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THERMOSYPHON FOR COOLING ELECTRONIC COMPONENTS

Field of the Invention

The present invention relates to thermosyphons and more particularly to thermosyphons for cooling electronic components such as, for example, central
5 processing units (CPUs), graphics processing units (GPUs) and concentrating solar cells.

Background of the Invention

Thermal management is an important aspect in the design of electronic packaging. Proper thermal management of electronic devices ensures that
10 operating temperatures remain within a reliable operating range. Operating at temperatures beyond the set boundary is undesirable as it leads to lower device performance, an increased probability of failure and a reduced lifespan.

With the introduction of multi-core processors and high-power electronics, component heat fluxes have risen to new higher levels and there is concern that
15 current heat management technologies will not be able to cope with future heat load requirements. Thus, there is a need for a cooling device that is capable of dissipating waste heat generated by electronic components effectively.

Summary of the Invention

Accordingly, in a first aspect, the present invention provides a thermosyphon
20 including an evaporator section, a condenser section coupled to the evaporator section, and a condensate guide lining an inner portion of the evaporator section and inner surfaces of the condenser section. The condensate guide defines a vapour core in the evaporator and condenser sections and is configured to return condensate to the evaporator section regardless of an orientation of the



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thermosyphon. Advantageously, this allows operation of the thermosyphon at various physical orientations with minimal or no performance degradation.

Preferably, the condensate guide includes a plurality of pores, the pores of the condensate guide being sized to allow vapour to pass through and prevent
5 condensate flow through. Advantageously, this aids in returning the condensate to the evaporator section.

A boiling enhancement structure may be coupled to the evaporator section. Advantageously, the boiling enhancement structure enhances nucleate boiling at the evaporator section and thereby increases the boiling heat transfer coefficient.

10 The boiling enhancement structure may include a plurality of pin fins. Preferably, a separation between adjacent ones of the pin fins is less than a bubble characteristic length of a working fluid in the evaporator section. Advantageously, the bubble confinement effect enhances nucleate boiling of the working fluid and consequently increases heat transfer away from the heat source.

15 In a preferred embodiment, the boiling enhancement structure is configured to draw the condensate back to the evaporator section. Advantageously, this enhances the heat transfer process.

Preferably, the boiling enhancement structure is integrally formed with a heat receiving portion of the evaporator section. Advantageously, this reduces the heat
20 transfer resistance.

In yet another preferred embodiment, a thermal interface material is coupled to the heat receiving portion of the evaporator section. Advantageously, this further reduces the heat transfer resistance.

Preferably, a working fluid is provided in the evaporator section in an amount
25 sufficient to submerge the boiling enhancement structure. Advantageously, this maximizes the boiling heat transfer. The working fluid is preferably in a saturated state.

One of a plurality of grooves and a plurality of knurls may be formed on the inner surfaces of the condenser section for condensation enhancement.

In one embodiment, a port is provided for charging the evaporation section with a working fluid and for deaerating the thermosyphon.

5 In a second aspect, the present invention provides a thermosyphon including an evaporator section, a condenser section coupled to the evaporator section, and a boiling enhancement structure coupled to the evaporator section. The boiling enhancement structure includes a plurality of pin fins. Advantageously, the boiling enhancement structure enhances nucleate boiling at the evaporator section and
10 increases both the boiling heat transfer coefficient and critical heat flux.

Other aspects and advantages of the invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

Brief Description of the Drawings

15 Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

FIG. 1 is an enlarged cross-sectional view of a thermosyphon in accordance with one embodiment of the present invention; and

FIG. 2 is an enlarged perspective view of a boiling enhancement structure for
20 the thermosyphon of FIG. 1.

Detailed Description of An Exemplary Embodiment

The detailed description set forth below in connection with the appended drawings is intended as a description of a presently preferred embodiment of the invention, and is not intended to represent the only form in which the present

invention may be practiced. It is to be understood that the same or equivalent functions may be accomplished by different embodiments that are intended to be encompassed within the scope of the invention.

Referring now to FIG. 1, a thermosyphon 10 for cooling electronic components such as, for example, central processing units (CPUs) and graphics processing units (GPUs) is shown. The thermosyphon 10 includes an evaporator section 12, a condenser section 14 coupled to the evaporator section 12, and a condensate guide 16 lining an inner portion of the evaporator section 12 and inner surfaces of the condenser section 14. A vapour core 18 is defined in the evaporator and condenser sections 12 and 14 by the condensate guide 16. A boiling enhancement structure 20 is coupled to the evaporator section 12. A working fluid 22 is provided in the evaporator section 12 in an amount sufficient to submerge the boiling enhancement structure 20. The boiling enhancement structure 20 is integrally formed with a heat receiving portion 24 of the evaporator section 12. A thermal interface material 26 is coupled to the heat receiving portion 24 of the evaporator section 12. A port 28 is provided for deaerating the thermosyphon 10 and for charging the evaporation section 12 with the working fluid 22. A plurality of fins 30 is coupled to the condenser section 14.

The thermosyphon 10 is hermetically-sealed and is configured to receive heat from a heat source (not shown). The heat source may have a high heat flux and examples of the heat source include, but are not limited to, central processing units (CPUs), graphics processing units (GPUs) and concentrating solar cells.

In the embodiment shown, the heat receiving portion 24 of the evaporator section 12 includes a base plate 32. The base plate 32 may be mounted or attached to the heat source. The base plate 32 is preferably fabricated from a thermally conductive material such as, for example, aluminium, copper, silver or graphite.

The condenser section 14 is connected to and in fluid communication with the evaporator section 12. In the embodiment shown, the condenser section 14 includes a tube 34 and a top cover 36, the top cover 36 sealing one end of the tube 34. To ensure that the thermosyphon 10 is hermetically sealed, the tube 34 and the top cover 36 are bonded via a bonding process such as welding, soldering or diffusion. The tube 34 is preferably made of a thermally conductive material such as, for example, aluminium, copper, silver or graphite.

In the embodiment shown, the condenser section 14 is provided with an external means of heat exchange in the form of the cooling fins 30 extending from the tube 34 of the condenser section 14. The fins 30 are attached to the tube 34 with a degree of interference in order to have proper contact and thereby avoid the presence of gaps that could deteriorate the heat transfer performance of the fins 30. The fins 30 are preferably made of a thermally conductive material such as, for example, copper or aluminium. Although the use of air-cooled fins is described in the present embodiment, it should be appreciated by those of ordinary skill in the art that the present invention is not limited by the cooling method employed to cool the condenser section 14. In alternative embodiments, the condenser section 14 may be cooled by other well known methods of cooling such as, for example, evaporative cooling, liquid cooling, spray cooling and impinging jet.

Further, for condensation enhancement, an inner surface of the tube 34 of the condenser section 14 may be formed with a plurality of grooves or a knurled surface.

The condensate guide 16 is configured to return condensate to the evaporator section 12 regardless of an orientation of the thermosyphon 10. The condensate guide 16 is porous and the pores of the condensate guide 16 are sized to allow vapour to pass through and prevent condensate flow through. More particularly, the pores of the condensate guide 16 are designed small enough such that liquid is held by surface tension against liquid flow. The condensate guide 16 lines the boiling enhancement structure 20, the inner walls of the tube 34 and an inner surface of the

top cover 36. Accordingly, when vapour condensation occurs in the condenser section 14, the working fluid 22 in vapour form is allowed to pass through the condensate guide 16 but the condensate is prevented from returning to the vapour core 18, and the condensate guide 16 guides the flow of the condensate back to the
 5 evaporator section 12. Orientation independence of the thermosyphon 10 is thus achieved with the condensate guide 16. The condensate guide 16 may be made from a perforated sheet, a metallic wire mesh for structural integrity, or other porous medium. In one embodiment, the pores of the condensate guide 16 have a diameter of between about 0.1 millimetre (mm) and about 2 mm.

10 The vapour core 18 serves as a conduit for vapour generated from the evaporator section 12 to flow into the condenser section 14 and is therefore designed in a manner such that vapour flow is not constricted so as to prevent pressure build up in the evaporator section 12.

The boiling enhancement structure 20 is employed within the evaporator
 15 section 12 and forms a part of the internal surface of the evaporator section 12.

Referring now to FIG. 2, the boiling enhancement structure 20 of the thermosyphon 10 of FIG. 1 is shown. In the embodiment shown, the boiling enhancement structure 20 comprises a plurality of pin fins 38 integrally formed or mounted on an interior surface of the base plate 32. As can be seen from FIG. 2, a
 20 circular groove 40 is formed in the base plate 32 for receiving the tube 34 of the condenser section 14.

The boiling enhancement structure 20 improves the boiling heat transfer coefficient by increasing the number of nucleation sites and the heat transfer surface area. Additionally, the boiling enhancement structure 20 also improves the
 25 critical heat flux by effectively minimizing the build-up of vapour film in the evaporator section 12 which causes dry out.

In a preferred embodiment, a separation between adjacent ones of the pin fins 38 is less than a bubble characteristic length of the working fluid 22 in the

evaporator section 12. Advantageously, it has been shown through experimentation that the bubble confinement effect enhances nucleate boiling of the working fluid 22 and consequently increases heat transfer away from the heat source. The bubble characteristic length of the working fluid 22 may be computed with the following
 5 equation:

$$\text{bubble characteristic length} = \sqrt{\frac{\sigma}{g(\rho_l - \rho_g)}} \quad (1)$$

where σ represents surface tension, g represents gravitational acceleration, ρ_l represents liquid density, and ρ_g represents vapour density.

The boiling enhancement structure 20 is configured to draw the condensate
 10 back to the evaporator section 12. More particularly, the boiling enhancement structure 20 serves as a thermally activated pumping unit that absorbs condensate from the condenser section 12.

The boiling enhancement structure 20 and the base plate 32 may be fabricated from a thermally conductive material such as, for example, aluminium, copper, silver
 15 or graphite. The pin fins 38 may be bonded to the base plate 32 via known bonding methods such as, for example, soldering, brazing or diffusion.

In the embodiment shown, each of the pin fins 38 has a square profile. In one embodiment, each of the pin fins 38 has a height of between about 2 mm and about 20 mm and a thickness of between about 0.5 mm and about 5 mm. However, it
 20 should be understood that the pin fins 38 are not limited to these geometric parameters as optimization of the geometric parameters such as fin profile, fin thickness and fin height is determined based on the thermal properties of the material from which the boiling enhancement structure 20 and the base plate 32 are made and the boiling heat transfer coefficient of the working fluid 22 for a specific
 25 geometry.

In alternative embodiments, the boiling enhancement structure 20 may be other forms of fins, grooves or an open-cell metal foam.

The provision of the groove 40 in the base plate 32 helps to facilitate bonding of the evaporator section 12 to the condenser section 14.

5 Referring again to FIG. 1, the working fluid 22 is preferably in a saturated state. Advantageously, this ensures that the working fluid 22 undergoes phase change instantaneously at any temperature within the component operating range. Examples of the working fluid 22 include, for example, water, a refrigerant or a dielectric fluid. In the embodiment shown, the boiling enhancement structure 20 is
10 fully immersed in the working fluid 22. Advantageously, this maximizes the boiling heat transfer.

The thermal interface material 26 serves to reduce thermal interface resistance between the heat receiving portion 24 and the heat source.

The port 28 functions as an evacuation port that is sealed subsequent to
15 liquid charging and deaeration. In the embodiment shown, the port 28 is provided in the form of a tube and is located on the top cover 36.

The operation of the thermosyphon 10 will now be described with reference to FIG. 1.

In use, an electronic component generates heat. Heat from the electronic
20 component is absorbed by the base plate 32 and spreads from the base plate 32 to the boiling enhancement structure 20 where nucleate boiling of the working fluid 22 occurs and the working fluid 22 changes from a liquid to a vapour. Vapour bubbles are formed on the heated surface of the boiling enhancement structure 20 creating a higher pressure region in the evaporator section 12. The higher pressure at the
25 evaporator section 12 drives the vapour through the vapour core 18 to the condenser section 14 where pressure is lower.

As the walls of the condenser section 14 are at a lower temperature compared to the vapour, the vapour condenses into a liquid condensate on the walls of the condenser section 14 and releases latent heat of vaporization in the process. The heat released from the condensation process is rejected to an external medium via the fins 30 coupled to the condenser section 14.

The liquid condensate is enclosed by the walls of the condenser section 14 and the condensate guide 16 and is forced to flow between the walls of the condenser section 14 and the condensate guide 16 back to the evaporator section 12 by gravity and the capillary force provided by the boiling enhancement structure

As is evident from the foregoing discussion, the present invention provides an orientation-free, two-phase thermosyphon that effectively transfers heat from a heat dissipating component to a colder medium. Advantageously, through the provision of a condensate guide lining an inner portion of the evaporator section and inner surfaces of the condenser section, the thermosyphon of the present invention can be operated at various physical orientations with minimal or no performance degradation.

While the preferred embodiments of the invention have been illustrated and described, it will be clear that the invention is not limited to these embodiments only. Numerous modifications, changes, variations, substitutions and equivalents will be apparent to those skilled in the art without departing from the scope of the invention as described in the claims.

Further, unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise", "comprising" and the like are to be construed in an inclusive as opposed to an exclusive or exhaustive sense; that is to say, in the sense of "including, but not limited to".

CLAIMS

1. A thermosyphon, comprising:
an evaporator section;
5 a condenser section coupled to the evaporator section; and
a condensate guide lining an inner portion of the evaporator section and inner
surfaces of the condenser section, the condensate guide defining a vapour core in
the evaporator and condenser sections, wherein the condensate guide is configured
to return condensate to the evaporator section regardless of an orientation of the
10 thermosyphon.
2. The thermosyphon of claim 1, wherein the condensate guide includes a
plurality of pores, the pores of the condensate guide being sized to allow vapour to
pass through and prevent condensate flow through.
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3. The thermosyphon of claim 1, further comprising a boiling enhancement
structure coupled to the evaporator section.
4. The thermosyphon of claim 3, wherein the boiling enhancement structure
20 comprises a plurality of pin fins.
5. The thermosyphon of claim 4, wherein a separation between adjacent
ones of the pin fins is less than a bubble characteristic length of a working fluid in
the evaporator section.
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6. The thermosyphon of claim 3, wherein the boiling enhancement structure
is configured to draw the condensate back to the evaporator section.
7. The thermosyphon of claim 3, wherein the boiling enhancement structure
30 is integrally formed with a heat receiving portion of the evaporator section.

8. The thermosyphon of claim 7, further comprising a thermal interface material coupled to the heat receiving portion of the evaporator section.

9. The thermosyphon of claim 3, further comprising a working fluid in the evaporator section, wherein the working fluid is provided in an amount sufficient to submerge the boiling enhancement structure.

10. The thermosyphon of claim 9, wherein the working fluid is in a saturated state.

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11. The thermosyphon of claim 1, wherein one of a plurality of grooves and a plurality of knurls are formed on the inner surfaces of the condenser section.

12. The thermosyphon of claim 1, further comprising a port for charging the evaporation section with a working fluid and for deaerating the thermosyphon.

13. A thermosyphon, comprising:
an evaporator section;
a condenser section coupled to the evaporator section; and
a boiling enhancement structure coupled to the evaporator section, the boiling enhancement structure comprising a plurality of pin fins.

14. The thermosyphon of claim 13, wherein a separation between adjacent ones of the pin fins is less than a bubble characteristic length of a working fluid in the evaporator section.

15. The thermosyphon of claim 13, wherein the boiling enhancement structure is configured to draw condensate back to the evaporator section.

16. The thermosyphon of claim 13, wherein the boiling enhancement structure is integrally formed with a heat receiving portion of the evaporator section.

17. The thermosyphon of claim 16, further comprising a thermal interface material coupled to the heat receiving portion of the evaporator section.

5 18. The thermosyphon of claim 13, further comprising a working fluid in the evaporator section, wherein the working fluid is in a saturated state.

19. The thermosyphon of claim 18, wherein the working fluid is provided in an amount sufficient to submerge the boiling enhancement structure.

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20. The thermosyphon of claim 13, wherein one of a plurality of grooves and a plurality of knurls are formed on an inner surface of the condenser section.

21. The thermosyphon of claim 13, further comprising a port for charging the
15 evaporation section with a working fluid and for deaerating the thermosyphon.

22. The thermosyphon of claim 13, further comprising a condensate guide defining a vapour core in the evaporator and condenser sections, wherein the condensate guide is configured to return condensate to the evaporator section
20 regardless of an orientation of the thermosyphon.

23. The thermosyphon of claim 22, wherein the condensate guide includes a plurality of pores, the pores of the condensate guide being sized to allow vapour to pass through and prevent condensate flow through.