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27 AAVID THERMALLOY LLC and
28 BOYD CORPORATION

**UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF CALIFORNIA**

22 AAVID THERMALLOY LLC,
23 Plaintiff,
24 v.
25 COOLER MASTER CO., LTD. and
26 CMI USA, INC.,
27 Defendants.

Case No. 4:17-cv-05363-JSW

**DECLARATION OF NELSON J. GERNERT
IN CONNECTION WITH CLAIM
CONSTRUCTION**

1 COOLER MASTER CO., LTD.,
2 Counter-Claim Plaintiff,
3 v.
4 AAVID THERMALLOY LLC and
5 BOYD CORPORATION,
6 Counter-Claim Defendants.
7

8 1. I, Nelson J. Gernert, have been employed as a VP of Engineering and Technology
9 at Aavid Thermacore, Inc., which is a subsidiary of Aavid Thermalloy, LLC, since December 12,
10 1983 and I make this declaration based on my personal knowledge and experience.

11 2. This Declaration is in response to portions of the Declaration of Dr. Himanshu
12 Pokharna, dated June 29, 2018, regarding the meaning of the disputed claim terms “vapor
13 chamber, “lip”, “spacer”, and “hollow column”.

14 3. I have worked in the thermal management products industry since December 1983,
15 within which I have been involved in the, development, manufacture, and sale of vapor chambers.
16 My CV is attached hereto as Exhibit A.

17 4. In preparation of this Declaration I considered the following materials:

- 18 • The patents-in-suit, including U.S. Patent Nos. 7,066,240 (“240 patent”),
19 7,100,679 (“679 patent”) and 7,100,680 (“680 patent”).
- 20 • The parties’ Joint Claim Construction and Prehearing Statement Pursuant to
21 Patent L.R. 4-3 filed on June 22, 2018 (“JCCPS”) and the evidence cited in
22 that document.
- 23 • The Declaration of Dr. Himanshu Pokharna in Connection with Claim
24 Construction.
- 25 • Any other patent(s), publication(s) or other material(s) cited in this declaration.

26 **I. Background**

27 5. Effectively filed on May 12, 1999, the patents-in-suit relate to “a heat pipe for
28 cooling an integrated circuit chip, with the heat pipe designed to be held in direct contact with the

1 integrated circuit.” ‘240 patent, Col. 1, ll. 11-13.¹

2 6. A heat pipe is a passive, two-phase device that uses evaporation (vaporization) and
3 condensation of a working fluid to transport and dissipate heat. They are thus similar in some
4 respects to a thermosyphon, as explained in the Introduction of David Reay & Peter Kew, Heat
5 Pipes (5th ed., 2006) (hereafter, Heat Pipes):

6 The heat pipe is similar in some respects to the thermosyphon and it is
7 helpful to describe the operation of the latter before discussing the heat pipe. . . .
8 A small quantity of water is placed in a tube from which air is then evacuated and
9 the tube sealed. The lower end of the tube is heated where causing the liquid to
10 vapourise and the vapour to move to the cold end of the tube where it is
11 condensed. The condensate is returned to the hot end by gravity. Since the latent
12 heat of evaporation is large, considerable quantities of heat can be transported with
13 a very small temperature difference from end to end. Thus, the structure will also
14 have a high effective thermal conductance. The thermosyphon has been used for
15 many years and various working fluids have been employed. . . . One limitation of
16 the basic thermosyphon is that in order for the condensate to be returned to the
17 evaporator region by gravitational force, the latter must be situated at the lowest
18 point.

19 *Id.* at 1.

20 7. Unlike a thermosyphon, however, heat pipes generally utilize “capillary forces to
21 return condensate to the evaporator.” Heat Pipes at 1. As a result, in heat pipes, “the evaporator
22 position is not restricted and it may be used in any orientation.” *Id.*; *see also id.* at 9 (“The heat
23 pipe differs from the thermosyphon by virtue of its ability to transport heat *against gravity* by an
24 evaporation-condensation cycle.”) (emphasis in original). The creation of capillary forces in a
25 heat pipe is typically performed by a *separate structure* applied to the interior walls of the heat
26 pipe, such as sintered powder or wire mesh wick. Other means include forming grooves in the
27 wall of the heat pipe.

28 8. In addition, although the term “heat pipe” has been used to refer to other heat
transfer devices in which condensate return is achieved by other means (*e.g.*, centripetal force,
osmosis, or electrohydrodynamics), Heat Pipes at 1, this is not how the term was generally
understood by those of ordinary skill in the art at the time of the invention of the patents-in-suit.

¹ The citations to the Aavid patents herein are provided with reference to the ‘240 patent; the corresponding portions of the ‘679 and ‘680 patents are incorporated by reference.

1 These “special types of heat pipes” are not typical, and were not typical at the time of the
2 invention of the patents-in-suit. *See id.* at 215. Indeed, as further explained in Heat Pipes, “[t]he
3 three basic components of a heat pipe are as follows: (i) The working fluid (ii) The wick or
4 capillary structure (iii) The container.” *Id.* at 108. Also, “[a]bove all, the heat pipe must be leak-
5 tight to a very high degree.” *Id.* at 169; *see also id.* at 126 (“[The container] has . . . to be leak-
6 proof, to maintain the pressure differential across its wall and to enable the transfer of heat to take
7 place into and from the working fluid.”).

8 9. In the context of electronics cooling applications, heat pipes frequently take the
9 form of a “flat plate unit,” such as an embedded heat pipe or a vapor chamber heat pipe, for “heat
10 spreading” or “temperature flattening.” *See Heat Pipes* at 323-25. Other forms include tubular
11 heat pipes, micro-heat pipes, loop heat pipes, and direct contact systems. *Id.* Vapor chamber heat
12 pipes, sometimes referred to as “vapor chambers,” are particularly advantageous, as they alleviate
13 spreading resistance found in solid heat sink construction. They are typically used to provide a
14 thermal management solution for cooling critical electronic components, such as integrated
15 circuit chips, in applications for the consumer, server, and telecommunications markets. Vapor
16 chamber heat pipes are typically constructed of stamped or machined plates with a hollow center
17 for vapor flow, consistent with the invention described in the patents-in-suit. And the hollow
18 center allows spreading of heat with an extremely high thermal conductivity, as opposed to the
19 substantially unidirectional transport of heat provided by more traditional heat pipe designs.
20 Thus, for example, as semiconductors have gotten smaller and faster, they generate more and
21 more heat and that heat needs to be drawn away in an efficient manner and vapor chamber heat
22 pipes are the solution.

23 10. I also note the following online tutorial, which I understand was sponsored by
24 Cooler Master: <https://m.youtube.com/watch?v=M4POFT3Ctek>. This tutorial provides further
25 background information consistent with my Declaration and has been transcribed in part below:

26 A heat pipe is a vacuum-sealed metal tube that contains a working fluid that
27 changes from liquid to gas when heat is applied at one end of the tube. This
28 heated gas moves quickly to the other end where it condenses or turns back into
 liquid, then travels via a wick material, usually sintered metal back to the end with

1 the heat source. This design allows heat pipes to transfer heat much more
2 efficiently than a solid piece of metal and they have the added advantage of being
3 much lighter. On top of that, modern heat pipe designs perform really well in any
4 orientation, even upside down, that's why most high performance CPU or graphics
5 card coolers use heat pipe technology in some way these days. But heat pipes do
6 have some limitations. They only transfer heat in one direction, and their thin
7 round shape means they are physically difficult to get close to a very small heat
8 source.

9 There are a couple of solutions, such as embedding them into a solid chunk of
10 metal to spread the heat out to the connected pipes, but then we are relying on the
11 relatively inefficient heat transfer of copper. We can get heat directly to the heat
12 pipes by flattening them out and putting them right up against something, but now,
13 due to the sheer size of our heat pipes again, and the size of our heat source, we
14 can only connect a handful of heat pipes. If only we had something that could be
15 used in high heat flux applications, like on a CPU that could spread that thermal
16 energy out incredibly efficiently so we could use traditional fins or even heat pipes
17 to spread the heat even further, that would enable efficient operation of larger heat
18 sinks than before, and oh, snap, the topic of this video. I am talking, of course,
19 about vapor chambers.

20 A vapor chamber, much like a heat pipe, is made of a vacuum-sealed flat metal
21 structure that contains a working fluid that changes from liquid to gas when heat is
22 applied anywhere on its surface. This heated gas moves quickly throughout the
23 inside of the vapor chamber where it finds somewhere cooler than its boiling point
24 and condenses and then travels via a wick material back to the heat source. A
25 couple of subtle differences there, the most important of which is a vapor
26 chamber's phenomenal ability to spread heat out in any direction, up to 700 watts
27 per centimeter squared can be spread out. They use a series of internal posts to
28 keep them from collapsing. Remember, there is a vacuum inside, and they are
manufactured for everything from mundane stuff like cooling down a PC all the
way to specialized designs that can be as huge as they want, or as thin as .5
millimeters, according to Wikipedia, although the thinnest I could find was 1.5
millimeters from Celsia Technologies, and they can be deployed in outer space.

Notably, the tutorial's use of terminology (*e.g.*, vapor chamber, vacuum sealed, wick material,
etc.) is consistent with that used by me, those of ordinary skill in the art, and the patents-in-suit.
Nowhere do they mention thermosyphon or wickless heat pipe technologies.

II. Level of Skill in the Art

11. I have been informed that the words of a patent claim are generally given their
ordinary and customary meaning, which is the meaning that the term would have to a person of
ordinary skill in the art in question at the time of the invention (*i.e.*, as of the effective filing date
of the patent application—here, May 12, 1999) after reading the entire patent.

1 12. I have been informed that patent claim terms must be interpreted in light of the
2 “intrinsic” record, which includes the patent claims, specification, and prosecution history, and
3 that the patent specification is the single best guide to the meaning of a disputed term.

4 13. I have been informed that “extrinsic” evidence consisting of all evidence external
5 to the patent, including expert testimony and dictionaries, may also be used in claim construction
6 analysis, but may never be relied upon to construe claims in a manner that is inconsistent with the
7 intrinsic evidence.

8 14. I have been informed that the following factors may be considered in determining
9 the level of ordinary skill:

- 10 • the educational level of the patent applicants;
- 11 • the type of problems encountered in the art;
- 12 • previous solutions to those problems;
- 13 • the rapidity with which innovations are made in the art;
- 14 • the sophistication of the relevant technology; and
- 15 • the educational level of active workers in the art.

16 15. In my experience, most people working in the art at the time of the invention of the
17 patents-in-suit had a bachelor’s degree in mechanical engineering or a related field, or had an
18 equivalent level of education and training in the thermal management products industry. For
19 instance, at the time of the invention, Thermacore employed roughly 20 engineers and technicians
20 who worked on the design and development of various heat pipe technologies. Many of them,
21 including myself, had bachelor’s degrees in mechanical engineering. Others I knew in the
22 industry had similar educational backgrounds. I also am familiar with the educational level of the
23 inventors, Peter M. Dussinger and Thomas L. Myers, as I was working with them at Thermacore
24 at the time of the invention. Mr. Dussinger was a chemical engineer, who had been working as an
25 engineer at Thermacore for nearly 15 years, including several years of experience working with
26 heat pipes. Mr. Myers was a certified welder with several years of experience working with heat
27 pipes as well. Based upon the education, training, knowledge, and experience that I have
28 acquired over the past 34 years studying, researching, and working in the field of heat pipes, it is

1 my opinion that a person of ordinary skill in the art of the patents-in-suit would have a bachelor's
2 degree in engineering and at least three years of experience working with heat pipes or other heat
3 transfer devices for thermal management in electronics and computer systems; or an equivalent
4 level of education, training, or work experience in the field of heat pipes.

5 16. At paragraph 25 of Dr. Pokharna's Declaration, he states his opinion that:

6 a person of ordinary skill in the art in the context of the patents-in-suit for claim
7 construction around 1999 would have earned at least a graduate degree, such as an
8 M.S., Ph.D., or equivalent thereof, in mechanical engineering or a closely-related
9 field and possessed at least three years of specialized experience in designing and
developing heat pipes or other heat transfer devices for thermal management in
electronics and computer systems.

10 Pokharna Decl. ¶ 25. It appears that, based on paragraph 25 of Dr. Pokharna's declaration, as to
11 the level of ordinary skill in the art, neither of the inventors of the patents-in-suit would qualify,
12 in Dr. Pokharna's opinion, as being skilled in the art with respect to their own inventions.

13 17. I have set forth below my opinions as to the proper construction of the disputed
14 claim terms as follows:

15 **III. "Vapor Chamber"**

Disputed Claim Term	Asserted Claims	Aavid's Proposed Construction	Defendants' Proposed Construction
"vapor chamber"	'240 patent: claims 9-13 '679 patent: claims 1, 2 '680 patent: claims 1-3, 5	A vacuum sealed chamber wherein a heat transfer fluid is evaporated and condensed and capillary forces are utilized to spread heat	Enclosed and sealed void or cavity in which a suitable quantity of liquid is present to be evaporated (or vaporized) and condensed to transport or spread heat

22 18. In my opinion, in the context of the patents-in-suit, the term "vapor chamber"
23 would have been understood by those of ordinary skill in the art at the time of the invention to
24 mean "a vacuum sealed chamber, wherein a heat transfer fluid is evaporated and condensed and
25 capillary forces are utilized to spread heat."

26 19. As an initial matter, one of ordinary skill in the art at the time of the invention
27 reading the patents-in-suit would have recognized that asserted claims 9-13 of the '240 patent, 1,
28

1 2, 4, and 5 of the '679 patent, and 1-3 and 5-8 of the '680 patent are directed to a vapor chamber
2 heat pipe. The asserted claims clearly describe this type of heat pipe, as each refers to the recited
3 "vapor chamber" being defined by two bonded plates. In addition, the titles of the patents-in-suit
4 specifically describe the invention as an "INTEGRATED CIRCUIT HEAT PIPE HEAT
5 SPREADER," which also is reflected in the preambles of the asserted claims (e.g., "[a] heat pipe
6 for spreading heat"). The specification describes the invention similarly in the "Summary of the
7 Invention" and the "Detailed Description" See, e.g., '240 patent, Col. 1, ll. 50-51 ("The present
8 invention is an inexpensive heat pipe heat spreader for integrated circuit chips"); Col. 1, ll. 57-58
9 ("the heat pipe heat spreader"); Col. 1, l. 61 ("The heat spreader of the present invention"); Col.
10 1, l. 67 ("the heat spreader"); Col. 2, l. 2 ("the heat spreader"); Col. 2, l. 25 ("the heat spreader");
11 Col. 3, ll. 57 ("the same heat pipe heat spreader"). Thus, in my opinion, it would have been
12 understood that the term "vapor chamber" refers to a chamber that spreads heat, rather than one
13 that merely transports heat (such as along a single axis as in more traditional heat pipe designs). I
14 therefore disagree with the incorporation of the word "transport" as an alternative to "spread" in
15 Defendants' proposed construction, which Dr. Pokharna never appears to explain.

16 20. I also disagree with Dr. Pokharna's suggestion that the term "vacuum" in Aavid's
17 proposed construction is confusing and unnecessary. A vacuum seal, as would have been readily
18 understood by one of ordinary skill in the art at the time of the invention, refers to an *airtight seal*.
19 In other words, it defines the level of seal required. Maintaining a vacuum seal is critical in the
20 design of heat pipes, and is repeatedly emphasized as an important aspect of the invention, as
21 reflected in the following references of the patents-in-suit:

22 The internal structure of the heat pipe is an *evacuated* vapor chamber with a
23 limited amount of liquid.

24 '240 patent, Col. 2, ll. 3-4 (emphasis added).

25 The spacers also make it possible to provide holes into and through the vapor
26 chamber, an apparent inconsistency since *a heat pipe vacuum chamber is supposed*
27 *to be vacuum tight*. This is accomplished by bonding the spacers, if they are solid,
28 to both plates of the heat pipe, or, if they are embossed in one plate, bonding the
portions of the depressions which contact the opposite plate to that opposite plate.
With the spacer bonded to one or both plates, a through hole can be formed within
the spacer and it has no effect on the vacuum integrity of the heat pipe vapor

1 *chamber, from which the hole is completely isolated.*

2 *Id.*, Col. 2, ll. 11-39 (emphasis added).

3 Heat pipe 10 is then *evacuated to remove all non-condensable gases* and a suitable
4 quantity of heat transfer fluid is placed within it. This is the conventional method
5 of constructing a heat pipe, and is well understood in the art of heat pipes.

6 *Id.*, Col. 3, ll. 30-34 (emphasis added).

7 *Holes 12 penetrate heat pipe 10 without destroying its vacuum integrity because of*
8 *their unique location.*

9 *Id.*, Col. 4, ll. 19-20 (emphasis added).

10 The only requirement for forming hole 50 within a depression 26 is that *the bottom*
11 *of depression 26 must be bonded to inner surface 28 of contact plate 18 to prevent*
12 *loss of vacuum within the heat pipe.*

13 *Id.*, Col. 4, ll. 40-43 (emphasis added). Thus, in my opinion, and based on the intrinsic evidence
14 in the patent specification, it would have been understood by one of skill in the art that the term
15 “vapor chamber” refers to a vacuum sealed chamber in the context of the patents-in-suit.

16 21. It further is my opinion that one of ordinary skill in the art reading the entire patent
17 would have understood that the above-noted heat spreading function is accomplished via
18 evaporation and condensation of a heat transfer fluid, or liquid, and the use of capillary forces.
19 Dr. Pokharna seems to agree that there must be a heat transfer fluid, or liquid, present within the
20 chamber to be evaporated (or vaporized) and condensed, but adds that it must be of a “suitable
21 quantity.” In my opinion, this adds unnecessary ambiguity to the claim language and would not
22 be read into the term “vapor chamber” by one of ordinary skill in the art at the time of the
23 invention. Indeed, both parties’ proposed interpretations use functional language that already
24 implicitly limits the amount of heat transfer fluid that would be understood to be present in the
25 chamber. For instance, under Defendants’ proposed construction, the heat transfer fluid must be
26 in an amount capable of being evaporated and condensed to spread or transport heat. Under
27 Aavid’s proposed construction, it must be in an amount capable of being evaporated, condensed,
28 and transported via capillary action to spread heat. One of ordinary skill in the art would not have
29 understood the term “vapor chamber” to include any further limitation on the amount of heat
30 transfer fluid present in the chamber.

1 22. Dr. Pokharna also takes issue with the incorporation of “capillary forces” in
2 Aavid’s proposed construction, but a capillary structure is a basic feature of the typical heat pipe,
3 and the patents-in-suit repeatedly emphasize the importance of capillary action in both the
4 “Summary of the Invention” and the “Detailed Description,” as set forth below:

5 *Porous capillary wick material also covers the inside surfaces of the heat pipe and*
6 *has a substantial thickness surrounding the surfaces of the spacers within the heat*
7 *pipe, thus forming pillars of porous wick surrounding the supporting spacers. The*
8 *wick material therefore spans the space between the plates in multiple locations.*

9 The spacers thus serve important purposes. They support the flat plates
10 and prevent them from deflecting inward and distorting the plates to deform the
11 flat surfaces which are required for good heat transfer. The spacers also serve as
12 critical support for the portions of the capillary wick which span the internal space
13 between the plates. *The capillary wick pillars which span the space between the*
14 *plates provide a gravity independent characteristic to the heat spreader, and the*
15 *spacers around which the wick pillars are located assure that the capillary wick is*
16 *not subjected to destructive compression forces.*

17 ‘240 patent, Col. 2, ll. 11-39 (emphasis added).

18 *Heat pipe 10 also includes internal sintered metal capillary wick 30 which covers*
19 *the entire inside surface of contact plate 18. As is well understood in the art of*
20 *heat pipes, a capillary wick provides the mechanism by which liquid condensed at*
21 *the cooler condenser of a heat pipe is transported back to the hotter evaporator*
22 *where it is evaporated. The vapor produced at the evaporator then moves to the*
23 *condenser where it again condenses. The two changes of the state, evaporation at*
24 *the hotter locale and condensation at the cooler site, are what transport heat from*
25 *the evaporator to the condenser.*

26 *In the present invention, heat pipe 10 also has capillary wick pillars 32*
27 *which bridge the space between contact plate 18 and cover plate 20. Pillars 32*
28 *thereby interconnect cover plate 20 and contact plate 18 with continuous capillary*
29 *wick. This geometry assures that, even if heat pipe 10 is oriented so that cover*
30 *plate 20 is lower than contact plate 18, liquid condensed upon inner surface 34 of*
31 *cover plate 20 will still be in contact with capillary pillars 32.*

32 ‘240 patent, Col. 3, ll. 47-65 (emphasis added).

33 23. Dr. Pokharna states that, in a heat pipe, “[g]ravity or optionally a capillary wick
34 brings the condensed liquid back to the evaporation location, thus completing a ‘loop.’” Pokharna
35 Decl., ¶ 17. Dr. Pokharna also states as follows:

36 36. Fourth, the limitation in Aavid’s proposed construction requiring
37 that “capillary forces [be] utilized” in a “vapor chamber” is unnecessarily
38 restrictive because there is no such requirement either in the context of the patents-
in-suit or in the general art at the time around the purported invention. Indeed, at

1 that time, there had existed vapor chambers that did not utilize or otherwise require
2 capillary forces. The original parent application for the patents-in-suit that
3 ultimately issued as U.S. Patent No. 6,302,192 (the “192 patent”) had claims that
4 did not include a “wick.” (See Prosecution History of the ‘192 patent, original
5 claims 1-5.) A person of ordinary skill in the art would have understood that an
6 additional and optional structure known as a “wick” *might* be present in a vapor
7 chamber. It is such “wick” that would utilize the “capillary forces” to help with
8 the function of transporting and spreading heat. But this “wick” was not always
9 present in all vapor chambers that had existed at the time of the purported
10 invention, nor was it required. (See, e.g., Takahashi (4:48-64), U.S. Pat. No.
11 4,012,770 (13:53-63); U.S. Pat. No. 4,165,472 (1:55-60, 4:23-30, 6:60-7:7); U.S.
12 Pat. No. 6,817,097 (3:1-9, 21-36, reference 113).) In a vapor chamber without a
13 wick, capillary force would not be utilized to spread or transport heat. Thus,
14 Aavid’s proposed construction reads in an unnecessary limitation of “capillary
15 forces [be] utilized” in a “vapor chamber.”

16 Pokharna Decl., ¶ 36.

17 24. Dr. Pokharna’s discussion of “wick” and “capillary forces” is completely divorced
18 from the technology disclosed in the patents-in-suit. There is absolutely no disclosure in the
19 patents-in-suit of any embodiment of the inventions’ claims that does not use capillary forces.
20 There is also no disclosure of any embodiment of the invention that uses “gravity” as opposed to
21 a capillary wick. In fact, as noted above, the Aavid patents state as follows: “The capillary wick
22 pillars . . . provide a gravity independent characteristic to the heat spreader” ‘240 patent,
23 Col. 2, ll. 24-25. Dr. Pokharna appears to be attempting to conflate vapor chamber heat pipes
24 with thermosyphons to bolster Defendants’ invalidity contentions (I understand that the
25 Takahashi reference above is one of Defendants’ alleged invalidity references), but in my
26 opinion, one of ordinary skill in the art at the time of the invention would have recognized that the
27 asserted claims are not directed toward thermosyphons.

28 25. Indeed, at the time of the invention of the patents-in-suit, the inventors were
working to develop a better means for cooling of the processors inside laptops, computers, and
servers. These products must be able to operate in all orientations, at least because: (i) the
designer could choose to configure the processor in many orientations; (ii) the end users would
use them in many orientations; and (iii) heat flux from the processor was high, such that a
thermosyphon likely would not work. The use of a capillary structure in the context of the

1 patents-in-suit is essential, and I completely disagree with Dr. Pokharna that one ordinary skill in
2 the art at the time of the invention would have read the term “vapor chamber” in the context of
3 the patents-in-suit as not requiring the utilization of capillary forces.

4 26. I also note that capillary forces can be utilized to spread or transport heat without
5 adding a separate wick. As noted above, capillary action can be created by forming capillary
6 structures such as grooves in the wall of a heat pipe, for instance, in which case a separate
7 material would not be needed to create capillary action. For this same reason, I disagree with Dr.
8 Pokharna’s opinion that the recitation of a “wick” in dependent claims 3, 8, and 10 of the ‘240
9 patent demonstrates that “the utilization of capillary forces” is optional. *See Pokharna Decl.*,
10 ¶ 37. I also note that each of those dependent claims recite more than merely the presence of a
11 wick—they recite “a wick positioned upon . . . confronting interior surfaces.” In other words,
12 they recite a separate structural element (*e.g.*, the patents-in-suit describe a sintered powder
13 wicking material) and where that element is located within the vapor chamber.

14 27. Finally, I note that Dr. Pokharna resorts to extrinsic dictionary definitions in his
15 attempt to define the word “chamber.” In my opinion, this is completely unnecessary, as the
16 term “chamber” is readily understandable by one of ordinary skill in the art. One of ordinary skill
17 in the art would not have needed to refer to a non-technical dictionary definition to understand the
18 meaning of “chamber” within the claim term “vapor chamber.”

19 28. As Dr. Pokharna should be aware, Aavid’s proposed construction of the term
20 “vapor chamber” is not only consistent with how the term is used in the patents-in-suit, it is
21 consistent with how his own colleagues were using the term around the time of the invention. Dr.
22 Pokharna’s Declaration states that his “experience includes leading a team of over 25 engineers at
23 Intel Corporation in the development of thermal management technology in laptop computers.”
24 Pokharna Decl., ¶ 2. Dr. Pokharna also stated that he has “over sixty issued or pending patents,”
25 *id.*, and I am informed that he was a co-inventor on several patents at Intel with a man named Eric
26 Distefano. *E.g.*, U.S. Patent Nos. 6,903,930, 2005/0145371, and 2007/0076376.

27 29. Mr. Distefano is also named as a co-inventor on U.S. Patent No. 6,437,983 (the
28 “‘983 Intel Patent”) assigned to Intel Corporation and filed on June 29, 2001, entitled “VAPOR

CHAMBER SYSTEM FOR COOLING MOBILE COMPUTING SYSTEMS.” The ‘983 Intel Patent describes vapor chambers as follows:

One cooling approach uses vapor chambers. The vapor chamber loses heat within the computing system by convection and radiation. *Typically, a vapor chamber is a vacuum vessel with a wick structure lining the inside walls that is saturated with a working liquid.* As heat is applied, the fluid at that location immediately vaporizes and the vapor rushes to fill the vacuum. Wherever the vapor comes into contact with a cooler wall surface, it will condense, releasing its latent heat of vaporization. *The condensed fluid returns to the heat source via capillary action, ready to be vaporized again and repeat the cycle. The capillary action of the wick lining the inside walls enables the vapor chamber to work in any orientation with respect to gravity.*

‘983 Intel Patent, Col. 1, ll. 32-44 (emphasis added). This description of vapor chambers in the ‘983 Intel Patent is consistent with my understanding of vapor chambers, the description of vapor chambers in the patents-in-suit, and the understanding of those having ordinary skill in the art at the time of the invention having read the patents-in-suit.

30. In sum, the above-cited statements from the ‘983 Intel Patent and the specifications of the patents-in-suit all support the construction of “vapor chamber” as 1) a vacuum sealed chamber; 2) wherein a heat transfer fluid is evaporated and condensed; and 3) capillary forces are utilized to spread heat. Dr. Pokharna’s proposed construction of “vapor chamber” does not comport with the descriptions of vapor chambers above because, at a minimum, it does not include a vacuum sealed chamber utilizing capillary forces to spread heat.

IV. “Lip”

Disputed Claim Term	Asserted Claims	Aavid’s Proposed Construction	Defendants’ Proposed Construction
“lip”	‘240 patent: claims 11-13 ‘679 patent: claim 5 ‘680 patent: claims 1-3, 5	Portion of the plate defined by the bonded region of the plate’s inner or interior surface	Portion of the plate comprising a region bonded to another plate

31. In my opinion, in the context of the patents-in-suit, the term “lip” would have been understood by those of ordinary skill in the art at the time of the invention to mean the “portion of

the plate defined by the bonded region of the plate's inner or interior surface.”

32. The ‘240 patent specification is instructive as to how one of skill in the art would define “lip”:

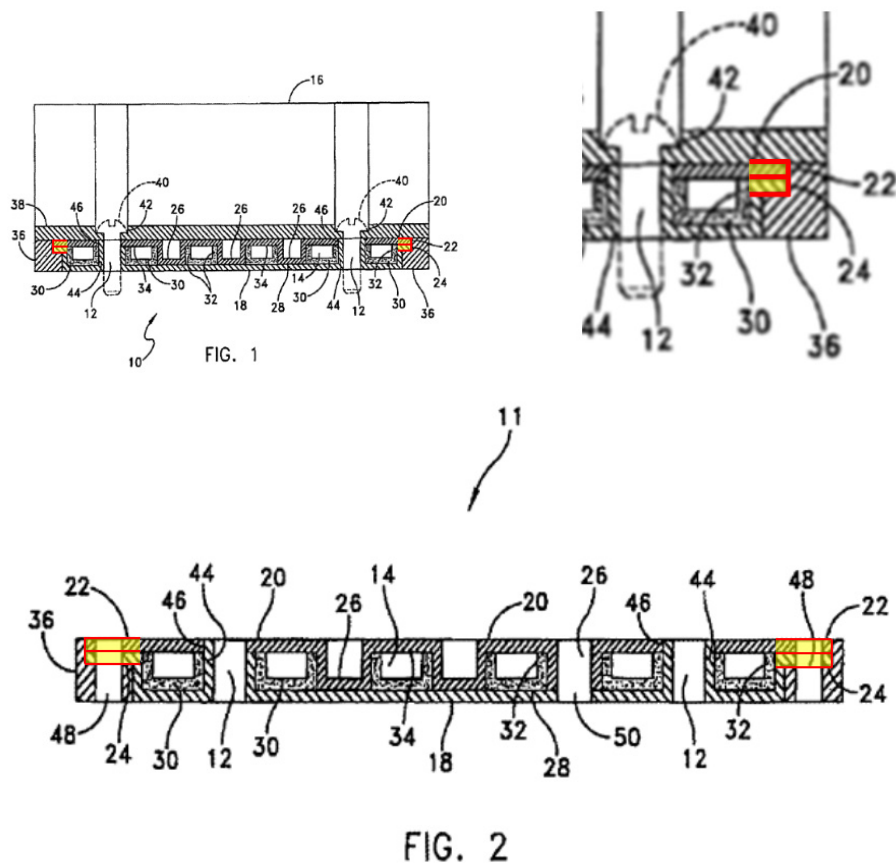
Contact plate 18 and cover plate 20 are sealed together at their peripheral lips 22 and 24 by conventional means, such as soldering or brazing, to form heat pipe 10.

‘240 patent, Col. 3, ll. 27-31 (emphasis added).

The only requirement for forming hole 50 within a depression 26 is that the *bottom of depression 26 must be bonded to inner surface 28 of contact plate 18 to prevent loss of vacuum within the heat pipe*. Of course, the region of the peripheral edges is also a sealed structure since bonding between lips 22 and 24 is inherent because heat pipe 11 must be sealed at its edges to isolate the interior from the outside atmosphere.

‘240 patent, Col. 4, ll. 41-48, Figs 1, 2, 3 (emphasis added).

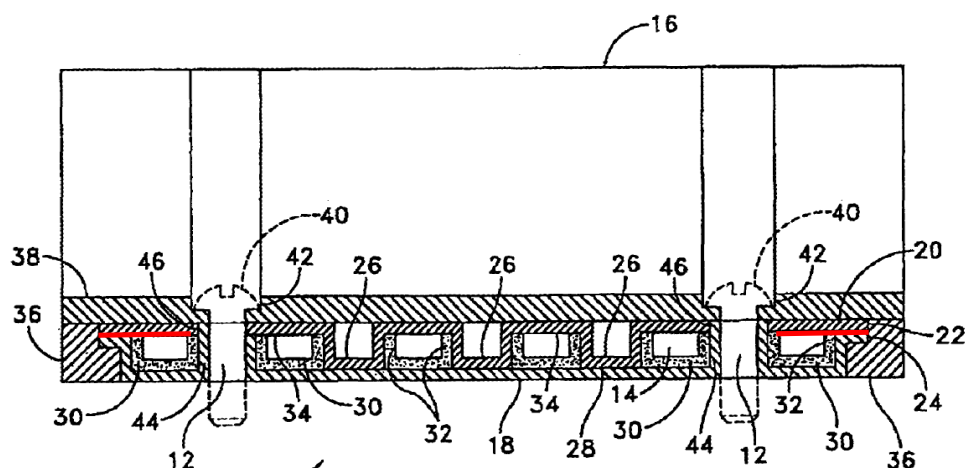
33. The bonded region of the plate's inner surface 28 forming the “lips” is shown in Figures 1 and 2 of the patent specification, highlighted below:



1 (I note for purposes of clarity that structures 36 and 38 above refer to a frame and fin plate,
2 respectively, and do not define the vapor chamber. Rather, the vapor chamber is defined by
3 contact plate 18 and cover plate 20.)

4 34. I believe that Dr. Pokharna's construction of "lip" is deficient because it would
5 essentially read the term "lip" out of the patent claims. A review of three particular asserted
6 claims confirms this. For example, claim 9 of the '240 patent states in part, "a boundary structure
7 including spaced-apart first and second plates that define an enclosed vapor chamber." Claim 11
8 of the the '240 patent states in part, "a peripheral lip located at an edge of said boundary structure
9 at which said peripheral lip of said first plate is sealingly bonded to said peripheral lip of said
10 second plate so as to define an enclosed vapor chamber." Finally, claim 12 of the '240 patents
11 states in part, "said edge lips of said first and second plates being sealingly bonded together so as
12 to define a vapor chamber." If Dr. Pokharna's construction were adopted, the term lip would
13 have no meaning. Indeed, for the "spaced-apart first and second plates" of claim 9 to "define an
14 enclosed vapor chamber," the plates would have to include peripheral or edge portions that are
15 bonded together. In addition, the lips cannot simply be edges bonded together, or the term "edge"
16 loses meaning in the context of claim 12. In my opinion, one of ordinary skill in the art having
17 read the patent would understand that structure being identified by recitation of "lips" is the
18 portion of the plates defined by the bonded region of their inner or interior surface.

19 35. I disagree with Dr. Pokharna's statement that this understanding is "self-
20 contradictory and cannot exist." The idea the bonded region cannot be part of the plate's "inner
21 or interior surface" once its actually bonded is nonsensical. Dr. Pokharna appears to conflate the
22 inner or interior surface of the plates with the portions of those surfaces that ultimately form the
23 interior walls of the vapor chamber. In my opinion, one of skill in the art reading the claim and
24 looking at the figures would easily be able to see that the bonded, peripheral or edge portions of
25 those surfaces also define the "lips." One need only follow the inner or interior surface of the
26 plate to where it is bonded to confirm that it is the inner or interior surface that is being bonded,
27 as can be seen in Figure 1 of the patents-in-suit, reproduced below:
28



V. “Spacer”

Disputed Claim Term	Asserted Claims	Aavid’s Proposed Construction	Defendants’ Proposed Construction
“spacer”	‘240 patent: claim 11 ‘679 patent: claim 5 ‘680 patent: claim 1	A structure, apart from the separately claimed depression, that is configured to maintain a space or clearance between the plates and provides support for a capillary wick	Plain and ordinary meaning If a construction is necessary: Structure used to maintain a space or clearance between the plates

36. In my opinion, in the context of the patents-in-suit, the term “spacer” would have been understood by those of ordinary skill in the art at the time of the invention to mean “a structure, apart from the separately claimed depression, that is configured to maintain a space or clearance between the plates and provides support for a capillary wick.”

37. The ‘240 patent specification is instructive as to how one of skill in the art would define “spacer”:

Furthermore, the heat pipe heat spreader is constructed to assure precise flatness and to maximize heat transfer from the heat source and to the heat sink, and has holes through its body to facilitate mounting.

‘240 patent, Col. 1, ll. 57-60.

The spacers prevent the plates from bowing inward, and therefore maintain the vital flat surface for contact with the integrated circuit chip. These spacers can be solid columns, embossed depressions formed in one of the plates, or a mixture of

the two. Porous capillary wick material also covers the inside surfaces of the heat pipe and has a substantial thickness surrounding the surfaces of the spacers within the heat pipe, thus forming pillars of porous wick surrounding the supporting spacers.

'240 patent, Col. 2, ll. 5-15 (emphasis added).

The spacers thus serve important purposes. They support the flat plates and prevent them from deflecting inward and distorting the plates to deform the flat surfaces which are required for good heat transfer. The spacers also serve as critical support for the portions of the capillary wick which span the internal space between the plates. The capillary wick pillars which span the space between the plates provide a gravity independent characteristic to the heat spreader and the spacers around which the wick pillars are located assure that the capillary wick is not subjected to destructive compression forces.

'240 patent, Col. 2, ll. 18-28 (emphasis added).

While contact plate 18 is essentially flat with the exception of peripheral lip 24, cover plate 20 includes multiple depressions 26. Depressions 26 are formed and dimensioned so that, when contact plate 18 and cover plate 20 are joined, the flat portions of depressions 26 are in contact with inner surface 28 of contact plate 18. Depressions 26 thereby assure that the spacing between contact plate 18 and cover plate 20 will be maintained even though pressure differentials between the inside volume of heat pipe 10 and the surrounding environment might otherwise cause the plates to deflect toward each other.

'240 patent, Col. 3, ll. 36-46 (emphasis added).

Capillary pillars 32 are wrapped around and supported by depressions 26, which prevents the structurally weaker capillary pillars 32 from suffering any damage.

'240 patent, Col. 3, ll. 36-46 (emphasis added).

38. The "capillary pillars 32" are shown in Figure 2 in the specification, highlighted below:

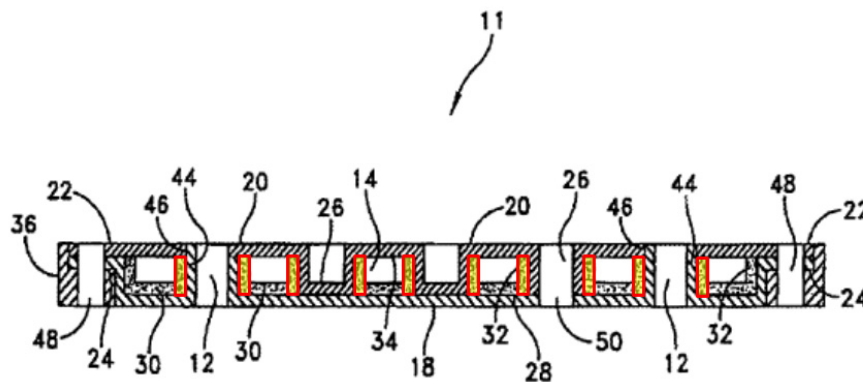


FIG. 2

1 '240 patent, Col. 4, ll. 2-5, Figure 2.

2 39. Dr. Pokharna's discussion of "spacer" appears at paragraphs 40-46 of his
3 declaration. At paragraph 43 of Dr. Pokharna's declaration, he states that the "definition
4 proposed by Aavid is problematic because it adds other requirements such as the spacer not being
5 the depression and being able to provide support for a capillary wick."

6 40. I disagree with Dr. Pokharna because the asserted claims reciting a "spacer"
7 separately recite a "depression," and other claims (*e.g.*, dependent claim 2 of the '240 patent)
8 recite it as an additional element as well. Thus, while the patents-in-suit acknowledge that the
9 spacers can be solid columns or embossed depressions formed in one of the plates, one of
10 ordinary skill in the art reading the patent would have understood that the claimed "spacer" refers
11 to a structure apart from the claimed "depression." Indeed, one skilled in the art would have
12 understood that the claimed "depression" relates to a depression having an opening to facilitate
13 formation of a mounting hole through the vapor chamber. The specification of the '240 patent
14 describes such a structure as follows:

15 FIG. 2 is a cross section view of an alternate embodiment of the flat plate heat pipe
16 11 of the invention with through holes 48 located within peripheral lips 22 and 24
17 of the heat pipe and *hole 50 shown in another sealed structure, one of the*
18 *depressions 26. The only requirement for forming hole 50 within a depression 26*
19 *is that the bottom of depression 26 must be bonded to inner surface 28 of contact*
20 *plate 18 to prevent loss of vacuum within the heat pipe.* Of course, the region of
the peripheral edges is also a sealed structure since bonding between lips 22 and
24 is inherent because heat pipe must be sealed at its edges to isolate the interior
from the outside atmosphere.

21 '240 patent, Col. 4, ll. 36-48 (emphasis added).

22 41. Although this depression may serve a spacing and support function, that function
23 is always carried out in the specification using additional structures (*e.g.*, depressions 26) without
24 openings or holes, as shown in Figures 1-3 for instance and described below:

25 Depressions 26 are formed and dimensioned so that, when contact plate 18 and
26 cover plate 20 are joined, the flat portions of depressions 26 are in contact with
27 inner surface 28 of contact plate 18. Depressions 26 thereby assure that the
28 spacing between contact plate 18 and cover plate 20 will be maintained even
though pressure differentials between the inside volume of heat pipe 10 and the
surrounding environment might otherwise cause the plates to deflect toward each
other.

1 '240 patent, Col. 3, ll. 36-46. In my opinion, one of ordinary skill in the art would have
2 understood the term "spacer" in the context of the asserted claims to refer to an additional
3 structure that is configured to maintain a space or clearance between the plates.

4 42. The specifications of the patents-in-suit also make it clear that this structure
5 provides support for a wick, which is described as a "critical" and an "important" feature of the
6 invention. For example, as previously noted, the specification states as follows:

7 The spacers thus serve *important* purposes. They support the flat plates and
8 prevent them from deflecting inward and distorting the plates to deform the flat
9 surfaces which are required for good heat transfer. *The spacers also serve as*
10 *critical support for the portions of the capillary wick which span the internal*
11 *space between the plates.* The capillary wick pillars which span the space between
the plates provide a gravity independent characteristic to the heat spreader and the
spacers around which the wick pillars are located assure that the capillary wick is
not subjected to destructive compression forces.

12 '240 patent, Col. 2, ll. 18-28 (emphasis added). In my opinion, one of ordinary skill in the art
13 would have read the wick-support feature to be an essential element of the term "spacer."

14 VI. "Hollow Column"

15 Disputed Claim Term	Asserted Claims	Aavid's Proposed Construction	Defendants' Proposed Construction
16 "hollow 17 column"	'240 patent: claims 9, 10, 12 18 '860 patent: claims 2, 5, 6, 8 19	Plain and ordinary meaning If a construction is necessary: a columnar structure defining an unfilled or empty space	Cylindrical structure surrounding a void or cavity

20 43. In my opinion, in the context of the patents-in-suit, the term "hollow column"
21 would have been understood by those of ordinary skill in the art at the time of the invention to
22 mean "a columnar structure defining an unfilled or empty space."

23 44. The '240 patent specification is instructive as to how one of skill in the art would
24 define "hollow column":

25 Furthermore, the heat pipe heat spreader is constructed to assure precise flatness
26 and to maximize heat transfer from the heat source and to the heat sink, *and has*
holes through its body to facilitate mounting.

27 '240 patent, Col. 1, ll. 57-60 (emphasis added).

28 *These spacers can be solid columns,* embossed depressions formed in one of the

1 plates, or a mixture of the two.

2 ‘240 patent, Col. 2, ll. 9-11 (emphasis added).

3 *The spacers also make it possible to provide holes into and through the vapor*
4 *chamber, an apparent inconsistency since a heat pipe vacuum chamber is supposed*
5 *to be vacuum tight.*

6 ‘240 patent, Col. 2, ll. 29-32 (emphasis added).

7 *With the spacer bonded to one or both plates, a through hole can be formed within*
8 *the spacer and it has no effect on the vacuum integrity of the heat pipe vapor*
9 *chamber, from which the hole is completely isolated.*

10 ‘240 patent, Col. 2, 36-39 (emphasis added).

11 *FIG. 1 is a cross section view of the preferred embodiment of a flat plate heat pipe*
12 *10 of the invention with through holes 12 through its vapor chamber 14 and in*
13 *contact with finned heat sink 16.*

14 ‘240 patent, Col. 3, ll. 21-24 (emphasis added).

15 *Holes 12 penetrate heat pipe 10 without destroying its vacuum integrity*
16 *because of their unique location. Holes 12 are located within sealed structures*
17 *such as solid columns 44, and since columns 44 are bonded to cover plate 20, at*
18 *locations 46, holes 12 passing through the interior of columns 44 have no affect on*
19 *the interior of heat pipe 10.*

20 ‘240 patent, Col. 4, ll. 19-24 (emphasis added).

21 Columns 44 have a 0.250 inch outer diameter, and holes 12 are 0.210 in diameter.

22 ‘240 patent, Col. 4, ll. 34-35.

23 . . . lips 22 and 24 are slightly longer in FIG 2 to accommodate holes 48, and hole
24 50 is shown.

25 ‘240 patent, Col. 4, ll. 50-51.

26 45. Dr. Pokharna’s discussion of “hollow column” appears at paragraphs 47-49 of his
27 declaration. At paragraph 48 of his declaration, Dr. Pokharna states that “a person of ordinary
28 skill in the art around the time of the purported invention, in reading the specification of the
patents-in-suit, would have understood the phrase “hollow column” to mean “a cylindrical
structure surrounding a void or cavity.”

46. I disagree with Dr. Pokharna’s statement because the construction would not be
understood by one of skill in the art and would introduce ambiguity into the claim language. For
instance, in the context of claim 12, the “hollow column” must be “integral with [the] first plate,”

1 yet must also provide for a mounting hole that extends through both plates when coaxially aligned
2 with a hole in the second plate. Dr. Pokharna never explains how this would be possible with a
3 column that surrounds a cavity or void. And though he claims the specification shows such an
4 arrangement, I disagree. The columns identified in the specification clearly show an unfilled or
5 empty space defined by a columnar structure that is open at both the top and bottom ends of the
6 structure.

7 47. It is important to note that the term “column” would have been understood by one
8 ordinary skill in the art having read the patent to imply support, which is confirmed by the
9 portions of the specification reproduced above. And here, the columns are hollow to facilitate
10 mounting through holes. Further, in the context of the patents-in-suit, it is important that the
11 column provides support to the vapor chamber when bolted on to a processor. Columns similarly
12 are used to support roofs, for example—as in the Pantheon. In addition to the issues noted above,
13 Dr. Pokharna’s definition, which merely refers to a generic “cylindrical structure,” provides no
14 acknowledgement regarding strength, whereas Aavid’s recitation of a “columnar structure”
15 properly does.

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Pursuant to 28 U.S.C. § 1746, I declare under penalty of perjury that the foregoing is true
and correct.

Executed on July 13, 2018.

A handwritten signature in cursive script, reading "Nelson J. Gernert", written in black ink.

Nelson J. Gernert

EXHIBIT A



Nelson J. Gernert has been with Thermacore since 1983 (+30 years engineering experience), and is a co-owner in this \$32M year business. Thermacore is a recognized global leader in thermal management with over 40 years of experience in the design, development, and manufacture of thermal management solutions. Thermacore's 125,000+ sq. ft. of manufacturing space is distributed among five manufacturing facilities located in North America (4) and the United Kingdom (1). The company headquarters is located in Lancaster, PA.

Currently, Mr. Gernert is the Vice President of Engineering and Technology at Thermacore. His group of engineers and technicians are responsible for the development and manufacture of advanced heat transfer and heat pipe technologies that support military, aerospace and commercial applications. The company heritage is based on heat pipe technology. It is a passive, two-phase device that uses vaporization and condensation of a working fluid that transports and dissipates heat better than any solid metal conductor. When Mr. Gernert started at Thermacore, the heat pipe was just a laboratory curiosity. Today, the heat pipe is now a mainstream product used for thermal control in products that touch everyone's life such as laptops, desktops and gaming consoles. The heat pipe and various product derivatives have transitioned into many military and aerospace applications as well.

In addition, Mr. Gernert's organization is responsible for the development of advanced heat transfer technologies to support future product opportunities for mission specific applications. Much of the advanced development work is funded by various Government organizations such as NASA, DoD, DoE, DARPA and government laboratories. Mr. Gernert has extensive experience working with the government and securing funding for heat transfer related development programs.

Mr. Gernert has primarily worked on research and development contracts directly related to heat transfer and heat pipe technology in support of many diverse applications. The engineering developmental areas that Mr. Gernert has supported during his career include:

Aircraft Thermal Control: Mr. Gernert pioneered the development and qualification of heat pipe and Loop Heat Pipe (LHP) technologies for aircraft use. As a result, heat pipe and LHP technology are routinely used in many aircraft applications which includes F/16, F/18, and the Joint Strike Fighter (JSF). In addition, a considerable amount of work has been done in the area of hypersonic aircraft thermal control.

Materials Processing: Mr. Gernert has developed heat pipe products for materials processing, i.e. crystal growth using liquid metal based heat pipes that work up to temperatures of 1800°C. These products are used to grow materials that are used in making electronics and night vision

googles.

Spacecraft Thermal Control: Many years have been devoted to developing and producing various thermal technologies for use on spacecraft and satellites. These technologies include constant conductance heat pipes (CCHPs), variable conductance heat pipes (VCHP), loop heat pipes (LHP), composite material heat pipes and laminated material heat pipes. These products remove heat from the interior of the spacecraft and reject it to the environment through radiation heat transfer. One of the most notable projects was the historic orbital flight of the Moon Mineralogy Mapper (M3) where scientists made a breakthrough discovery of significantly absorbed water on the moon. To help support this mission, Thermacore's thermal solutions were used, which included sophisticated radiator panels and high performance thermal straps, along with design and fabrication services.

Education

B.S. in Mechanical Engineering, Pennsylvania State University, State College, PA (1983)

Inventor or Co-Inventor on the following Patents:

Patent No.	Title
4917177	Cooled Artery Extension
6430024	Capacitor with Heat Pipe Cooling
4807697	External Artery Heat pipe
6675874	Heat Pipe System for Cooling Flywheel Energy Storage Systems
5273635	Electrolytic Heater
6169660	Stress Relieved Integrated Circuit Cooler
6446706	Flexible Heat Pipe
6808011	Heat Pipe System for Cooling Flywheel Energy Storage Systems

Recipient of NASA Space Act Awards - This award provides recognition for inventions and other scientific and technical contribution that have helped NASA to achieve its aeronautical and space goals.

1. High Performance Ambient Temperature Heat Pipe, November 1987
2. Heat Pipe Radiator Constructed from a Laminate Film, July 1993
3. Vacuum tight Carbon/Epoxy Composite Tubing, October 1993
4. Three Zone Crystal Growth Furnace using a Single Heat Pipe Element, April 1993
5. Constant Temperature Cold Zone Moving Gradient Furnace, April 1993
6. A Durable, Vacuum Tight Laminate for Heat Pipe Construction, September 1997
7. Flexible Heat Pipe, February 2004

Authored or Co-Authored the following Magazine Articles:

1. Gernert, N.J., North, M.T., Baldassarre, G.J., *High Performance Thermal Management Solutions for LEDs*, Lighting Technology Magazine, November/December 2013.
2. Gernert, N.J., North, M.T., *Heat Pipe Thermal Ground Planes with CTE Matching Increase Efficiency of Power-Generating Components*, The Journal of Modular Embedded Design, Fall 2011, Volume 15 Number 3.
3. Gernert, N.J., *Passive Heat Transfer Devices Respond to Satellite Application Demands*, ECN: Electronic Component News; Dec 2010, Vol. 54 Issue 14, p18.
4. Gernert, N.J., Wert, K., Cruse, E., *Multi-Kilowatt Heat Pipe Heat Sink Performance*, Official Proceedings of the International High Frequency Power Conversion; 125-131, 2001.
5. Engelhardt, Andreas, Gernert, N.J., Toth, J. E., *Novel Conduction-Cooling Techniques Enable Full VPX Functionality*, VME and Critical Systems, October 2011.
6. Gernert, N.J., *Heat-Pipe/Heat-Sink Technology Improves 6-kW Cooling*, Power Electronics Technology, October 2009

Authored or Co-Authored the following Technical Publications

1. Gernert, N.J., Fale, J.E., *Orientation Insensitive Loop Heat Pipes*, IECEC-98-J213 33rd Intersociety Engineering Conference on Energy Conversion, Colorado Springs, CO, August 2-6, 1998.
2. Zuo, Z.J., Fale, J.E., Gernert, N.J., “*Study of a Drainage Disk Thermosyphon Condenser Design*”, Enhanced Heat Transfer, 1999, Vol. 00, pp. 1-10.
3. Phillips, A.L., Gernert, N.J., *Loop Heat Pipe Anti-icing System for UAV*, 33rd Intersociety Engineering Conference on Energy Conversion, IECEC 98-240, Colorado Springs, CO, August 2-6, 1998.
4. Phillips, A.L., Fale, J.E., Gernert, N.J., Sarraf, D.B., Bienert, W.J., *Loop Heat Pipe Qualification for High Vibration and High-g Environments*, AIAA-98-0885, Reno Nevada, January 1998.

5. Zuo, Z., J., Fale, J.E., Gernert, N.J., *Study of a Drainage Disk Thermosyphon Condenser Design*, IECEC 98-030, 33rd Intersociety Engineering Conference on Energy Conversion, Colorado Springs, CO, August 2-6, 1998.
6. Zuo, Z., J., Fale, J., Gernert, N., J., *Thermosyphon Flooding Prediction*, IECEC 98-031, 33rd Intersociety Engineering Conference on Energy Conversion, Colorado Springs, CO, August 2-6, 1998.
7. Fale, J.E., Gernert, N.J., *Flexible Heat Pipe Radiator*, ICES-981682, 28th International Conference on Environmental Systems, Danvers, Massachusetts, July 13-16, 1998
8. Fale, J.E., Zuo, Z.J., Gernert, N.J., Goryca, M.L., *High Power Heat Pipe Heat Exchanger Development*, ICES-981682, 28th International Conference on Environmental Systems, Danvers, Massachusetts, July 13-16, 1998.
9. R. M. Shaubach and N. J. Gernert "High Performance Flexible Heat Pipes," 20th AIAA Thermophysics Conference, Williamsburg, Virginia, June 19-21, 1983.
10. N. J. Gernert, "Analysis and Performance Evaluation of Heat Pipes With Multiple Heat Sources", 4th AIAA Thermophysics and Heat Transfer Conference, Boston, Massachusetts, June 2-4, 1986.
11. N.J. Gernert, D.B. Sarraf, M. Steinburg, "Flexible Heat Pipe Cold Plates for Aircraft Thermal Control", 1991 SAE Aerotech Conference, Paper No. 912105, Long Beach, CA, September 24-27, 1991.
12. R. M. Shaubach, N.J. Gernert, "Sodium Heat Pipe with Sintered Wick and Artery Effects of Non-Condensable-Gas on Performance", Space Nuclear Power Conference, Albuquerque, New Mexico, January 1992.
13. N.J. Gernert, D.B. Sarraf, "A Thermal Analysis of an F/A-18 Wing Section for Actuator Thermal Control", 1992 SAE Aerospace Atlantic Conference, Paper No. 921023, Dayton, Ohio, April 7-10, 1992.
14. N.J. Gernert, S.D. Garner, "Ultra Lightweight Unfurlable Radiator for Lunar Base Heat Rejection", Space Nuclear Power and Propulsion Conference, Albuquerque, New Mexico, January 1993.
15. Gernert, N.J., Donovan, K.G., "Unfurlable Radiator for Lunar Base Heat Rejection", Paper #941326, 24th ICES and 5th ESSECS, Friedrichshafen, Germany, June 20-23, 1994.
16. Gernert, N.J., Fale, J.E., "Unfurlable Space Based Heat Pipe Radiator", Paper #961456, 26th ICES, Monterey, CA, July 8-11, 1996.

17. Baldassarre, G.J., Gernert, N.J., Gillies, D.C., Lehoczky, S.L., Palosz, W., *"The Moving Gradient Heat Pipe Furnace (MGHPF) for Microgravity Crystal Growth"*, 9th IHPC, Albuquerque, NM, May 1-5, 1996.
18. Gillies, D.C., Lehoczky, S.L., Gernert, N.J., Baldassarre, G.J., Bahr, C.W., *"The Moving Gradient Heat Pipe Furnace, and its Potential for Use in Space Flight Operations"*, AIAA 94-4450, AIAA Space Programs and Technologies Conference, September 27-29, 1994, Huntsville, AL.
19. Gernert, N.J., Sarraf, D.B., Armstrong, D.L., Blood, S. A., *"Aluminum Foil Lined Composite Tubing"*, STAIF-96, 2nd Spacecraft Thermal Control Symposium, Albuquerque, NM, January, 1996.
20. Gernert, N.J., Sarraf, D.B., Guenther, R., Miller-Hulbert, K., *"Composite Material Heat Pipe Radiator"*, (1996), STAIF-96, 2nd Spacecraft Thermal Control Symposium, Albuquerque, NM, January, 1996.
21. Gernert, N. J., Brown, J., *"Development of a Flexible Loop Heat Pipe Cold Plate"*, SAE Paper No. 951436, Aerospace Atlantic Conference, Dayton, Ohio, May 23-25, 1995.
22. Baldassarre, G. J., Gernert, N. J., Gottschlich, J., *"Loop Heat Pipe for Avionics Thermal Control"*, SAE Paper No. 961318, Aerospace Atlantic Conference, Dayton, Ohio, May 22-23, 1996.
23. Gernert, N. J., Baldassarre, G. J., Gottschlich, J. M., *"Fine Pore Loop Heat Pipe Wick Structure Development"*, Paper No. 961319, SAE Aerospace Atlantic Conference, Dayton, OH, May 22-23, 1996.
24. Sarraf, D.B., Gernert, N.J., *"Loop Heat Pipe Radiator"*, 2nd Spacecraft Thermal Control Symposium, STAIF 96, AIP Conference Proceedings 361, Albuquerque, NM, 1996.
25. Baldassarre, G.J., Gernert, N.J., Goryca, M.L., *"Heat Pipe Radiator for the M109 A6 Howitzer"*, , SAE Paper 960371, SAE International Congress & Exposition, Detroit, MI, February 26-29, 1996.
26. Shaubach, R.M., Gernert, N.J., *"Cold Fusion"*, Encyclopedia of Energy Technology and the Environment, First Edition, Wiley-Interscience, John Wiley & Sons, Inc.

Special Awards:

2014 Inducted into Eastern Lebanon Country School District (ELCO) Hall of Fame. This honor is presented to those former students that have excelled in their careers.

EXHIBIT B



US007066240B2

(12) **United States Patent**
Dussinger et al.

(10) **Patent No.:** **US 7,066,240 B2**
(45) **Date of Patent:** **Jun. 27, 2006**

(54) **INTEGRATED CIRCUIT HEAT PIPE HEAT SPREADER WITH THROUGH MOUNTING HOLES**

(75) Inventors: **Peter M. Dussinger**, Lititz, PA (US);
Thomas L. Myers, Lititz, PA (US)

(73) Assignee: **Thermal Corp.**, Wilmington, DE (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 751 days.

(21) Appl. No.: **09/852,322**

(22) Filed: **May 9, 2001**

(65) **Prior Publication Data**

US 2002/0023742 A1 Feb. 28, 2002

Related U.S. Application Data

(63) Continuation of application No. 09/310,397, filed on May 12, 1999, now Pat. No. 6,302,192.

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

(52) **U.S. Cl.** **165/104.26; 165/104.33; 361/700; 257/715**

(58) **Field of Classification Search** 165/80.2, 165/80.3, 104.21, 104.26, 104.33, 185, 46; 361/700; 257/714, 715; 174/15.2, 16.3
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,209,062 A	9/1965	Scholz	174/15
3,490,718 A	1/1970	Vary	244/1
3,519,067 A	7/1970	Schmidt	165/32
3,543,841 A	12/1970	Eastman et al.	165/80
3,680,189 A	8/1972	Noren	29/157.3

3,827,480 A	8/1974	Gammel et al.	165/105
3,834,457 A	9/1974	Madsen	165/105
4,046,190 A	9/1977	Marcus et al.	165/105
4,047,198 A	9/1977	Sekhon et al.	357/82
4,118,756 A	10/1978	Nelson et al.	361/385
4,145,708 A	3/1979	Ferro et al.	357/82

(Continued)

FOREIGN PATENT DOCUMENTS

DE	1284506	12/1968	
DE	1402509	8/1975	
FR	2579371	9/1986	
JP	52 034 673	3/1977	
JP	54-154277	5/1979	
SU	407160	4/1974	
SU	589531	1/1978	
SU	987357	1/1983	
SU	1261029	* 9/1986	165/104.26
SU	1476-297	4/1989	

OTHER PUBLICATIONS

Fujikura Ltd, Drawing of Lobster Heat Pipe, Part No. FHP-47201, Sep. 25, 1995.

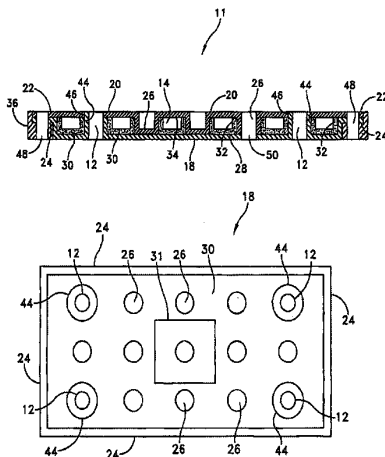
(Continued)

Primary Examiner—Ljiljana Ciric
(74) *Attorney, Agent, or Firm*—Duane Morris LLP

(57) **ABSTRACT**

The apparatus is a heat pipe with superior heat transfer between the heat pipe and the heat source and heat sink. The heat pipe is held tightly against the heat source by mounting holes which penetrate the structure of the heat pipe but are sealed off from the vapor chamber because they each are located within a sealed structure such as a pillar or the solid layers of the casing surrounding the vapor chamber. Another feature of the heat pipe is the use of more highly heat conductive material for only that part of the wick in the region which contacts the heat source, so that there is superior heat conductivity in that region.

14 Claims, 3 Drawing Sheets



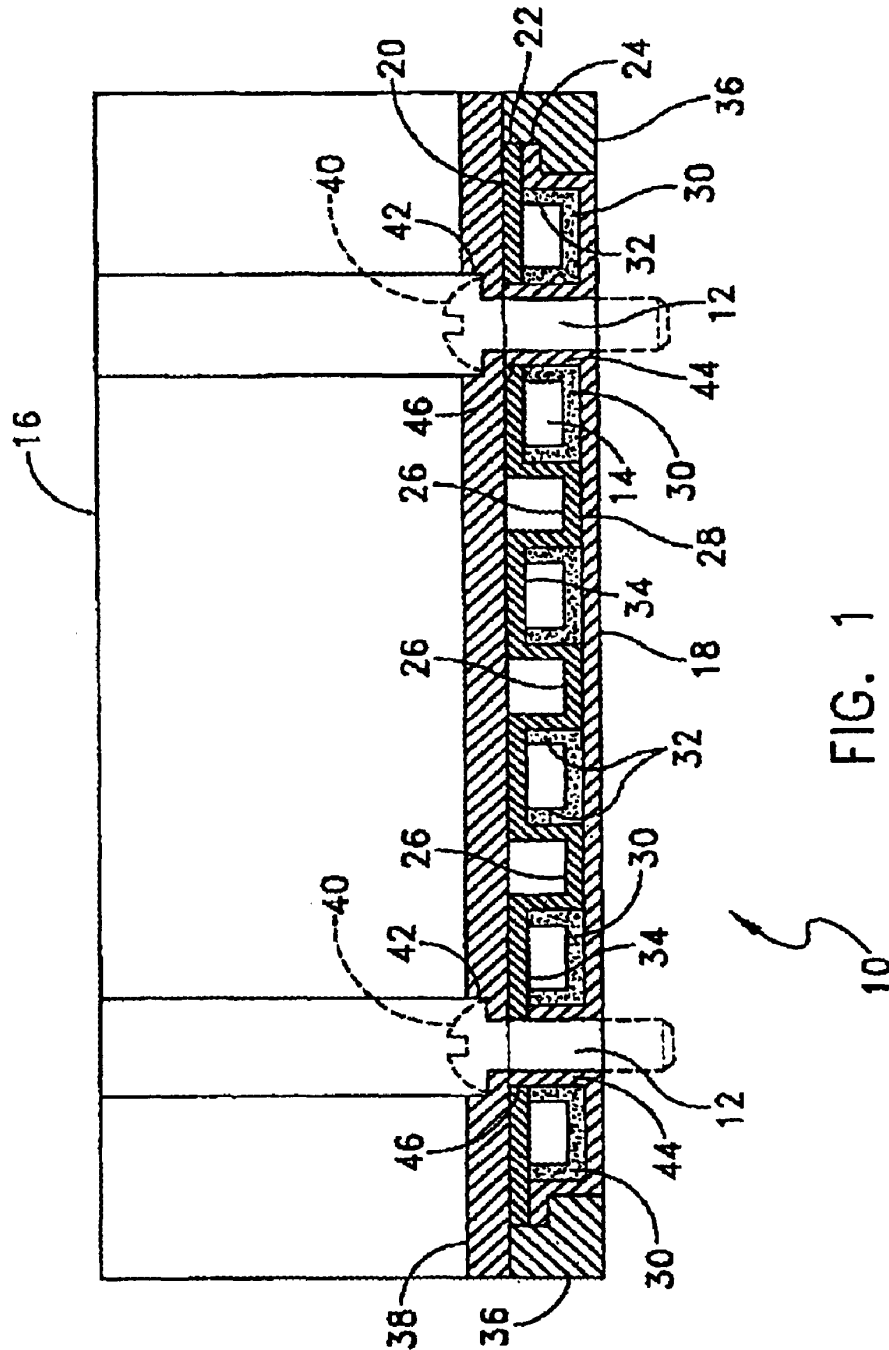
U.S. PATENT DOCUMENTS

4,461,343 A 7/1984 Token et al. 165/104.26
 4,793,405 A * 12/1988 Diggelmann et al. .. 165/104.33
 5,000,256 A 3/1991 Tousignant 165/46
 5,052,472 A 10/1991 Takahashi et al. 165/1
 5,305,184 A 4/1994 Andresen et al. 361/699
 5,305,185 A 4/1994 Samarov et al. 361/704
 5,323,292 A 6/1994 Brzezinski 361/689
 5,386,143 A 1/1995 Fitch 257/715
 5,390,077 A 2/1995 Paterson 361/700
 5,427,174 A 6/1995 Lomolino, Sr. et al. 165/1
 5,465,782 A 11/1995 Sun et al. 165/104.26
 5,513,070 A 4/1996 Xie et al. 361/700
 5,642,776 A 7/1997 Meyer, IV et al. 165/104.26
 5,694,295 A 12/1997 Mochizuki et al. 361/699
 5,754,401 A 5/1998 Saneinejad et al. 361/705
 5,784,256 A 7/1998 Nakamura et al. 361/699
 5,880,524 A 3/1999 Xie 257/704
 6,082,443 A 7/2000 Yamamoto et al. 165/104.26
 6,212,074 B1 4/2001 Gonsalves et al. 361/717
 6,256,201 B1 7/2001 Ikeda et al. 361/704
 6,263,959 B1 7/2001 Ikeda et al. 165/104.26
 6,269,866 B1 8/2001 Yamamoto et al. 165/104.26
 6,317,322 B1 11/2001 Ueki et al. 361/700

OTHER PUBLICATIONS

Fujikura Ltd, Report No. FHP-95-185, Lobster Heat Pipe for Cooling Alpha, Oct. 25, 1995, pp. 1-3.
 Fujikura America, Inc., Heat Pipe Quotation, Oct. 31, 1995.
 Low-Cost Cooling Package Article, by C. Nuccio, IBM Technical Disclosure Bulletin, vol. 18, No. 11, Apr. 1976, pp. 3761-3762.
 Conduction Cooled Heat Plate For Modular Circuit Package Article, by R.J. Dombrowskas and P.O. Patch, IBM Technical Disclosure Bulletin, vol. 13, No. 2, Jul. 1970, p. 442.
 Engineering Drawing No. FHP-0430-01 for Heat Sink Assembly by Sun Microsystems dated Apr. 30, 2001.
 Facsimile Cover Sheet from Sun Microsystems regarding drawing CH090W-971119 (980204) dated Feb. 4, 1998.
 Engineering Drawing No. CH090W-971119 dated Feb. 4, 1998 (see 980204 on drawing).
 Engineering Drawing dated Feb. 26, 1998.
 Auslegeschrift DE 1 284 506, "Supporting Plate for Temperature-Sensitive Electric Components," Translation from German, ICA Translation Number 32 596c.*

* cited by examiner



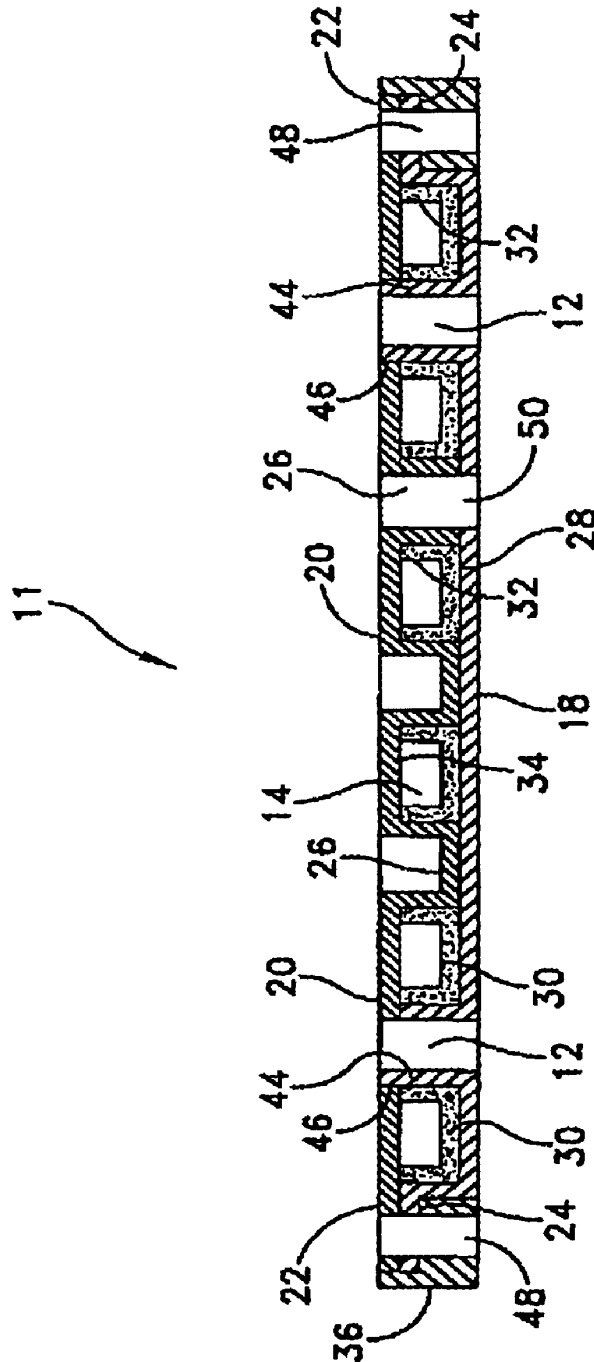


FIG. 2

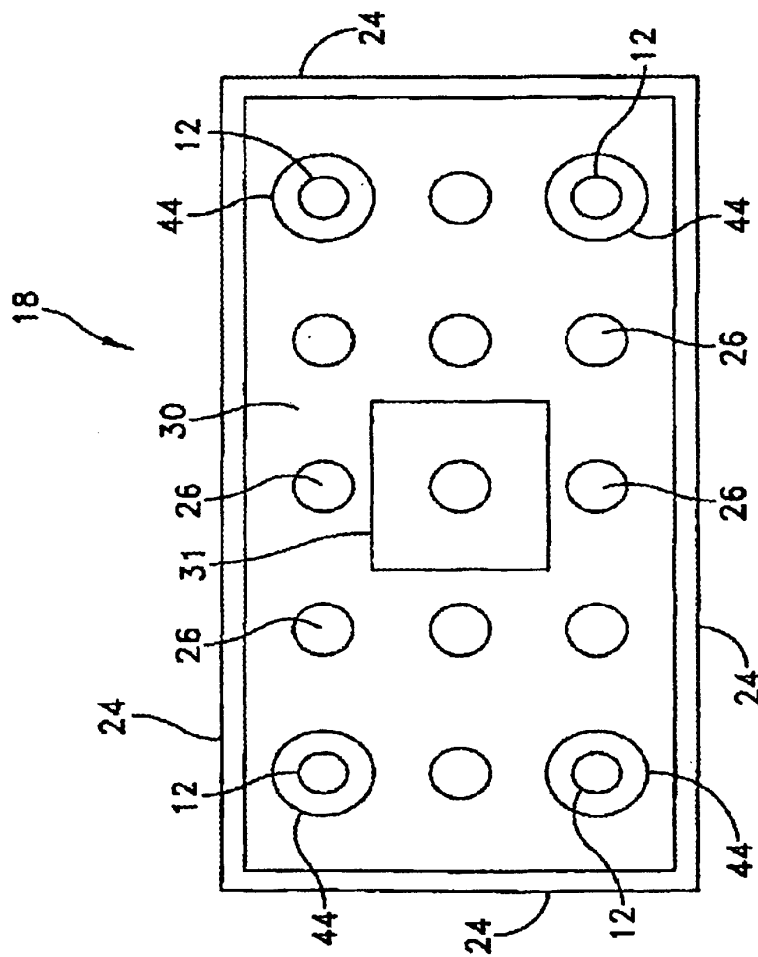


FIG. 3

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INTEGRATED CIRCUIT HEAT PIPE HEAT SPREADER WITH THROUGH MOUNTING HOLES

This application is a continuation application of U.S. application Ser. No. 09/310,397, filed on May 12, 1999, now U.S. Pat. No. 6,302,192.

BACKGROUND OF THE INVENTION

This invention relates generally to active solid state devices, and more specifically to a heat pipe for cooling an integrated circuit chip, with the heat pipe designed to be held in direct contact with the integrated circuit.

As integrated circuit chips decrease in size and increase in power, the required heat sinks and heat spreaders have grown to be larger than the chips. Heat sinks are most effective when there is a uniform heat flux applied over the entire heat input surface. When a heat sink with a large heat input surface is attached to a heat source of much smaller contact area, there is significant resistance to the flow of heat along the heat input surface of the heat sink to the other portions of the heat sink surface which are not in direct contact with the contact area of the integrated circuit chip. Higher power and smaller heat sources, or heat sources which are off center from the heat sink, increase the resistance to heat flow to the balance of the heat sink. This phenomenon can cause great differences in the effectiveness of heat transfer from various parts of a heat sink. The effect of this unbalanced heat transfer is reduced performance of the integrated circuit chip and decreased reliability due to high operating temperatures.

The brute force approach to overcoming the resistance to heat flow within heat sinks which are larger than the device being cooled is to increase the size of the heat sink, increase the thickness of the heat sink surface which contacts the device to be cooled, increase the air flow which cools the heat sink, or reduce the temperature of the cooling air. However, these approaches increase weight, noise, system complexity, and expense.

It would be a great advantage to have a simple, light weight heat sink for an integrated circuit chip which includes an essentially isothermal surface even though only a part of the surface is in contact with the chip, and also includes a simple means for assuring intimate contact with the integrated circuit chip to provide good heat transfer between the chip and the heat sink.

SUMMARY OF THE INVENTION

The present invention is an inexpensive heat pipe heat spreader for integrated circuit chips which is of simple, light weight construction. It is easily manufactured, requires little additional space, and provides additional surface area for cooling the integrated circuit and for attachment to heat transfer devices for moving the heat away from the integrated circuit chip to a location from which the heat can be more easily disposed of. Furthermore, the heat pipe heat spreader is constructed to assure precise flatness and to maximize heat transfer from the heat source and to the heat sink, and has holes through its body to facilitate mounting.

The heat spreader of the present invention is a heat pipe which requires no significant modification of the circuit board or socket because it is held in intimate contact with the integrated circuit chip by conventional screws attached to the integrated circuit mounting board. This means that the invention uses a very minimum number of simple parts. Furthermore, the same screws which hold the heat spreader

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against the chip can also be used to clamp a finned heat sink to the opposite surface of the heat spreader.

The internal structure of the heat pipe is an evacuated vapor chamber with a limited amount of liquid and includes a pattern of spacers extending between and contacting the two plates or any other boundary structure forming the vapor chamber. The spacers prevent the plates from bowing inward, and therefore maintain the vital flat surface for contact with the integrated circuit chip. These spacers can be solid columns, embossed depressions formed in one of the plates, or a mixture of the two. Porous capillary wick material also covers the inside surfaces of the heat pipe and has a substantial thickness surrounding the surfaces of the spacers within the heat pipe, thus forming pillars of porous wick surrounding the supporting spacers. The wick material therefore spans the space between the plates in multiple locations.

The spacers thus serve important purposes. They support the flat plates and prevent them from deflecting inward and distorting the plates to deform the flat surfaces which are required for good heat transfer. The spacers also serve as critical support for the portions of the capillary wick which span the internal space between the plates. The capillary wick pillars which span the space between the plates provide a gravity independent characteristic to the heat spreader, and the spacers around which the wick pillars are located assure that the capillary wick is not subjected to destructive compression forces.

The spacers also make it possible to provide holes into and through the vapor chamber, an apparent inconsistency since a heat pipe vacuum chamber is supposed to be vacuum tight. This is accomplished by bonding the spacers, if they are solid, to both plates of the heat pipe, or, if they are embossed in one plate, bonding the portions of the depressions which contact the opposite plate to that opposite plate. With the spacer bonded to one or both plates, a through hole can be formed within the spacer and it has no effect on the vacuum integrity of the heat pipe vapor chamber, from which the hole is completely isolated.

An alternate embodiment of the invention provides the same provision for mounting the heat pipe heat spreader with simple screws even when the heat pipe is constructed without internal spacers. This embodiment forms the through holes in the solid boundary structure around the outside edges of the two plates. This region of the heat pipe is by its basic function already sealed off from the vapor chamber by the bond between the two plates, and the only additional requirement for forming a through hole within it is that the width of the bonded region be larger than the diameter of the hole. Clearly, with the holes located in the peripheral lips, the heat pipe boundary structure can be any shape.

Another alternate embodiment of the invention provides for improved heat transfer between the integrated circuit chip and the heat pipe heat spreader. This is accomplished by using a different capillary wick material within the heat pipe at the location which is directly in contact with the chip. Instead of using the same sintered copper powder wick which is used throughout the rest of the heat pipe, the part of the wick which is on the region of the heat pipe surface which is in contact with the chip is constructed of higher thermal conductivity sintered powder. Such powder can be silver, diamond, or many other materials well known in the art. This provides for significantly better heat transfer in the most critical heat transfer area, right at the integrated circuit chip.

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The present invention thereby provides a heat pipe with superior heat transfer characteristics, and the simplest of all mounting devices, just several standard screws.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross section view of the preferred embodiment of the heat pipe of the invention with through holes through its vapor chamber and in contact with a finned heat sink.

FIG. 2 is a cross section view of an alternate embodiment of the heat pipe of the invention with through holes in the peripheral lips and in a depression in one plate.

FIG. 3 is a plan view of an internal surface of the contact plate of the preferred embodiment of the invention showing the region of the capillary wick constructed of sintered higher heat conductivity powder.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 is a cross section view of the preferred embodiment of a flat plate heat pipe 10 of the invention with through holes 12 through its vapor chamber 14 and in contact with finned heat sink 16.

Heat pipe 10 is constructed by forming a boundary structure by sealing together two formed plates, contact plate 18 and cover plate 20. Contact plate 18 and cover plate 20 are sealed together at their peripheral lips 22 and 24 by conventional means, such as soldering or brazing, to form heat pipe 10. Heat pipe 10 is then evacuated to remove all non-condensable gases and a suitable quantity of heat transfer fluid is placed within it. This is the conventional method of constructing a heat pipe, and is well understood in the art of heat pipes.

The interior of heat pipe 10 is, however, constructed unconventionally. While contact plate 18 is essentially flat with the exception of peripheral lip 24, cover plate 20 includes multiple depressions 26. Depressions 26 are formed and dimensioned so that, when contact plate 18 and cover plate 20 are joined, the flat portions of depressions 26 are in contact with inner surface 28 of contact plate 18. Depressions 26 thereby assure that the spacing between contact plate 18 and cover plate 20 will be maintained even though pressure differentials between the inside volume of heat pipe 10 and the surrounding environment might otherwise cause the plates to deflect toward each other.

Heat pipe 10 also includes internal sintered metal capillary wick 30 which covers the entire inside surface of contact plate 18. As is well understood in the art of heat pipes, a capillary wick provides the mechanism by which liquid condensed at the cooler condenser of a heat pipe is transported back to the hotter evaporator where it is evaporated. The vapor produced at the evaporator then moves to the condenser where it again condenses. The two changes of state, evaporation at the hotter locale and condensation at the cooler site, are what transport heat from the evaporator to the condenser.

In the present invention, heat pipe 10 also has capillary wick pillars 32 which bridge the space between contact plate 18 and cover plate 20. Pillars 32 thereby interconnect cover plate 20 and contact plate 18 with continuous capillary wick. This geometry assures that, even if heat pipe 10 is oriented so that cover plate 20 is lower than contact plate 18, liquid condensed upon inner surface 34 of cover plate 20 will still be in contact with capillary pillars 32. The liquid will therefore be moved back to inner surface 28 which functions

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as the evaporator because it is in contact with a heat generating integrated circuit (not shown). Capillary pillars 32 are wrapped around and supported by depressions 26, which prevents the structurally weaker capillary pillars 32 from suffering any damage.

FIG. 1 also shows frame 36 which is typically used to surround and protect heat pipe 10. Frame 34 completely surrounds heat pipe 10 and contacts lip 24 of contact plate 18. When heat pipe 10 is used to cool an integrated circuit chip (not shown) which is held against contact plate 18, cover plate 20 is held in intimate contact with fin plate 38, to which fins 16 are connected. The entire assembly of heat pipe 10, frame 34, and fin plate 38 is held together and contact plate 18 is held against an integrated circuit chip by conventional screws 40, shown in dashed lines, which are placed in holes 42 in fin plate 38 and through holes 12 in heat pipe 10, and are threaded into the mounting plate (not shown) for the integrated circuit chip.

Holes 12 penetrate heat pipe 10 without destroying its vacuum integrity because of their unique location. Holes 12 are located within sealed structures such as solid columns 44, and since columns 44 are bonded to cover plate 20 at locations 46, holes 12 passing through the interior of columns 44 have no effect on the interior of heat pipe 10.

The preferred embodiment of the invention has been constructed as heat pipe 10 as shown in FIG. 1. This heat pipe is approximately 3.0 inches by 3.5 inches with a total thickness of 0.200 inch. Cover plate 20 and contact plate 18 are constructed of OFHC copper 0.035 inch thick, and depressions 26 span the 0.100 inch height of the internal volume of heat pipe 10. The flat portions of depressions 26 are 0.060 inch in diameter. Capillary wick 30 is constructed of sintered copper powder and averages 0.040 inch thick. Columns 44 have a 0.250 inch outer diameter, and holes 12 are 0.210 in diameter.

FIG. 2 is a cross section view of an alternate embodiment of the flat plate heat pipe 11 of the invention with through holes 48 located within peripheral lips 22 and 24 of the heat pipe and hole 50 shown in another sealed structure, one of the depressions 26. The only requirement for forming hole 50 within a depression 26 is that the bottom of depression 26 must be bonded to inner surface 28 of contact plate 18 to prevent loss of vacuum within the heat pipe. Of course, the region of the peripheral edges is also a sealed structure since bonding between lips 22 and 24 is inherent because heat pipe 11 must be sealed at its edges to isolate the interior from the outside atmosphere.

The only differences between heat pipe 11 of FIG. 2 and heat pipe 10 of FIG. 1 are that finned heat sink 16 is not shown in FIG. 2, lips 22 and 24 are slightly longer in FIG. 2 to accommodate holes 48, and hole 50 is shown. In fact, through holes 12 shown in FIG. 1 are also included in FIG. 2. Although it is unlikely that holes 12, holes 48, and hole 50 would be used in the same assembly, manufacturing economies may make it desirable to produce all the holes in every heat pipe so that the same heat pipe heat spreader can be used with different configurations of finned heat sinks. The unused sets of holes have no effect on the operation or benefits of the invention.

FIG. 3 is a plan view of the internal surface of the contact plate 18 of heat pipe 10 of the invention showing region 31 of capillary wick 30. Region 31 is constructed of sintered silver powder. While the balance of capillary wick 30 is conventional sintered metal such as copper, region 31 of capillary wick 30, which is on the opposite surface of contact plate 18 from the integrated circuit chip (not shown),

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is formed of powdered silver. The higher thermal conductivity of silver yields significantly better heat conduction through region 31 of the wick 30, and thereby reduces the temperature difference between the integrated circuit chip and the vapor within heat pipe 10. This reduction of temperature difference directly affects the operation of heat pipe 10, and essentially results in a similar reduction in the operating temperature of the chip.

The invention thereby furnishes an efficient means for cooling an integrated circuit and does so without the need for larger heat spreaders which not only add weight but also do not transfer heat away from the integrated circuit as efficiently as does the heat pipe of the invention.

It is to be understood that the form of this invention as shown is merely a preferred embodiment. Various changes may be made in the function and arrangement of parts; equivalent means may be substituted for those illustrated and described; and certain features may be used independently from others without departing from the spirit and scope of the invention as defined in the following claims. For example, through holes could also penetrate heat pipe boundary structures with curved surfaces or heat pipe boundary structures with offset planes which create several different levels for contact with heat sources or heat sinks.

What is claimed as new and for which Letters Patent of the United States are desired to be secured is:

1. A heat pipe for spreading heat comprising:

a boundary structure including spaced-apart first and second plates that define an enclosed vapor chamber; at least one depression formed in said first plate which projects into said vapor chamber and is sealingly bonded to said second plate so as to form a bonded region;

an opening defined through said bonded region wherein the perimeter of said opening is defined within a portion of said bonded region such that said opening is isolated from said vapor chamber; and

at least one depression formed in said second plate which projects into said vapor chamber and is sealingly bonded to said first plate.

2. A heat pipe for spreading heat according to claim 1 comprising at least one spacer positioned within said vapor chamber and extending between and contacting said first and second plates.

3. A heat pipe for spreading heat according to claim 1 wherein said spaced-apart first and second plates include confronting interior surfaces; and

a wick positioned upon said confronting interior surfaces including that portion of the interior surface of said first plate that forms a surface of said depression within said vapor chamber.

4. A heat pipe for spreading heat according to claim 1 wherein said wick is constructed with at least two separate sections of different materials, with one section being located on said first plate interior surface and being formed of a material with higher heat conductivity than sections located on said second plate interior surface.

5. A heat pipe for spreading heat according to claim 1 wherein said depression comprises an annular outer surface that is brazed to a corresponding annular edge surface in said second plate.

6. A heat pipe for spreading heat according to claim 1 wherein said first and second plates each include a peripheral lip located at an edge of said boundary structure at which said peripheral lip of said first plate is sealingly bonded to said peripheral lip of said second plate.

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7. A heat pipe for spreading heat according to claim 1 wherein said at least one depression formed in said second plate comprises a flat portion that is in contact with an inner surface of said first plate.

8. A heat pipe for spreading heat according to claim 1 wherein said spaced-apart first and second plates include confronting interior surfaces; and

a wick positioned upon said confronting interior surfaces including that portion of the interior surface of said first plate that forms a surface of said depression within said vapor chamber.

9. A heat pipe for spreading heat comprising:

a boundary structure including spaced-apart first and second plates that define an enclosed vapor chamber;

at least one hollow column having an exterior surface positioned within said vapor chamber with a first portion of said exterior surface sealingly bonded to at least one of said first and second plates, and having an open first end that opens through said first plate and an open second end that opens through said second plate so as to form at least one mounting hole that is isolated from said vapor chamber.

10. A heat pipe for spreading heat according to claim 9 wherein said spaced-apart first and second plates include confronting interior surfaces; and

a wick positioned upon said confronting interior surfaces of said first and second plates and having a second portion of said exterior surface of said at least one hollow column disposed within said vapor chamber.

11. A heat pipe for spreading heat comprising:

a boundary structure including a first plate and a second plate arranged in spaced apart relation, each of said plates including interior confronting surfaces and a peripheral lip located at an edge of said boundary structure at which said peripheral lip of said first plate is sealingly bonded to said peripheral lip of said second plate so as to define an enclosed vapor chamber;

at least one depression formed in said first plate which projects into said vapor chamber, is spaced from said peripheral lip of said first plate, and is sealingly bonded to said second plate so as to form a bonded region;

an opening defined through said first plate depression and said second plate wherein said depression comprises an annular outer surface that is sealingly bonded to a corresponding annular edge surface in said second plate and further wherein the perimeter of said opening is defined within a portion of said bonded region such that said opening is isolated from said vapor chamber;

at least one spacer extending between and contacting said first and second plates; and

a wick positioned upon said confronting interior surfaces including that portion of the interior surface of said first plate that forms a surface of said depression within said vapor chamber.

12. A heat pipe for spreading heat comprising:

a first plate having a circumferential edge lip bounding an inner surface and at least one hollow column that is integral with said first plate and which projects outwardly relative to said inner surface;

a second plate arranged in spaced apart confronting relation to said first plate and including a circumferential edge lip bounding an inner surface and at least one opening through said second plate, said edge lips of said first and second plates being sealingly bonded together so as to define a vapor chamber; wherein

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said at least one hollow column being sealingly bonded at one end to said second plate so as to coaxially align said at least one hollow column with said at least one opening in said second plate thereby to form a mounting hole that extends through said first plate and said second plate and is isolated from said vapor chamber.

13. A heat pipe for spreading heat comprising:

a first plate having a circumferential edge lip bounding an inner surface and at least one depression which projects outwardly relative to said inner surface;

a second plate arranged in spaced apart confronting relation to said first plate and including a circumferential edge lip bounding an inner surface and at least one opening through said second plate, said edge lips of said first and second plates being sealingly bonded together so as to define a vapor chamber; wherein

said at least one depression has an open ended tubular cross-section and an outer surface, a portion of which outer surface is sealingly bonded to said second plate so as to coaxially align said at least one depression with said at least one opening in said second plate thereby to form a mounting hole that extends through said first plate depression and said second plate and is isolated from said vapor chamber.

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14. A heat pipe for spreading heat comprising:

a first plate having a circumferential edge lip bounding an inner surface and at least one depression which projects outwardly relative to said inner surface;

a second plate arranged in spaced apart confronting relation to said first plate and including (i) a circumferential edge lip bounding an inner surface, (ii) at least one depression which projects into said vapor chamber and that is sealingly bonded to said inner surface of said first plate, and (iii) at least one opening through said second plate, said edge lips of said first and second plates being sealingly bonded together so as to define a vapor chamber; wherein

said at least one depression in said first plate has a tubular cross-section that opens at a first end and a second end and is sealingly bonded to said second plate at said second end so as to coaxially align said at least one first plate depression with said at least one opening in said second plate thereby to form a mounting hole that extends through said first plate depression and said second plate and is isolated from said vapor chamber.

* * * * *



US007100679B2

(12) **United States Patent**
Dussinger et al.

(10) **Patent No.:** **US 7,100,679 B2**
(45) **Date of Patent:** **Sep. 5, 2006**

(54) **INTEGRATED CIRCUIT HEAT PIPE HEAT SPREADER WITH THROUGH MOUNTING HOLES**

(75) Inventors: **Peter M. Dussinger**, Lititz, PA (US);
Thomas L. Myers, Lititz, PA (US)

(73) Assignee: **Thermal Corp.**, Wilmington, DE (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 157 days.

4,046,190 A	9/1977	Marcus et al.
4,047,198 A	9/1977	Sekhon et al.
4,118,756 A	10/1978	Nelson et al.
4,145,708 A	3/1979	Ferro et al.
4,461,343 A	7/1984	Token et al.
5,000,256 A	3/1991	Tousignant
5,052,472 A	10/1991	Takahashi et al.
5,166,864 A *	11/1992	Chitwood et al. 361/705
5,305,184 A	4/1994	Andresen et al.
5,305,185 A	4/1994	Samarov et al.

(Continued)

(21) Appl. No.: **10/739,709**

FOREIGN PATENT DOCUMENTS

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DE 1 284 506 12/1968

(65) **Prior Publication Data**

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(Continued)

OTHER PUBLICATIONS

Related U.S. Application Data

(63) Continuation of application No. 09/852,322, filed on May 9, 2001, now Pat. No. 7,066,240, which is a continuation of application No. 09/310,397, filed on May 12, 1999, now Pat. No. 6,302,192.

IBM Technical Disclosure Bulletin; *Conduction Cooled Heat Plate For Modular Circuit Package*; Dombrowskas and Patch; vol. 13, No. 2, pp. 442, Jul. 1970.

(Continued)

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

(52) **U.S. Cl.** **165/104.26**; 165/104.21

(58) **Field of Classification Search** 165/104.26,
165/104.21, 104.33, 80.3, 185; 361/700,
361/705; 257/715

See application file for complete search history.

(57) **ABSTRACT**

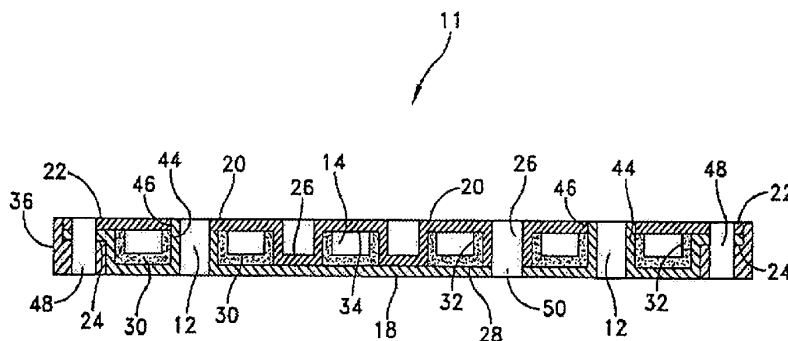
A heat pipe with superior heat transfer between the heat pipe and the heat source and heat sink. The heat pipe is held tightly against the heat source by mounting holes which penetrate the structure of the heat pipe but are sealed off from the vapor chamber because they each are located within a sealed structure such as a pillar or the solid layers of the casing surrounding the vapor chamber. Another feature of the heat pipe is the use of more highly heat conductive material for only that part of the wick in the region which contacts the heat source, so that there is superior heat conductivity in that region.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,209,062 A	9/1965	Scholz
3,490,718 A	1/1970	Vary
3,519,067 A	7/1970	Schmidt
3,543,841 A	12/1970	Eastman
3,680,189 A	8/1972	Noren
3,827,480 A	8/1974	Gammel et al.
3,834,457 A	9/1974	Madsen

7 Claims, 3 Drawing Sheets



US 7,100,679 B2

Page 2

U.S. PATENT DOCUMENTS

5,323,292 A 6/1994 Brzezinski
5,386,143 A 1/1995 Fitch
5,390,077 A 2/1995 Paterson
5,427,174 A 6/1995 Lomolino, Sr. et al.
5,465,782 A 11/1995 Sun et al.
5,513,070 A 4/1996 Xie et al.
5,642,776 A 7/1997 Meyer, IV et al.
5,694,295 A 12/1997 Mochizuki et al.
5,754,401 A 5/1998 Saneinejad et al.
5,757,621 A 5/1998 Patel
5,784,256 A 7/1998 Nakamura et al.
5,880,524 A 3/1999 Xie
6,082,443 A 7/2000 Yamamoto et al.
6,212,074 B1 4/2001 Gonsalves et al.
6,256,201 B1 7/2001 Ikeda et al.
6,263,959 B1 7/2001 Ikeda et al.
6,269,866 B1 8/2001 Yamamoto et al.
6,302,192 B1 10/2001 Dussinger et al.
6,317,322 B1 11/2001 Ueki et al.

6,356,448 B1 3/2002 DiBene, II et al.
6,535,386 B1 3/2003 Sathe et al.
6,650,544 B1 11/2003 Lai

FOREIGN PATENT DOCUMENTS

FR 2 579 371 9/1986
GB 1 402 509 8/1975
JP 54-154277 5/1979
SU 407160 4/1974
SU 589531 2/1978
SU 987357 1/1983
SU 1261029 9/1986
SU 1476297 4/1989

OTHER PUBLICATIONS

IBM Technical Disclosure Bulletin; *Low-Cost Cooling Package*,
Nuccio; vol. 18, No. 11, pp. 3761 & 3762, Apr. 1976.

* cited by examiner

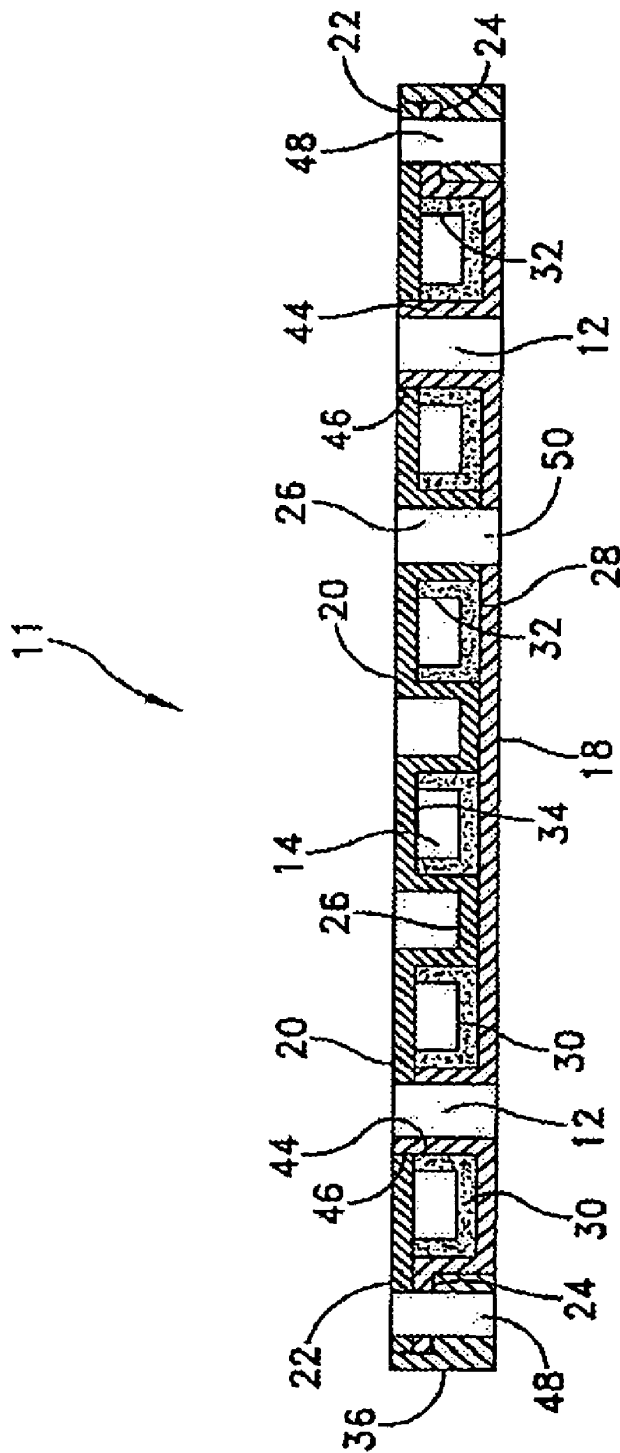


FIG. 2

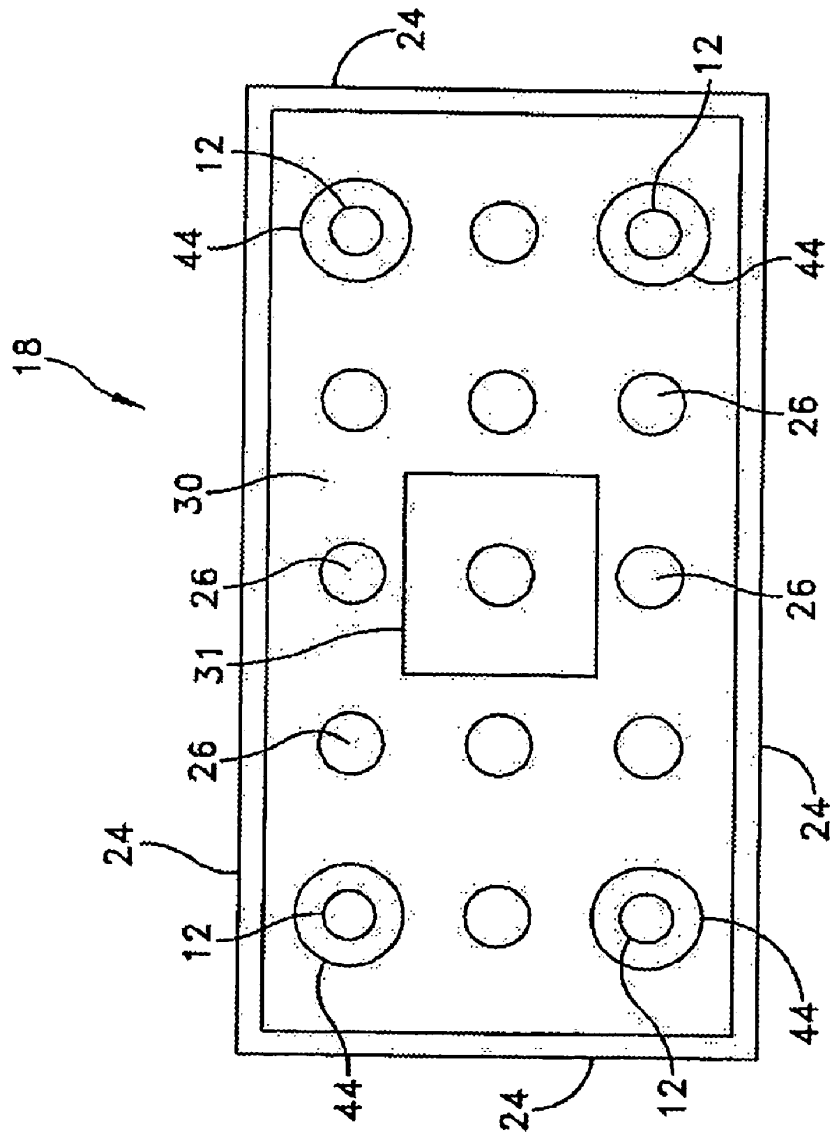


FIG. 3

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BACKGROUND OF THE INVENTION

This invention relates generally to active solid state devices, and more specifically to a heat pipe for cooling an integrated circuit chip, with the heat pipe designed to be held in direct contact with the integrated circuit.

As integrated circuit chips decrease in size and increase in power, the required heat sinks and heat spreaders have grown to be larger than the chips. Heat sinks are most effective when there is a uniform heat flux applied over the entire heat input surface. When a heat sink with a large heat input surface is attached to a heat source of much smaller contact area, there is significant resistance to the flow of heat along the heat input surface of the heat sink to the other portions of the heat sink surface which are not in direct contact with the contact area of the integrated circuit chip. Higher power and smaller heat sources, or heat sources which are off center from the heat sink, increase the resistance to heat flow to the balance of the heat sink. This phenomenon can cause great differences in the effectiveness of heat transfer from various parts of a heat sink. The effect of this unbalanced heat transfer is reduced performance of the integrated circuit chip and decreased reliability due to high operating temperatures.

The brute force approach to overcoming the resistance to heat flow within heat sinks which are larger than the device being cooled is to increase the size of the heat sink, increase the thickness of the heat sink surface which contacts the device to be cooled, increase the air flow which cools the heat sink, or reduce the temperature of the cooling air. However, these approaches increase weight, noise, system complexity, and expense.

It would be a great advantage to have a simple, light weight heat sink for an integrated circuit chip which includes an essentially isothermal surface even though only a part of the surface is in contact with the chip, and also includes a simple means for assuring intimate contact with the integrated circuit chip to provide good heat transfer between the chip and the heat sink.

SUMMARY OF THE INVENTION

The present invention is an inexpensive heat pipe heat spreader for integrated circuit chips which is of simple, light weight construction. It is easily manufactured, requires little additional space, and provides additional surface area for cooling the integrated circuit and for attachment to heat transfer devices for moving the heat away from the integrated circuit chip to a location from which the heat can be more easily disposed of. Furthermore, the heat pipe heat spreader is constructed to assure precise flatness and to maximize heat transfer from the heat source and to the heat sink, and has holes through its body to facilitate mounting.

The heat spreader of the present invention is a heat pipe which requires no significant modification of the circuit board or socket because it is held in intimate contact with the integrated circuit chip by conventional screws attached to

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the integrated circuit mounting board. This means that the invention uses a very minimum number of simple parts. Furthermore, the same screws which hold the heat spreader against the chip can also be used to clamp a finned heat sink to the opposite surface of the heat spreader.

The internal structure of the heat pipe is an evacuated vapor chamber with a limited amount of liquid and includes a pattern of spacers extending between and contacting the two plates or any other boundary structure forming the vapor chamber. The spacers prevent the plates from bowing inward, and therefore maintain the vital flat surface for contact with the integrated circuit chip. These spacers can be solid columns, embossed depressions formed in one of the plates, or a mixture of the two. Porous capillary wick material also covers the inside surfaces of the heat pipe and has a substantial thickness surrounding the surfaces of the spacers within the heat pipe, thus forming pillars of porous wick surrounding the supporting spacers. The wick material therefore spans the space between the plates in multiple locations.

The spacers thus serve important purposes. They support the flat plates and prevent them from deflecting inward and distorting the plates to deform the flat surfaces which are required for good heat transfer. The spacers also serve as critical support for the portions of the capillary wick which span the internal space between the plates. The capillary wick pillars which span the space between the plates provide a gravity independent characteristic to the heat spreader, and the spacers around which the wick pillars are located assure that the capillary wick is not subjected to destructive compression forces.

The spacers also make it possible to provide holes into and through the vapor chamber, an apparent inconsistency since a heat pipe vacuum chamber is supposed to be vacuum tight. This is accomplished by bonding the spacers, if they are solid, to both plates of the heat pipe, or, if they are embossed in one plate, bonding the portions of the depressions which contact the opposite plate to that opposite plate. With the spacer bonded to one or both plates, a through hole can be formed within the spacer and it has no effect on the vacuum integrity of the heat pipe vapor chamber, from which the hole is completely isolated.

An alternate embodiment of the invention provides the same provision for mounting the heat pipe heat spreader with simple screws even when the heat pipe is constructed without internal spacers. This embodiment forms the through holes in the solid boundary structure around the outside edges of the two plates. This region of the heat pipe is by its basic function already sealed off from the vapor chamber by the bond between the two plates, and the only additional requirement for forming a through hole within it is that the width of the bonded region be larger than the diameter of the hole. Clearly, with the holes located in the peripheral lips, the heat pipe boundary structure can be any shape.

Another alternate embodiment of the invention provides for improved heat transfer between the integrated circuit chip and the heat pipe heat spreader. This is accomplished by using a different capillary wick material within the heat pipe at the location which is directly in contact with the chip. Instead of using the same sintered copper powder wick which is used throughout the rest of the heat pipe, the part of the wick which is on the region of the heat pipe surface which is in contact with the chip is constructed of higher thermal conductivity sintered powder. Such powder can be silver, diamond, or many other materials well known in the

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art. This provides for significantly better heat transfer in the most critical heat transfer area, right at the integrated circuit chip.

The present invention thereby provides a heat pipe with superior heat transfer characteristics, and the simplest of all mounting devices, just several standard screws.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross section view of the preferred embodiment of the heat pipe of the invention with through holes through its vapor chamber and in contact with a finned heat sink.

FIG. 2 is a cross section view of an alternate embodiment of the heat pipe of the invention with through holes in the peripheral lips and in a depression in one plate.

FIG. 3 is a plan view of an internal surface the contact plate of the preferred embodiment of the invention showing the region of the capillary wick constructed of sintered higher heat conductivity powder.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 is a cross section view of the preferred embodiment of a flat plate heat pipe 10 of the invention with through holes 12 through its vapor chamber 14 and in contact with finned heat sink 16.

Heat pipe 10 is constructed by forming a boundary structure by sealing together two formed plates, contact plate 18 and cover plate 20. Contact plate 18 and cover plate 20 are sealed together at their peripheral lips 22 and 24 by conventional means, such as soldering or brazing, to form heat pipe 10. Heat pipe 10 is then evacuated to remove all non-condensable gases and a suitable quantity of heat transfer fluid is placed within it. This is the conventional method of constructing a heat pipe, and is well understood in the art of heat pipes.

The interior of heat pipe 10 is, however, constructed unconventionally. While contact plate 18 is essentially flat with the exception of peripheral lip 24, cover plate 20 includes multiple depressions 26. Depressions 26 are formed and dimensioned so that, when contact plate 18 and cover plate 20 are joined, the flat portions of depressions 26 are in contact with inner surface 28 of contact plate 18. Depressions 26 thereby assure that the spacing between contact plate 18 and cover plate 20 will be maintained even though pressure differentials between the inside volume of heat pipe 10 and the surrounding environment might otherwise cause the plates to deflect toward each other.

Heat pipe 10 also includes internal sintered metal capillary wick 30 which covers the entire inside surface of contact plate 18. As is well understood in the art of heat pipes, a capillary wick provides the mechanism by which liquid condensed at the cooler condenser of a heat pipe is transported back to the hotter evaporator where it is evaporated. The vapor produced at the evaporator then moves to the condenser where it again condenses. The two changes of state, evaporation at the hotter locale and condensation at the cooler site, are what transport heat from the evaporator to the condenser.

In the present invention, heat pipe 10 also has capillary wick pillars 32 which bridge the space between contact plate 18 and cover plate 20. Pillars 32 thereby interconnect cover plate 16 and contact plate 14 with continuous capillary wick. This geometry assures that, even if heat pipe 10 is oriented so that cover plate 16 is lower than contact plate 14, liquid

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condensed upon inner surface 34 of cover plate 20 will still be in contact with capillary pillars 32. The liquid will therefore be moved back to raised surface 28 which functions as the evaporator because it is in contact with a heat generating integrated circuit (not shown). Capillary pillars 32 are wrapped around and supported by depressions 26, which prevents the structurally weaker capillary pillars 32 from suffering any damage.

FIG. 1 also shows frame 36 which is typically used to surround and protect heat pipe 10. Frame 34 completely surrounds heat pipe 10 and contacts lip 24 of contact plate 18. When heat pipe 10 is used to cool an integrated circuit chip (not shown) which is held against contact plate 18, cover plate 20 is held in intimate contact with fin plate 38, to which fins 16 are connected. The entire assembly of heat pipe 10, frame 34, and fin plate 38 is held together and contact plate 18 is held against an integrated circuit chip by conventional screws 40, shown in dashed lines, which are placed in holes 42 in fin plate 38 and through holes 12 in heat pipe 10, and are threaded into the mounting plate (not shown) for the integrated circuit chip.

Holes 12 penetrate heat pipe 10 without destroying its vacuum integrity because of their unique location. Holes 12 are located within sealed structures such as solid columns 44, and since columns 44 are bonded to cover plate 20 at locations 46, holes 12 passing through the interior of columns 44 have no affect on the interior of heat pipe 10.

The preferred embodiment of the invention has been constructed as heat pipe 10 as shown in FIG. 1. This heat pipe is approximately 3.0 inches by 3.5 inches with a total thickness of 0.200 inch. Cover plate 20 and contact plate 18 are constructed of OFHC copper 0.035 inch thick, and depressions 26 span the 0.100 inch height of the internal volume of heat pipe 10. The flat portions of depressions 26 are 0.060 inch in diameter. Capillary wick 30 is constructed of sintered copper powder and averages 0.040 inch thick. Columns 44 have a 0.250 inch outer diameter, and holes 12 are 0.210 in diameter.

FIG. 2 is a cross section view of an alternate embodiment of the flat plate heat pipe 11 of the invention with through holes 48 located within peripheral lips 22 and 24 of the heat pipe and hole 50 shown in another sealed structure, one of the depressions 26. The only requirement for forming hole 50 within a depression 26 is that the bottom of depression 26 must be bonded to inner surface 28 of contact plate 18 to prevent loss of vacuum within the heat pipe. Of course, the region of the peripheral edges is also a sealed structure since bonding between lips 22 and 24 is inherent because heat pipe 11 must be sealed at its edges to isolate the interior from the outside atmosphere.

The only differences between heat pipe 11 of FIG. 2 and heat pipe 10 of FIG. 1 are that finned heat sink 16 is not shown in FIG. 2, lips 22 and 24 are slightly longer in FIG. 2 to accommodate holes 48, and hole 50 is shown. In fact, through holes 12 shown in FIG. 12 are also included in FIG. 2. Although it is unlikely that holes 12, holes 48, and hole 50 would be used in the same assembly, manufacturing economies may make it desirable to produce all the holes in every heat pipe so that the same heat pipe heat spreader can be used with different configurations of finned heat sinks. The unused sets of holes have no effect on the operation or benefits of the invention.

FIG. 3 is a plan view of the internal surface of the contact plate 18 of heat pipe 10 of the invention showing region 31 of capillary wick 30. Region 31 is constructed of sintered silver powder. While the balance of capillary wick 30 is conventional sintered metal such as copper, region 31 of

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capillary wick 30, which is on the opposite surface of contact plate 18 from the integrated circuit chip (not shown), is formed of powdered silver. The higher thermal conductivity of silver yields significantly better heat conduction through region 31 of the wick 30, and thereby reduces the temperature difference between the integrated circuit chip and the vapor within heat pipe 10. This reduction of temperature difference directly affects the operation of heat pipe 10, and essentially results in a similar reduction in the operating temperature of the chip.

The invention thereby furnishes an efficient means for cooling an integrated circuit and does so without the need for larger heat spreaders which not only add weight but also do not transfer heat away from the integrated circuit as efficiently as does the heat pipe of the invention.

It is to be understood that the form of this invention as shown is merely a preferred embodiment. Various changes may be made in the function and arrangement of parts; equivalent means may be substituted for those illustrated and described; and certain features may be used independently from others without departing from the spirit and scope of the invention as defined in the following claims. For example, through holes could also penetrate heat pipe boundary structures with curved surfaces or heat pipe boundary structures with offset planes which create several different levels for contact with heat sources or heat sinks.

The invention claimed is:

1. A heat pipe for spreading heat comprising:

a boundary structure including spaced-apart first and second plates that define an enclosed vapor chamber, and at least one spacer positioned within said vapor chamber and extending between and contacting said first and second plates;

a depression formed in said first plate which projects into said vapor chamber and is bonded to said second plate; and

an opening defined through said depression and said second plate wherein said opening is isolated from said vapor chamber.

2. A heat pipe for spreading heat according to claim 1 wherein said spaced-apart first and second plates include confronting interior surfaces; and

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a wick positioned upon said confronting interior surfaces including that portion of the interior surface of said first plate that forms a surface of said depression within said vapor chamber.

3. A heat pipe for spreading heat according to claim 2 wherein said wick is constructed with at least two separate sections of different materials, with one section being located on said first plate interior surface and being formed of a material with higher heat conductivity than another section located on said second plate interior surface.

4. A heat pipe for spreading heat according to claim 1 wherein said depression comprises an annular outer surface that is bonded to a corresponding annular edge surface in said second plate.

5. A heat pipe for spreading heat according to claim 1 wherein said first and second plates each include a peripheral lip located at an edge of said boundary structure which are bonded together.

6. A heat pipe for spreading heat comprising:

a boundary structure including spaced-apart first and second plates that define an enclosed vapor chamber wherein said spaced-apart first and second plates include confronting interior surfaces;

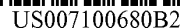
a depression formed in said first plate which projects into said vapor chamber and is bonded to said second plate; a wick positioned upon said confronting interior surfaces including that portion of the interior surface of said first plate that forms a surface of said depression within said vapor chamber;

an opening defined through said first plate depression and said second plate wherein said opening is isolated from said vapor chamber; and

a depression formed in said second plate which projects into said vapor chamber and is bonded to said first plate.

7. A heat pipe for spreading heat according to claim 6 wherein said depression formed in said second plate comprises a flat portion that is in contact with an inner surface of said first plate.

* * * * *



(10) **Patent No.:** **US 7,100,680 B2**
(45) **Date of Patent:** ***Sep. 5, 2006**

- (56) **References Cited**
- U.S. PATENT DOCUMENTS
- | | | | |
|-----------|---|---------|---------------|
| 3,209,062 | A | 9/1965 | Schotz |
| 3,490,718 | A | 1/1970 | Vary |
| 3,519,067 | A | 7/1970 | Schmidt |
| 3,543,841 | A | 12/1970 | Eastman |
| 3,680,189 | A | 8/1972 | Noren |
| 3,827,480 | A | 8/1974 | Gammel et al. |
| 3,834,457 | A | 9/1974 | Madsen |
| 4,046,190 | A | 9/1977 | Marcus et al. |
| 4,047,198 | A | 9/1977 | Sekhon et al. |

(Continued)

FOREIGN PATENT DOCUMENTS

DE	1 284 506	12/1968
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(Continued)

OTHER PUBLICATIONS

IBM Technical Disclosure Bulletin; *Conduction Cooled Heat Plate For Modular Circuit Package*; Dombrowskas and Patch; vol. 13, No. 2, pp. 442, Jul. 1970.

(Continued)

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(74) *Attorney, Agent, or Firm*—Duane Morris LLP

(57) **ABSTRACT**

The apparatus is a heat pipe with superior heat transfer between the heat pipe and the heat source and heat sink. The heat pipe is held tightly against the heat source by mounting holes which penetrate the structure of the heat pipe but are sealed off from the vapor chamber because they each are located within a sealed structure such as a pillar or the solid layers of the casing surrounding the vapor chamber. Another feature of the heat pipe is the use of more highly heat conductive material for only that part of the wick in the region which contacts the heat source, so that there is superior heat conductivity in that region.

11 Claims, 3 Drawing Sheets

(65) **Prior Publication Data**

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Related U.S. Application Data

- (60) Division of application No. 10/739,709, filed on Dec. 18, 2003, which is a continuation of application No. 09/852,322, filed on May 9, 2001, now Pat. No. 7,066,240, which is a continuation of application No. 09/310,397, filed on May 12, 1999, now Pat. No. 6,302,192.
- (51) **Int. Cl.**
F28D 15/00 (2006.01)
F28F 7/00 (2006.01)
- (52) **U.S. Cl.** **165/104.26**; 165/104.21;
165/83; 165/185; 165/76; 361/700; 257/715
- (58) **Field of Classification Search** 165/104.26,
165/104.21, 104.33, 80.3, 76, 185; 361/700;
257/715

See application file for complete search history.



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U.S. PATENT DOCUMENTS

4,118,756	A	10/1978	Nelson et al.
4,145,708	A	3/1979	Ferro et al.
4,461,343	A	7/1984	Token et al.
5,000,256	A	3/1991	Tousignant
5,052,472	A	10/1991	Takahashi et al.
5,305,184	A	4/1994	Andresen et al.
5,305,185	A	4/1994	Samarov et al.
5,323,292	A	6/1994	Brzezinski
5,386,143	A	1/1995	Fitch
5,390,077	A	2/1995	Paterson
5,427,174	A	6/1995	Lomolino, Sr. et al.
5,465,782	A	11/1995	Sun et al.
5,513,070	A	4/1996	Xie et al.
5,642,776	A	7/1997	Meyer, IV et al.
5,694,295	A	12/1997	Mochizuki et al.
5,754,401	A	5/1998	Saneinejad et al.
5,757,621	A	5/1998	Patel
5,784,256	A	7/1998	Nakamura et al.
5,880,524	A	3/1999	Xie
6,082,443	A	7/2000	Yamamoto et al.
6,212,074	B1	4/2001	Gonsalves et al.
6,256,201	B1	7/2001	Ikeda et al.
6,263,959	B1	7/2001	Ikeda et al.
6,269,866	B1	8/2001	Yamamoto et al.
6,302,192	B1	10/2001	Dussinger et al.
6,317,322	B1	11/2001	Ueki et al.
6,356,448	B1	3/2002	DiBene, II et al.
6,535,386	B1	3/2003	Sathe et al.
6,650,544	B1	11/2003	Lai

FOREIGN PATENT DOCUMENTS

FR	2 579 371	9/1986
GB	1 402 509	8/1975

JP	52034673	3/1977
JP	54-154277	5/1979
JP	62-078729	4/1987
JP	2-087344	3/1990
JP	6-301976	10/1994
JP	7-073508	3/1995
JP	9-017033	1/1997
SU	407160	4/1974
SU	589531	2/1978
SU	987357	1/1983
SU	126102 9	9/1986
SU	1261029	9/1986
SU	1476297	4/1989

OTHER PUBLICATIONS

IBM Technical Disclosure Bulletin; *Low-Cost Cooling Package*, Nuccio; vol. 18, No. 11, pp. 3761 & 3762, Apr. 1976.

Low-Cost Cooling Package Article, by C. Nuccio, IBM Technical Disclosure Bulletin, vol. 18, No. 11, Apr. 1976, pp. 3761-3762.

Conduction Cooled Heat Plate For Modular Circuit Package Article, R.J. Dombrowskas and P.O. Patch, IBM Technical Disclosure Bulletin, vol. 13, No. 2, Jul. 1970, p. 442.

Fujikura Ltd, Drawing of Lobster Heat Pipe, Part. No. FHP-47201, Sep. 25, 1995.

Fujikura Ltd, Report No. FHP-95-185, Lobster Heat Pipe For Cooling Alpha, Oct. 25, 1995, pp. 1-3.

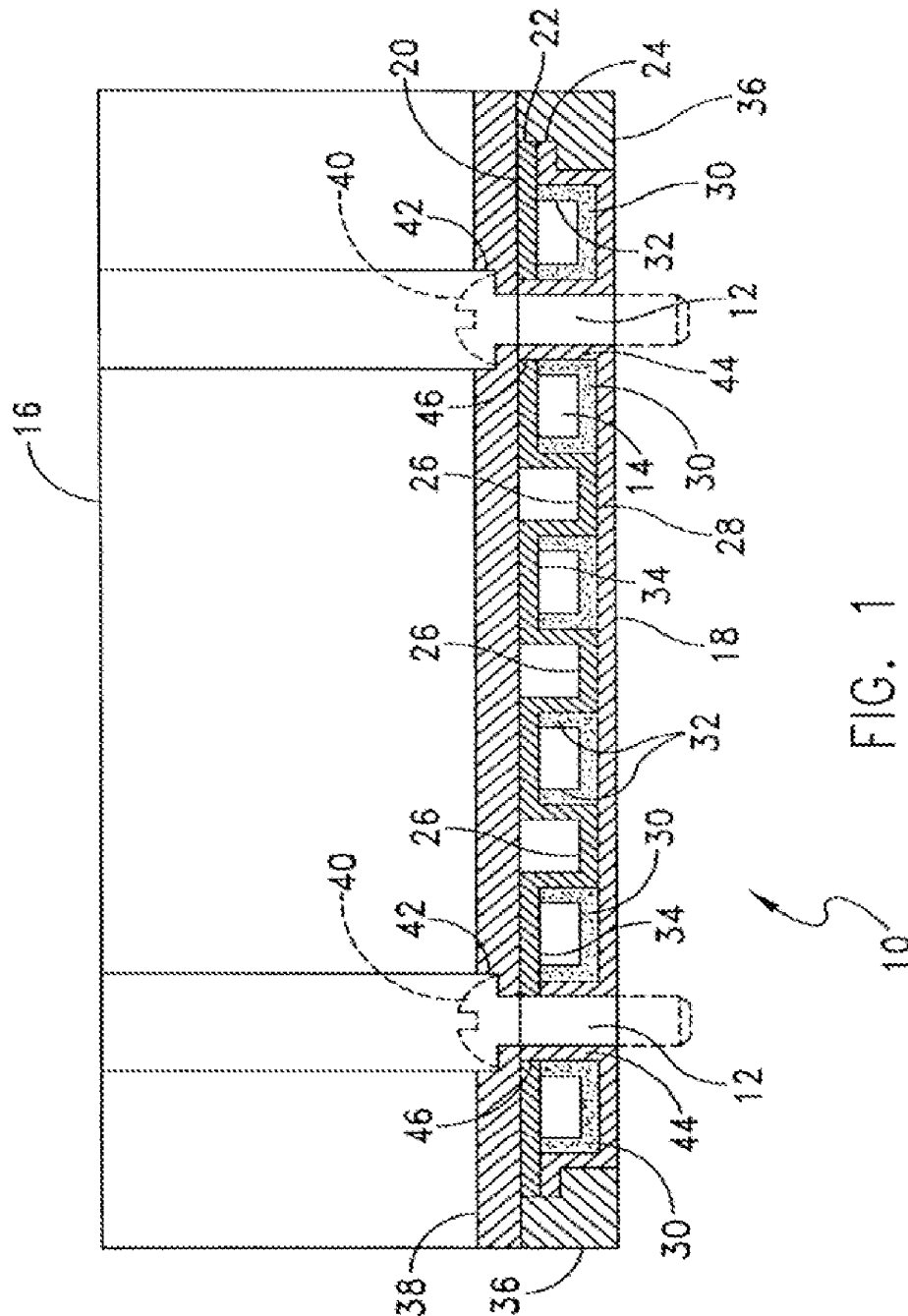
Fujikura America, Inc., Heat Pipe Quotation, Oct. 31, 1995.

Engineering Drawing No. FHP-0430-01 for Heat Sink Assembly by Sun Microsystems dated Apr. 30, 2001.

Facsimile Cover Sheet from Sun Microsystems regarding drawing CH090W-971119 (980204) dated Feb. 4, 1998.

Engineering Drawing No. CH090W-971119 dated Feb. 4, 1998 (see 980204 on drawing).

Engineering Drawing dated Feb. 26, 1998.



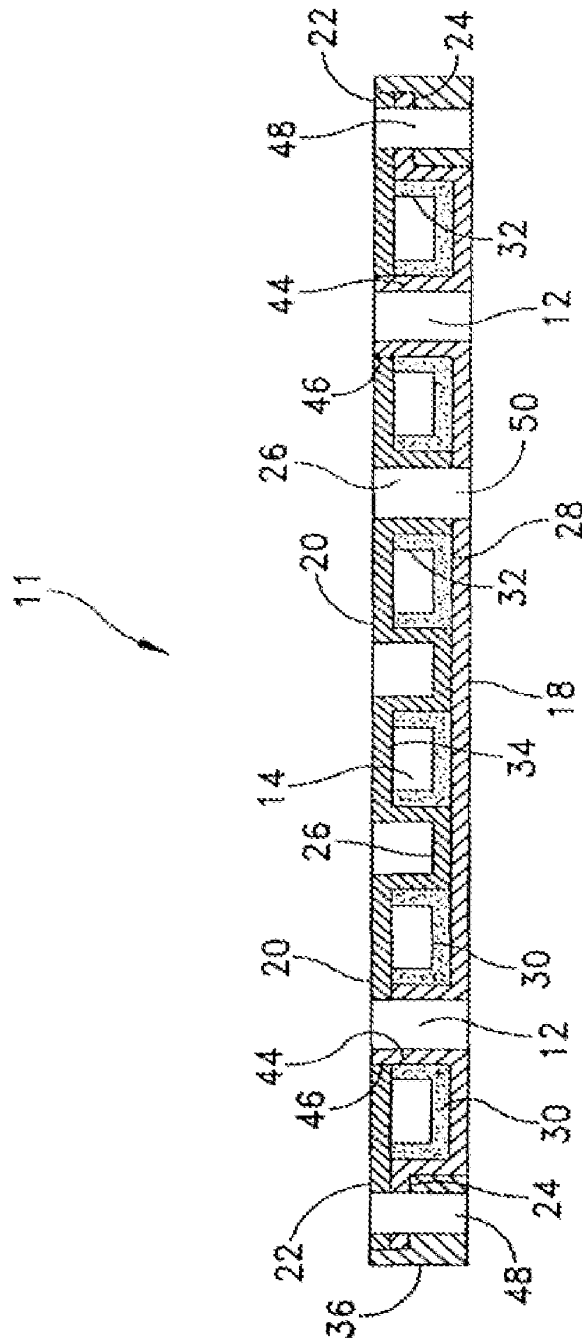


FIG. 2

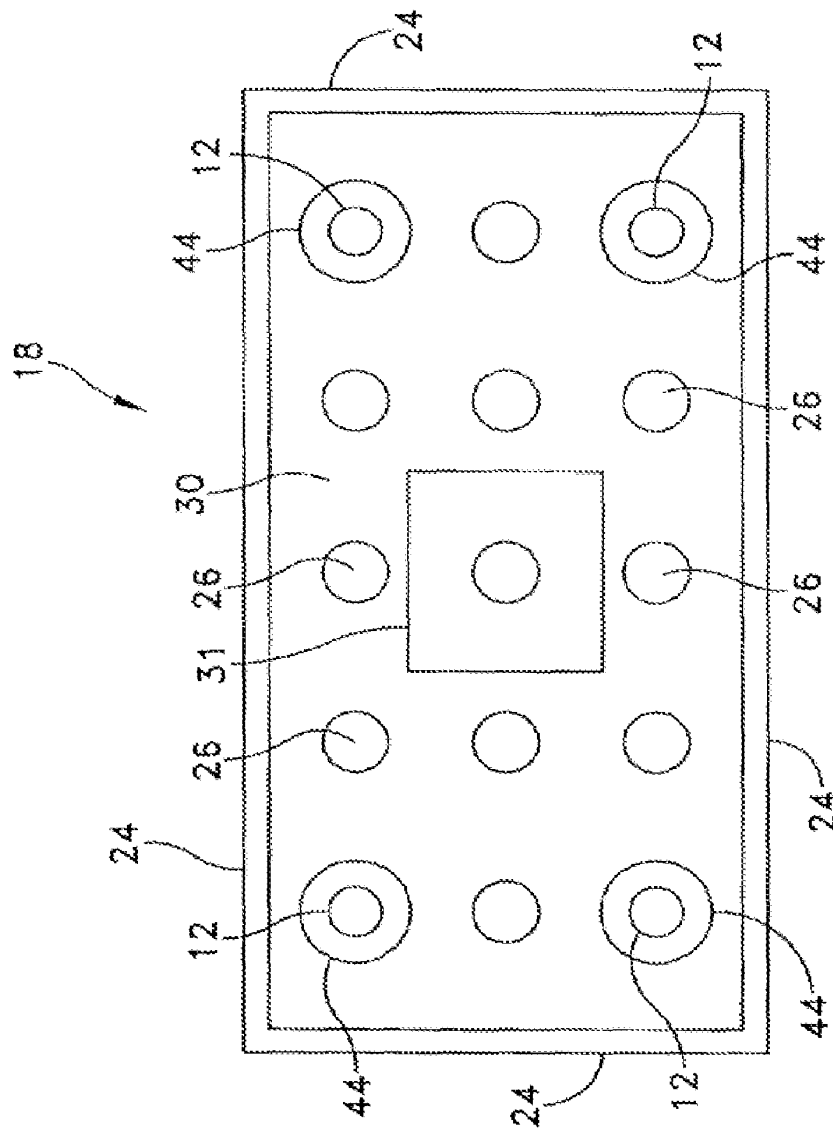


FIG. 3

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INTEGRATED CIRCUIT HEAT PIPE HEAT SPREADER WITH THROUGH MOUNTING HOLES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a Divisional application of U.S. Ser. No. 10/739,709, filed on Dec. 18, 2003, which is itself a Continuation application of copending U.S. application Ser. No. 09/852,322, filed on May 9, 2001 now U.S. Pat. No. 7,066,240, which is itself a continuation application of U.S. application Ser. No. 09/310,397, filed on May 12, 1999, and now issued as U.S. Pat. No. 6,302,192.

BACKGROUND OF THE INVENTION

This invention relates generally to active solid state devices, and more specifically to a heat pipe for cooling an integrated circuit chip, with the heat pipe designed to be held in direct contact with the integrated circuit.

As integrated circuit chips decrease in size and increase in power, the required heat sinks and heat spreaders have grown to be larger than the chips. Heat sinks are most effective when there is a uniform heat flux applied over the entire heat input surface. When a heat sink with a large heat input surface is attached to a heat source of much smaller contact area, there is significant resistance to the flow of heat along the heat input surface of the heat sink to the other portions of the heat sink surface which are not in direct contact with the contact area of the integrated circuit chip. Higher power and smaller heat sources, or heat sources which are off center from the heat sink, increase the resistance to heat flow to the balance of the heat sink. This phenomenon can cause great differences in the effectiveness of heat transfer from various parts of a heat sink. The effect of this unbalanced heat transfer is reduced performance of the integrated circuit chip and decreased reliability due to high operating temperatures.

The brute force approach to overcoming the resistance to heat flow within heat sinks which are larger than the device being cooled is to increase the size of the heat sink, increase the thickness of the heat sink surface which contacts the device to be cooled, increase the air flow which cools the heat sink, or reduce the temperature of the cooling air. However, these approaches increase weight, noise, system complexity, and expense.

It would be a great advantage to have a simple, light weight heat sink for an integrated circuit chip which includes an essentially isothermal surface even though only a part of the surface is in contact with the chip, and also includes a simple means for assuring intimate contact with the integrated circuit chip to provide good heat transfer between the chip and the heat sink.

SUMMARY OF THE INVENTION

The present invention is an inexpensive heat pipe heat spreader for integrated circuit chips which is of simple, light weight construction. It is easily manufactured, requires little additional space, and provides additional surface area for cooling the integrated circuit and for attachment to heat transfer devices for moving the heat away from the integrated circuit chip to a location from which the heat can be more easily disposed of. Furthermore, the heat pipe heat spreader is constructed to assure precise flatness and to

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maximize heat transfer from the heat source and to the heat sink, and has holes through its body to facilitate mounting.

The heat spreader of the present invention is a heat pipe which requires no significant modification of the circuit board or socket because it is held in intimate contact with the integrated circuit chip by conventional screws attached to the integrated mounting board. This means that the invention uses a very minimum number of simple parts. Furthermore, the same screws which hold the heat spreader against the chip can also be used to clamp a finned heat sink to the opposite surface of the heat spreader.

The internal structure of the heat pipe is an evacuated vapor chamber with a limited amount of liquid and includes a pattern of spacers extending between and contacting the two plates or any other boundary structure forming the vapor chamber. The spacers prevent the plates from bowing inward, and therefore maintain the vital flat surface for contact with the integrated circuit chip. These spacers can be solid columns, embossed depressions formed in one of the plates, or a mixture of the two. Porous capillary wick material also covers the inside surfaces of the heat pipe and has a substantial thickness surrounding the surfaces of the spacers within the heat pipe, thus forming pillars of porous wick surrounding the supporting spacers. The wick therefore spans the space between the plates in multiple locations.

The spacers thus serve important purposes. They support the flat plates and prevent them from deflecting inward and distorting the plates to deform the flat surfaces which are required for good heat transfer. The spacers also serve as critical support for the portions of the capillary wick pillars which span the space between the plates provide a gravity independent characteristic to the heat spreader, and the spacers around which the wick pillars are located assure that the capillary wick is not subjected to destructive compression forces.

The spacers also make it possible to provide holes into and through the vapor chamber, an apparent inconsistency since the heat pipe vacuum chamber is supposed to be vacuum tight. This is accomplished by bonding the spacers, if they are solid, to both plates of the heat pipe, or, if they are embossed in one plate, bonding the portions of the depressions which contact the opposite plate to that opposite plate. With the spacer bonded to one or both plates, a through hole can be formed within the spacer and it has no effect on the vacuum integrity of the heat pipe vapor chamber, from which the hole is completely isolated.

An alternate embodiment of the invention provides the same provision for mounting the heat pipe spreader with simple screws even when the heat pipe is constructed without internal spacers. This embodiment forms the through holes in the solid boundary structure around the outside edges of the two plates. This region of the heat pipe is by its basic function already sealed off from the vapor chamber by the bond between the two plates, and the only additional requirement for forming a through hole within it is that the width of the bonded region be larger than the diameter of the hole. Clearly, with the holes located in the peripheral lips, the heat pipe boundary structure can be any shape.

Another alternative embodiment of the invention provides for improved heat transfer between the integrated circuit chip and the heat pipe heat spreader. This is accomplished by using a different capillary wick material within the heat pipe at the location which is directly in contact with the chip. Instead of using the same sintered copper powder wick which is used throughout the rest of the heat pipe, the part of the wick which is on the region of the heat pipe surface

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which is in contact with the chip is constructed of higher thermal conductivity sintered powder. Such powder can be silver, diamond, or many other materials well known in the art. This provides for significantly better heat transfer in the most critical heat transfer area, right at the integrated circuit chip.

The present invention thereby provides a heat pipe superior heat transfer characteristics, and the simplest of all mounting devices, just several standard screws.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross section view of the preferred embodiment of a flat plate heat pipe 10 of the invention with through holes 12 through its vapor chamber 14 and in contact with finned heat sink 16.

FIG. 2 is a cross section view of an alternate embodiment of the heat pipe of the invention with through holes in the peripheral lips and in a depression in one plate.

FIG. 3 is a plan view of an internal surface the contact plate of the preferred embodiment of the invention showing the region of the capillary wick constructed of the sintered high heat conductivity powder.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 is a cross section view of the preferred embodiment of a flat plate heat pipe 10 of the invention with through holes 12 through its vapor chamber 14 and in contact with finned heat sink 16.

Heat pipe 10 is constructed by forming a boundary structure by sealing together two formed plates, contact plate 18 and cover plate 20. Contact plate 18 and cover plate 20 are sealed together at their peripheral lips 22 and 24 by conventional means, such as soldering or brazing, to form heat pipe 10. Heat pipe 10 is then evacuated to remove all non-condensable gases and a suitable quantity of heat transfer fluid is placed within it. This is the conventional method of constructing a heat pipe, and is well understood in the art of heat pipes.

The interior of heat pipe 10 is, however, constructed unconventionally. While contact plate 18 is essentially flat with the exception of peripheral lip 24, cover plate 20 includes multiple depressions 26. Depressions 26 are formed and dimensioned so that, when contact plate 18 and cover plate 20 are joined, the flat portions of depressions 26 are in contact with inner surface 28 of contact plate 18. Depressions 26 thereby assure that the spacing between contact plate 18 and cover plate 20 will be maintained even through pressure differentials between the inside volume of heat pipe 10 and the surrounding environment might otherwise cause the plates to deflect toward each other.

Heat pipe 10 also includes internal sintered metal capillary wick 30 which covers the entire inside surface of contact plate 18. As is well understood in the art of heat pipes, a capillary wick provides the mechanism by which liquid condensed at the cooler condenser of a heat pipe is transported back to the hotter evaporator where it is evaporated. The vapor produced at the evaporator then moves to the condenser where it again condenses. The two changes of state, evaporation at the hotter locale and condensation at the cooler site, are what transport heat from the evaporator to the condenser.

In the present invention, heat pipe 10 also has capillary wick pillars 32 which bridge the space between contact plate 18 and cover plate 20. Pillars 32 thereby interconnect cover

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plate 16 and contact plate 14 with continuous capillary wick. This geometry assures that, even if heat pipe 10 is oriented so that cover plate 16 is lower than contact plate 14, liquid condensed upon inner surface 34 of cover plate 20 will still be in contact with capillary pillars 32. The liquid will therefore be moved back to raised surface 28 which functions as the evaporator because it is in contact with a heat generating integrated circuit (not shown). Capillary pillars 32 are wrapped around and supported by depressions 26, which prevents the structurally weaker capillary pillars 32 from suffering any damage.

FIG. 1 also shows frame 36 which is typically used to surround and protect heat pipe 10. Frame 34 completely surrounds heat pipe 10 and contacts lip 24 of contact plate 18. When heat pipe 10 is used to cool an integrated circuit chip (not shown) which is held against contact plate 18, cover plate 20 is held in intimate contact with fin plate 38, to which fins 16 are connected. The entire assembly of heat pipe 10, frame 34, and fin plate 38 is held together and contact plate 18 is held against an integrated circuit chip by conventional screws 40, shown in dashed lines, which are placed in holes 42 in fin plate 38 and through holes 12 in heat pipe 10, and are threaded into the mounting plate (not shown) for the integrated circuit chip.

Holes 12 penetrate heat pipe 10 without destroying its vacuum integrity because of their unique location. Holes 12 are located within sealed structures such as solid columns 44, and since columns 44 are bonded to cover plate 20 at locations 46, holes 12 passing through the interior of columns 44 have no effect on the interior of heat pipe 10.

The preferred embodiment of the invention has been constructed as heat pipe 10 as shown in FIG. 1. This heat pipe is approximately 3.0 inches by 3.5 inches with a total thickness of 0.0200 inch. Cover plate 20 and contact plate 18 are constructed of OFHC copper 0.035 inch thick, and depressions 26 span the 0.100 inch height of the internal volume of heat pipe 10. The flat portions of depressions 26 are 0.060 inch in diameter. Capillary wick 30 is constructed of sintered copper powder and averages 0.040 inch thick. Columns 44 have a 0.250 inch outer diameter, and holes 12 are 0.210 in diameter.

FIG. 2 is a cross section view of an alternate embodiment of the flat plate heat pipe 11 of the invention with through holes 48 located within peripheral lips 22 and 24 of the heat pipe and hole 50 shown in another sealed structure, one of the depressions 26. The only requirement for forming hole 50 within a depression 26 is that the bottom of depression 26 must be bonded to inner surface 28 of contact plate 18 to prevent loss of vacuum within the heat pipe. Of course, the region of the peripheral edges is also a sealed structure since bonding between lips 22 and 24 is inherent because heat pipe 11 must be sealed at its edges to isolate the interior from the outside atmosphere.

The only differences between heat pipe 11 of FIG. 2 and heat pipe 10 of FIG. 1 are that finned heat sink 16 is not shown in FIG. 2, lips 22 and 24 are slightly longer in FIG. 2 to accommodate holes 48, and hole 50 is shown. In fact, through holes 12 shown in FIG. 12 are also included in FIG. 2. Although it is unlikely that holes 12, holes 48, and hole 50 would be used in the same assembly, manufacturing economies may make it desirable to produce all the holes in every heat pipe so that the same heat pipe heat spreader can be used with different configurations of finned heat sinks. The unused sets of holes have no effect on the operation or benefits of the invention.

FIG. 3 is a plan view of the internal surface of the contact plate 18 of the heat pipe 10 of the invention showing region

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31 of capillary wick 30. Region 31 is constructed of sintered silver powder. While the balance of capillary wick 30 is conventional sintered metal such as copper, region 31 of capillary wick 30, which is on the opposite surface of contact plate 18 from the integrated circuit chip (not shown), is formed of powdered silver. The higher thermal conductivity of silver yields significantly better heat conduction through region 31 of the wick 30, and thereby reduces the temperature difference between the integrated circuit chip and the vapor within heat pipe 10. This reduction of temperature difference directly affects the operation of heat pipe 10, and essentially results in a similar reduction in the operating temperature of the chip.

The invention thereby furnishes an efficient means for cooling an integrated circuit and does so without the need for larger heat spreaders which not only add weight but also do not transfer heat away from the integrated circuit as effectively as does the heat pipe of the invention.

It is to be understood that the form of this invention as shown is merely a preferred embodiment. Various changes may be made in the function and arrangement of parts; equivalent means may be substituted for those illustrated and described; and certain features may be used independently from others without departing from the spirit and scope of the invention as defined in the following claims. For example, through holes could also penetrate heat pipe boundary structures with curved surfaces or heat pipe boundary structures with offset planes which create several different levels for contact with heat sources or heat sinks.

The invention claimed is:

1. A heat pipe for spreading heat comprising:

- a boundary structure including a first plate and a second plate arranged in spaced apart relation, each of said plates including interior confronting surfaces and a peripheral lip located at an edge of said boundary structure which are bonded together so as to define an enclosed vapor chamber;
- a depression formed in said first plate which projects into said vapor chamber, is spaced from said peripheral lip, and is bonded to said second plate;
- an opening defined through said first plate depression and said second plate wherein said depression comprises an annular outer surface that is bonded to a corresponding annular edge surface in said second plate and further wherein said opening is isolated from said vapor chamber;
- at least one spacer extending between and contacting said first and second plates; and
- a wick positioned upon said confronting interior surfaces including that portion of the interior surface of said first plate that forms a surface of said depression within said vapor chamber.

2. A heat pipe for spreading heat comprising:

- a first plate having a circumferential edge lip bounding an inner surface and at least one hollow column that is integral with said first plate and which projects outwardly relative to said inner surface;
- a second plate arranged in spaced apart confronting relation to said first plate and including a circumferential edge lip bounding an inner surface and at least one opening through said second plate, said edge lips of said first and second plates being bonded together so as to define a vapor chamber; wherein
- a hollow column bonded at one end to said second plate so as to coaxially align said hollow column with one of said at least one openings in said second plate thereby

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to form a mounting hole that extends through said first plate and said second plate and is isolated from said vapor chamber.

3. A heat pipe for spreading heat comprising:

- a first plate having a circumferential edge lip bounding an inner surface and a depression which projects outwardly relative to said inner surface;
- a second plate arranged in spaced apart confronting relation to said first plate and including a circumferential edge lip bounding an inner surface and at least one opening through said second plate, said edge lips of said first and second plates being bonded together so as to define a vapor chamber; wherein
- said depression having an open ended tubular cross-section and an outer surface, a portion of which outer surface is bonded to said second plate so as to coaxially align said depression with one of said at least one openings in said second plate thereby to form a mounting hole that extends through said first plate depression and said second plate and is isolated from said vapor chamber.

4. A heat pipe for spreading heat comprising:

- a first plate having a circumferential edge lip bounding an inner surface and a hollow column which projects outwardly relative to said inner surface;
- a second plate arranged in spaced apart confronting relation to said first plate and including (i) a circumferential edge lip bounding an inner surface, (ii) at least one depression which projects into said vapor chamber and that is bonded to said inner surface of said first plate, and (iii) at least one opening through said second plate, said edge lips of said first and second plates being bonded together so as to define a vapor chamber; wherein
- said hollow column in said first plate opens at a first end and a second end and is bonded to said second plate at said second end so as to coaxially align said hollow column with said at least one opening in said second plate thereby to form a mounting hole that extends through said first plate depression and said second plate and is isolated from said vapor chamber.

5. An integrated circuit chip cooling structure comprising:

- a top plate having an edge lip that bounds a top surface and a bottom surface;
 - a bottom plate having an edge lip that bounds a top surface and a bottom surface, said edge lips of said top and bottom plates being bonded together so as to define a vapor chamber;
 - a capillary wick provided within said vapor chamber; wherein said top plate and said bottom plate each define at least one opening such that the at least one opening of said top plate and the at least one opening of said bottom plate are vertically aligned;
 - at least one hollow column extending between said top plate and said bottom plate, said at least one hollow column having a top end sealed to a periphery of said opening defined in said top plate and a bottom end sealed to a periphery of said opening defined in said bottom plate, said at least one hollow column having a central passageway sized to receive a fastener.
6. The integrated circuit chip cooling structure according to claim 5 comprising at least one heat sink, said at least one heat sink having a bottom surface attached to the top surface of said top plate and at least one mounting hole communicating with said at least one hollow column; and

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a fastener extending through said hollow column and through said mounting hole of said at least one heat sink to secure said heat sink to said top and bottom plates.

7. The integrated circuit chip cooling structure according to claim 6 wherein said at least one heat sink comprises a base and a plurality of fins located on one side of said base.

8. The integrated circuit chip cooling structure according to claim 5 wherein each of said at least one hollow column each has a top shoulder disposed near a top end and bonded to a bottom surface of said top plate around one opening.

9. The integrated circuit chip cooling structure according to claim 8 wherein each of said at least one hollow column each has a bottom end downwardly extending out of said bottom plate through one opening defined in said bottom plate.

10. The integrated circuit chip cooling structure according to claim 5 wherein said at least one hollow column has a top

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shoulder disposed near a top end and bonded to a bottom surface of said top plate around one opening defined in said top plate and a bottom shoulder disposed near a bottom end and bonded to a top surface of said bottom plate around one opening defined in said bottom plate.

11. The integrated circuit chip cooling structure according to claim 5 wherein said capillary wick comprises an upper planar wick located on a bottom surface of said top plate, a bottom planar wick located on a top surface of said bottom plate, and a plurality of vertical wick elements provided between said upper planar wick and said bottom planar wick, said vertical wicks each having a first end integral with one of said top and bottom plate and a second end supported on the other of said top and bottom plates; said at least one hollow column being inserted through said top planar wick and said bottom planar wick.

* * * * *



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(54) **VAPOR CHAMBER SYSTEM FOR COOLING
MOBILE COMPUTING SYSTEMS**

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(52) **U.S. Cl.** **361/700**; 165/104.26; 165/104.33;
174/15.2; 257/715; 361/701

(58) **Field of Search** 62/223; 165/104.21,
165/104.26, 104.33, 80.2–80.3, 185; 174/15.2;
257/715; 361/699, 687, 700, 701

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,329,993 A * 7/1994 Ettehadieh 165/104.33
6,105,662 A * 8/2000 Suzuki 165/104.33
6,111,749 A * 8/2000 Lamb et al. 361/104.33
6,269,865 B1 * 8/2001 Huang 165/104.33

* cited by examiner

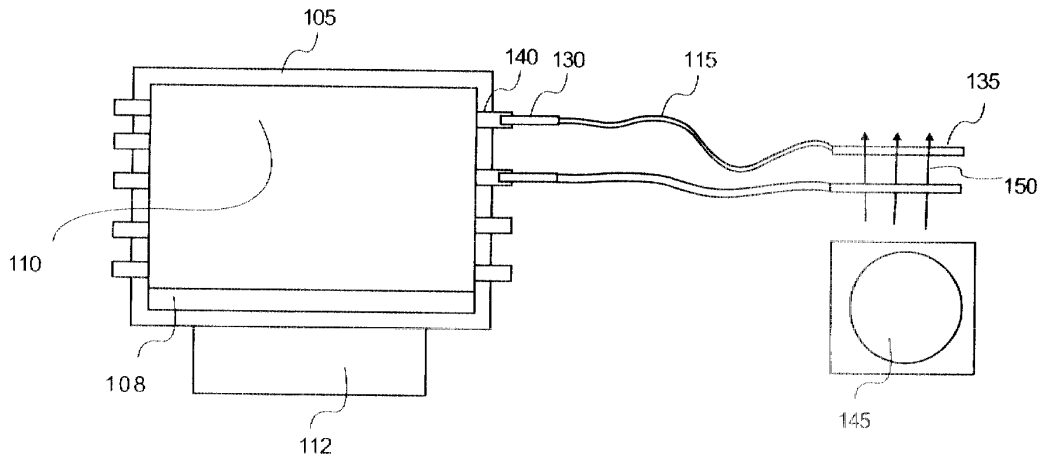
Primary Examiner—Gregory Thompson

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Zafman LLP

(57) **ABSTRACT**

A system including a vapor chamber including a liquid. The
vapor chamber is coupled with a die. The vapor chamber is
attached to a plurality of micro pipes (MPs). When heat is
generated by the die, the liquid is vaporized in the vapor
chamber generating vapor. The vapor flows through the MPs
to condensation ends of the MPs.

22 Claims, 4 Drawing Sheets



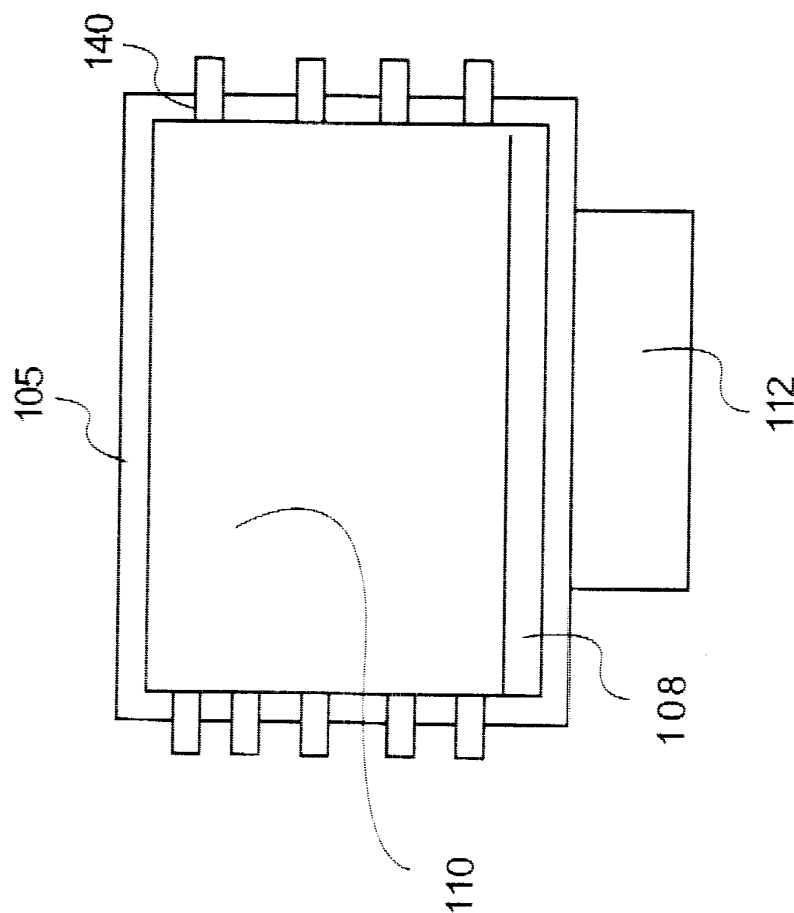


FIG. 1A

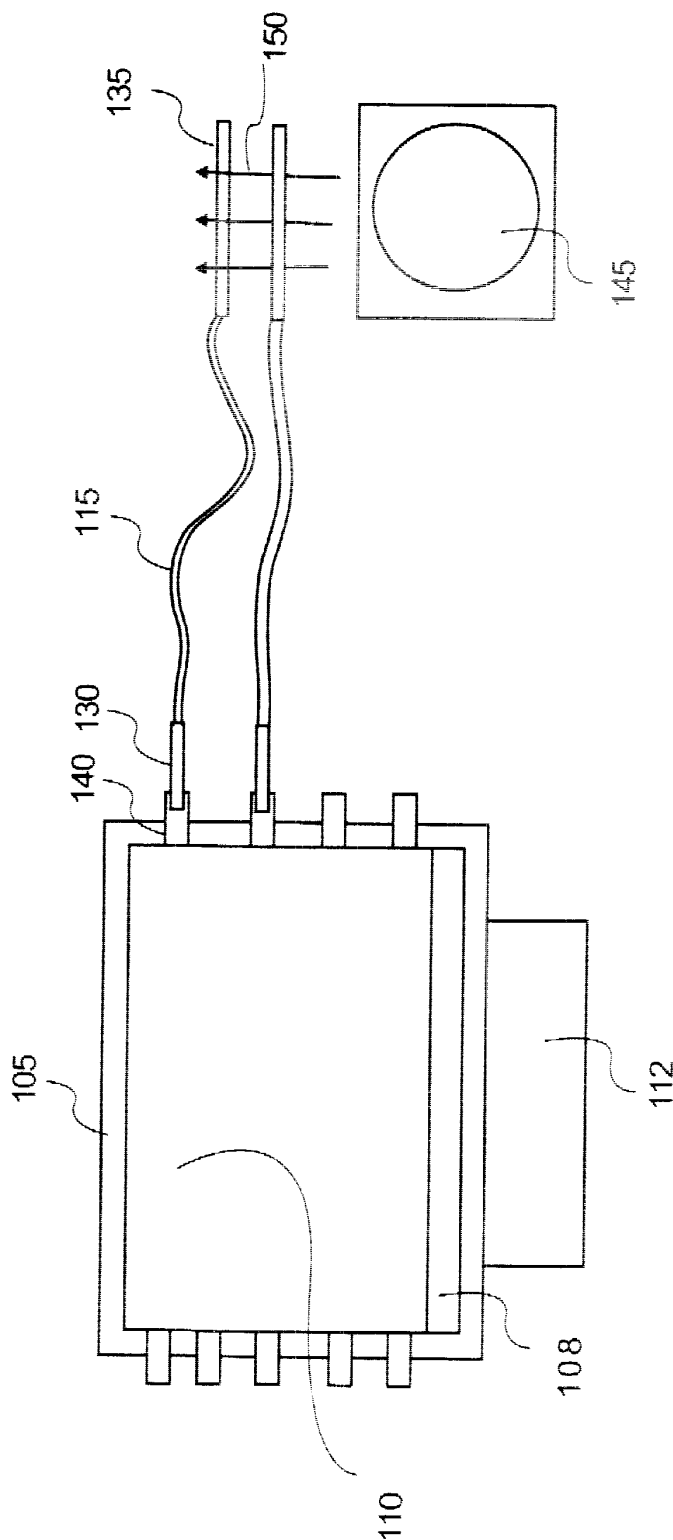


FIG. 1B

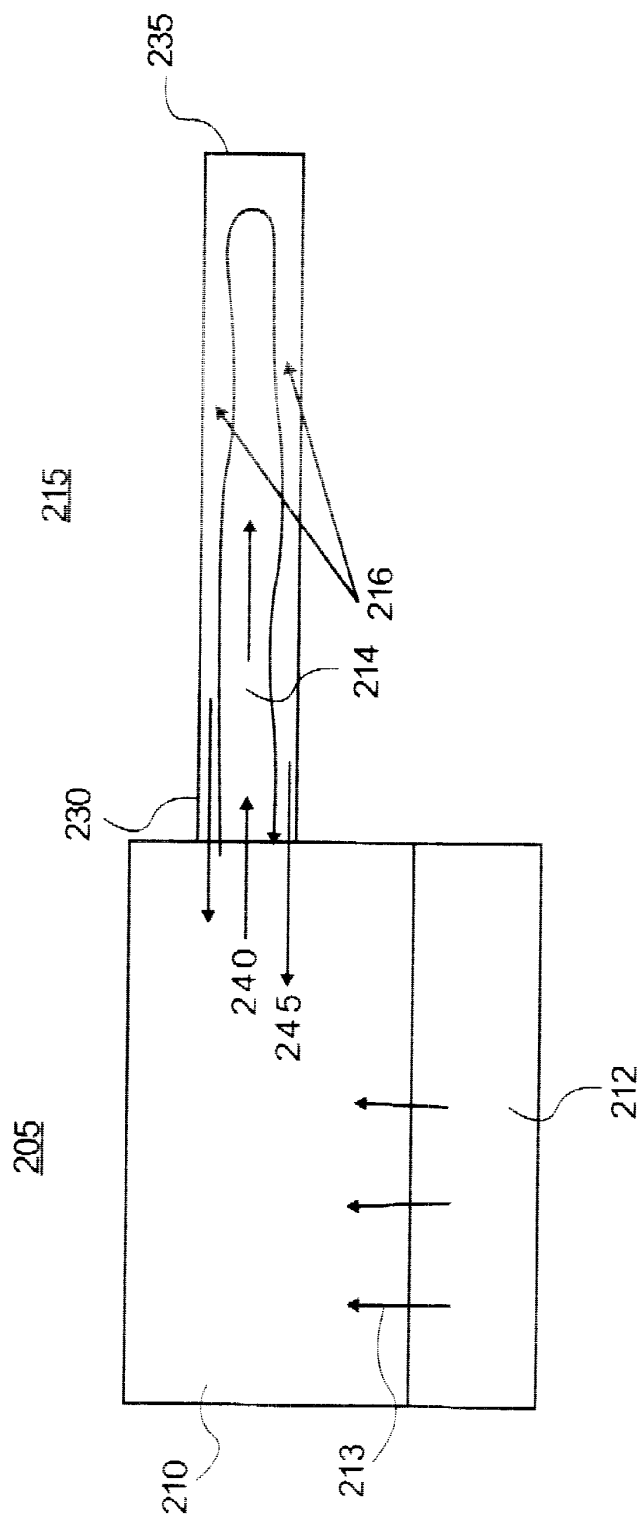


FIG 2

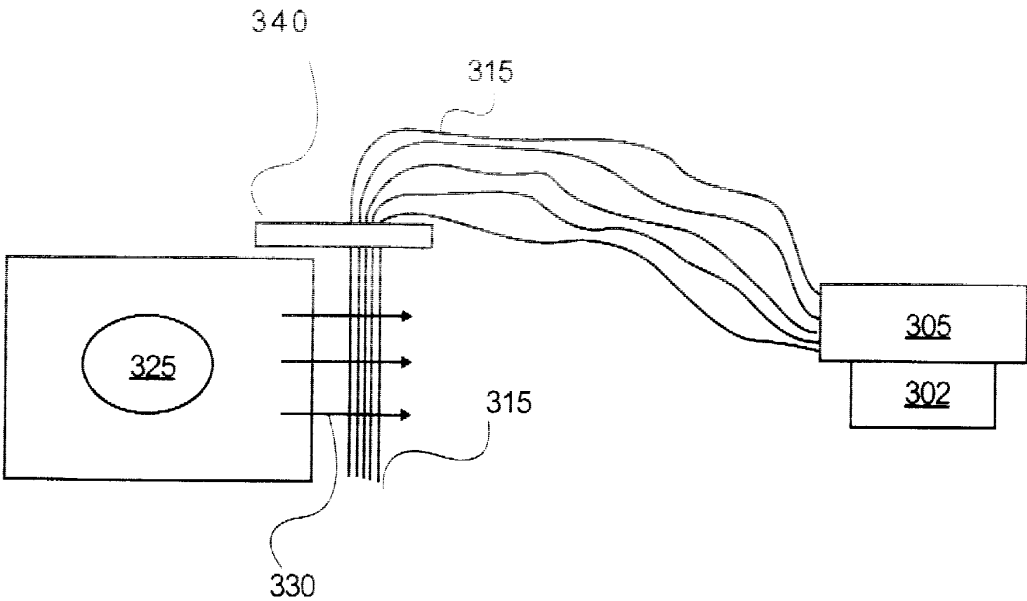


FIG. 3

VAPOR CHAMBER SYSTEM FOR COOLING MOBILE COMPUTING SYSTEMS

FIELD OF THE INVENTION

The invention is related to the field of thermal technology, and more specifically to cooling mobile computing systems using vapor chamber.

BACKGROUND

Electronic components from microprocessors to high-end power converters generate heat. The rejection of this heat is necessary for their optimum and reliable operation. As electronic design allows higher throughput in smaller packages, dissipating the heat load becomes a critical design factor.

There are different ways of dissipating heat. These include radiation, conduction and convection. Radiation means that the heat is simply radiated away from the object, through electromagnetic radiation. Conduction is the exchange of kinetic energy between molecules. Less energetic (lower temperature) particles gain kinetic energy by colliding with more energetic particles (through physical contact).

Convection is heat transfer by movement of a heated substance (gas or liquid). This means that the heat is transferred to the molecules of the gas (or liquid) surrounding the hot object, and then transported away through movement of molecules. When the gas or liquid around the object is forced into movement (e.g., by a fan blowing air across a heat sink), then it is forced convection. Many of today's electronic devices require cooling beyond the capability of standard metallic heat sinks.

One cooling approach uses vapor chambers. The vapor chamber loses heat within the computing system by convection and radiation. Typically, a vapor chamber is a vacuum vessel with a wick structure lining the inside walls that is saturated with a working liquid. As heat is applied, the fluid at that location immediately vaporizes and the vapor rushes to fill the vacuum. Wherever the vapor comes into contact with a cooler wall surface, it will condense, releasing its latent heat of vaporization. The condensed fluid returns to the heat source via capillary action, ready to be vaporized again and repeat the cycle. The capillary action of the wick lining the inside walls enables the vapor chamber to work in any orientation with respect to gravity.

One disadvantage of the vapor chamber is its lack of flexibility. Also, the vapor chamber needs to be connected to the heat sink through another thermal attach which can increase thermal resistance.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example, and not limitation, in the figures of the accompanying drawings in which:

FIG. 1A is a diagram illustrating one example of a vapor chamber in accordance with the present invention.

FIG. 1B is a diagram illustrating one example of a cooling system using a vapor chamber and multiple micro pipes.

FIG. 2 is a diagram illustrating one example of an operation of a vapor chamber cooling system.

FIG. 3 is a diagram illustrating one example of using multiple condensation ends of the micro pipes as heat exchanger in a cooling system using a vapor chamber.

DETAILED DESCRIPTION

In one embodiment, a method of and a system for cooling using a vapor chamber together with multiple micro pipes (MPs) are disclosed. Vapor from the vapor chamber flows

into the connected MPs to condensation ends of the MPs where it is condensed into working liquid. The working liquid is returned to the vapor chamber by capillary action in the inside walls of the MPs.

The following detailed description sets forth numerous specific details to provide a thorough understanding of the invention. However, those of ordinary skill in the art will appreciate that the invention may be practiced without these specific details. In other instances, well-known methods, procedures, protocols, components, algorithms, and circuits have not been described in detail so as not to obscure the invention.

FIG. 1A is a diagram illustrating one example of a vapor chamber in accordance with the present invention. The vapor chamber 105 includes a cavity section 110 containing a liquid 108 (e.g., water) that vaporizes when boiled. The vapor chamber 105 is coupled with the die 112 and absorbs heat generated by the die 112. The heat boils and vaporizes the liquid 108 in the cavity 110. The vapor chamber 105 also includes multiple vapor chamber connection points 140 to allow the vapor to escape. As will be described in more detail below, these vapor chamber connection points 140 also allow condensed liquid to return to the vapor chamber. The vapor chamber 105 is advantageous because it has low thermal resistance in vaporizing the liquid.

FIG. 1B is a diagram illustrating one example of a cooling system using a vapor chamber and multiple micro pipes. In one embodiment, connected to the vapor chamber 105 through the vapor chamber connection points 140 are micro pipes (MPs) 115. In one embodiment, each of the MPs 115 has a small cross section of length up to 1 millimeter (mm). Each of the MPs 115 has two ends 130 and 135. The end 135 is sealed and is used for heat release by condensation. The end 135 may be connected to fins of a heat exchanger (not shown). A fan 145 may be used to generate air flow 150 to cool the heat exchanger. The end 135 is also referred to as a condensation end.

The end 130 is connected to the vapor chamber 105 at a vapor connection point 140. The end 130 is an open end to draw in vapor from the vapor chamber 105 and to return condensed working liquid back into the vapor chamber 105. The end 130 is also referred to as an evaporation end. Note that each of the MPs 115 is different from the traditional heat pipes in that the each of the MPs 115 is sealed only at the condensation end 135. The evaporation end 130 is an open end so that it can be connected to the vapor chamber connection point 140 to draw in vapor. Once connected to the vapor chamber connection points 140, the vapor chamber 105 and the MPs 115 form a closed cooling system.

Each of the MPs 115 has a central insulated section made of flexible material (e.g., plastics, etc.). The small cross section of the MPs 115 and the flexible material allow the MPs 115 to easily conform to space and size constraints of mobile computing systems. The central insulated section reduces convection and radiation from the MPs 115.

In one embodiment, the MPs 115 have internal walls lined with a capillary structure or wick similar to the internal wall structures of heat pipes. As such, internal operation of the MPs 115 is similarly to those of the heat pipes including the capillary force pushing the condensed liquid from the evaporation end 135 toward the condensation end 130. Internal operation of heat pipes is known to one skilled in the art.

FIG. 2 is a diagram illustrating one example of an operation of a vapor chamber cooling system. More than one MP may be attached to the vapor chamber 205 for parallel removal of vapor from the cavity 210 of the vapor chamber 205. The vapor chamber 205 includes a working liquid 212. As heat enters the vapor chamber 205, the heat causes the working liquid 212 to vaporize. The vaporization of the

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working liquid **212** generates a force **213** that pushes the vapor into the cavity region **210**. The vapor then escapes from the cavity region **210** into the open evaporation end **230** of the MP **215**, as illustrated by direction **240**.

The vaporized working fluid creates a pressure gradient, which forces the vapor to flow along the MP **215** the cooler condensation end **235** of the MP **215**, where the vapor is condensed giving up its latent heat of vaporization. The condensation end **235** may be connected to a heat exchanger (not shown) where the vapor is condensed back into the working liquid. The working liquid is then returned toward the evaporation end **130** and to the vapor chamber **205**, as illustrated by direction **245**.

The wicking material inside the MP **215** serves as a pump to return the cooled working liquid from the condensation end **235** by capillary forces. The vapor chamber **205** and the MP **215** provide a cooling system that offers flexibility and low resistance. The MP **215** is advantageous because it is insulated, flexible and can conform to different space and size constraints.

FIG. **3** is a diagram illustrating one example of using multiple condensation ends of the MPs as heat exchanger in a cooling system using a vapor chamber. The multiple MPs **315** are connected to the vapor chamber **305**, which in turn is attached to the die **302**. In one embodiment, the condensation ends **335** of the MPs **315** are metallic (e.g., copper, aluminum, etc). As described above, the condensation ends **335** are typically attached to a heat exchanger (not shown).

In one embodiment, airflow **330** generated by a fan **325** is applied toward the condensation ends **335** allowing the condensation ends **335** serve as the heat exchanger and thereby eliminating a need for a separate heat exchanger. For example, the condensation ends **335** may be attached to a holder **340** and strategically aligned to allow sufficient amount of the airflow **330** to go around the condensation ends **335**. The airflow **330** serves to cool the condensations ends **335** thereby condensing the vapor back into its liquid form. Capillary force carry the working liquid through the MPs **315** back to the vapor chamber **305**.

Although the invention has been described with notebook applications, one skilled in the art would recognize that the cooling system using the vapor chamber with multiple MPs may also be applied to other applications to provide more efficient heat dissipation and/or to conform with space and size constraints.

From the above description and drawings, it will be understood by those of ordinary skill in the art that the particular embodiments shown and described are for purposes of illustration only and are not intended to limit the scope of the invention. Those of ordinary skill in the art will recognize that the invention may be embodied in other specific forms without departing from its spirit or essential characteristics. References to details of particular embodiments are not intended to limit the scope of the claims.

What is claimed is:

1. A system, comprising:

a die;

a vapor chamber coupled with the die, the vapor chamber including a working liquid; and

a plurality of micro pipes (MPs) attached to the vapor chamber at vapor chamber connection points, wherein heat generated by the die causes the working liquid in the vapor chamber to vaporize generating vapor, the vapor flowing from the vapor chamber through the MPs toward condensation ends of the MPs.

2. The system of claim 1, wherein each of the plurality of MPs has a small cross section.

3. The system of claim 2, wherein the cross section is up to 1 mm.

4. The system of claim 2, wherein each of the MPs comprises a central insulated section made of flexible

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material, the central insulated section having an internal surface structured to provide capillary action.

5. The system of claim 4, wherein the vapor is condensed into the working liquid at the condensation end, and wherein the working liquid is returned to the vapor chamber by the capillary action.

6. The system of claim 3, wherein the condensation end is metallic.

7. The system of claim 6, wherein the condensation end is attached to a heat exchanger.

8. The system of claim 6, wherein airflow is applied to the condensation end to provide condensation of the vapor.

9. An apparatus, comprising:

a vapor chamber having a liquid and a cavity region; and

multiple tubes connected to the vapor chamber at connection points on the vapor chamber, each of the multiple tubes having a vapor region and a liquid region, wherein when heat is transferred to the vapor chamber the liquid is vaporized into vapor sending the vapor into the cavity region and out into the multiple tubes at the connection points, the vapor flowing through each of the multiple tubes in the vapor region toward a condensation end of the tube where the vapor is condensed into liquid, the liquid returned in the liquid region back to the vapor chamber by capillary force.

10. The system of claim 9, wherein each of multiple tubes is a heat pipe having a central insulated section made of flexible material, the central insulated section having a capillary wicking internal surface.

11. The system of claim 10, wherein each of the multiple tubes has a cross section of length up to 1 millimeter (mm).

12. The system of claim 9, wherein the tube is sealed at the condensation end and connected to the connection point at an opposite end.

13. The system of claim 12, wherein the condensation end is metallic.

14. The system of claim 13, wherein the condensation end is attached to a heat exchanger.

15. The system of claim 13, wherein the condensation end serves as a heat exchanger by directing airflow toward the condensation end.

16. A method, comprising:

attaching a vapor chamber to a die, the vapor chamber including a cavity region, a liquid and multiple connection points; and

connecting a tube to each of the multiple connection points at an open end of the tube such that when heat is absorbed from the die by the vapor chamber, the liquid is vaporized into vapor, the vapor flowing into the cavity region and out to the tubes at the connection points toward a closed end of the tube.

17. The method of claim 16, wherein the closed end of the tube is metallic.

18. The method of claim 17, further comprising condensing the vapor into liquid at the closed end of the tube.

19. The method of claim 18, wherein the tube comprises a central insulated section made of flexible material, the central insulated section having a capillary wicking internal surface, wherein the liquid is returned to the vapor chamber by capillary force.

20. The method of claim 18, wherein the closed end of the tube is attached to a heat exchanger.

21. The method of claim 18, wherein the condensing the vapor comprises directing airflow to the closed end of the tube.

22. The method of claim 16, wherein the tube has a cross section of up to 1 millimeter.

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Heat Pipes

Theory, Design and Applications

Reay • Kew

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David Reay
and Peter Kew

Heat Pipes

Theory, Design
and Applications



Fifth Edition

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INTRODUCTION

The heat pipe is a device of very high thermal conductance. The idea of the heat pipe was first suggested by Gaugler [1] in 1942. It was not, however, until its independent invention by Grover [2, 3] in the early 1960s that the remarkable properties of the heat pipe became appreciated and serious development work took place.

The heat pipe is similar in some respects to the thermosyphon and it is helpful to describe the operation of the latter before discussing the heat pipe. The thermosyphon is shown in Fig. 1a. A small quantity of water is placed in a tube from which the air is then evacuated and the tube sealed. The lower end of the tube is heated causing the liquid to vapourise and the vapour to move to the cold end of the tube where it is condensed. The condensate is returned to the hot end by gravity. Since the latent heat of evaporation is large, considerable quantities of heat can be transported with a very small temperature difference from end to end. Thus, the structure will also have a high effective thermal conductance. The thermosyphon has been used for many years and various working fluids have been employed. (The history of the thermosyphon, in particular the version known as the Perkins Tube, is reviewed in Chapter 1.) One limitation of the basic thermosyphon is that in order for the condensate to be returned to the evaporator region by gravitational force, the latter must be situated at the lowest point.

The basic heat pipe differs from the thermosyphon in that a wick, constructed for example from a few layers of fine gauze, is fixed to the inside surface and capillary forces return the condensate to the evaporator. (See Fig. 1b.) In the heat pipe the evaporator position is not restricted and it may be used in any orientation. If, of course, the heat pipe evaporator happens to be in the lowest position, gravitational forces will assist the capillary forces. The term 'heat pipe' is also used to describe high thermal conductance devices in which the condensate return is achieved by other means, for example centripetal force, osmosis or electrohydrodynamics.

Several methods of condensate return are listed in Table 1. A review of techniques is given by Roberts [4], and others are discussed by Reay [13], Jeyadeven et al. [14] and Maydanik [15].

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ference, Bologna. ESA Report

conference, Minsk, Byelorussia

at Microfluidics Seminar, East
ilbride, 2005.

formance evaluation of citric
and Magn. Mater., Vol. 289,

Appl. Therm. Eng., Vol. 25,

t Pipe Conference, 2002. Appl.

he IV International Conference,
'Heat Pipes', Minsk, 2000.

HISTORICAL DEVELOPMENT

The heat pipe differs from the thermosyphon by virtue of its ability to transport heat *against gravity* by an evaporation–condensation cycle. It is, however, important to realise that many heat pipe applications do not need to rely on this feature, and the Perkins tube, which predates the heat pipe by several decades and is basically a form of thermosyphon, is still used in heat transfer equipment. The Perkins tube must therefore be regarded as an essential part of the history of the heat pipe.

1.1 THE PERKINS TUBE

Angier March Perkins was born in Massachusetts, USA at the end of the eighteenth century, the son of Jacob Perkins, also an engineer [1]. In 1827, A.M. Perkins came to England, where he subsequently carried out much of his development work on boilers and other heat distribution systems. The work on the Perkins tube, which is a two-phase flow device, is attributed in the form of a patent to Ludlow Patton Perkins, the son of A.M. Perkins in the mid-nineteenth century. A.M. Perkins, however, also worked on single-phase heat distribution systems, with some considerable success, and although the chronological development has been somewhat difficult to follow from the papers available, the single-phase systems preceded the Perkins tube, and some historical notes on both systems seem appropriate.

The catalogue describing the products of A.M. Perkins & Sons Ltd, published in 1898, states that in 1831 A.M. Perkins took out his first patent for what is known as 'Perkins' system of heating by small bore wrought iron pipes. This system is basically a hermetic tube boiler in which water is circulated in tubes (in single phase and at high pressure) between the furnace and the steam drum, providing an indirect heating system. The boiler using hermetic tubes, described in UK Patent No. 6146, was produced for over 100 years on a commercial scale. The specification describes this closed cycle hot water heater as adapted for sugar making and refining evaporators, steam boilers and also for various processes requiring molten metals for alloying or working of other metals at high temperatures, suggesting that the

of the early life test data (often now discarded in paper copies of reports from company libraries etc.). Thus, apart from examples where the fluids have been discarded due to environmental or other considerations (for example refrigerants such as R11 and R113), the historical data are retained in this new edition of *Heat Pipes*. The majority of the fluids, materials and operating conditions remains the same, so the life test data remain valid and should be of not just archival value to those entering the heat pipe field. These data, and some additional results, are given in Section 3.5.1.

However, the importance of life tests at each laboratory, once new designs are made, remains great, as explained in Chapter 5.

The three basic components of a heat pipe are as follows:

- (i) The working fluid
- (ii) The wick or capillary structure
- (iii) The container.

In the selection of a suitable combination of the above, inevitably a number of conflicting factors may arise, and the principal bases for selection are discussed below.

3.1 THE WORKING FLUID

A first consideration in the identification of a suitable working fluid is the operating vapour temperature range and a selection of fluids is shown in Table 3.1. Within the approximate temperature band several possible working fluids may exist, and a variety of characteristics must be examined in order to determine the most acceptable of these fluids for the application being considered. The prime requirements are as follows:

- (i) Compatibility with wick and wall materials
- (ii) Good thermal stability
- (iii) Wettability of wick and wall materials
- (iv) Vapour pressures not too high or low over the operating temperature range
- (v) High latent heat
- (vi) High thermal conductivity
- (vii) Low liquid and vapour viscosities
- (viii) High surface tension
- (ix) Acceptable freezing or pour point.

The selection of the working fluid must also be based on thermodynamic considerations which are concerned with the various limitations to heat flow occurring within the heat pipe. These were also discussed in Chapter 2 and are the viscous, sonic, capillary, entrainment and nucleate boiling limitations.

The following equation is given for the thermal conductivity of sintered metal fibre wicks:

$$k_w = \varepsilon^2 k_l + (1 - \varepsilon)^2 k_s + \frac{4\varepsilon(1 - \varepsilon)k_l k_s}{k_l + k_s} \quad (3.7)$$

Values obtained using this equation may be compared with data obtained experimentally by Semena and his co-workers [42, 51]. A more detailed discussion of metal felt wicks, with a presentation of data on other wick properties, is given by Acton [52].

3.4 THE CONTAINER

The function of the container is to isolate the working fluid from the outside environment. It has, therefore, to be leak-proof, to maintain the pressure differential across its walls and to enable the transfer of heat to take place into and from the working fluid.

Selection of the container material depends on several factors. These are as follows:

- (i) Compatibility (both with working fluid and the external environment).
- (ii) Strength-to-weight ratio.
- (iii) Thermal conductivity.
- (iv) Ease of fabrication, including weldability, machineability and ductility.
- (v) Porosity.
- (vi) Wettability.

Most of these are self-explanatory. A high strength-to-weight ratio is more important in spacecraft applications, and the material should be non-porous to prevent the diffusion of gas into the heat pipe. A high thermal conductivity ensures minimum temperature drop between the heat source and the wick.

The thermal conductivity of some wall materials is given in Appendix 2.

3.5 COMPATIBILITY

Compatibility has already been discussed in relation to the selection of the working fluid, wick and containment vessel of the heat pipe. However, this feature is of prime importance and warrants particular attention here.

The two major results of incompatibility are corrosion and the generation of non-condensable gas. If the wall or wick material is soluble in the working fluid, mass transfer is likely to occur between the condenser and the evaporator, with solid material being deposited in the latter. This will result either in local hot spots or blocking of the pores of the wick. Non-condensable gas generation is probably the most common indication of heat pipe failure and, as the non-condensables

5

HEAT PIPE MANUFACTURE AND TESTING

The manufacture of conventional capillary driven heat pipes involves a number of comparatively simple operations, particularly when the unit is designed for operation at temperatures of the order of, say 50–200 °C. It embraces skills such as welding, machining, chemical cleaning and nondestructive testing, and can be carried out following a relatively small outlay on capital equipment. The most expensive item is likely to be the leak detection equipment. (Note that many procedures described are equally applicable to thermosyphons.)

With all heat pipes, however, cleanliness is of prime importance to ensure that no incompatibilities exist (assuming that the materials selected for the wick, wall and working fluid are themselves compatible), and to make certain that the wick and wall will be wetted by the working fluid. As well as affecting the life of the heat pipe, negligence in assembly procedures can lead to inferior performance, due, for example, to poor wetting. Atmospheric contaminants, in addition to those likely to be present in the raw working fluid, must be avoided. Above all, the heat pipe must be leak-tight to a very high degree. This can involve outgassing of the metal used for the heat pipe wall, end caps, etc., although this is not essential for simple low-temperature operations.

Quality control cannot be overemphasised in heat pipe manufacture, and in the following discussion of assembly methods, this will be frequently stressed.

A substantial part of this chapter is allocated to a review of life test procedures for heat pipes. The life of a heat pipe often requires careful assessment in view of the many factors that can affect long-term performance, and most establishments seriously involved in heat pipe design and manufacture have extensive life test programmes in progress. As discussed later, data available from the literature can indicate satisfactory wall/wick/working fluid combinations, but the assembly procedures used differ from one manufacturer to another, and this may introduce an unknown factor that will necessitate investigation.

6

SPECIAL TYPES OF HEAT PIPE

The variety of heat pipes, in terms of their geometry, function and/or the methods used to transport the liquid from the condenser to the evaporator, is great. Some types of heat pipe have become less popular over the decades or have ceased to be regarded as 'special', for example flat plate heat pipes and vapour chambers (see Chapters 5 and 8 for examples of the latter types). Other types have seen a reawakening of interest, brought about by demands for increasing miniaturisation and the need to enhance performance, in particular liquid return flow rates. The use of electrokinetic forces is one technique in which the 'wheel has gone full circle'.

Where heat pipe types have been omitted from the discussion in this Chapter, but were present in earlier editions, some suggestions for further reading are retained in the Bibliography section in the Appendices.

The following types will be described below:

Variable conductance heat pipes

Thermal diodes

Pulsating (oscillating) heat pipes

Loop heat pipes (LHPs) and capillary pumped loops (CPLs)

Micro-heat pipes

Use of electrokinetic forces

Rotating heat pipes

Miscellaneous types – sorption heat pipe (SHP); magnetic fluid heat pipes

6.1 VARIABLE CONDUCTANCE HEAT PIPES

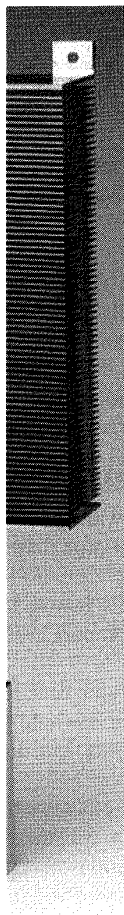
The variable conductance heat pipe (VCHP), sometimes called in a specific variant the gas-controlled or gas-loaded heat pipe, has a unique feature that sets it apart from other types of heat pipe. This is its ability to maintain a device mounted at the evaporator at a near constant temperature, independent of the amount of power being generated by the device.

Variable conductance heat pipes are now routinely used in many applications (see also Chapter 7). These applications range from thermal control of components

array

(s) being cooled

electrical isolation. Figure 8.1 shows isolated inserts in the adiabatic wall off kilovolts of electricity. This



Courtesy of Thermacore Interna-

particular assembly is used on high-speed trains to cool power electronics. The internal working fluid is a dielectric too.¹

In applications where size and weight need to be kept a minimum (this applying to most applications in the twenty-first Century), the near-isothermal operation of the heat pipe may be used to raise the temperature of fins or other forms of extended surface. This leads to higher heat transfer to the ultimate heat sink (for example, air in the case of laptop computers), and the advantage may be used to uprate the device or reduce the size and weight of the metallic heat sink.

There are two possible ways of using the heat pipe here

- mount the component to be cooled directly onto the heat pipe;
- mount the component onto a plate into which the heat pipes are inserted.

8.1.2 Flat plate heat pipes

The second of the five categories of heat pipes likely to be the most useful in electronics cooling is the flat plate unit. It is often used for 'heat spreading' or 'temperature flattening', and is highly effective in this role. The applications of the flat plate unit include, but are not limited to

- multicomponent array temperature flattening;
- multicomponent array cooling;
- doubling as a wall of a module or mounting plate;
- single-component temperature flattening.

The ability of flat plate heat pipes (and vapour chambers) to double as structural components opens up many possibilities and of course not just related to electronics thermal management. The example shown in Fig. 8.2, although not strictly a flat plate heat pipe, rather heat pipes in a flat plate, is the first step towards producing the near-isothermal surface.

8.1.2.1 Embedded heat pipes

It is very common to take the standard heat pipes and embed them into the base of a heat sink as shown in Fig. 8.3. This allows the use of the high volume, lower cost heat pipes in a heat sink design. The heat pipes are flattened, soldered or epoxied into the heat sink and then machined to create a flat mounting surface to the electronics being cooled.

¹ Electrically insulated heat pipes have been examined in a number of electrical engineering areas too. One of the authors was involved many years ago with the A. Reyrolle Switchgear Company, testing heat pipes for use at up to 33 kV potential, examining the suitable dielectric fluids and wall materials. As in many application areas, including cooling buried cable junctions, judicious use of heat pipes to remove hotspots can allow upgrading of equipment at minimum extra cost.

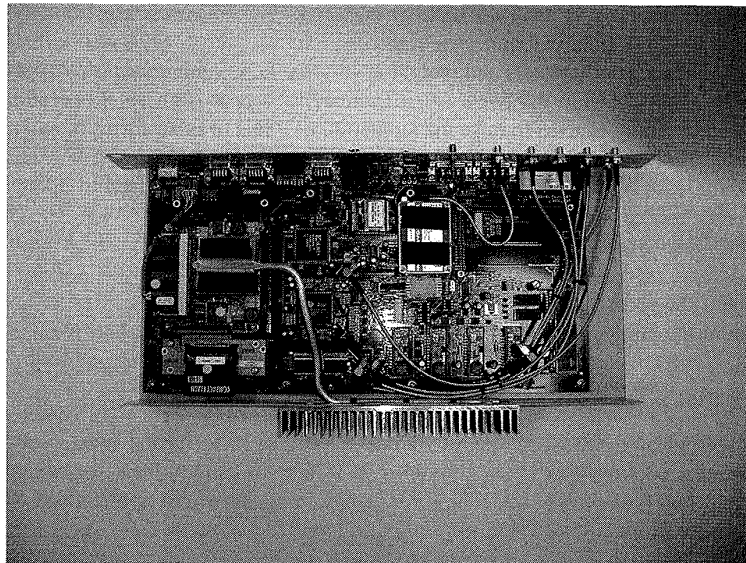


Fig. 8.2 Component (10W processor chip) on evaporator block (centre left) with heat dissipated from natural convection heat sink (centre bottom). Courtesy of Thermacore International Inc. (See also the case study in Section 8.2.2 and Fig. 8.25.)

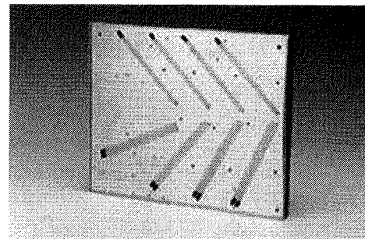
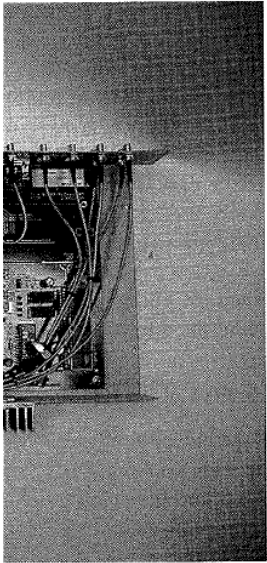


Fig. 8.3 Heat pipes embedded in a heat sink – 'approaching' a flat plate heat pipe (Courtesy of Thermacore International Inc.).

8.1.2.2 Vapour chamber heat pipe

A flat plate heat pipe is shown in Fig. 8.4. This flat plate heat pipe design is hollow on the inside and the vapour is free to travel throughout. It is either soldered or epoxied to the heat sink.



ator block (centre left) with heat
pipes (bottom). Courtesy of Thermacore
and Fig. 8.25.)



ing' a flat plate heat pipe (Courtesy

plate heat pipe design is hollow
throughout. It is either soldered or

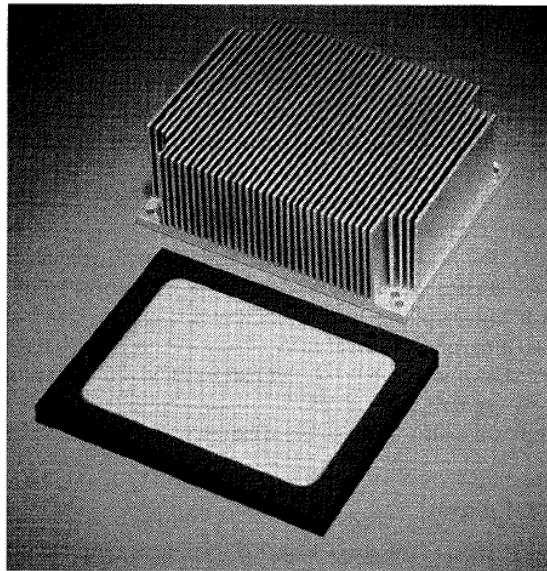


Fig. 8.4 A vapour chamber flat plate heat pipe (Courtesy of Thermacore International Inc.).

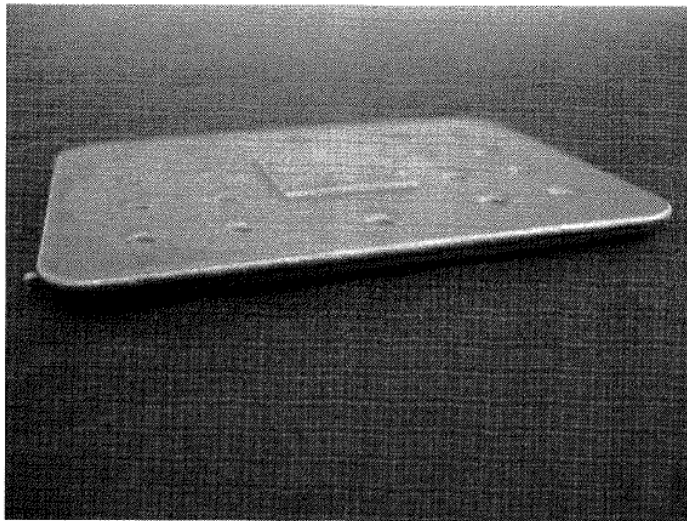


Fig. 8.5 The Therma Base flat plate heat pipe/vapour chamber. In this variant, the dimples show where penetrations (to locate components) can be safely made (Courtesy of Thermacore International Inc.).