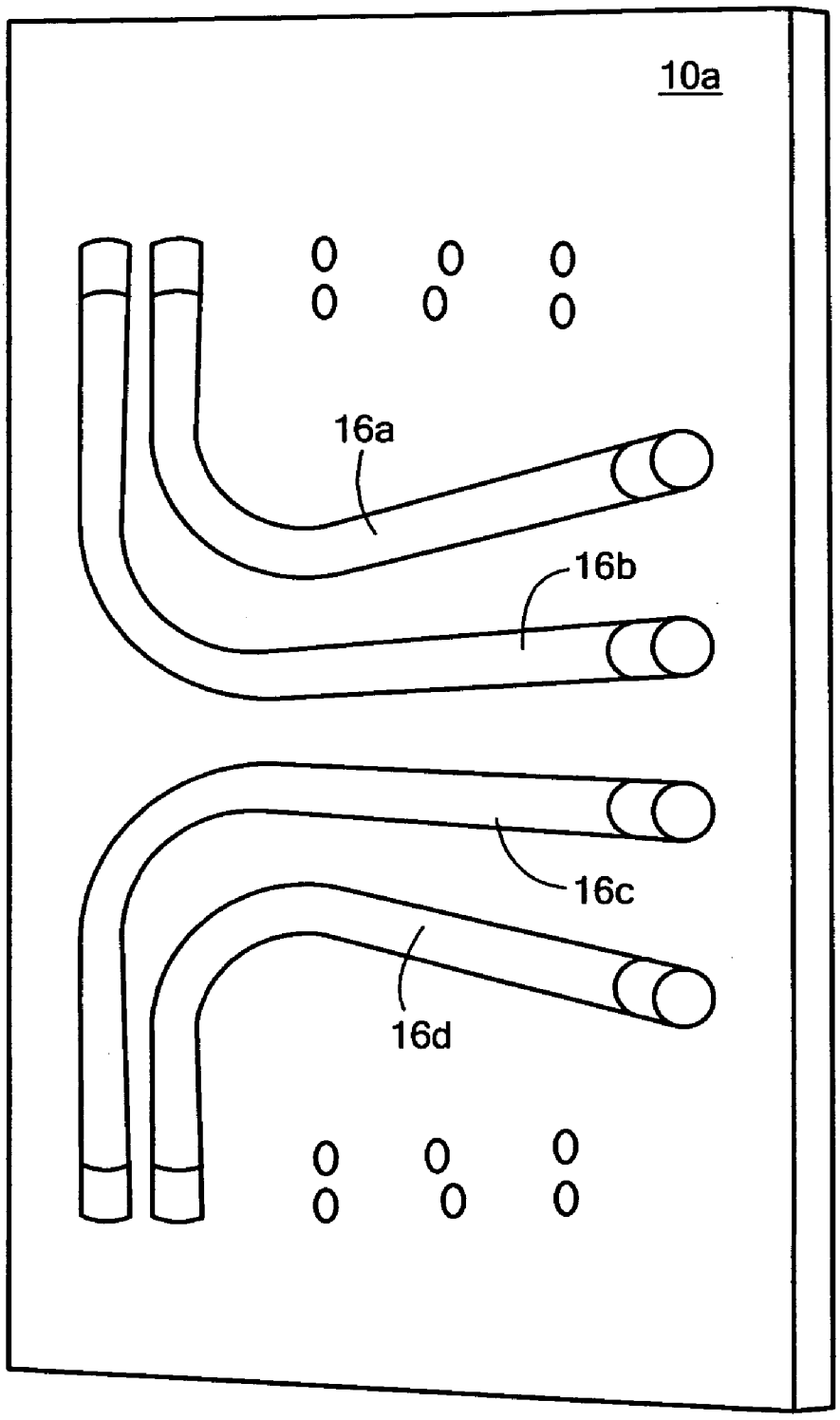


FIG. 4

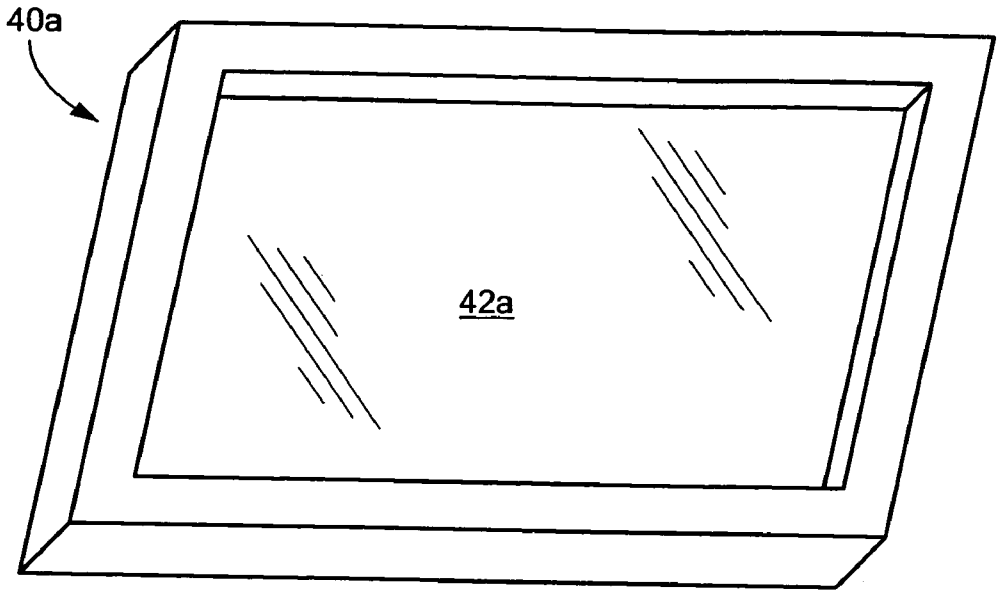


FIG. 5A

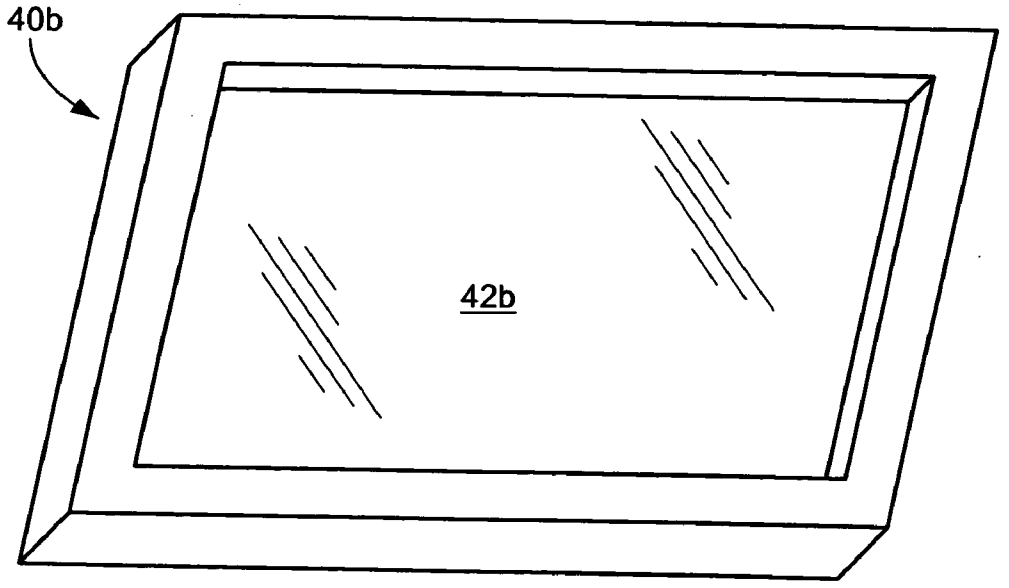


FIG. 5B

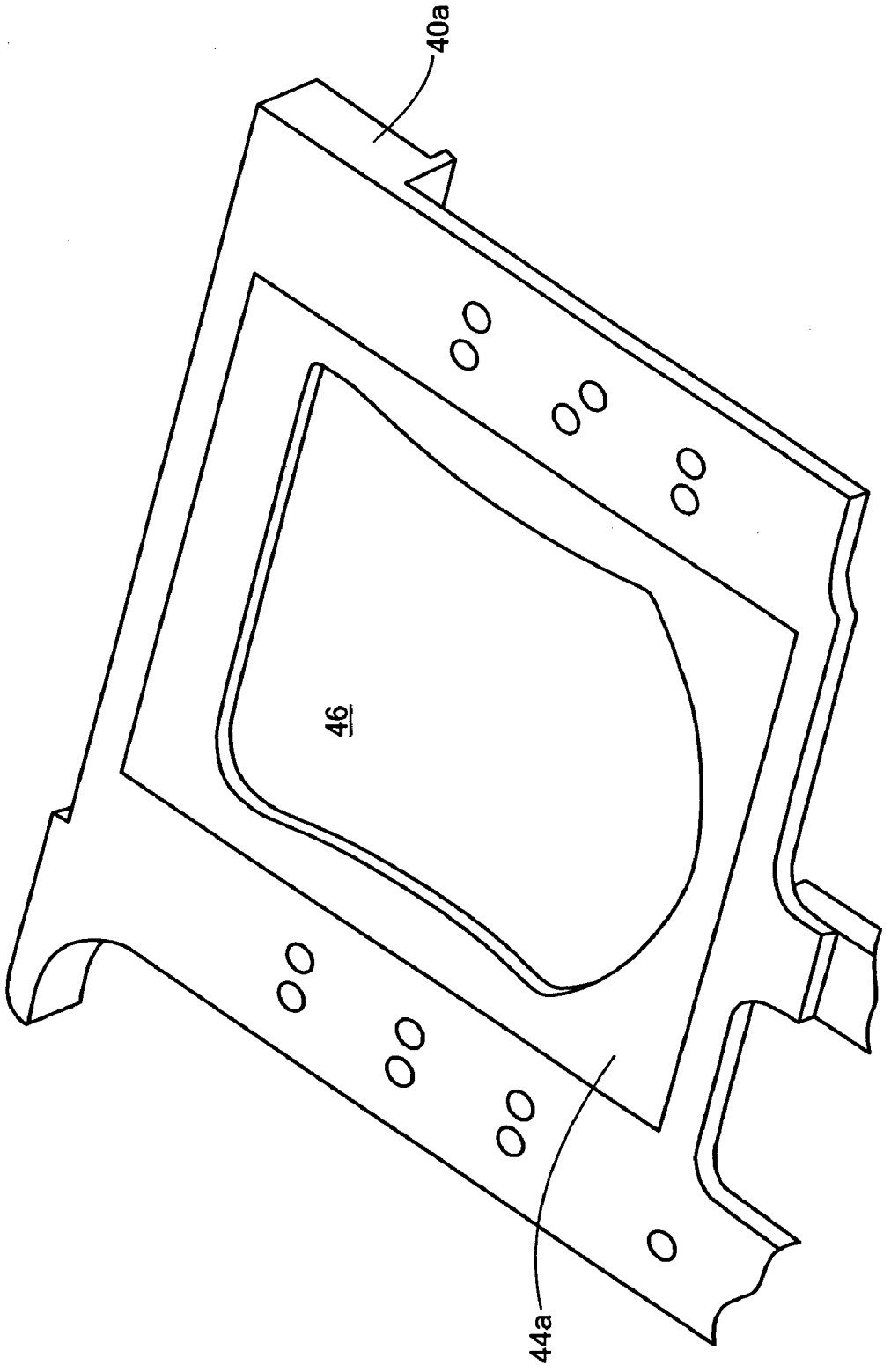


FIG. 6

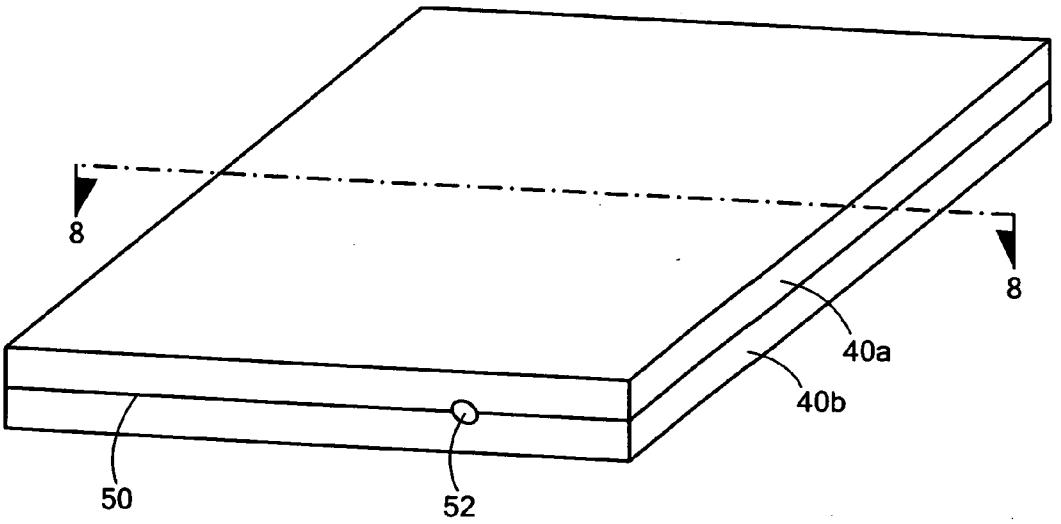


FIG. 7

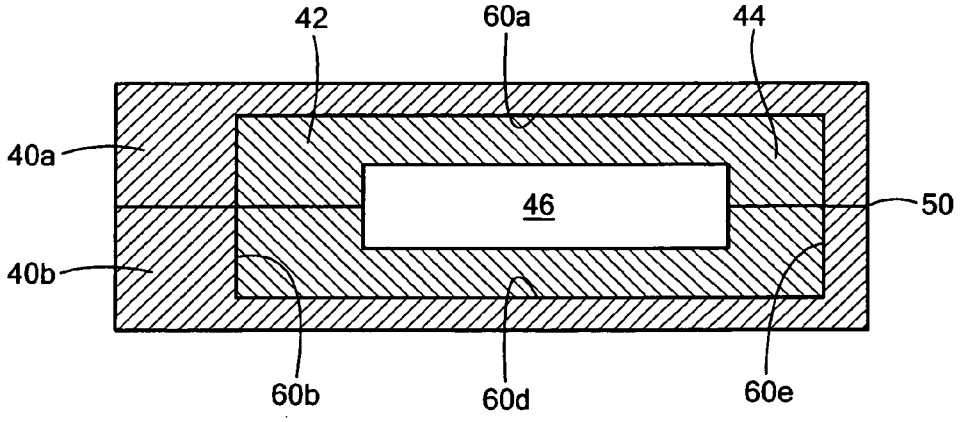


FIG. 8

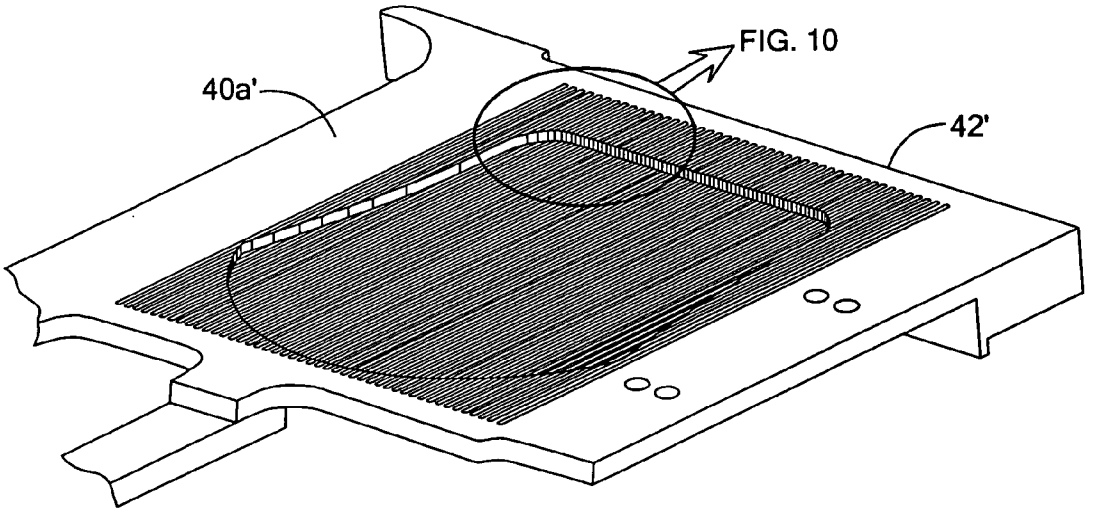


FIG. 9

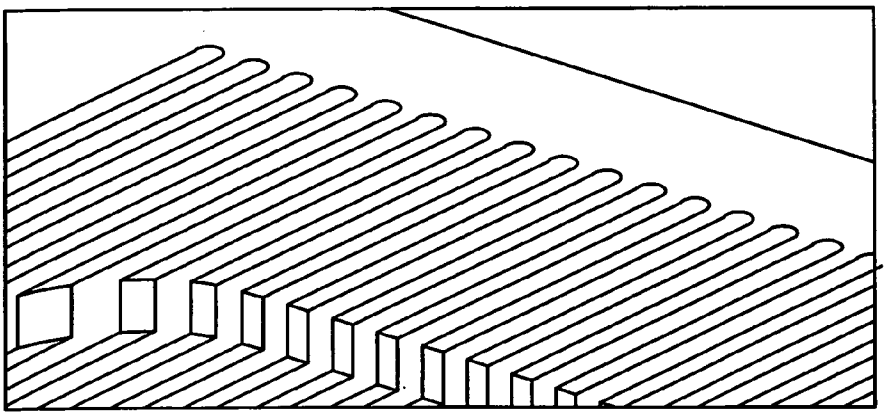


FIG. 10

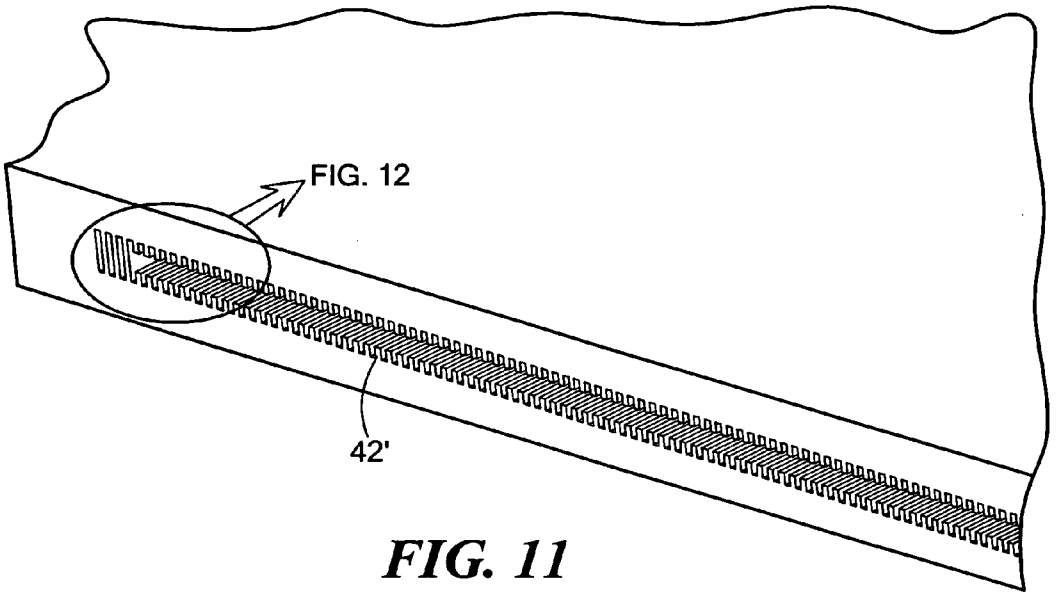


FIG. 11

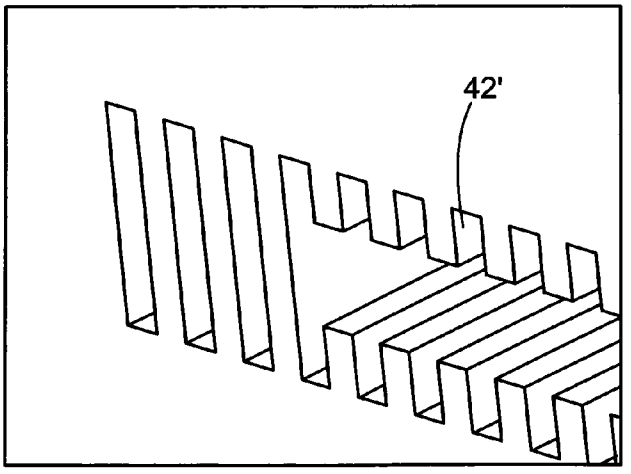


FIG. 12

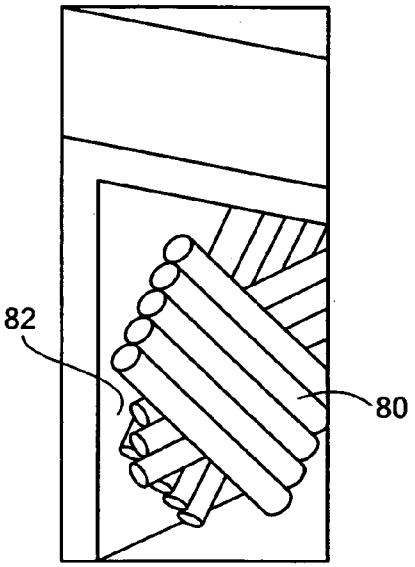


FIG. 13

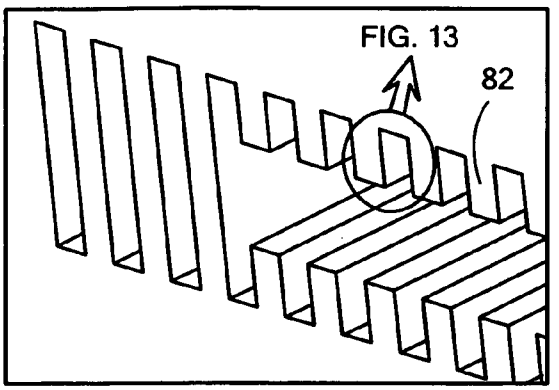


FIG. 14

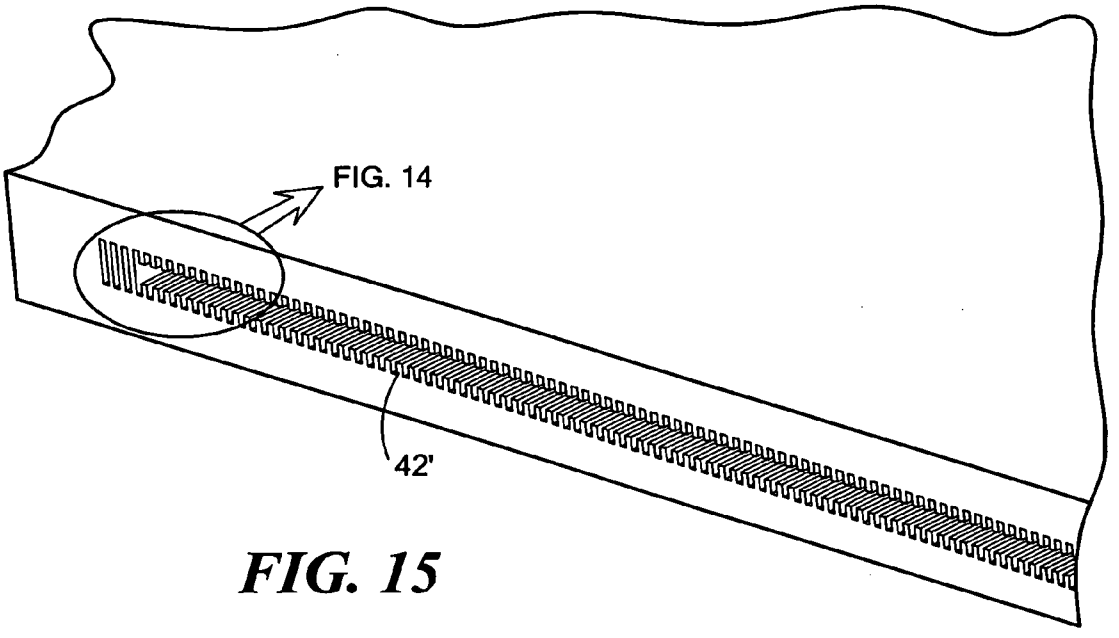


FIG. 15

HEAT EXCHANGER ASSEMBLY

FIELD OF THE INVENTION

[0001] The subject invention relates to heat transfer, heat exchanger assemblies, and cold plates.

BACKGROUND OF THE INVENTION

[0002] Heat exchangers are used to cool electronic components generating heat. In one example, a cold plate assembly used in connection with radar transmit and receive modules is made of aluminum and includes therein copper heat pipes.

[0003] One problem with copper is that it is heavy which is a concern in ship and airborne applications. Historically, aluminum can be used for the cold plate housing, allowing weight optimization, but when integrated with the copper heat pipe can introduce the possibility for galvanic corrosion. When solder, or other materials, are used as the barrier material between the cold plate housing and heat pipe, voids introduce thermal resistances, contribute to local galvanic corrosion opportunity, and reliability problems. Moreover, the current process of making the cold plates limits design flexibility and is labor intensive and expensive. Copper is also becoming increasingly costly.

[0004] Aluminum heat pipes available on the market today suffer from reduced thermal efficiency. When integrated with aluminum cold plates, the dissimilar metal problem is solved and the possibility for galvanic corrosion is reduced to, but the result is reduced thermal performance. This reduced performance limits applications. Additionally, these heat pipes suffer from poor reliability and manufacturability issues. Attempts at plating either aluminum or copper cold plates and copper heat pipes with a tin-lead composition to eliminate corrosion resulted in additional thermal interfaces, an added expense, and additional manufacturing steps.

[0005] Given that in a radar assembly there can be thousands of cold plates, a new cold plate technology would be beneficial.

BRIEF SUMMARY OF THE INVENTION

[0006] It is therefore an object of this invention to provide an improved heat exchanger assembly.

[0007] It is a further object of this invention to provide such a heat exchanger assembly which does not suffer from galvanic corrosion.

[0008] It is a further object of the subject invention to provide such an assembly which exhibits improved reliability.

[0009] It is a further object of the subject invention to provide such an assembly which exhibits a lower thermal resistance.

[0010] It is a further object of the subject invention to provide such an assembly which can be manufactured easily and at a lower cost.

[0011] It is a further object of the subject invention to provide such a heat exchanger assembly which can be made lighter.

[0012] It is a further object of the subject invention to provide such an assembly which has a higher cooling capacity.

[0013] It is a further object of the subject invention to provide such an assembly which can be tailored to any desired shape and with an integral vapor chamber configured to meet the thermal and mechanical design requirements as well as cost goals and other needs of the design community.

[0014] It is a further object of the subject invention to provide such an improved heat exchanger assembly which acts as a synergistic structure, providing both improved structural and thermal dissipation properties.

[0015] It is a further object of the subject invention to provide such a heat exchanger which serves, in one particular example, as a cold plate for radar transmit and receiver module.

[0016] The invention results from the partial realization that, in one example, all the materials used in a heat exchanger (e.g., a cold plate) can be the same to prevent galvanic corrosion if metal foam is used as the wick and stir welding is used to hermetically seal the vapor chamber in which the metal foam resides.

[0017] The subject invention features an improved heat exchanger assembly comprising first and second plates made of a predetermined thermally conductive material such as aluminum configured when mated to form a hermetically sealed vapor chamber. In one application, a wick made of the same predetermined thermally conductive material resides in the vapor chamber forming a gas chamber. In one example, the wick is foamed aluminum.

[0018] The wick could also be braided. Typically, the wick lines the vapor chamber. In one preferred embodiment, a peripheral stir weld is used to hermetically seal the first and second plates. Also, brazing could be used to hermetically seal the first and second plates. There is usually a port into the vapor chamber and a plug made of the same predetermined material inertia welded forming a hermetic seal. The predetermined material used could also include copper, carbon, or other materials. Typically, the wick is attached to the walls of the vapor chamber. The wick can be brazed, bonded, or foamed in place to the walls of the vapor chamber. Advantageously, the wick can be compressed or formed (e.g., machined) into a desired shape. The wick can include fins and the fins may include nanotubes. In one particular example, first and second plates made of aluminum are configured when mated to form a hermetically seals vapor chamber, an aluminum foam wick lines the vapor chamber forming a gas chamber, and a peripheral stir weld hermetically seals the first and second plates.

[0019] The subject invention also features an improved heat exchanger assembly including a structure made of a predetermined thermally conductive material forming a hermetically sealed vapor chamber therein and a wick made of the same or a galvanically compatible thermally conductive material in the vapor chamber forming a gas chamber. In one particular example, the structure includes first and second plates configured (e.g., via cavities formed in each plate) when mated to form the hermetically sealed vapor chamber between the plates.

[0020] The subject invention also features a method of making an improved heat exchanger assembly. One preferred method includes forming cavities in first and second plates made of a predetermined thermally conductive material which when mated form a vapor chamber between the plates. A wick made of the predetermined thermally conductive material is inserted in the vapor chamber to form a gas chamber. Ultimately, the vapor chamber is hermetically sealed typically by stir welding.

[0021] Typically, the wick is foamed or braided aluminum, copper, carbon, or some other material. Hermetically sealing the vapor chamber by brazing the plates is also a viable

method. A port into the vapor chamber is sealed using inertia welding of a plug preferably made of the same predetermined material.

[0022] The subject invention also includes a three dimensional scaleable, flexible form factor integrated vapor chamber, joined by friction stir welding, yielding a synergistic structure that optimizes mechanical strength and thermal properties.

[0023] The subject invention also can be constructed of one, two, or more plates when mated form a chamber, or chambers. A wick made of a predetermined thermally conductive material is inserted in the vapor chamber, or chambers, to form a gas chamber(s). Ultimately, the vapor chamber is hermetically sealed typically by friction stir welding.

[0024] Additional manufacturing processes can be leveraged to create the vapor chamber in one or more plates. Such examples include gun drilling, casting, machining, EDM, etc. The wick may include fins and the fins may include nanotubes.

[0025] The subject invention, however, in other embodiments, need not achieve all these objectives and the claims hereof should not be limited to structures or methods capable of achieving these objectives.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0026] Other objects, features and advantages will occur to those skilled in the art from the following description of a preferred embodiment and the accompanying drawings, in which:

[0027] FIG. **1** is a schematic three-dimensional front view of a prior art cold plate used in connection with radar transmit and receive modules;

[0028] FIG. **2** is a highly schematic top view showing one portion of the cold plate shown in FIG. **1**;

[0029] FIG. **3** is a highly schematic front view of a prior art heat pipe used in connection with the cold plate shown in FIGS. **1-2**;

[0030] FIG. **4** is a schematic top view showing four heat pipes installed in a cold plate;

[0031] FIG. **5**A-**5**B are schematic three-dimensional top views showing an example of first and second plates used to form the structure of an improved heat exchanger assembly in accordance with the subject invention;

[0032] FIG. **6** is a schematic three-dimensional top view showing a particular configuration of cold plate with the wick material installed therein in accordance with one example of the subject invention;

[0033] FIG. **7** is a schematic three-dimensional top view showing a completed heat exchanger assembly in accordance with an example of the subject invention;

[0034] FIG. **8** is a schematic cross-sectional front view of the complete assembly shown in FIG. **7**;

[0035] FIG. **9** is a sectional view of a vapor chamber with a finned wick in accordance with the subject invention;

[0036] FIG. **10** is a more detailed view of the wick fins;

[0037] FIG. **11** is a view of the finned wick sectioned across the vapor chamber;

[0038] FIG. **12** is another more detailed view of the finned wick;

[0039] FIG. **13** is a view showing carbon nanotubes added to the fins of the wick;

[0040] FIG. **14** is a view showing the fins including the carbon nanotubes of FIG. **13**; and

[0041] FIG. **15** is a view of a sectioned vapor chamber including the fins of FIG. **14**.

DETAILED DESCRIPTION OF THE INVENTION

[0042] Aside from the preferred embodiment or embodiments disclosed below, this invention is capable of other embodiments and of being practiced or being carried out in various ways. Thus, it is to be understood that the invention is not limited in its application to the details of construction and the arrangements of components set forth in the following description or illustrated in the drawings. If only one embodiment is described herein, the claims hereof are not to be limited to that embodiment. Moreover, the claims hereof are not to be read restrictively unless there is clear and convincing evidence manifesting a certain exclusion, restriction, or disclaimer.

[0043] There is shown in FIG. **1** an example of a prior art cold plate **10** for radar transmit and receive modules **12***a*-**12***d*. Cold plate **10** typically includes two halves one of which is schematically shown in FIG. **2**. Cold plate half **10***a*, typically made of aluminum, is machined to form channels as shown at **14***a*-**14***b* then nickel under plated with gold over plated. The other cold plate half is machined and plated in a similar fashion to form mirror image channels. Copper heat pipes such as heat pipe **16**, FIG. **3** are then laid in the channels as shown in FIG. **4**. The other cold plate half is then mated onto cold plate half **10***a* using solder paste spread over the machined faces of the cold plate halves.

[0044] As explained in the background section above, one problem with copper used as the cold plate material is that it is heavy which is a concern in ship and airborne applications. When aluminum is used instead for the cold plate material, the copper heat pipes **16***a*-**16***d*, FIG. **4** therein resulted in a galvanic mismatch which can then lead to corrosion and reliability problems. The use of different materials in a heat exchanger can also increase the thermal resistance of the assembly. Moreover, the process of making a cold plate such as the one shown in FIG. **1** can be labor intensive and costly. Other problems associated with the prior art discussed more fully in the background section above.

[0045] FIGS. **5**A-**5**B show first and second plates **40***a* and **40***b* in accordance with an example of the subject invention made of a predetermined thermally conductive material (such as aluminum) configured, when mated to form a hermetically sealed vapor chamber. In this particular example, the vapor chamber is formed via machining cavity **42***a* in one face of plate **40***a* and machining cavity **42***b* in one face of plate **40***b*. FIG. **6** shows the addition of aluminum foam wick material **44***a* lining the vapor chamber and forming gas chamber **46**. One source of aluminum foam is available from ERG Materials and Aerospace Corp. (Oakland, Calif.) under the brand name "Duocel." Typically, the aluminum foam lines all the walls defining the vapor chamber. The wick material may be formed in place in the chamber.

[0046] FIG. **7** shows two such plates hermetically sealed via peripheral friction stir weld **50**. Stir welding is an autogenous process meaning no additional materials are required which could galvanically corrode. Stir welding also reliably seals plates **40***a* and **40***b* with low distortion while retaining the original mechanical properties of the cold plate material which solder and other joining methods cannot provide. Soldering, bonding, and other techniques can be used to join the plates. If composite materials are used, thermal bonding techniques may be used. Metal foam wick material **44**, FIG. **8** in vapor chamber **42** forming chamber **46** is beneficial because it is made of the same material as plates **40***a* and **40***b* and the cell and tendon size can be optimized for the best capillary

action for any particular application and chamber configuration. The foam aluminum wick can be sized, shaped, or layered to maximize fluid transfer via capillary action. The chamber size can be optimized and can be designed to maximize gas transfer to the condenser section of the heat exchanger. But, wick material **44** could also be braided aluminum and brazing could also be used to hermetically seal plates **40***a* and **40***b*. The wick material is typically the same as the material forming the chamber but, at the least, the two materials should be galvanically matched.

[0047] FIG. **7** also shows a port into vapor chamber **42**, FIG. **8** plugged via aluminum cylinder **52**, FIG. **7** inertial welded into the port. Again, if aluminum is used for plates **40***a* and **40***b*, aluminum is preferably used for both the wick material (aluminum foam) and the plug sealing the port. Other choices for all three components are copper and carbon based materials. Conductive composite materials may be used. Wick material **42**, FIG. **8** which lines the walls **60***a*-**60***e* of the vapor chamber and which defines gas chamber **46** can be placed in the vapor chamber, brazed to the walls of the vapor chamber, foamed in place on the walls of the vapor chamber, or bonded to the walls of the vapor chamber. Metal wick material **44** can be compressed or molded or cast into any desired shape, it can be layered, or machined. The wick may be configured to form fins. A sintered wick or a nanotube wick may be used. Also, although the heat exchanger assembly shown in FIGS. **7-8** includes plates **40***a* and **40***b*, any structure forming a hermetically sealed vapor chamber including a wick made of the same material or a galvanically matched material as the structure is within the scope of the subject invention. Gun drilling, casting, machining, EDM, and other processes may be used to form the chamber. And, plates **40***a* and **40***b* can be of any desired size, shape, configuration, and thickness.

[0048] Manufacturing a heat exchanger in accordance with the example given above includes machining or otherwise forming cavities **42***a* and **42***b*, FIGS. **5**A-**5**B in a face of plates **40***a* and **40***b*; installing the metallic wick material in each chamber as shown in FIG. **6**; hermetically sealing plates **40***a* and **40***b* as shown in FIG. **7** but leaving a port as discussed above; adding a coolant such as water, ammonia, alcohol, or the like to the wick material via the port; heating the assembly until all of the air exits gas chamber **46**, FIG. **8**; and plugging the orifice as shown at **52** in FIG. **7** (typically by inertia welding).

[0049] FIG. **11** shows an embodiment with plate **40***a*' with finned wick **42**' therein, also shown in FIGS. **10-12**.

[0050] In one example, the fin thickness was 0.010" and the fin spacing was 0.010". The result is a custom machined vapor chamber. Varying fin heights and sizes optimize liquid transport via fin wicking. FIGS. **13-15** show another embodiment where a custom machined vapor chamber includes oriented carbon nanotubes **80**, FIG. **13**, attached to the fins **82**, FIGS. **14-15** to improve the wicking action of the liquid cooling medium.

[0051] The result in any embodiment is an improved heat exchanger assembly. Because all of the materials used are the same or gavanically compatible, galvanic corrosion is not typically a problem resulting in improved reliability. Because all of the materials used are the same, there is also typically a lower thermal resistance. The heat exchanger assembly of the subject invention can be manufactured easily and at a lower cost. If aluminum is used as discussed above for plates **40***a* and **40***b*, for wick **42**, and for plug **52** (FIG. **7**), the heat exchanger assembly is considerably lighter than a prior art copper based cold plate. A heat exchanger in accordance with the subject invention typically has higher cooling capacity and is more efficient. The use of the metal foam material as a wick also has the benefit of increasing the wicking volume and the gas handling volume above and beyond a typical heat pipe capacity. Thermal conductivity is improved because the thermal path only includes one aluminum plate, the foam aluminum wick, and the vapor chamber verses the prior art design with heat pipes wherein the thermal path included a copper plate, an under plate, and over plate, solder, a void or flux, the copper heat pipe, and the sinter material within the copper heat pipe. The use of a three dimensional scaleable, flexible form factor integrated vapor chamber, joined by friction stir welding, achieves a synergistic structure that optimizes mechanical strength and thermal properties.

[0052] Although specific features of the invention are shown in some drawings and not in others, this is for convenience only as each feature may be combined with any or all of the other features in accordance with the invention. The words "including", "comprising", "having", and "with" as used herein are to be interpreted broadly and comprehensively and are not limited to any physical interconnection. Moreover, any embodiments disclosed in the subject application are not to be taken as the only possible embodiments. As noted, structures other than plates may be used to form the vapor chamber.

[0053] In addition, any amendment presented during the prosecution of the patent application for this patent is not a disclaimer of any claim element presented in the application as filed: those skilled in the art cannot reasonably be expected to draft a claim that would literally encompass all possible equivalents, many equivalents will be unforeseeable at the time of the amendment and are beyond a fair interpretation of what is to be surrendered (if anything), the rationale underlying the amendment may bear no more than a tangential relation to many equivalents, and/or there are many other reasons the applicant can not be expected to describe certain insubstantial substitutes for any claim element amended.

[0054] Other embodiments will occur to those skilled in the art and are within the following claims.

What is claimed is:

1. An improved heat exchanger assembly comprising:

first and second plates made of a predetermined thermally conductive material configured when mated to form a hermetically sealed vapor chamber; and

a wick made of the predetermined thermally conductive material in the vapor chamber forming a gas chamber.

2. The assembly of claim **1** in which the wick is foam.

3. The assembly of claim **1** in which the wick is braided.

4. The assembly of claim **1** in which the wick lines the vapor chamber.

5. The assembly of claim **1** in which a peripheral friction stir weld hermetically seals the first and second plates.

6. The assembly of claim **1** in which brazing hermetically seals the first and second plates.

7. The assembly of claim **1** further including a port into the vapor chamber.

8. The assembly of claim **7** further including a plug made of the predetermined material inertia welded in the port.

9. The assembly of claim **1** in which the predetermined material includes aluminum.

10. The assembly of claim **1** in which the predetermined material includes copper.

11. The assembly of claim **1** in which the predetermined material includes carbon composites.

12. The assembly of claim **1** in which the wick is attached to walls of the vapor chamber.

13. The assembly of claim **12** in which the wick is brazed to the walls of the vapor chamber.

14. The assembly of claim **12** in which the wick is bonded to the walls of the vapor chamber and in which the wick is foamed in placed to the walls of the vapor chamber.

15. The assembly of claim **1** in which the wick is compressed into a desired shape.

16. The assembly of claim **1** in which the wick is machined, molded, or cast into a desired shape.

17. The assembly of claim **16** in which the wick includes fins.

18. The assembly of claim **17** in which the fins include nanotubes.

19. An improved heat exchanger assembly comprising:

first and second plates made of aluminum configured when mated to form a hermetically sealed vapor chamber;

an aluminum foamed wick lining the vapor chamber forming a gas chamber; and

a peripheral stir weld hermetically sealing the first and second plates.

20. The heat exchanger assembly of claim **19** further including a port into the vapor chamber.

21. The heat exchanger assembly of claim **20** further including a plug inertia welded in the port.

22. An improved heat exchanger assembly comprising:

a structure made of a first predetermined thermally conductive material forming a hermetically sealed vapor chamber therein; and

a wick made of a predetermined thermally conductive material the same as the first thermally conductive material or a material galvanically matched with the first thermally conductive material in the vapor chamber forming a gas chamber.

23. The heat exchanger assembly of claim **22** in which the structure includes first and second plates configured when mated to form the hermetically sealed vapor chamber between the plates.

24. A method of making an improved heat exchanger assembly, the method comprising:

forming cavities in first and second plates made of a predetermined thermally conductive material when mated forming a vapor chamber between the plates;

inserting a wick made of the predetermined thermally conductive material in the vapor chamber to form a gas chamber; and

hermetically sealing the vapor chamber.

25. The method of claim **24** in which the wick is foam.

26. The method of claim **24** in which the wick is braided.

27. The method of claim **24** in which the wick lines the vapor chamber.

28. The method of claim **24** in which hermetically sealing the vapor chamber includes stir welding the plates.

29. The method of claim **24** in which hermetically sealing the vapor chamber includes brazing the plates.

30. The method of claim **24** further including forming a port into the vapor chamber.

31. The method of claim **29** further including sealing the port with a plug made of the predetermined material.

32. The method of claim **31** in which sealing includes inertia welding.

33. The method of claim **24** in which the predetermined material includes aluminum.

34. The method of claim **24** in which the predetermined material includes copper.

35. The method of claim **24** in which the predetermined material includes carbon composites.

36. The method of claim **24** in which the wick is attached to walls of the vapor chamber.

37. The method claim **36** in which the wick is brazed to the walls of the vapor chamber.

38. The method of claim **36** in which the wick is molded or cast, and bonded to the walls of the vapor chamber.

39. The method of claim **24** further including the step of compressing the wick into a desired shape.

40. The method of claim **26** further including the step of forming the wick into a desired shape.

41. The method of claim **40** in which the wick is formed to include fins.

42. The method of claim **41** further including adding nanotubes to the fins.

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