HEAT TRANSFER DEVICE AND METHOD OF PRODUCING SUCH A DEVICE

BACKGROUND AND FIELD OF INVENTION

A heat transfer device for transferring heat from a heat source to a heat-dissipating region is disclosed. The heat transfer device is particularly useful in thermal management of electronic components including micro-processors, liquid crystal displays (LCD), micro-electro-mechanical systems (MEMS), illuminating or radiating and like devices where the operation of such components produces excess heat that needs to be transferred away or as a heating element for rapid and controlled heater.

Many devices, due to their operation and throughput, produce heat which accumulates and adversely affect their performance unless the heat is transferred away or dissipated. This is particular true for semiconductor devices such as processing devices (where the ever-increasing VLSI and processing speed and amount of data bits processed), liquid crystal displays (LCD), illuminating devices such as light-emitting diodes (LED), etc. where various heat transfer devices are being employed for thermal management.

An example of a heat transfer devices is a heat pipe which may be employed in a flexible structure comprising multiple laminates such as that disclosed in U.S. Patent No. 6,446,706 , in which Figures 1 and 2 are reproduced here as FIGURES 1a and 1b (Prior art). Figure 1a is a perspective view of a preferred heat pipe (10) described in US6,446,706 and includes outer laminate layers (12,14). As shown in Figure 1b, the

heat pipe (10) includes a sealed outer casing (26) comprising a polypropylene layer (28), a first metal foil layer (32) attached to the polypropylene layer (28) by a first adhesive layer (30), a second metal foil layer (12) attached to the first metal foil layer (32) by a second adhesive layer (34), and a wick layer (24) which is formed using a flexible and porous material.

The heat pipe further includes a separation layer (18) which supports the wick layer (24) such that the wick layer (24) stays in close contact with the outer casing (26) and allows vapour to flow in many directions in the casing. The separation layer (18) is preferably realized as a mesh screen made of polypropylene. The wick layer (24) is made of a copper felt material. The copper felt comprises micro-fibres, each having a diameter of 20 micro inches and a length of 0.2 inches, and copper powder filled in the wick structure in an amount of 20% to 60% of the total volume of the wick structure.

Whilst the flexibility of the laminated layers allows it to be affixed over and conforms to a device to be cooled, contact surfaces between the various laminate layers and the flexible heat pipe may be affected by the flexible material and configuration, thus affecting effective heat conduction.

There are several limitations associated with this prior art. Firstly it is difficult to make the heat pipe which has a complex inner structure. Since the wick layer (24) is made of copper felt it is very difficult to maintain regular and strong contact between the inner surfaces of the outer casing and the wick layer (24). As such, forming of micro paths in the wick layer (24) is irregular, causing non-uniform capillary force that drives the flow.

This creates high flow resistance which causes weak capillary force. Accordingly, when the coolant evaporates due to heat from a heat source, the flow of the vaporised coolant may be cut off. Moreover, heat conductivity varies from point to point. Thus, reproducibility of the heat transfer device is poor. Another limitation is the thinness of the copper felt. Due to difficulty in manufacturing thin copper felt the total thinness of the heat pipe is limited by the thickness of the copper felt.

FIGURE 2 (Prior Art) illustrates a plate-type heat transfer device according to Korean Patent Laid-Open Publication Number 10-2004-18107. The heat transfer device comprises an upper plate (200), and a lower plate (100) disposed under the upper plate (200), having a gap between the upper plate (200) and the lower plate (100), in which the lower surface of the lower plate (100) corresponds to an evaporation part P1 and is in contact with a heat source. The heat transfer device further comprises wick plates (120) disposed so as to be in close contact with the upper surface of the lower plate (100) due to the surface tension of liquid coolant, and a spacer plate (110) for maintaining the distance between the lower plate (100) and the wick plate (120).

The liquid coolant circulates between the evaporation part P1 and a condensation part P2. That is, the liquid phase coolant continuously flows to the evaporation part P1 by means of capillary force generated between it and the lower plate, enters a vapour phase at the evaporation part P1, flows in a vapour phase toward the condensation part P2, and condenses at the condensation part P2. The spacer plate (110) serves to maintain the distance between the lower plate (100) and the wick plate (120) by using the surface tension generated between of them.

This second prior art has also limitations. Micro machining is needed to manufacture a thin and complex structure to be inserted between an upper plate and a lower plate, thus limiting mass production. Accordingly, the device's enclosure can be manufactured no thinner than several mm thick. The device's configuration is structured according to the liquid coolant flows in gaps formed between planar wicks provided in the wick plate (120), or gaps formed between the wick plate (120) and the lower plate. Since the device incorporates micro structures, such as bridges, for connecting protrusions formed on the lower plate and the upper plate or connecting planar wicks, in order to form uniform gaps and to be mounted in the device' confined enclosure, it is difficult to precisely machine such micro structures, as the micro structures are so complex and are several millimetres thick. Also, non-uniform gaps can result in drying out of the liquid phase coolant at the evaporation part, thereby causing fatal failure of the heat transfer device. In particular, mass production of such micro structures is more difficult since the structure is so much complex and machining errors can occur.

FIGURE 3 is an illustration of third prior art of a flat sheet type heat transfer device disclosed in Korean Unexamined Patent Application No. 10-2004-91617. The heat transfer device shown in FIG. 3 comprises an upper metal plate (300), a lower metal plate (350), a pressuring support structure (310), and a plurality of thin plates (320) and (322), the pressuring pressure tension structure (310) and the thin plates (320) and (322) being interposed between the upper plate (300) and the lower plate (350). Each of the thin plates has through patterns that are parallel to each other, formed by a micromachining process. The pressuring pressure tension structure (310) is made of a

porous material such as a mesh screen having through holes dense enough so that vapour, generated by the vaporization of coolant, occurring because the heat source is in contact with the lower surface of the lower plate (350), can move in a vertical direction.

The pressuring pressure tension structure (310) presses at least a portion of the parallel patterns of the thin plates (320) and (322) when assembled. Due to the pressure from the pressuring support plate (310), the parallel patterns of the thin plates (320) and (322) are form close contact with the upper surface of the lower plate (350), so that micro gaps, smaller than those of the patterns in an initial state, are formed. The micro gaps form fine coolant passages that are of few micro meters which are difficult to realize by the processing method such as etching or machining.

It is an object of this invention to provide a heat transfer device and method for producing such a device which addresses at least one of the disadvantages of the prior art and/or to provide the public with a useful choice.

SUMMARY OF THE INVENTION

In a first aspect, there is provided a heat transfer device for dissipating heat away from a heat source, the heat transfer device comprising: liquid coolant enclosed within a housing, and a layer of sorbent capable of completely sorbing the liquid coolant.

In a second aspect, there is provided a method of producing a heat transfer device of the first aspect, the method comprising the step of:

arranging the layer of sorbent capable of completely sorbing the liquid coolant within the housing.

Advantageously, the method includes the step of wetting the layer of sorbent with the liquid coolant prior to arranging the layer of sorbent within the housing. Alternatively, the method may further comprise the step of arranging the layer of sorbent within the housing, and thereafter injecting a sufficient amount of the liquid coolant that is capable of being completely sorbed by the layer of sorbent.

Sorbent materials inherently has micro/nano channels that allows the transport of liquid coolant such as by capillary action and thus, this reduces the cost of the heat transfer device as compared to a mesh structure where micro-machining is required to create the micro-channels. The use of a sorbent material of a sufficient amount that completely sorbs the liquid coolant also has an advantage of preventing a possible dry out when the heat transfer device is in use. During production of the device, if sorbent is wetted with the liquid coolant prior to being arranged within the housing, this simplifies the manufacturing step since this obviates an extra step of injecting the liquid coolant into the housing of the heat transfer device.

Preferably, the sorbent is capable of sorbing the liquid coolant in an amount 0.5 to 10 times of its own volume. Advantageously, the heat transfer device further comprises a pressure member arranged to impart continuous pressure to at least one portion of the sorbent layer. The at least one portion is selected so as to create greater vapour space for the vaporisation. Preferably, the at least one portion of the sorbent layer corresponds to

a region of the heat transfer device that is arranged to contact with the heat source so that this increases the rate of heat transfer.

The at least one portion of the sorbent layer may correspond to a region of the heat transfer device that is spaced from the heat source. The region may be near a condensation region to increase the rate of condensation of the vaporised coolant.

Preferably, the pressure member is arranged to impart continuous pressure to at two distinct portions of the sorbent layer, the two distinct portions corresponding respectively to a first region of the heat transfer device that is arranged to contact with the heat source and a second region of the heat transfer device that is spaced from the heat source. This improves the efficiency of the heat transfer since this creates greater vapour space when the first region operates as an evaporation region and the second region operates as a condensation region.

The pressure member may also include a support base having two end regions and a bridge portion connecting the two end regions, the width of the bridge portion is narrower than the width of the two end regions, and wherein each of the end regions carries a plurality of projections to impart pressure at the two distinct portions. The plurality of projections may be arranged in an array.

Other arrangements of the plurality of projections are envisaged to increase vapour space between the evaporation and condensation regions. For example, the pressure member includes a plurality of spaced projections arranged in a row, with the row

extending between the evaporation and condensation regions. Specifically, the pressure member may include a support base having two end regions and a bridge portion connecting the two end regions, the width of the bridge portion is narrower than the width of the two end regions, and wherein the row of spaced projections extends from one end region to the other end region.

The pressure member may comprise laterally extending rib members.

Preferably, the height of each of the projections is not more than 5mm when measured from the top surface of the support base. At such dimensions, it has been found that the projections impart sufficient pressure onto the sorbent to create greater vapour space and still have a heat transfer device that is generally thin.

The pressure member may be integrally formed with the sorbent layer. Alternatively, the pressure member may form part of the housing.

The sorbent may include fibres such as natural fibres, synthetic fibres or carbon nanotubes. Preferably, the longitudinal axes of the fibres are aligned in a direction that is substantially parallel to the direction of heat transfer to enhance the transfer of heat. Advantageously, the fibres are arranged to create a continuous capillary channel between evaporation and condensation regions of the heat transfer device. Even more advantageously, fluid trapping cavities of the fibres are arranged to trap the liquid coolant in micro/nano-meter size bubbles. At such sizes, the bubbles "explode" during

evaporation and there is a sudden release of energy to enhance the heat transfer efficiency.

Preferably, the fibres are processed to withstand temperatures of at least 200°C without decaying. A preferred example of the sorbent is carbon nanotube. Preferably, the average ratio of diameter to length of a strand of fibre is < 0.05. Preferably, the fibres are capable of sorbing the liquid coolant up to 90% of its volume.

Each of the fibres may have at least one tubular passage in the order of micro or nano-meter for intra-fibre capillary flow of liquid or vaporised coolant. Preferably, the at least one tubular passage's average diameter is less than 1.0 mm with a cross-sectional area of less than 0.79 mm^2. The at least one tubular passage may have at least 10% of the fibre volume and the fibre wall thickness is less than 1.0 mm. Further, the fibres may have diameters in the range of about 5.0nm to 50μm. These dimensions or structures of the fibres have been found to increase the capillary effect and thus increasing the heating efficiency.

It is common for fibres to be coated with agents/chemicals to be resistant against heat/fire, to provide electrical insulation or to be anti-static. However, it has been found that such agents/chemicals are not preferred for the heat transfer device. In fact, it has been found that preferably, the fibres should be processed so that the fibres are non-reactive or inert to the coolant and/or to the material of the housing at high temperatures. Preferably, the temperature is at least more than 200°C. Thus, it is preferred that the fibres can withstand these temperatures without decaying or peeling.

Preferably, the fibres are laid to converge towards a heat source region and diverge out to a heat dissipation region. The fibres may be interwoven to form a structural shape.

Alternatively, the sorbent may include pulp, paper, fabric or non-woven fabric.

Preferably, the liquid coolant has phase change properties between -40°C and 200°C.

In a third aspect, there is provided a heat transfer device for dissipating heat away from a heat source, the heat transfer device comprising

a housing;

a layer of sorbent, liquid coolant and a pressure member enclosed within the housing, the pressure member arranged to impart continuous pressure to at least one portion of the sorbent layer.

With the pressure member, it is possible to accentuate pressure at selected points where it is necessary to maximum the surface area for heat conduction and thus increases the efficiency of the heat transfer.

It is envisaged that preferred features of the first and/or second aspect may be applied to third aspect and vice versa.

The plurality of projections may have polygonal or cylindrical shapes. The projections may be spaced equidistantly in a range of about 0.2 to about 20 mm. The ratio of

distance between adjacent projections to a projection average diameter may be 7:3. It has been found that with such dimensions, the projections impart sufficient pressure to create greater vapour space in the sorbent to enhance the heat transfer. Preferably, the pressure member is arranged to impart pressure to at two distinct portions of the sorbent layer, the two distinct portions corresponding respectively to a first region of the heat transfer device that is arranged to contact with the heat source and a second region of the heat transfer device that is spaced from the heat source.

In a fourth aspect, there is provided a heat transfer device comprising:

- at least an aggregate of fibres or sheet of fibres with internal passages and holes capable of capillary transport of liquids from a heat source region to heat dissipation region and *vice versa*;
- a supply of coolant fluid in sufficient amount absorbed or contained by said fibres or sheet of fibres with internal passages and holes capable of capillary transport of liquids;
- pressure tension member comprising a strong yet resilient structure placed within said confined space and exerting pressure on said aggregate of fibres or sheet of fibres with internal passages and holes capable of capillary transport of liquids against said heat source region and/or heat dissipation region , wherein
  - a plurality of undulations are provided on said pressure tension member ; and
- a casing enclosing hermetically the aforesaid in a confined space.

In a fifth aspect, there is provided a method for transferring heat from a heat source region to a heat dissipation region of a heat transfer device comprising the steps of:

- providing a plurality of fibres or sheet of fibres with internal passages and holes capable of capillary transport of liquids convecting means capable of capillary convection of coolant fluid, wherein said convecting means are aggregated in a form contacting a heat source region at one end and a heat dissipation region at another end;
- supplying coolant fluid in sufficient amount, and absorbed and/or contained by said fibres or sheet of fibres with internal passages and holes capable of capillary transport of liquids conduit means;
- imparting pressure on said fibres or sheet of fibres with internal passages and holes capable of capillary transport of liquids conduit means with pressure tensioning means, including
- providing undulating means on said pressure tensioning means; and
- carrying out aforesaid means and steps in a hermetically confined space.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiment of the invention will now be described, by way of example, with reference to the accompanying drawings in which,

FIGURE 1a (Prior art) and FIGURE 1b (Prior art) respectively illustrate a perspective view and schematic cross-sectional view of a heat pipe disclosed in US-6,446,706;

FIGURE 2 (Prior art) is an disassembled view of a heat transfer device disclosed in KR-10-2004-0018107 (Unexamined Publication);

FIGURE 3 (Prior art) is a dissembled view of a heat transfer device disclosed in KR-10-2004-91617 (Laid-open Application);

FIGURE 4a shows a portion of a carbon nanotube sheet and FIGURE 4b shows the carbon nanotube sheet of Figure 4a after coming into contact with liquid;

FIGURE 5 is a heat transfer device of a first embodiment of this invention in unassembled form;

Figure 6 is a heat transfer device of a second embodiment of this invention in unassembled form;

FIGURE 7a is a cross section view of the heat transfer device of Figure 5 along the central axis; and FIGURE 7b is a sectional end view of the heat transfer device of Figure 5 and 7a along the direction C-C'.

FIGURE 8 shows a variation of the heat transfer device of Figure 5;

FIGURE 9 shows a variation of the heat transfer device of Figure 6;

Figure 9a is a cross section view of the heat transfer device of Figure 8 along the central axis and Figure 9b is a sectional end view of the heat transfer device of Figure 5 and 7a along the direction B-B';

FIGURES 10 and 11 are examples of how a sorbent layer and a pressure tension member of the heat transfer device illustrated in Figures 5 and 6 may be integrally formed;

FIGURES 12a, 12b and 12c are perspective, detail (and expanded view of the circled portion of Figure 12a) and cross sectional views of a base plate of the heat transfer device of Figure 5 with channels on its inner surface;

FIGURES 13 and 14 show variations of a housing for the heat transfer device of FIGURES 5 and 6;

FIGURE 15 is a schematic diagram of a fibre having two tubular passages;

FIGURE 16 is an SEM photograph of an actual fibre having four tubular passages;

FIGURE 17 is an SEM photograph of another actual fibre that has a single tubular passage;

FIGURE 18 is a scanning electron microscope photograph of fibres;

FIGURE 19 is a flowchart illustrating process steps for producing the heat transfer device of FIGURE5;

FIGURE 20 is a further variation of the structure of the pressure tension member;

FIGURE 21 is a sectional view in the direction E-E along the central longitudinal axis of the pressure tension member of FIGURE 20;

FIGURE 22 is an even further variation of the structure of the pressure tension member; and

FIGURE 23 is a section view in the direction F-F along the central longitudinal axis of the pressure tension member of FIGURE 22.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Figure 5 is a heat transfer device (50) of a first embodiment of this invention in which the heat transfer device (50) comprises a cover plate (51) and a base plate (52) defining a casing for housing components for the heat transfer device (50). In this embodiment, the cover and base plates (51,52) are made of polymer. The heat transfer device (50)

further includes a layer of sorbent material (60) and a pressure tension member (70) arranged between the cover and base plates (51,52).

The sorbent material (60) is able to sorb (i.e. absorb and/or adsorb) completely the liquid coolant that is required for the heat transfer device to transfer heat from a heat source. In other words, the quantity of the liquid coolant is such that it is completely adsorbed or absorbed by the sorbent material. Examples of a sorbent material are interwoven fibres of a suitable structure such as pulp, paper, fabric or non-woven fabric or non-woven fibres such as natural fibres like cellulose, synthetic fibres or carbon nanotubes. Such sorbent materials inherently have internal passages and holes capable of carrying/holding liquid as well as capillary transport of liquids.

In this embodiment, a layer of carbon nanotube is used as the sorbent material (60). The carbon nanotube layer is processed such that it does not emit any form of gas or vapour, or peal off at given operating temperature ranges and is non-reactive with the other components of the device such as the cover and base plates (51,52) and the pressure tension member (70). Moreover, carbon nanotubes exhibit good adsorption and absorption characteristics and this can be seen from Figure 4a, which shows a layer of carbon nanotube prior to coming into contact with a liquid and Figure 4b which shows the wet state of the carbon nanotube layer after coming into contact with the layer.

A preferred coolant is a liquid having liquid-gas phase transition that is in the range of – 40°C to 200°C and in this embodiment, with carbon nanotube as the sorbent material, water is used as the liquid coolant and the amount of liquid coolant to the layer of

carbon nanotube is such that the carbon nanotube is able to sorb the liquid coolant of up to 80% of the carbon nanotube's volume.

The pressure tension member (70) is arranged between the cover plate 51 and the layer of carbon nanotube (60) so as to provide support for the heat transfer device 50. The pressure tension member (70) should be rigid and strong enough to withstand external pressure when the heat transfer device is attached to a heat source and to maintain internal vapour space to allow the heat transfer when external deformation occurs. In this respect, the pressure tension member (70) should also be configured to have maximum vapour space. It should also be rigid enough to support the heat transfer device (50) from collapsing or imploding due to external pressure or force, or due to decrease in internal pressure due to excessive coolant vaporisation etc.

As shown in Figure 5, the pressure member (70) of this embodiment has two end portions (74,76) and a bridge portion (78) connecting the two end portions (74,76), the bridge portion having a narrower width than the two end portions (74,76). The pressure member (70) further includes an array of projecting members (80) carried by each end portion (74,76) on upper and bottom surfaces of the pressure member (70) (Figure 5 only shows the upper surface whereas for a sectional view of the projecting members projecting from both the upper and bottom surfaces, see Figure 7a) . The projecting members (80) are selectively arranged at locations on the end portions (74,76) where the pressure should be accentuated especially, at the regions operating as an evaporator and condenser.

Figure 7a is a cross sectional side view of the assembled heat transfer device (50) of Figure 5 that shows the projecting members (80) extending from the upper and bottom surfaces of the pressure member (70) and Figure 7b is a sectional view in the direction of line C-C'. The cross section view of Figure 7a shows more clearly two end regions (54,56) that can be used either as an evaporator or a condenser and the principle of operation will be described later.

Each of the projecting members (80) is L-shaped with a rectangular abutment surface (80a) that is planar to engage with the inner surface of the top cover plate 51. The projecting members (80) are integrally formed with the end portions (74,76) of the pressure tension member (70) by mould-pressing the appropriate part of the pressure tension member. The height of each projecting member that protrudes out of the pressure tension member (70) is preferably less than 5 mm and each of the projecting members is preferably placed equidistantly with each other in a range of about 0.2 to about 20 mm. The ratio of distance between adjacent projecting members to projecting member's diameter is preferably 7:3. To elaborate, the specific dimension of each projecting member (80) is not critical but if the distance between centres of adjacent projecting members (80) is P, and the length of the rectangular abutment surface of each projecting member is Q, then the ratio P:Q is preferably 7:3. Of course if the projecting member takes a bulbous shape, then the diameter of the bulbous projecting member should be considered.

In this embodiment, the pressure tension member (70) is a series of interwoven rigid wires made of metal. Other types of material are also suitable such as polymers and

ceramics. The material chosen should also be inert from chemical reaction with the liquid coolant and should not emit any gas. It is also preferred that the pressure tension member (70) has good thermal properties.

The pressure tension member (70) should have at least 70% open area with wires having a cutout space along the length of the pressure tension member (70) of being greater than 30% of the wire to provide enough vapour passage through the cutout area and this also gives flexibility for the pressure tension member (70) to be bent and still rigid enough to sustain pressure.

Figure 19 is a flowchart illustrating the process steps for producing the heat transfer device (50) and at step (500), the cover and base plates (51,52) are cleaned and dried to remove impurities as is normally the case. At step (502), the layer of carbon nanotube (60) is wet with water (as the coolant) so that coolant required for the heat transfer device to operate is sorbed by the layer of carbon nanotube (60). At step (504), the layer of carbon nanotube (60) is placed against the inner surface of the base plate (52).

At step 506, the pressure member (70) is aligned with the layer of carbon nanotube (60) with the projecting members (80) of the bottom surface for asserting pressure on corresponding portions of the layer of carbon nanotube (60). At step (508), the cover plate (51) is mated to the base plate (52) so that the pressure member (70) and the projecting members (80) are urged against the carbon nanotube layer (60) and the base plate (52).

Next, at step (510) the cover plate (51) and base plate (52) are bonded or wielded together. At step (512), a discharge orifice is created in between the cover plate (51) and the base plate (52) and air in the enclosed space between the cover plate (51) and the base plate (52) is discharged out of the casing through the discharge orifice to reduce pressure in the enclosed space. At step (514), the discharge orifice is sealed so that the heat transfer device (50) is hermetically sealed and the heat transfer device is ready to be used.

With the above process, since the carbon nanotube is capable of sorbing the liquid coolant that is required for operation of the heat transfer device, this obviates a need of an additional coolant injection process prior to the pressure reduction step (512). Accordingly, the manufacturing method is simplified.

An operation of the heat transfer device (50) of the first embodiment will now be described. To use the heat transfer device (50) to dissipate heat away from an external heat source such as an electronic component, a first end region (54) of the base plate (52) is arranged to be in contact with the electronic component (not shown). The contact may be achieved by using a layer of thermal adhesive to adhere the first end region of the base plate (52) to the electronic component. As a result, the first end region (54) operates as an evaporator while a second end region (56) operates as a condenser (56). Heat generated by the electronic component is transferred via the base plate (52) to the liquid coolant carried by the layer of carbon nanotube (60).The efficiency of the heat transfer is improved due to the presence of the projecting members (80) carried by the first end portion (74) of the pressure tension member (70) which corresponds to the first

end region, so that the projecting members (80) assert pressure on that portion of the carbon nanotube layer (60). This is because the assertion of the projecting members (80) onto the carbon nano-tube layer (60) maximise the surface area contact between the carbon-nanotube (60) and the base plate (52) and thus maximise conduction of heat from the electronic component to the liquid coolant to be conducted away.

The liquid coolant absorbs the heat and when its evaporating temperature is reached, the liquid coolant vaporises with the vapour diffusing through the porous carbon nanotube to reach the second end region (56) operating as the condenser. At the condenser (56), which is an ambient temperature, dissipates the heat from the vapour to the surrounding environment and this causes the vaporised coolant to condense. The presence of the carbon nanotube at the second region (56) draws the condensed coolant from the condenser (i.e. second region (56)) to the evaporator (i.e. first region (54)) by capillary action so as to return the coolant to the evaporator to repeat the heat transfer . In this way, heat from the electronic component is continuously being dissipated away.

To maximise fluid (liquid coolant and vaporised coolant) circulation between the condenser (56) and the evaporator (54) under negative gravity conditions, the inner surface (52b) of the base plate (52) are provided with a plurality of micro/nano channels (57) as illustrated in Figures 12a, 12b and 12c . These channels may be formed by wet etching, dry etching, machining, pressing or casting. The depth of these channels is preferably less than 500 micrometers and the cross sectional area should preferably be less than 2.5mm^2 with the aspect ratio being less than 2.0 and greater than 0.01.

Figure 8 shows a variation of the first embodiment of the heat transfer device (50) in which instead of one layer carbon nanotube (60) as the sorbent material, there is a second layer of sorbent material (61) sandwiched between the pressure tension member (70) and the cover plate (51) and similarly, the carbon nanotube is also arranged to sorb a certain quantity of coolant liquid that is used for the heat transfer. With the addition of the second layer of carbon nanotube (60), the heat transfer device is no longer limited by orientation since either the cover plate (51) or base plate (52) can be arranged to be in contact with a heat source. Also, this could also increase the efficiency of the heat transfer since heat transferred from the cover plate (51) to the liquid coolant in the second layer of the carbon nanotube (61) can also be transferred to the liquid coolant in the first layer of the carbon nanotube (60) and in this way, a greater amount of heat can be dissipated. In other words, with the second carbon nanotube layer, it increases the capillary effect and direction of heat transfer. Further, another difference with the first embodiment is that the bridge portion (79) is configured with a hollow rectangular cavity (79a) to create more vapour space to aid the vaporisation process.

Sectional views of the variation of the first embodiment are shown in Figures 9a and 9b.

A second embodiment of the heat transfer device (150) is shown in Figure 6 with like parts having the same reference numerals as the first embodiment but with an addition of a hundred. In the second embodiment, the heat transfer device (150) also includes a cover plate (150) and a base plate (152), both plates of similar construction as the first embodiment, a pressure tension member (170) and a layer of carbon nano-tube (160) arranged between the cover plate and the base plate (152). The function of the carbon

nano-tube layer (160) and the overall operation of the heat transfer device (150) of the second embodiment are similar to the first embodiment and thus, will not be elaborated here.

However, the difference lies in the structure of the pressure tension member (170). The pressure tension member (170) also has two end regions (170,174) but instead of two substantially rectangular regions, the two end regions include laterally extending rib members (184) that extend from the sides of the pressure tension member (170) in a symmetrical arrangement. As shown in Figure 6, each end region has a four pairs of extending rib members. The pressure tension member (170) also carries a plurality of projecting members (180) that are arranged in a row along a central longitudinal axis of the pressure tension member (170). In this way, the projecting members (180) creates pressure points along a passage linking the two regions so as to maximise surface area contact between the sorbent layer (160) and the base plate (152) and thus more efficient conduction of heat between the two regions.

With the use of projecting members (180), this enables selective application of pressure and thus, the pressure applied by the pressure tension member (176) is non-uniform. As with most fluids, the evaporation and condensation points would be subject to pressure. Our present device may provide two types of pressure, namely the accentuate pressure exerted by the undulations (projecting members) and, due to the 3-dimensional void passage way network created by the configuration of undulations of the pressure tension member, vapour pressure arising from the amount of coolant evaporated in the confined space. Depending on the amount of the coolant in gas phase, the temperature

of the void and nature of the passage way, i.e. whether a dead end or a connected passage, a vapour pressure gradient may arise between the heat source region and heat dissipation region. This might assist in providing a suitable range of temperature and pressure for effecting the desired phase transitions of the coolant for an efficient thermal conduction.

A variation of the second embodiment is shown in Figure 9 with the additional of a second layer of carbon nanotube (161) to enhance the functionality of the heat transfer device (150), just like the variation of the first embodiment illustrated in Figure 8.

The described embodiments should not be construed as limitative. For example, in both embodiments, the pressure tension members (70, 170) are described as independent components from the cover plate (51,151), base plate (52,152) and the sorbent layer (60,160). However, the pressure tension member (70, 170) may be formed as part of the cover plate (51,151) and/or the base plate (51/151). In other words, the projecting members (80,180), the extending rib members (184) may be integrally formed with the cover plate (51,151) so that selective pressure can still be asserted onto the sorbent layer (10,160). Also, the pressure tension member may be integrally formed with the layer of sorbent material (60,160) such as that shown in Figures 10 and 11. In Figure 10, sorbent material (200) is preformed or cut into a desired shape and size to define projecting elements (202) with the projecting elements (202) arranged near the ends of the layer of sorbent material (60) corresponding to the regions of the heat transfer device 50,150 that operate as evaporator/condenser. In this way, pressure is similarly asserted on the layer of sorbent material (60) to increase the heat transfer efficiency.

Also, the pressure tension member (70,170) may not be necessary depending on applications.

Figure 11 is another example of having an integrated pressure tension member and a layer of sorbent material having spaced projecting members (204) arranged in a row along the longitudinal axis of the layer of sorbent material (60).

The liquid coolant used in the described embodiments is water but other suitable coolants may be used such as alcohol or liquid metal (e.g. Indium).

The described embodiment uses carbon nanotube as an example of a sorbent material. However, other types of sorbents may be used and it is preferred that the sorbent material sorbs the liquid coolant in an amount 0.5 to 10 times of its own volume. Also, fibres are particularly good sorbents since they have internal passages and holes capable of sorbing the liquid coolant and also capable of capillary transport of fluid. A molecular structure of a fibre can be seen from Figure 17 which is a SEM photograph of an open end of a single strand of fibre. It can be seen that this strand of fibre has a single hollow tubular fluid passage. Figure 18 shows a scanning electron microscope photograph of an aggregate of fibres that shows the porosity of fibres with internal passages and holes capable of capillary transport of liquid. Fibres having more than one tubular passage are shown in FIGURES 15 and 16 in which Figure 15 is a schematic representation of a fibre having two tubular passages (400) and Figure 16 is a SEM photograph of a fibre having four-tubular passages.

The cover and base plates (51,52,151,152) are shown as separate parts in the described embodiment but this is not essential. For example, Figure 13 shows a heat transfer device (300) including a first plate (302) pivotally connected to a second plate (304) at one edge (306). The first and second plates (302,304) may be closed to enclose two layers of sorbent (308), liquid coolant sorbed by the sorbent (308) and a pressure tension member (310) of similar construction as the one described in the first embodiment. Figure 14 is an end view of the heat transfer device (300) of Figure 13 which illustrates the pivotal connection between the first and second plates (302,304). For avoidance of doubt, the heat transfer device (300) is sealed/bonded at its ends but in these figures, they are shown as open to show the internal components.

Depending on the configuration of the heat transfer device, distribution and configuration of the projecting members (80,180) and the rib members (84) may be adapted accordingly and may be symmetrical or asymmetrical, to maximise surface area contact and thus maximise conduction of heat from the heat source to the liquid coolant to be conducted away. The rib member (84) may be regarded as generally H-shaped protuberances but other configurations are envisaged and similarly may be used for the first embodiment.

The projecting members (80,180) in the described embodiments are generally L-shaped but hooked shaped, polygonal, bulbous or cylindrical-like shapes are also envisaged. The projecting members may be formed by machining, casting, press-moulding or like

processes or combination thereof. The L-shaped projecting members (80,180), for example, may be fabricated by mould-pressing the appropriate part of the pressure tension member.

The pressure tension member (70,170) may preferably be fabricated from metals, polymers, ceramics, silicon, organic or inorganic materials, stable such that it does not emit any form of gas or vapour at given working temperature ranges or peal off and non-reactive with coolant.

The sorbent may be selected from non-metallic, synthetic, inorganic and organic materials which are stable and does not emit any form of gas or vapour and peal off at given operating temperature ranges and non-reactive with the other components of the device such as the casing's inner surface and the pressure tension member. A particularly preferred material is carbon nanotubes. With such materials, the tubular structure of the fibres may be industrially produced with one or more hollow tubular passage therein in the order of micro- or nano-metre for effective intra-fibre capillary flow of the coolant in liquid phase.

On the physical dimensions of fibres, if this is used, the average ratio of diameter to length of each strand of fibre is preferable less than 0.05. The preferred fibres or sheet of fibres with internal passages and holes would be one that can absorb or contain up to 90% of its volume. A preferred tubular passage diameter is less than 1.0 mm with a cross-sectional area of less than 0.79 mm^2. The tubular passage should ideally occupy at least 10% of the fibre volume and the fibre wall thickness should be less than 1.0

mm. Overall, the fibres or sheet of fibres with internal passages and holes capable of capillary transport of liquids ideal diameters are in the range of about 50 μm to 5.0 mm.

The depth of the channels must be less than 500 micrometers and the cross sectional area must be less than 2.5mm^2 with the aspect ratio being less than 2.0 and greater than 0.01.

The fibres or sheet of fibres with internal passages and holes capable of capillary transport of liquids may be aggregated in any suitable way to form a structure that may range in density from loose to packed form. The aggregation may be achieved by a suitable treatment such as weaving, spinning, laying, aligning or simply grown and the like so that the strands of fibres are laid longitudinally from a heat source region to a heat dissipation region so as to create a longitudinal channel for continuous capillary effect. For example, the fibres may be interwoven to form a structural shape with each fibre strand spaced at less than 500 μm. With such close proximity of the strands together, in addition to the intra-strand capillary action through the hollow tubular passage inside each fibre when the coolant fluid is absorbed or contained thereinto, the adsorption and containment of the coolant fluid on the external fibre strand surface may also be promote inter-fibre or inter-strand capillary action of closely placed adjacent fibres as a result of the adsorption or affinity of the fibres' surfaces for the coolant fluid.

It is preferred that the fibres are laid in a manner that converge towards the heat source region and diverge out to the heat dissipation region.

In the described embodiments, the projecting members (80,180) are arranged to project from both directions but it is envisaged that the projecting members may project from one direction only to create concentrated pressure points directly against the sorbent layer in one direction. Similarly, in the first embodiment, the projecting members (80) are arranged to face the cover plate (51) but it is envisaged that the projecting members (80) may face and contact the sorbent layer directly. Further, there can be variations to the configurations of the projecting members such as that shown in Figures 20-23. To elaborate, Figure 20 shows a first variation of the projecting members (280) that is similar to the one shown in Figure 5 but instead of the projecting members on the same surface of the pressure tension member extending in the same direction, the first variation has alternate rows of the projecting members (280) extending in opposing directions (similar components of this variations have similar reference numerals as the embodiment of Figure 5 except with the addition of 200; i.e. cover plate (251), base plate (252), pressure tension member (270) and sorbent layer (260)). Figure 21 is a sectional view along the central longitudinal axis view from arrows E-E and this shows the projecting members (280) projecting alternately.

Figure 22 shows a second variation that is similar to the configuration of the pressure member shown in Figure 6 except that the projecting members (380) also alternates projecting either from the upper surface or bottom surface of the pressure tension member (370) and a sorbent layer 360 arranged between a cover plate 351 and the pressure tension member (370) with the pressure tension member arranged between the sorbent layer (360) and a base plate (352) (like components of this variation uses the same reference numerals as the embodiment shown in Figure 6 except with the addition

of 200). Figure 23 is a sectional view along the central longitudinal axis view from arrows F-F and this shows projecting members (380) projecting from opposing surfaces.

In the first embodiment, channels (57) are formed on the base plate 52 to enhance capillary action and similar channels may be formed on the inner surface of the cover plate 51 and also for the cover and base plates of the second embodiment. These channels (57) may be formed by wet etching, dry etching, machining, pressing or casting or combinations thereof.

The cover plate and the base plate that forms the housing for the heat transfer device may be fabricated from metals, non-porous polymers, ceramics, crystalline, inorganic or organic materials having good thermal conduction, or composites. Preferably, the chosen materials results in a housing that is resilient to increase internal vapour pressure. The device's dimension is defined principally by the dimensions of the casing which for practical reasons should not be more than 10.0 mm. The casing wall should not be more than 5.0 mm thick whereas the confined space enclosed in the casing is less than 5.0 mm.

The described embodiments include description a method of producing a heat transfer device that wets the sorbent layer prior to arranging the sorbent layer within the housing. Of course, this may not be necessary and the sorbent layer may first be arranged within the housing and after sealing the cover and base plates, pressure within the housing is reduced by discharging air out of the housing through the discharge orifice and liquid coolant is injected through the discharge orifice.

Alternatively, the housing (i.e. space between the cover and base plates) is filled with coolant, and a small amount of the coolant is extracted from the space in order to reduce the pressure of the space.

The aforesaid configuration of the device and method may be implemented in a device for heat transfer to be in thermal contact with another device or article, particularly for semiconductor devices, chipset, circuit board or electronic components wherein excess heat produced has to be removed for optimal performance or where rapid and controlled heating is required.

Having now fully described the invention, it should be apparent to one of ordinary skill in the art that many modifications can be made hereto without departing from the scope as claimed.

CLAIMS

1. A heat transfer device for dissipating heat away from a heat source, the heat transfer device comprising:

liquid coolant enclosed within a housing, and

a layer of sorbent capable of completely sorbing the liquid coolant.

2. A heat transfer device according to claim 1, wherein the sorbent is capable of sorbing the liquid coolant in an amount 0.5 to 10 times of its own volume.

3. A heat transfer device according to claim 1 or 2, further comprising a pressure member arranged to impart continuous pressure to at least one portion of the sorbent layer.

4. A heat transfer device according to claim 2, wherein the pressure member is integrally formed with the sorbent layer.

5. A heat transfer device according to claim 2, wherein the pressure member forms part of the housing.

6. A heat transfer device according to any of claims 3 to 5, wherein said at least one portion of the sorbent layer corresponds to a region of the heat transfer device that is arranged to contact with the heat source.

7. A heat transfer device according to any of claims 3 to 5, wherein said at least one portion of the sorbent layer corresponds to a region of the heat transfer device that is spaced from the heat source.

8. A heat transfer device according to any of claims 3 to 5, wherein the pressure member is arranged to impart pressure to at two distinct portions of the sorbent layer, the two distinct portions corresponding respectively to a first region of the heat transfer device that is arranged to contact with the heat source and a second region of the heat transfer device that is spaced from the heat source.

9. A heat transfer device according to claim 8, wherein the pressure member includes a support base having two end regions and a bridge portion connecting the two end regions, the width of the bridge portion is narrower than the width of the two end regions, and wherein each of the end regions carries a plurality of projections to impart pressure at the two distinct portions.

10. A heat transfer device according to claim 9, wherein the plurality of projections are arranged in an array.

11. A heat transfer device according to claim 3 to 5, wherein the pressure member includes a plurality of spaced projections arranged in a row.

12. A heat transfer device according to claim 11, wherein the pressure member includes a support base having two end regions and a bridge portion connecting the two end

regions, the width of the bridge portion is narrower than the width of the two end regions, and wherein the row of spaced projections extends from one end region to the other end region.

13. A heat transfer device according to any of claims 3 to 12, wherein the pressure member comprises laterally extending rib members.

14. A heat transfer device according to claim 9 or 12, wherein the height of each of the projections are not more than 5mm when measured from the top surface of the support base.

15. A heat transfer device according to any preceding claim, wherein the sorbent includes fibres .

16. A heat transfer device according to claim 15 wherein the longitudinal of the fibres are aligned in a direction that is substantially parallel to the direction of heat transfer.

17. A heat transfer device according to claim 15 or 16 wherein the fibres are arranged to create a continuous capillary channel between evaporation and condensation regions of the heat transfer device.

18. A heat transfer device according to any of claims 15 to 17, wherein fluid trapping cavities of the fibres are arranged to trap the liquid coolant in micro/nano-meter size bubbles.

19. A heat transfer device according to any of claims 15 to 18, wherein the fibres are processed to withstand temperatures of at least 200°C without decaying.

20. A heat transfer device according to any of claims 15 to 19 wherein the fibre is carbon nanotube.

21. A heat transfer device according to any of claims 15 to 20, wherein the average ratio of diameter to length of a strand of fibre is < 0.05.

22. A heat transfer device according to claim 15 or 21, wherein the fibres are capable of sorbing the liquid coolant up to 90% of its volume.

23. A heat transfer device according to any of claims 15 to 22, wherein each of the fibres has at least one tubular passage in the order of micro or nano-meter for intra-fibre capillary flow of liquid or vaporised coolant.

24. A heat transfer device according to claim 23 wherein the at least one tubular passage's average diameter is less than 1.0 mm with a cross-sectional area of less than 0.79 mm^2.

25. A heat transfer device according to claim 24 wherein the at least one tubular passage is at least 10% of the fibre volume and the fibre wall thickness is less than 1.0 mm.

26. A heat transfer device according to any of claims 15 to 25 wherein the fibres have diameters in the range of about 5.0nm to 50μm.

27. A heat transfer device according to Claim 15 to 26 wherein the fibres are laid to converge towards a heat source region and diverge out to a heat dissipation region.

28. A heat transfer device according to Claim 15 to 26 wherein the fibres are interwoven to form a structural shape.

29. A heat transfer device according to claim any of claims 1 to 14, wherein the sorbent includes pulp, paper, fabric or non-woven fabric.

30. A heat transfer device according to any preceding claim, wherein the liquid coolant has phase change properties between -40°C and 200°C.

31. A method of producing a heat transfer device according to any preceding claims, the method comprising the step of:

arranging the layer of sorbent capable of completely sorbing the liquid coolant within the housing.

32. A method of producing a heat transfer device according to claim 31, further comprising the step of wetting the layer of sorbent with the liquid coolant prior to arranging the layer of sorbent within the housing.

33. A method of producing a heat transfer device according to claim 31, further comprising the step of arranging the layer of sorbent within the housing, and thereafter injecting a sufficient amount of the liquid coolant that is capable of being completely sorbed by the layer of sorbent.

34. A heat transfer device for dissipating heat away from a heat source, the heat transfer device comprising

a housing;

a layer of sorbent, liquid coolant and a pressure member enclosed within the housing, the pressure member arranged to impart continuous pressure to at least one portion of the sorbent layer.

35. A heat transfer device according to claim 34, wherein the pressure member is integrally formed with the sorbent layer.

36. A heat transfer device according to claim 34 wherein the pressure member forms part of the housing.

37. A heat transfer device according to any of claims 34 to 36, wherein the pressure member includes a plurality of projections.

38. A heat transfer device according to claim 37, wherein the plurality of projections are arranged in an array.

39. A heat transfer device according to claim 37, wherein the pressure member includes a plurality of spaced projections arranged in a row.

40. A heat transfer device according to any of claims 37 to 39, wherein the plurality of projections has polygonal or cylindrical shapes.

41. A heat transfer device according to claim 40 wherein the projections are spaced equidistantly in a range of about 0.2 to about 20 mm.

42. A heat transfer device according to claim 41 wherein the ratio of distance between adjacent projections to a projection average diameter is 7:3.

43. A heat transfer device according to any of claims 34 to 42, wherein the pressure member is arranged to impart pressure to at two distinct portions of the sorbent layer, the two distinct portions corresponding respectively to a first region of the heat transfer device that is arranged to contact with the heat source and a second region of the heat transfer device that is spaced from the heat source.

44. A heat transfer device comprising:

- at least an aggregate of fibres or sheet of fibres with internal passages and holes capable of capillary transport of liquids from a heat source region to heat dissipation region and *vice versa*;
- a supply of coolant fluid in sufficient amount absorbed or contained by said fibres or sheet of fibres with internal passages and holes capable of capillary transport of liquids;
- pressure tension member comprising a strong yet resilient structure placed within said confined space and exerting pressure on said aggregate of fibres or sheet of fibres with internal passages and holes capable of capillary transport of liquids against said heat source region and/or heat dissipation region , wherein
  - a plurality of undulations are provided on said pressure tension member ; and
- a casing enclosing hermetically the aforesaid in a confined space.

45. A method for transferring heat from a heat source region to a heat dissipation region of a heat transfer device comprising the steps of:

- providing a plurality of fibres or sheet of fibres with internal passages and holes capable of capillary transport of liquids convecting means capable of capillary convection of coolant fluid, wherein said convecting means are aggregated in a form contacting a heat source region at one end and a heat dissipation region at another end;
- supplying coolant fluid in sufficient amount, and absorbed and/or contained by said fibres or sheet of fibres with internal passages and holes capable of capillary transport of liquids conduit means;

- imparting pressure on said fibres or sheet of fibres with internal passages and holes capable of capillary transport of liquids conduit means with pressure tensioning means, including
  - providing undulating means on said pressure tensioning means; and
- carrying out aforesaid means and steps in a hermetically confined space.