US 20100155033A1

(19) United States

(12) Patent Application Publication

Holley et al.

(10) Pub. No.: US 2010/0155033 A1

(43) Pub. Date: Jun. 24, 2010

(54) THERMAL MANAGEMENT SYSTEM USING MICRO HEAT PIPE FOR THERMAL MANAGEMENT OF ELECTRONIC COMPONENTS

(75) Inventors: **Woodrow W. Holley**, Malden, MA (US); **Jerome P. Fanucci**, Lexington, MA (US)

Correspondence Address:
WEINGARTEN, SCHURGIN, GAGNEBIN & LEBOVICI LLP
TEN POST OFFICE SQUARE
BOSTON, MA 02109 (US)

(73) Assignee: **KAZAK COMPOSITES, INC.**, Woburn, MA (US)

(21) Appl. No.: **12/607,619**

(22) Filed: **Oct. 28, 2009**

Related U.S. Application Data

(60) Provisional application No. 61/109,004, filed on Oct. 28, 2008.

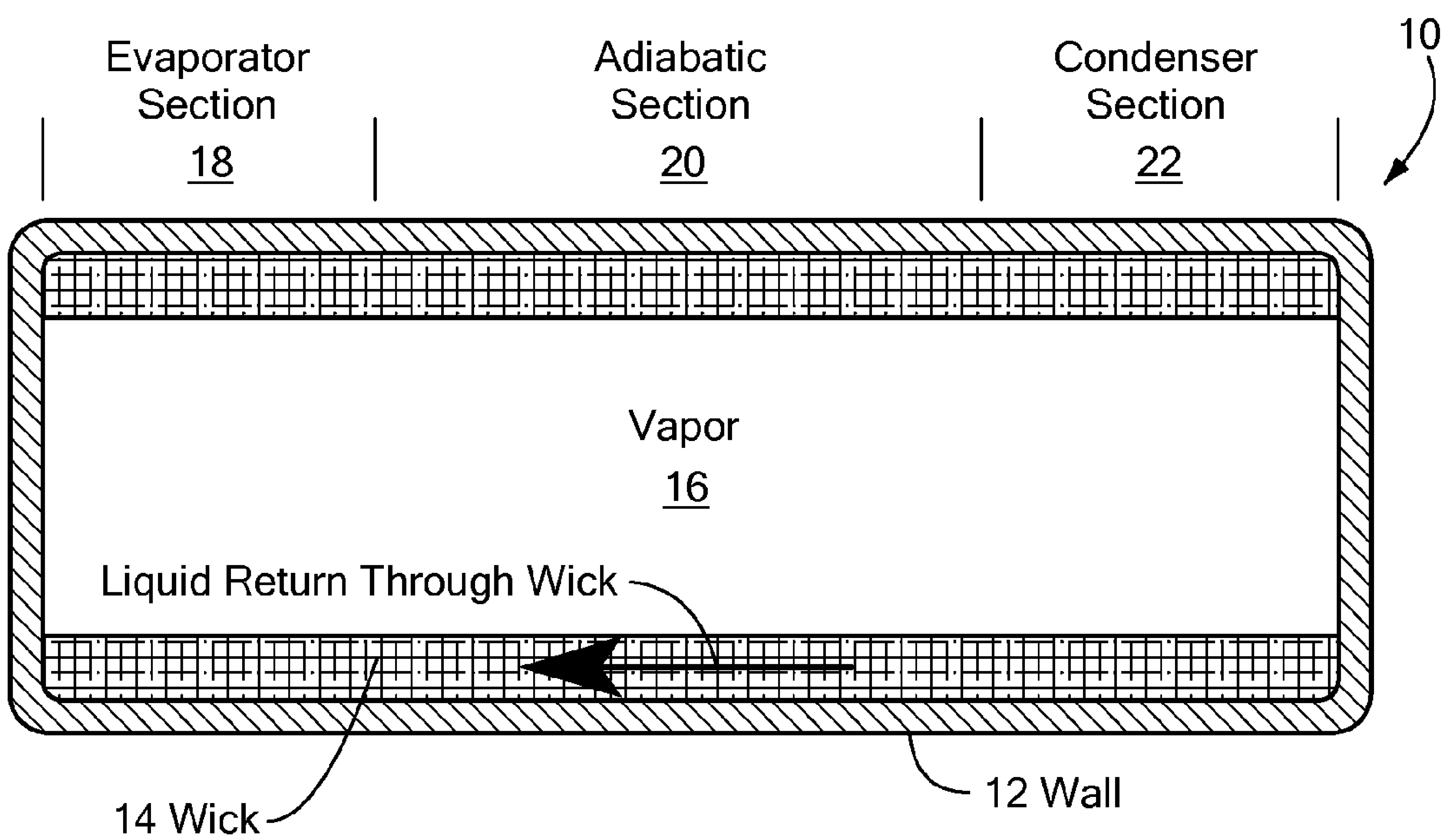
Publication Classification

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

(52) **U.S. Cl.** **165/104.26**; 29/890.03

(57) **ABSTRACT**

A thermal management system includes a base element and a heat producing element disposed for heat transfer from the heat producing element to the base element. An adherent zone includes an adherent element in physical attachment between the heat producing element and the base element. A heat transfer zone, separate from the adherent zone, includes a heat pipe between the heat producing element and the base element. The heat pipe includes a circulatory flow path between an evaporator section and a condenser section, and a working fluid on the circulatory flow path.



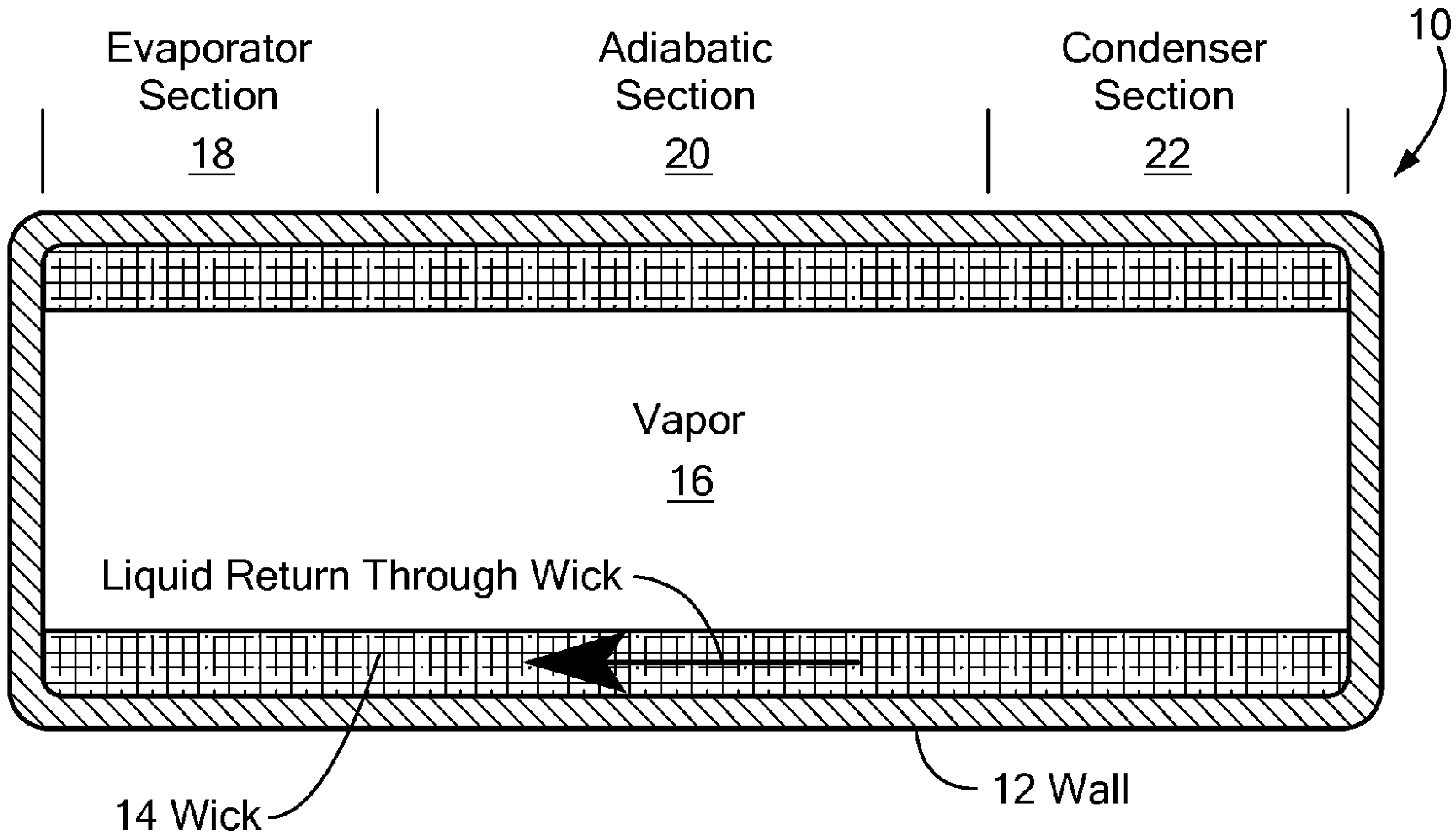

Evaporator Section 18
Adiabatic Section 20
Condenser Section 22
10
Vapor 16
Liquid Return Through Wick
14 Wick
12 Wall

FIG. 1A

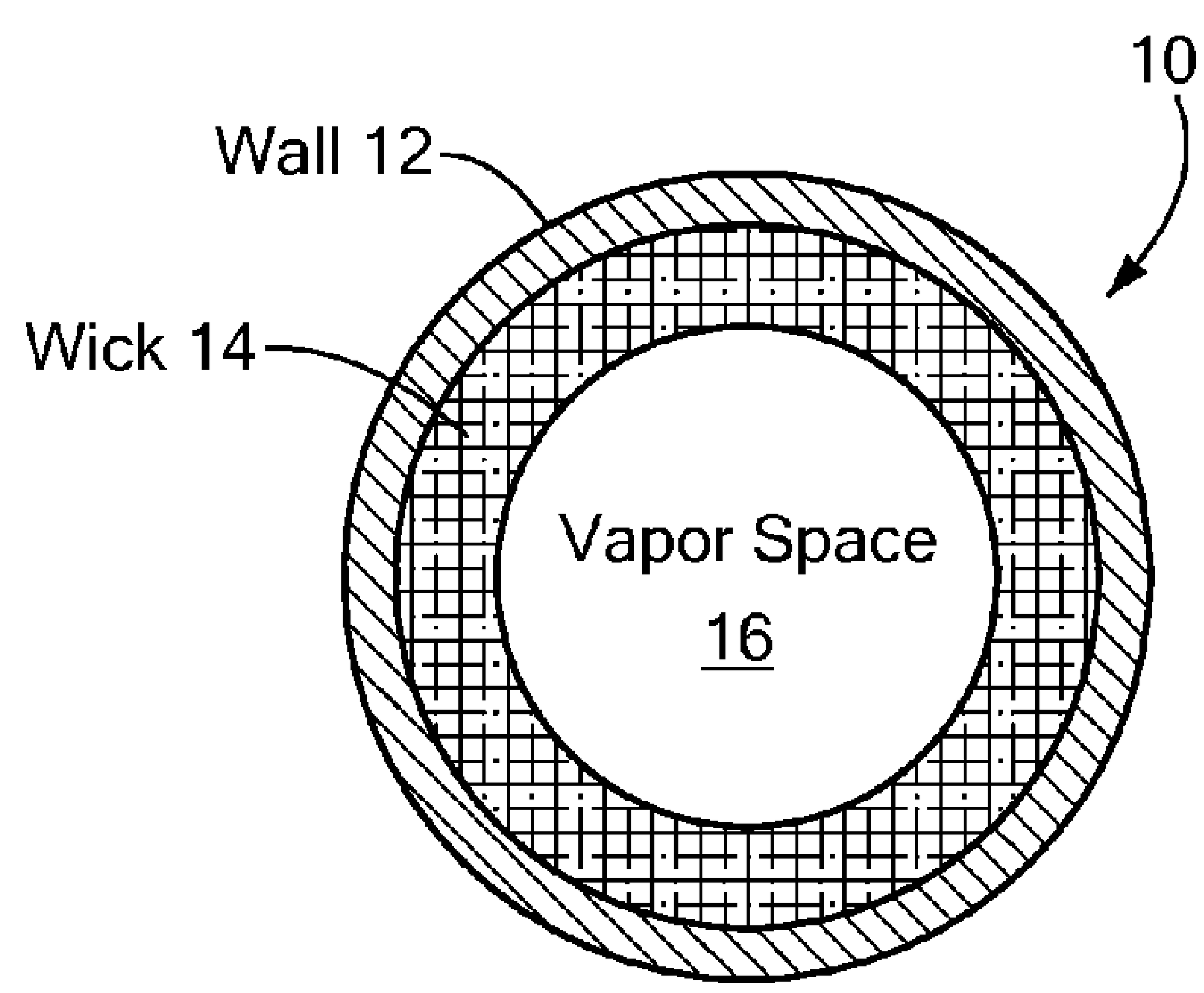

10
Wall 12
Wick 14
Vapor Space 16

FIG. 1B

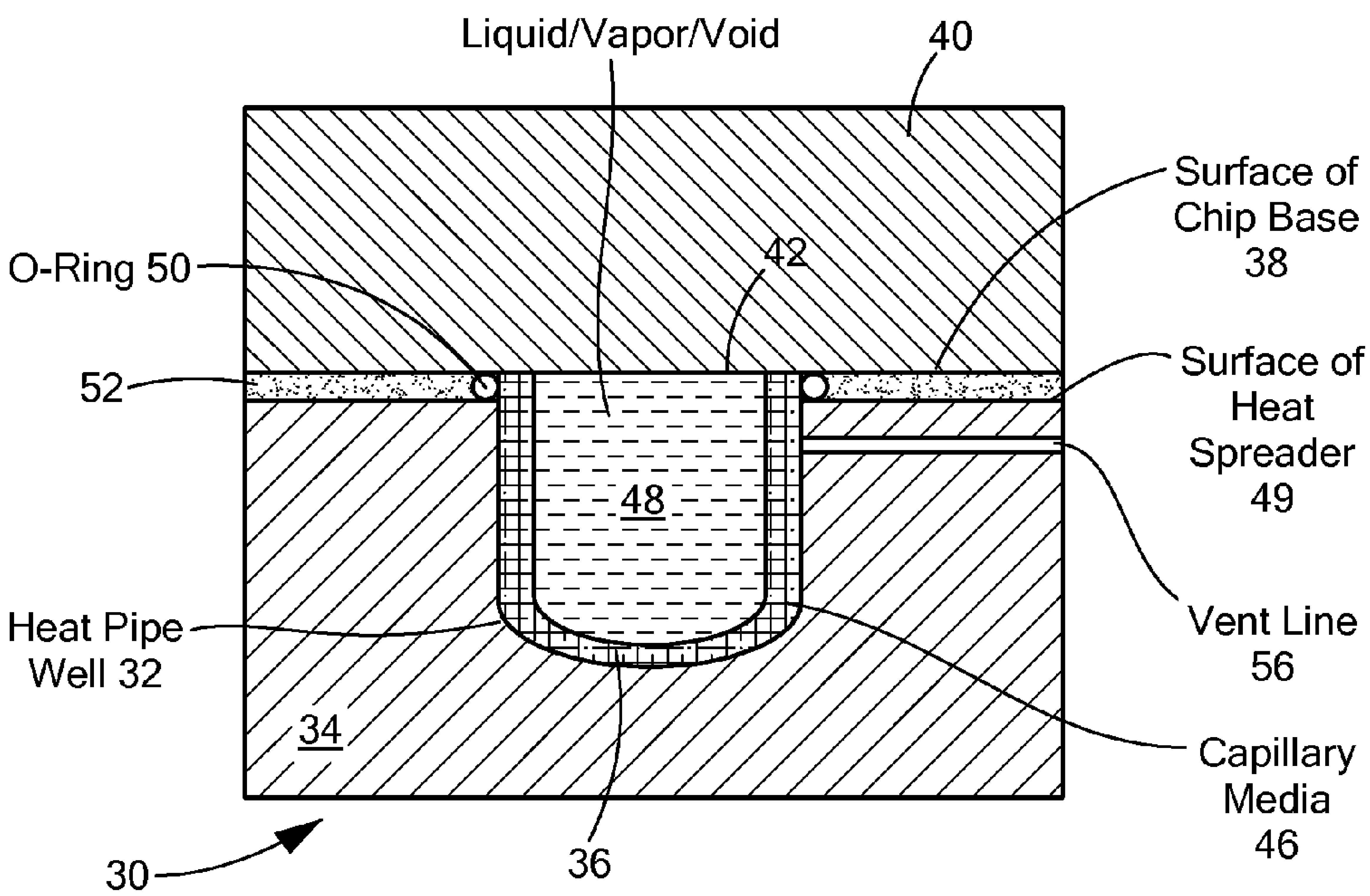

Liquid/Vapor/Void
40
Surface of Chip Base 38
O-Ring 50
42
52
Surface of Heat Spreader 49
48
Vent Line 56
Heat Pipe Well 32
34
Capillary Media 46
30
36

FIG. 2

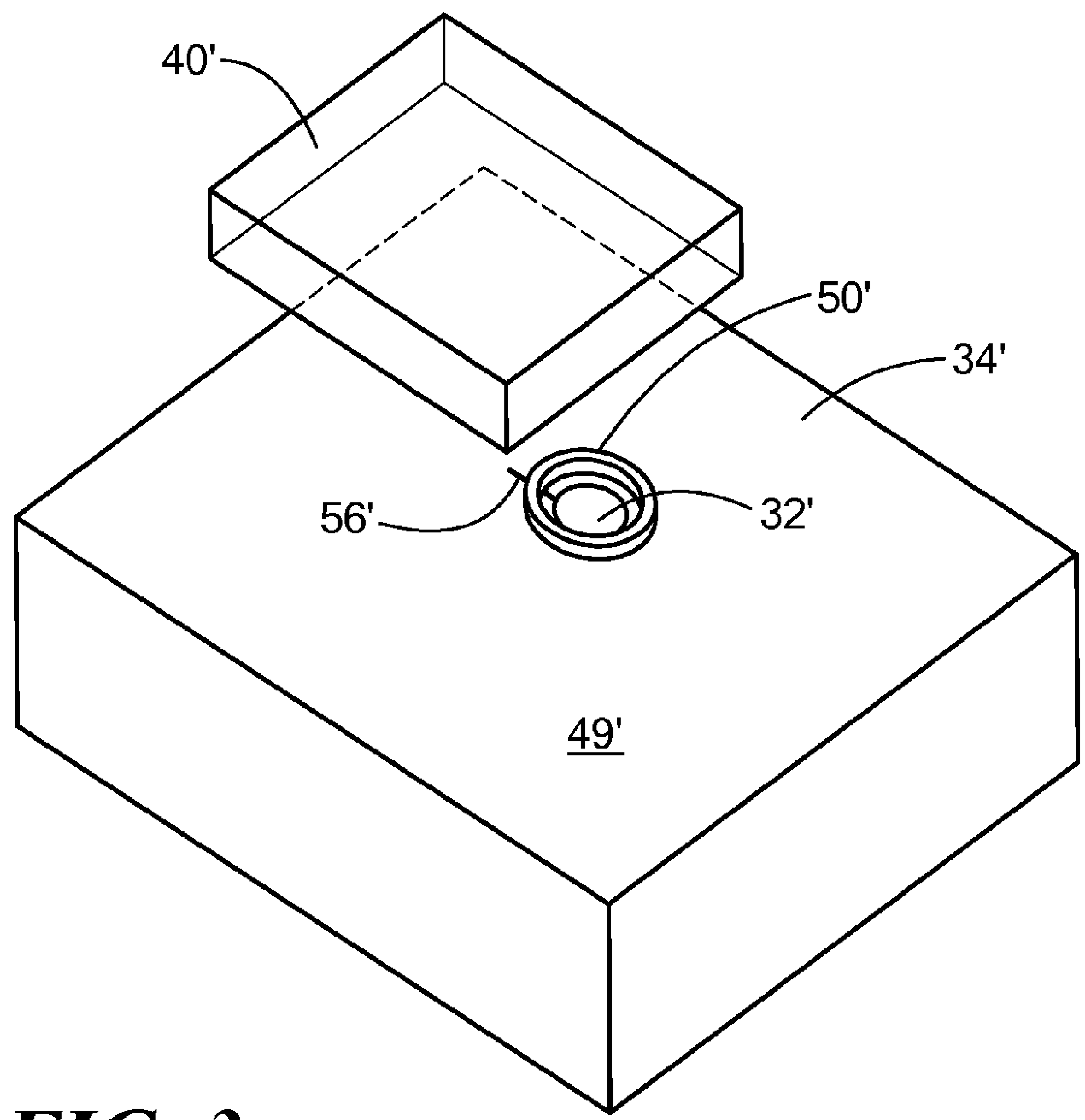

40'
50'
34'
56'
32'
49'

FIG. 3

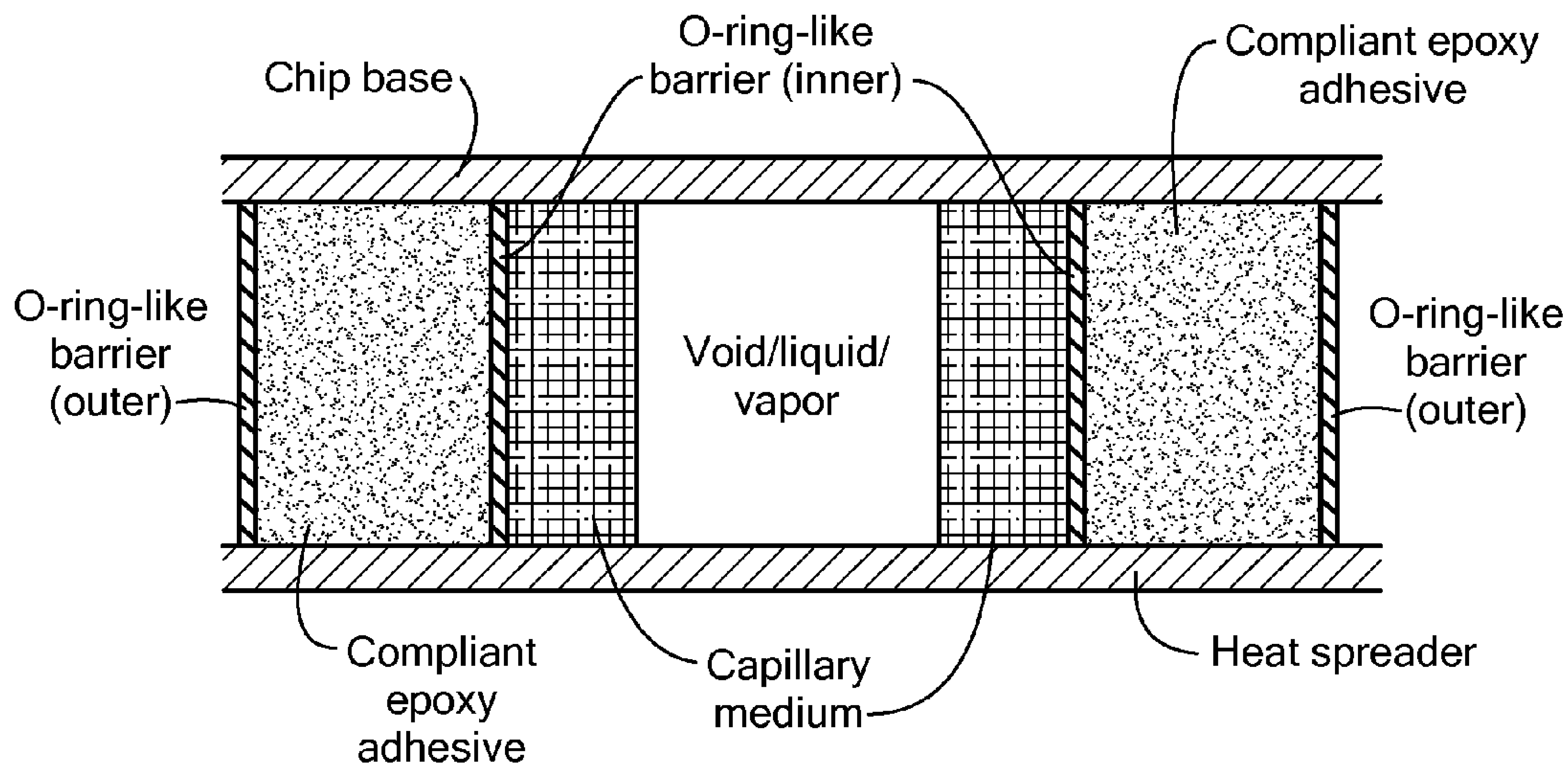

Chip base
O-ring-like barrier (inner)
Compliant epoxy adhesive
O-ring-like barrier (outer)
Void/liquid/ vapor
O-ring-like barrier (outer)
Compliant epoxy adhesive
Capillary medium
Heat spreader

FIG. 4

THERMAL MANAGEMENT SYSTEM USING MICRO HEAT PIPE FOR THERMAL MANAGEMENT OF ELECTRONIC COMPONENTS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] Benefit is claimed under 35 U.S.C. §119(e) of U.S. Provisional Application No. 61/109,004, filed Oct. 28, 2008, the disclosure of which is incorporated by reference herein.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] This invention was made under Air Force Contract FA8650-09-M-5013. The Government may have certain rights to this invention.

BACKGROUND OF THE INVENTION

[0003] As electronic components become more miniaturized and the number of interconnects per chip increases, heat removal becomes a limiting barrier to enhanced performance. A principal pathway for heat removal is via conductance from the chip base to a heat spreader and from the heat spreader to the printed wire board or possibly to a heat sink device. Adherent substances, commonly epoxy resins, filled with thermally conductive particulates such as carbon or aluminum are used as an attachment layer between the electronic components.

[0004] An evaporative cooling system has been used for some high-end applications, in which an appropriate liquid is sprayed directly onto the chip surface. The liquid vaporizes (heat transport) and is then condensed and re-circulated. A mini pump circulates the recovered liquid through a heat exchanger (heat removal) and creates the spray force.

[0005] Heat pipes have been used for a variety of applications including electronic systems. Metallic heat pipes of a tapered design have been employed for direct cooling of processor chips. The condenser end is typically attached to a finned heat sink for heat removal and the evaporator end is attached to the chips or dies by conventional adherents. These types of heat pipes have been designed with diameters of about 1 mm and lengths of 10 mm. Application of heat pipes with respect to electronic applications has been traditionally directed toward removal of the heat buildup in the cabinet generally rather than specific components.

SUMMARY OF THE INVENTION

[0006] The present invention provides a thermal management system in which physical bonding and compliancy issues are separated from the issue of efficient thermal conductivity. The present system provides a heat transfer zone(s) directed principally to thermal conductivity and an adherent zone(s) directed to physical attachment with only secondary concern for heat conductivity.

[0007] In one embodiment, a thermal management system includes a base element and a heat producing element disposed for heat transfer from the heat producing element to the base element. An adherent zone includes an adherent element in physical attachment between the heat producing element and the base element. A heat transfer zone, separate from the adherent zone, is formed of a heat pipe in thermal communication between the heat producing element and the base element. The heat pipe is formed as a well in the base element and includes a capillary medium adjacent at least a portion of an internal wall of the well. The heat pipe includes a circulatory flow path having an evaporator section in thermal communication with the heat producing element and a condenser section in thermal communication with the base element. A working fluid flows on the circulatory flow path. The heat producing element forms at least a portion of the evaporator section. The base element forms at least a portion of the condenser section. The adherent element includes an annular seal element surrounding the heat pipe between confronting surfaces of the heat producing element and the base element.

[0008] A method for manufacturing a thermal management system is also provided. In one embodiment, the method includes providing a heat producing element and a base element, and forming a well in the base element. A vent passage is formed in a surface of the base element extending outwardly from an edge of the well. A capillary medium is disposed within the well and surrounding a central space within the well. An adherent element is placed surrounding the well on the surface of the base element and crossing the vent passage. The heat producing element and the base element are assembled with the adherent element between confronting surfaces thereof to form an assembly with a working fluid disposed in the well. A portion of the working fluid is boiled off. The adherent element flows into the vent passage and around the edge of the well to seal off the well and attach the base element and the heat producing element.

DESCRIPTION OF THE DRAWINGS

[0009] The invention will be more fully understood from the following detailed description taken in conjunction with the accompanying drawings in which:

[0010] FIGS. **1**A and **1**B conceptually illustrate a heat pipe;

[0011] FIG. **2** is a schematic cross-sectional side view of an embodiment of a heat pipe assembly of a thermal management system;

[0012] FIG. **3** is a schematic isometric view of a further embodiment of a heat pipe assembly of a thermal management system; and

[0013] FIG. **4** is a schematic cross-sectional side view of a still further embodiment of a heat pipe assembly of a thermal management system.

DETAILED DESCRIPTION OF THE INVENTION

[0014] The disclosure of U.S. Provisional Application No. 61/109,004, filed Oct. 28, 2008, is incorporated by reference herein.

[0015] A bottleneck in transferring heat between components of electronics systems lies at the thermal interfaces between components. Depending on the specific components involved, this thermal interface may be between the die itself and a heat slug or spreader, or a heat slug and heat spreader, or a heat spreader and heat sink. In these cases, an imperfect but comparatively flat surface is presented to be brought into intimate contact with another corresponding flat surface. Except for the die itself, the surfaces are typically metallic, with copper, copper/molybdenum and aluminum being common.

[0016] None of these components has a completely smooth surface, and air pockets exist between the two materials. Air has a very high thermal resistance and hence is a poor heat conductor. To improve the thermal pathway at this interface, thermal compounds are used to fill in the gaps between the two surfaces. These compounds are typically organic polymers filled with thermally conductive particulates such as carbon or aluminum, and are commonly provided as thermal tape, thermal pads, thermal grease, or thermal epoxy. None of these compounds, however, completely removes the air pockets. Also, the inherent thermal conductivity of most organic polymers is low. As such, these compounds are an improvement thermally over having no gap filler, but they are still a bottleneck in the thermal pathway. These forms of attachment do perform an adequate job of providing adhesion and compliancy between the surfaces and are generally an acceptably convenient method of attachment and detachment.

[0017] The present thermal management system, however, provides a different and more viable approach to forming the thermal pathway by separating the mechanical issue of physical bonding and compliancy from the thermal issue of efficient thermal conductivity. In general, the thermal management system provides an attachment area that includes one or more zones dedicated principally to thermal conductivity and one or more other zones dedicated principally to mechanical bonding in which heat conductivity is of secondary concern. The thermal management system is appropriate for a variety of applications, and is particularly suitable for improving the thermal pathways for electronic components. The system can be readily applied to several of the common components found in typical electronic circuit designs.

[0018] The thermal connection of the system uses a micro sized heat pipe in an evaporative cooling cycle, conceptually illustrated in FIGS. **1**A and **1**B. The heat pipe **10** is formed with a closed housing **12**, such as a cylindrical or tapered tube wall with closed ends. A capillary section **14**, formed from any suitable capillary or wicking material, is applied to the inner wall and surrounds a central vapor or void space **16**. The heat pipe is defined along its axial length into an evaporator section **18**, an adiabatic section **20**, and a condenser section **22**. An appropriate working fluid in the vapor space vaporizes in the evaporator section and flows through the adiabatic section to the condenser section where it is condensed. The fluid returns through the capillary section under capillary pressure for recirculation to the evaporator section. The heat pipe is shown with a cylindrical configuration in FIG. **1**; a tapered configuration can also be used, for example, by providing a tapered housing wall and/or tapering the capillary medium.

[0019] The present thermal management system uses this heat pipe concept while separating the attachment into two zones, one dedicated to thermal attachment and the other to physical attachment. The system uses an in situ fabricated heat pipe that is held in place by various physical attachments, such as polymeric adhesives and/or mechanical devices or mechanisms, such as clips, clamps and screws. These physical attachments also serve as the physical attachment between the components. The thermal pathway between components is improved by utilizing the surfaces of the existing components as an integral part of the heat pipe design. This eliminates the requirement to physically "attach" the thermal pathway, although physical attachment of the heat pipe walls and of the components still exists. The efficiency of the vaporization/condensation mechanism with its latent heat of vaporization inherently overcomes the problems associated with conventional attachment from a thermal transport perspective.

[0020] In one embodiment, referring more particularly to FIG. **2**, a micro heat pipe **30** is formed from a container or well **32** provided in a base element **34**, such as a heat spreader. The base element forms the wall and also serves as the condenser end **36** of the heat pipe at the bottom of the well. The surface **38** of a chip base **40** (a die or attached slug), the heat source, serves as the evaporator end **42** of the heat pipe. Enclosed in the well and attached to the wall is an appropriate capillary media **46**. A working fluid **48** is sealed within the heat pipe well. The surface **38** of the chip base and the surface **48** the heat spreader are interfaced by an adherent element **50**. In the embodiment of FIG. **2**, the adherent element includes an annular or O-ring seal element surrounding the well opening, which seals the heat pipe. Additional adhesive material **52** to hold the components (the chip base and the heat spreader) together may be applied outside the O-ring seal element. Alternatively or in addition, a mechanical device or mechanism (not shown) may be used to clamp or hold the parts together and compress the O-ring in order to form a pressure tight seal.

[0021] The heat pipe well communicates via a vent passage **56** drilled into the spreader from one of its edges to the outside environment. During manufacture, the vent passage is used to evacuate ambient non-condensable gases from the interior of the heat pipe and is subsequently sealed, discussed further below. The vent pipe can also serve to introduce the working fluid into the heat pipe. Application of vacuum to the heat pipe well via a vent passage can also apply a force to hold the surfaces in place during manufacture.

[0022] In another embodiment, illustrated in FIG. **3**, the vent passage **56'** is formed as a channel in the surface **48'** of the base element **34'**, such as the heat spreader. The adherent element **50'** is an annular or O-ring seal element surrounding the well **32'** on the surface of the heat spreader. During manufacture, the O-ring reflows into the vent passage and serves both to seal the well and adhere the heat spreader to the heat source.

[0023] The container wall isolates the working fluid and capillary medium from the environment. The wall should be leak proof, non-porous (to prevent gas diffusion), and capable of maintaining the pressure differential. The wall material should be compatible (corrosion resistant) with the working fluid and the external environment. A good wettability with respect to the working fluid and low coefficient of thermal expansion are also desirable. High thermal conductivity also improves the operational efficiency. Suitable materials for the container wall include metals such as aluminum and copper. Oxygen-free high conductivity (OFHC) copper provides good heat dissipative properties for heat pipes.

[0024] The working fluid is chosen with consideration for thermodynamic concerns relating to heat flow occurring within the heat pipe. The latent heat that is absorbed by the liquid that results in vaporization and then released upon condensation is the primary heat transfer medium of a heat pipe. General considerations include high latent heat of vaporization, high thermal conductivity, good compatibility with the wick and wall materials, good thermal stability, high surface tension, and a vapor pressure over the operating range that is high enough to avoid high vapor velocities yet not so high as to require a high pressure wall to contain it.

[0025] The choice of the working fluid and the selection of the container material should be considered together. The heat pipe can be constructed largely from the existing materials used in the construction of the heat slug, spreader, or sink. The choice of a working fluid is driven in part by compatibility with the metals typically used in these applications, such as aluminum, copper and copper/molybdenum. Corrosion resistance, avoidance of in situ reactions creating contamination or outgases, and wettability characteristics are criteria among the working fluid selections in addition to other operational considerations.

[0026] Several working fluids are known to operate effectively over the temperature range of the high power electronics and are thus suitable for heat pipe applications. The selection of fluid depends on the specific metal surfaces that must be interfaced, the specific operating temperature range, and optimization with respect to wettability, viscosity, and surface tension. Compatibility with the other materials is a concern especially with respect to chemical reactions that may produce corrosion or out-gassing. Suitable working fluids for the present system include water, ammonia, and certain hydro-fluorocarbon solvents.

[0027] The capillary medium, a porous structure with interconnecting pores, generates a capillary pressure capable of transporting the condensed working fluid from the condenser section to the evaporator section of the heat pipe. The capillary medium also usually assists in distributing the fluid around the evaporator section to improve its contact with the hot areas.

For operation of a heat pipe, the following criteria apply:

$$\Delta P_{Capillary,\,Max} \geqq \Delta P_{Liquid} + \Delta P_{Vapor} + \Delta P_{Gravity} \quad \text{(Equation 1)}$$

where:

[0028] ΔP=the capillary pumping pressure

[0029] ΔP_{Liquid}=the pressure drop necessary to return liquid from the condenser

[0030] ΔP_{Vapor}=the pressure drop necessary to move vapor from evaporator to condenser

[0031] $\Delta P_{Gravity}$=the pressure due to the gravitational head.

[0032] Most of the physical characteristics described as desirable for the wall material also apply to the capillary material. Thus, it also should be non-corrosive with respect to the working fluid, have high thermal conductivity, and good wettability to the working fluid. The maximum capillary head that can be generated by a wick increases with decreasing pore size. This can be seen from the generalized equations (see Equations 2, 3 & 4) relating the pressure drop at the capillary head, and evaporator head to the capillary driving pressure. The effective radius of the wick pores appears in the denominator of the equations. Thus, the value of ΔP increases as r decreases.

$$\Delta P_{Capillary} = \Delta P_{Evaporator} - \Delta P_{Condenser} \quad \text{(Equation 2)}$$

$$\Delta P_{Evaporator} = 2\sigma_1(\cos\theta_E)/r_E \quad \text{(Equation 3)}$$

$$\Delta_{Condenser} = 2\sigma_1(\cos\theta_c)/r_C \quad \text{(Equation 4)}$$

where:

[0033] $\Delta P_{Capillary}$=capillary driving pressure

[0034] $\Delta P_{Evaporator}$=capillary head at the evaporator

[0035] $\Delta P_{Condenser}$=capillary head at the condenser

[0036] σ_1=surface energy per unit surface area

[0037] θ_E and θ_C=surface angles of the liquid surface with the evaporator and condenser wick surfaces

[0038] r_E and r_C=effective radii of the evaporator and condenser wick pores

[0039] A variety of capillary media can be used. In one embodiment, a carbon nanotube material is a suitable capillary medium. Carbon nanotube materials exhibit high thermal conductivity and good corrosion resistance. In this material, carbon nanotubes are dispersed in a binder material, such as a thermosetting or thermoplastic resin. The binder material supports the carbon nanotubes and adheres to the container wall. In one embodiment, a phenolic resin is used as the binder material for carbon nanotubes. Other capillary media can also be used, such as other carbon nanofibers, meshes made of metals (such as stainless steel or aluminum), gauzes, felts, sintered materials (such as glass or ceramics), and foams. In another embodiment, open grooves or channels can be formed in the wall. The open channels can be further covered with a capillary material, such as, for example, composite wicks or arterial wicks. Self-supporting materials can also be used.

[0040] Lower density (equivalent to larger pore size) improves permeability. A good working balance of permeability and capillary pressure should be achieved. Also as can be seen from Equations 2, 3, and 4, varying the pore size (fiber density) from evaporator to condenser from smaller to larger sizes can be used to increase capillary pressure versus a homogeneous pore size.

[0041] The adherent element can be chosen from conventional adhesive materials commonly employed for attachment, although more latitude can be used as the choice is no longer constrained by the need for the best thermal conductivity. The adherent element (for example, the O-ring) should have many of the features associated with the container wall material. This material is a fraction of the wall length of the well when installed, yet should be able to meet most of the requirements expected of a suitable wall material in heat pipe applications. The material should exhibit chemical inertness with respect to the working fluid so that contaminants or out-gases are not produced that would diminish the operation of the heat pipe. The material should be capable of withstanding the high temperature environment without deterioration and maintain an effective seal against the internal vapor pressure of the working fluid. The material should be pliable to form the initial seal and compliant in operation in order to accommodate thermal expansion differentials between the two interfaces.

[0042] The present system can take advantage of a wider range of adherent material choices, because the material is no longer used as the primary thermal route. This allows opportunities to optimize its performance with respect to maintaining intimate physical contact while working against the working fluid's pressure so as to maintain the seal and to provide additional support to the seal in the lateral direction to resist deformation or movement.

[0043] A variety of high temperature sealing materials is available. Epoxy resins and other suitable adherents that are commercially available are generally acceptable. A stiff B-staged epoxy has been found to be suitable. Epoxy performs of Epoxy DC-202LT commercially available from Multi-Seals Inc. of Connecticut has been found to be suitable, although a wider range of epoxy systems can be used. The epoxy can be placed between the heat source and base element during manufacture. The entire assembly can be placed within a vacuum chamber, which is evacuated of air and non-condensable gases. The epoxy can then reflow and cure. In this way, the heat pipe and working fluid can be sealed off from the local environment. A polytetrafluoroethylene (PTFE) material may also be a suitable material in this application. Use of a PTFE, such as TEFLON®, has been limited in prior art thermal applications partially due to its very low thermal conductivity. The percentage of PTFE or other polymeric material to be used in this system is a small fraction of the wall material, thereby having a minor or negligible negative influence on the performance. A small groove or channel (not shown) can be used to help seat the adherent material to the surface of the base element. Adherent materials can also be applied as preformed sheets or as liquids that are cured in place.

[0044] The adherent element may include a supplemental attachment such as a mechanical device or mechanism to clamp or otherwise hold the components together. Mechanical devices or mechanisms can include, for example, a spring clip device, clamp, or screws. Supplement adhesive can also serve to maintain the intimate contact between the parts and an O-ring as well as provide lateral support to the O-ring.

[0045] One method for manufacturing a thermal management system, such as that shown in FIG. **3**, is as follows. A heat sink or heat spreader unit is provided as the base element from a suitable material, such as aluminum or copper. A well is drilled in the heat sink or spreader unit to a suitable depth, determined by the application, for example 0.1 to 1.0 inch for many electronic components. The width of the well is selected to match the dimensions of the heat producing device to be cooled. For example, a width of 0.25 inch matches many typical integrated circuit dimensions. A micro-channel for the vent is then machined on the surface extending out perpendicularly from the edge of the well.

[0046] The capillary medium is then introduced into the well. The capillary medium can be applied in any suitable manner, such as by spraying, brushing, or in any other manner. The capillary medium includes a binder material as needed to adhere to the wall surface of the well. The capillary medium should adhere to as much of the wall surface as possible.

[0047] A volume of working fluid is then introduced into the well, allowing for some fluid to be boiled off under vacuum. A liquid boils when its vapor pressure reaches its surrounding atmospheric pressure, as is known in the art. The level of vacuum is selected so that the boiling temperature of the working fluid is greater than the cure temperature of the epoxy, so that the fluid does not boil off before the epoxy reflows and cures.

[0048] A circular or ring-shaped epoxy preform is placed on the heat spreader surrounding the well and crossing the micro-channel. The preform is sufficiently stiff to be set in place without hanging down or impinging into the micro-channel. The preform dimensions (for example, inner and outer diameters and thickness) are also sufficient to match the diameter of the well while still allowing the epoxy to reflow without sealing off or encroaching into the well during subsequent manufacturing steps.

[0049] The heat producing device is then placed on the heat spreader, covering the well and the epoxy preform and compressed with a weight if necessary. The assembly is placed in an oven and heated to allow the epoxy to reflow and cure. The weight helps compress the epoxy after the heat is applied. This process provides a consistent bond line between the heat source device and the heat spreader or heat sink and forces the epoxy down into the micro-channel sealing the well off from the surrounding environment. This manufacturing process avoids the heating, venting, and sealing steps common to prior art heat pipe manufacturing processes.

[0050] Other methods of introducing the working fluid and purging the non-condensable gases are possible, for example, for use with the embodiment of FIG. **2**. One approach is to evacuate the well, with all components held in place, and then introduce the working fluid by vacuum suction and pressure assistance if necessary. A detachable valve system on an external tube attached to the vent passage can be provided to accommodate this method. The external tube can then be cold pinch welded closed and the valve system removed. Another approach involves introducing the working fluid such as by syringe or other dispensing device and then heating the well area to produce the working fluid vapor. As a consequence the non-condensable gases will also be purged along with the escaping working fluid vapor. When sufficient purging has occurred and with sufficient working fluid still trapped in the well, the section of external tubing can be cold pinch welded. Alternatively, the vent hole may be plugged in any suitable manner to close the system.

[0051] In another embodiment of a thermal management system (FIG. **4**), two concentric containment barriers interface between two surfaces, one surface being a chip base, the other surface being a heat spreader. The inner barrier retains a capillary medium and appropriate evaporative fluid encased within. An adherent material is contained between the inner barrier and the outer barrier.

[0052] In operation, the working fluid gathers heat from the hot surface (the chip base), vaporizes and travels away from the hot surface toward the cold surface (the heat spreader) in the void space. The fluid condenses at or near the cold surface and releases its heat. Thus, the process effectively moves the heat from the hot to the cold surface. The condensed fluid through the force of capillary action is wicked via the capillary media back to the hot surface and thus restarts the heating phase of the cycle. Thus, for a small sacrifice of adherent area, a highly thermal conductive heat pipe area is created.

[0053] The present thermal management system provides a continuous thermal pathway while adhering the two devices together, being compliant to the differences in thermal expansion between the two surfaces, and in many applications being capable of easy removal and reinstallation for replacement of failed chips.

[0054] The system also address challenges to constructing a micro sized heat pipe in situ with the materials, structures and environments presented with most processor components. For example, the heat pipe must produce sufficient capillary pressure to be an effective operating system. The physical attachment of the components must be sufficient to accommodate the pressure in the heat pipe during operation.

[0055] The present system utilizes a technology that can be more efficient than current practices. As a general rule heat pipe capacity increases with diameter and thus design solutions to benefit a variety of situations are possible. The concept can also be extended to situations where the components to be thermally attached are not in close physical proximity to one another.

[0056] The system also permits products to be swapped out under field conditions with only routine expertise and tools for replacement of defective processors. The materials involved in the small quantities needed are not comparatively costly. The fabrication steps are few and involve techniques and processes that can be understood by those of skill in the art. Therefore, a competitively low cost and high value product can result.

[0057] The invention is not to be limited by what has been particularly shown and described, except as indicated by the appended claims.

What is claimed is:

1. A thermal management system comprising:

a base element and a heat producing element disposed for heat transfer from the heat producing element to the base element;

an adherent zone comprising an adherent element in physical attachment between the heat producing element and the base element; and

a heat transfer zone, separate from the adherent zone, comprising a heat pipe in thermal communication between the heat producing element and the base element, the heat pipe comprising a circulatory flow path comprising an evaporator section in thermal communication with the heat producing element and a condenser section in thermal communication with the base element, and a working fluid on the circulatory flow path.

2. The system of claim 1, wherein the circulatory flow path of the heat pipe comprises a central space and a capillary medium surrounding the central space.

3. The system of claim 2, wherein the capillary medium is comprised of carbon nanotubes, carbon nanofibers, metal mesh, gauze, felt, a sintered material, or a foam.

4. The system of claim 1, wherein the adherent element comprises an annular seal element surrounding the heat pipe between confronting surfaces of the heat producing element and the base element.

5. The system of claim 4, wherein the seal element comprises an epoxy material.

6. The system of claim 1, wherein the adherent element comprises an adhesive material between confronting surfaces of the heat producing element and the base element.

7. The system of claim 1, wherein the adherent element comprises a mechanical attachment between the heat producing element and the base element.

8. The system of claim 1, wherein the heat pipe comprises a well formed in the base element, a capillary medium disposed adjacent at least a portion of an internal wall of the well.

9. The system of claim 1, wherein the heat producing element comprises at least a portion of the evaporator section of the heat pipe.

10. The system of claim 1, wherein the base element comprises at least a portion of the condenser section of the heat pipe.

11. The system of claim 1, further comprising a vent tube between the heat pipe and ambient, the vent tube sealed from ambient during manufacture.

12. The system of claim 1, further comprising a containment barrier around the heat pipe.

13. The system of claim 1, wherein the heat producing element comprises an integrated circuit, a chip, a die, a heat slug, or a heat spreader.

14. The system of claim 1, wherein the base element comprises a heat slug, a heat spreader, or a heat sink.

15. A method for manufacturing a thermal management system, comprising:

providing a heat producing element and a base element;

forming a well in the base element;

forming a vent passage in a surface of the base element extending outwardly from an edge of the well;

disposing a capillary medium within the well and surrounding a central space within the well;

placing an adherent element surrounding the well on the surface of the base element and crossing the vent passage;

assembling the heat producing element and the base element with the adherent element between confronting surfaces thereof to form an assembly with a working fluid disposed in the well;

boiling off a portion of the working fluid; and

flowing the adherent element into the vent passage and around the edge of the well to seal off the well and attach the base element and the heat producing element.

16. The method of claim 15, wherein the step of boiling off a portion of the working fluid comprises applying a vacuum to the assembly through the vent passage.

17. The method of claim 15, wherein the step of boiling off a portion of the working fluid comprising heating the assembly.

18. The method of claim 15, wherein in the step of placing the adherent element, the adherent element comprises a solid ring-shaped perform comprised of an epoxy material.

* * * * *