A heat exchange device including a first surface configured to be in contact with a source of heat to be discharged and a second surface configured to be in contact with a coolant. The device includes a plurality of recesses fluidically insulated from one another, each recess leading onto the second surface via at least one channel, each channel having a length and a transverse size that prevents the coolant from entering the recess. The second surface has better wettability properties with respect to the coolant and the inner surfaces of the channels and the recesses have wettability properties less than or equal to those of the second surface.
THERMAL EXCHANGE DEVICE WITH INCREASED THERMAL EXCHANGE COEFFICIENT AND METHOD FOR PRODUCTION OF SUCH A DEVICE

TECHNICAL FIELD AND PRIOR ART

[0001] The present invention relates to a method for production of surfaces providing an increased thermal exchange coefficient. These surfaces can be used in thermal exchangers.

[0002] Miniaturisation of electronic components, and notably power components, poses the problem of the integration of devices to dissipate the heat emitted by these components. In the field of microelectronics and power electronics, the thermal flows which must be dissipated continue to increase, and require ever-greater reduction of thermal resistance. The thermal flows to be dissipated often have average values around 150-200 W/cm², but they can reach 1000 W/cm². At these levels of heat flow density, cooling methods known as "passive" methods, such as dissipators with fins or monophasic liquid systems rapidly reach the maximum power they are able to extract.

[0003] Other solutions have therefore been devised, such as liquid/vapour biphasic heat transfer devices. Technologies using these transfers are heat pipes, thermostorps, capillary loops or two-phase pumped loops. The component to be cooled is located in the cold area of the cooling device, i.e. the evaporator.

[0004] Heat pipes enable the thermal conductivity of a heat dissipator to be increased. Heat pipes allow a thermal power extracted from a given area to be transferred to a secondary area, which is often more accessible, or has better heat exchanges for dissipation. A heat pipe is a closed system in which a liquid fluid in equilibrium with its vapour is placed. A heat pipe includes an area forming an evaporator on the side of the electronic component, where the heat to be dissipated by vapour formation is absorbed. The vapour produced in the evaporator migrates through the core of the heat pipe as far as a condensation area, where the absorbed heat is released by liquification of the vapour, and the heat is therefore dissipated. The condensate returns to the evaporation area under the effect of capillary forces.

[0005] A heat pipe can be added on to the electronic component or integrated in the component; in the case of micro-electronic chips this consists in installing a network of channels directly on the silicon substrate, thus reducing the thermal resistance.

[0006] Yet another solution is the system of two-phase pumped loops, using a motor system, a condenser and an evaporator.

[0007] All these solutions therefore use a thermal exchange surface in contact with the component, either added on to the component to be cooled, or formed in the substrate of the component to be cooled, where this surface is intended to extract the heat generated inside the component. This extraction, as explained above, occurs through a change of phase by evaporation of a liquid.

[0008] The desired cooling preferably takes place with a small temperature difference.

[0009] There are then two possibilities for increasing the transferred thermal flow densities: either to increase the thermal exchange area, or to increase the thermal exchange coefficient. Due to the encumbrance problems relating to the continual quest for miniaturisation and production costs, more attention has been paid to increasing the thermal exchange coefficient.

[0010] This increase of the thermal exchange coefficient is obtained by encouraging nucleation of vapour bubbles and the appearance of a large number of vapour bubbles causing dissipation of the heat. Nucleation is preferably sought with little overheating of the surface, in order to avoid damaging the component to be cooled. Formation of vapour bubbles is favoured by having a surface with a low wettability. Conversely, detachment of the vapour bubbles is favoured by having a surface with a good wettability. It is consequently sought to reconcile on the same surface properties of good and low wettability.

[0011] The favoured solution is to create nucleation sites by trapping gas in cavities located between the surface and the liquid. These gas cells facilitate the appearance of vapour nuclei which, as they grow, are transformed into vapour bubbles.

[0012] The document "Designing Superoleophobic Surfaces", Anish Tuteja et al. in Science, 218, 1618 (2007), pages 1619 to 1622, describes the production of cavities, called reentrant cavities, in the surface; these cavities are interconnected.


[0014] Since the cavities are interconnected there is a substantial risk that the cavities will become filled with water. In this case the cavities are flooded, preventing the appearance of vapour nuclei.

[0015] It is, consequently, one aim of the present invention to provide a thermal exchange surface the thermal exchange coefficient of which is improved.

[0016] It is another aim of the present invention to provide a method for production of such a thermal exchange surface.

ACCOUNT OF THE INVENTION

[0017] The previously declared aim is attained by a thermal exchange device including a first face intended to be in contact with a source of heat to be dissipated, and a second face intended to be in contact with a liquid, where the said device includes all the way through it, between the first and the second face, multiple cavities separated from one another, which emerge in the second face through at least one duct. The dimensions of each duct, in terms of both lengthways and transverse dimensions, are such that they form a barrier to the liquid, with the meniscus positioned in the duct; the liquid is therefore prevented from penetrating into the cavity. In addition, the surface in contact with the liquid has hydrophobic qualities and the inner surface of the ducts and of the cavities has lesser hydrophobic qualities compared to those of the surface in contact with the liquid.

[0018] Thus, the cavities are not flooded and the gas trapped in the cavities allows vapour nuclei to form. In addition, the production of separate cavities, i.e. the presence of solid matter, which is thermally more conducting over the gas, between the cavities prevents the appearance of a continuous vapour layer which would act as a thermal barrier, thus causing the structure to become heated.

[0019] In other words, the thermal exchange surface is stratified; it includes a first layer close to the heat source,
having cavities in which the vapour is trapped, and a second layer in contact with the cooling liquid, pierced by ducts connecting the cavities to the outside; a vapour nucleus appears, grows and leaves the cavity to form a vapour bubble at the surface which, in its turn, will grow and become detached from the surface due to the hydrophilic surface.

The duct may have a tapered geometry, where its lesser diameter intersects the cavity, or a tubular geometry of diameter less than that of the cavity, to form a restriction.

The main subject-matter of the present invention is therefore a thermal exchange device including a first face intended to be in contact with a source of heat to be dissipated, and a second face intended to be in contact with a cooling liquid, where the said device includes, through its thickness, between the first and second faces, multiple cavities of average radius, in which:

the said cavities are isolated from one another in a fluid manner by walls, where each cavity emerges in the second face through at least one duct, where the length of each duct is greater than the average radius of ducts, where the transverse dimension of the duct in the area of the connection with the cavity is chosen such that it forms a restriction between the cavity and the duct, and where the second face is pierced with apertures formed by the ducts, and in which:

the said second face has properties of good wettability in relation to the cooling liquid, such that the contact angle of the liquid is less than 90° and the contact angle between the liquid and the inner surfaces of the ducts and cavities is greater than or equal to that between the liquid and the second face.

Advantageously, the ducts have a maximum diameter of between 0.1D, and D1, and the number of ducts (10) is defined such that n=0.5×(D1/Di)3.

In a particular manner, \( V_{\text{total, ducts}} > (P/P_{\text{atm}}) \times V_{\text{cavity}} \) is chosen, where

\( V_{\text{total, ducts}} \) is the volume formed by the sum of the volumes of each of the ducts penetrating into a cavity,

\( V_{\text{cavity}} \) is the volume of a cavity,

\( P \) is the absolute pressure of the cooling liquid,

\( P_{\text{atm}} \) is the atmospheric pressure.

For example, the walls separating the cavities have a minimum thickness of between 0.1 times and 0.2 times the average diameter of the cavities, and the apertures formed in the second face are separated by a small distance compared to the diameter of the apertures.

In a particularly advantageous manner, the ducts have a tapered shape, smaller base of which is located in the area of the connection with the cavities.

For example, the thermal exchange device includes a matrix in which the cavities and the ducts are produced and a layer deposited on the second face, where the said matrix has a low wettability in relation to the liquid and the said layer has a good wettability in relation to the liquid.

It may be arranged such that the thermal exchange device includes areas with apertures formed by the ducts emerging in the second face, called structured areas, and areas without apertures, called unstructured areas. For example, the structured areas have a side measuring between 10 μm and 50 μm, where the said areas are separated from one another by a distance of between 50 μm and 500 μm.

Another subject-matter of the present invention is a method for production of a thermal exchange device according to the present invention, in which the cavities are obtained by the deposit of discrete elements on a substrate, by burying these discrete elements in a layer of material forming the matrix of the thermal exchange device, in order to produce in the matrix of ducts until reaching the discrete elements, and to eliminate the said discrete elements.

The method may include the following steps:

- a) deposit on a substrate of a barrier layer,
- b) deposit of a layer of discrete elements of greater average diameter, intended to demarcate the cavities,
- c) deposit of a layer on and between the discrete elements of greater average diameter, where the said layer is intended to form the matrix of the device,
- d) deposit of discrete elements of smaller average diameter on the layer forming the matrix,
- e) deposit of a continuous layer on and between the discrete elements of smaller average diameter (30),
- f) removal of the discrete elements of smaller average diameter revealing apertures in the areas of which the layer forming the matrix is exposed,
- g) production of ducts in the layer forming the matrix in the area of the apertures until reaching the discrete elements of greater average diameter,
- h) elimination of the discrete elements of greater average diameter.

The discrete elements are, for example, made from silica or polymer, for example polystyrene, and these discrete elements are eliminated by dissolving them by chemical attack.

The discrete elements of smaller average diameter have, for example, an average diameter less than or equal to the average diameter of the discrete elements of greater diameter.

The method for production of a thermal exchange device according to the present invention can include a step of reduction of the size of the discrete elements of greater average diameter before step c) deposit and/or a step of reduction of the size of the discrete elements of smaller average diameter before step e), for example by dry etching.

The layer deposited in step e) advantageously has a good wettability in relation to the cooling liquid, for example silica.

The material forming the matrix is, for example, hydrogenated amorphous carbon.

The method for production of a thermal exchange device according to the present invention may include, before step b), a step of deposit of a preliminary layer of material forming the matrix.

The method for production of a thermal exchange device according to the present invention may also include a step of installation of a mask on the substrate before step f) of removal of the discrete elements of smaller diameter, so as to allow the discrete elements of smaller average diameter to be removed only in the area of the unmasked areas.

**BRIEF DESCRIPTION OF THE ILLUSTRATIONS**

The present invention will be better understood using the description which follows and the appended illustrations, in which:

**FIG. 1A** is a perspective lengthways section view of an example embodiment of a portion of a thermal exchange device according to the present invention,

**FIG. 1B** is a detailed view of FIG. 1A,
FIG. 2 is a perspective lengthways section view of another example embodiment of a portion of a thermal exchange device according to the present invention.

FIGS. 3A to 3C are schematic diagrams of the operation of the thermal exchange device according to the present invention.

FIG. 4 is a top view of a device according to the present invention, with partial structuring.

FIGS. 5A to 5I are schematic representations of different steps of production of a thermal exchange device according to the present invention.

FIG. 6 is a schematic representation of a variant of the step represented in FIG. 5C.

FIGS. 7A and 7B are section and top view schematic representations of a thermal exchange device according to the present invention, having structured areas and unstructured areas.

DETAILED ACCOUNT OF PARTICULAR EMBODIMENTS

FIGS. 1A, 1B and 2 are section views; however, the hatchings are not represented.

In FIGS. 1A and 1B a first example embodiment of a thermal exchange device D according to the present invention can be seen.

Such a device, generally called a thermal exchange surface, takes the form of a plate 2 which may be flat or may have a profile suitable for the area to be cooled.

For the description we shall confine ourselves to a flat plate, but it is well understood that all shapes of plate come within the scope of the present invention.

Plate 2 includes a first face 4 intended to come into contact with the source of heat to be dissipated, and a second face 6 intended to come into contact with a liquid, the boiling of which enables the heat to be dissipated.

The first 4 and second 6 faces are separated by a distance e, forming the thickness of the plate.

According to the present invention, plate 2 includes cavities 8 located on the side of the first face 4 near the heat source, and therefore at a certain distance from the second face 6, where each cavity 8 is connected to the second face 6 by at least one duct 10. Ducts 10 form a barrier to the penetration of the liquid into the cavities.

The size of cavities 8 is chosen such that it is greater than or equal to the critical size of a vapour nucleus, to favour its growth.

The ducts have a lengthways dimension or length separating face 6 from cavity 8 designated H. Ducts 10 emerge in face 6 from openings 11 of diameter D₂.

Length H is chosen such that the distance to be travelled by the liquid between two diametrically opposed ends of apertures 11 is greater than length H, in order to favour the transverse wetting of the duct compared to the lengthways wetting, which reduces the risk of flooding cavity 8. Length H is therefore greater than diameter D₂.

It is sought to avoid flooding the cavity completely; however, it is acceptable that a portion of the cavity is flooded, leaving a free volume which is sufficient to form a vapour nucleus.

Advantageously, the ducts and cavities are dimensioned such that ducts 10 form a barrier to the penetration of the liquid into the cavities, and prevent the liquid from entering the cavities for a given absolute pressure P of the liquid. In this case, the total volume of the ducts emerging in the cavity is chosen such that it is greater than the volume of the cavity according to the expression below, in order to prevent even partial flooding of the cavity:

$$V_{\text{total ducts}} > P \cdot \cos \alpha \cdot V_{\text{cavity}}$$

where $V_{\text{total ducts}}$ is the volume formed by the sum of the volumes of each of ducts 10 penetrating into a cavity 8.

and where $V_{\text{cavity}}$ is the volume of a cavity 8.

$P$ is the absolute pressure of the liquid,

$\alpha$ is the wettability difference between face 6 and aperture 11.

In the example represented in FIGS. 1A and 1B, approximately four ducts connect each cavity to second face 6. Indeed, it is not necessarily the entire section of each duct which intercepts the cavity.

Also according to the invention, each cavity 8 is physically separated from the other cavities 8, i.e. there is no fluid connection between them. The cavities with their ducts 10 are separated from one another by walls 13 having a thickness $L_1$ between cavities 8, and a thickness $L_2$ between apertures 11.

Cavities 8 are intended to be filled with vapour, each cavity with its ducts consequently forms a vapour cell. The presence of walls 13 between each vapour cell enables the appearance of a vapour layer to be prevented, which would prevent the heat dissipation from occurring. The walls allow continuous dissipation of heat by conduction.

In addition, connection area 12 between each duct 10 and associated cavity 8 takes the form of a bottleneck. To this end, the diameter of the portion of the duct intersecting the wall of the cavity is less than that of the cavity.

In addition, surface 6 has properties of good wettability in relation to the cooling liquid, i.e. the contact angle $\alpha$ is less than 90°. In the case of water the surface is said to be hydrophilic. The inner surface of cavities 8 and the inner surfaces of ducts 10 have wettability properties which are at least identical to those of surface 6, i.e. the wetting angle on the inner surfaces of the cavities and of the ducts is greater than or equal to $\alpha$.

Consequently, it is possible to use a hydrophilic material to produce the device, where surface 6 and the inner surfaces of the cavities and the ducts then have the same wettability. In an alternative and particularly advantageous manner, it is possible to use a hydrophobic material to produce the device, and to include a hydrophilic treatment at the surface for face 6, where face 6 has a good wettability and the inner surfaces of the cavities and the ducts have a lesser hydrophobicity, and therefore a lesser wettability. In the latter case, the nucleation and detachment of the bubbles are particularly favoured.

In the represented example, ducts 10 have a tapered shape, the larger base of which 10.1 forms aperture 11 and the smaller base of which 10.2 is connected to the cavity.

Ducts having a tubular shape of constant diameter do not, however, go beyond the scope of the present invention.

In addition, cavities of spherical shape are represented; however the invention applies to cavities of any shape. The indicated diameter is an average diameter.

The presence of this restriction between cavity 8 and duct 10, and the associated volume ratio ($\frac{V_{\text{total ducts}}}{V_{\text{cavity}}}$) enable the cooling liquid to be prevented from penetrating into cavity 8. The wettability difference between face 6 and
duct 10, together with the force resulting from the pressure difference between the liquid and the vapour, both advantageously oppose penetration of the liquid into the cavity.

0087 The average diameter of cavity 8 is designated D1. The diameter of apertures 11 is designated D2.

0088 In the example of FIGS. 1A and 1B, D2 is equal to 0.5D1.

0089 In FIG. 2, another example embodiment of a thermal exchange device according to the present invention can be seen, in which the diameter of ducts 10 connecting cavity 8 to second face 6 is appreciably smaller, and its number is appreciably greater compared to the device in the figures. In this example, D2 is approximately equal to 0.1D1.

0090 Advantageously, D2 is between 0.1D1 and D1; I2 is non-zero, but very much less than D2, and preferentially less than 0.25D2, and length H is greater than D2. If D2=I2, ducts 10 will preferably be tapered, in order to demarcate a bottleneck effectively.

0091 It is also sought preferentially to have a rate of aperture of face 6 greater than 50%, i.e. the ratio between the area of holes 11 and the total area of face 6 is greater than 0.5. This aperture rate is directly related to the number of ducts 10.

0092 Advantageously a number n is chosen such that:

\[ n > 0.5 \times (D1/D2)^2 \]

0093 As an example, D1 may be between 0.5 μm and 5 μm; D2 may therefore be between 0.1 μm and 5 μm. I2 may be between 0.1 μm and 1 μm, I1 is between 0.1 μm and 0.5 μm and H is between 0.2 μm and 30 μm and greater than D2.

0094 The cavities according to the present invention can be produced across the entire surface of the thermal exchange device. The entire face 6 will consequently include apertures 11. This structuring can then be as much as several cm².

0095 It may also be decided to produce cavities only in localised areas where it is known, for example, that the quantity of heat to be extracted is greater.

0096 It may be preferable to produce structured areas 16 which are roughly equivalent to the size of a vapour bubble, i.e. less than approximately 1 mm, surrounded by unstructured area 18, such that each structured area 16 forms part of all the cavities generates one bubble at a time. Unstructured area 18 has a good wettability; it therefore facilitates the release of the bubble. Conversely, the number of bubbles generated is lower. An example of such a surface is represented in FIG. 4. Distance d1 between two structured areas 16 is, for example, between 50 μm and 500 μm, and width d2 of structured areas 16 of square shape is, for example, between 10 μm and 50 μm.

0097 If the entire surface is structured the number of structured bubbles is very large; conversely detachling them may be less easy. It should be noted that in all cases the apertures of ducts 10 emerging in face 6 are always surrounded by a hole-free area, which ensures the presence of liquid favouring bubble release, and re-wetting of the surface, preventing the critical boiling flow from being impaired. This area can vary in size, depending on the embodiment.

0098 We shall now explain the operation of the device according to the present invention by means of diagrams 3A to 3C.

0099 In FIGS. 3A to 3C a thermal exchange device D according to the present invention can be seen in contact by its first face 4 with an element to be cooled 14, and by its second face 6 with a liquid L, for example water.

0100 Device D includes a structured area 16, as represented in FIGS. 1A and 1B or 2, and an unstructured area 18, i.e. one which is free of cavities.

0101 The heat traverses plate 2 by conduction.

0102 The liquid in contact with face 6 is partially vaporised, and the vapour is trapped in cavities 8. Due to the configuration of the duct the liquid does not penetrate into the cavity, and the meniscus is located inside ducts 10. Vapour nuclei appear in the cavities. The pressure in the cavities increases, the size of the cavity being greater than the critical nucleation size, and the nuclei grow and rise in ducts 10 as far as surface 6. At the surface the nuclei regroup to form a bubble 20 which continues to grow. Bubble 20 then covers the entire structured area, as can be seen in FIG. 3A.

0103 The liquid in contact with the vapour bubble is vapourised, which causes the bubble to grow as can be seen in FIG. 3B. This bubble, by growing, extends beyond structured area 16, which is non-wetting, and comes into contact with unstructured area 18 which is, on the contrary, highly wetting. The high wettability of unstructured area 18 in relation to the liquid causes a reduction of the contact angle between the vapour bubble and second face 6 and an acceleration of the advance of the liquid towards the axis of the bubble, and the effect of this is to cause the vapour bubble to become detached.

0104 Thus, due to the invention, the energy required to activate nucleation is greatly reduced, and generation of vapour bubbles is then favoured. Their detachment is also favoured by the presence of wetting areas around the ducts.

0105 A device in which it is arranged such that each cavity 8 connected to face 6 by one or more ducts 10 produces only one vapour bubble may be envisaged. However, it is advantageous to use several cavities to produce one bubble. Indeed, there is a risk that a cavity is filled with liquid, and that it does not therefore contain any gas. In this case nucleation is very difficult. This cavity therefore produces no or very few bubbles. This filling may be due to a defect of the cavity following its production. Conversely, if it is arranged such that several cavities produce one bubble, it is possible to be sure in all cases that, even if one of them has a defect, the others will form functional nucleation sites.

0106 We shall now describe an example of a method for production of such cavities.

0107 In FIGS. 5A to 5I the different steps of a method for production according to the present invention of a thermal exchange device according to the present invention can be seen.

0108 In a first step (FIG. 5A), a substrate 22 is chosen on which the cavities will be produced. This substrate may be made of metal, for example of aluminium, copper or an alloy, or of silicon. This substrate 22 forms the element from which the heat must be dissipated.

0109 In a subsequent step represented in FIG. 5B, a barrier layer 24 is deposited on one face of substrate 22. This layer 24 is intended to provide the adhesion of the layer in which the cavities will be produced, which may be a layer of carbon in the form of hydrogenated amorphous carbon (or DLC: Diamond-Like-Carbon). The material constituting layer 24 is chosen to resist the subsequent chemical attacks, and such that its etching speed is very much lower than that of the balls intended to demarcate the cavities, as we shall see in due course. This enables blistering of the layer of DLC to be prevented.
Barrier layer 24 is made, for example, from silicon carbide (SiC) or from Nichrome (NiCr), deposited by chemical deposit in the vapour phase, or by physical deposit in the vapour phase. It is between 100 nm and 500 nm thick. In a subsequent step, represented in FIG. 5C, a layer of balls 26 is deposited on layer 24 forming a layer of balls. These balls are deposited, for example, by means of a process of the Langmuir-Blodgett type. The deposit obtained by a process of the Langmuir-Blodgett type is a compact deposit, i.e. each ball is in contact in the plane with six other balls, forming a hexagonal pattern. The next step is to reduce the compactness of the layer of balls, by reducing the size of the balls by dry etching of the RIE (Reactive Ion Etching) type. The balls are thus no longer in contact, which will allow cavities which are not interconnected to be produced. If the deposit of the balls 26 allows non-compact stacking, for example by means of a technology of the “Shallow Trench Isolation” type, or through the use of polymer or copolymer micelles, this step of reduction of compactness is not necessary.

The balls are made, for example, from silica or from a polymer, for example polystyrene, and have a diameter of between 0.5 μm and 5 μm. In the represented example these are balls, but the use of discrete elements of any shape does not go beyond the scope of the present invention.

In a subsequent step represented in FIG. 5D, layer 28, which will form the plate in which will be formed cavities 8 and ducts 10, is deposited on balls 26 and between the balls so as to cover them uniformly and to form walls 13 between the balls which, after they are eliminated, will be replaced by cavities 8. Firstly, the material of layer 28 is chosen such that it can be etched by plasma etching, and secondly such that it is sufficiently rigid for the layer to retain full integrity when balls 26 have been eliminated, i.e. such that layer 28 does not collapse in on itself due to the porosity caused by the elimination of balls 26.

The material of layer 28 is preferably chosen so as to provide low wettability in relation to the cooling liquid, i.e. such that it is hydrophobic in the case of water, to favour the appearance of vapour bubbles.

For example, layer 28 is of the DLC type deposited by a chemical deposit in the vapour phase or a physical deposit in the vapour phase. DLC is hydrophilic; however it has the advantage of having great chemical selectivity in relation to silica, enabling it to resist the dissolution of the silica bubbles by hydrofluoric acid, as will be seen in due course.

Layer 28 has, for example, a thickness such that a duct of height H as defined previously can be produced, where H is greater than D₂. Layer 28 is not necessarily of constant thickness; moreover a corrugated profile, as is visible in FIG. 5D, enables the thermal exchange area to be increased.

In the case of polymer balls, an additional hard mask made of SiC and less than 100 nm thick is advantageously deposited on balls 26 before the deposit of layer 28, preventing the balls from disappearing when ducts 10 are produced by etching of layer 28.

In a subsequent step represented in FIG. 5E, another deposit of balls 30 is accomplished on layer 28; these balls have a diameter less than or equal to that of balls 26. The deposit is accomplished in a similar manner to that of balls 26.

If the deposit is compact a step of reduction of compactness is undertaken.

In a subsequent step represented in FIG. 5F, a continuous layer 32 is deposited on layer of balls 30 and on the areas of layer 28 between the balls. This layer is very thin in relation to the ball diameter, so as to enable the balls to be removed, for example in an ultrasound bath in a subsequent step.

Layer 32 is chosen such that it has substantial selectivity compared to the material of layer 28. DLC in the example given, with the etching method which will be used to etch layer 28. In the present case this is oxygen plasma etching.

This layer is preferably chosen to provide good wettability in relation to the cooling liquid. Thus it will not be necessary to eliminate it, since it is this which will finally be in contact with the cooling liquid. However, a layer 32 may be included which will be eliminated after production of ducts 10.

For example, layer 32 is made of silica, deposited by chemical deposit in the vapour phase or by physical deposit in the vapour phase.

In a subsequent step represented in FIG. 5G, balls 30 are eliminated, and this elimination is obtained by applying ultrasound in a deionised water bath. A layer 32 is then obtained, pierced with apertures 34 in the positions of balls 32, and these apertures 34 lead to layer 28.

In a subsequent step represented in FIG. 5H, ducts 10 are produced. To do so, layer 28 is etched by dry etching by a plasma in the area of apertures 34 as far as balls 26. If layer 28 is made of DLC and balls 26 are made of silica, an oxygen plasma may be chosen which produces sufficient selectivity to etch layer 28 without etching silica balls 26. If layer 28 is made of DLC and balls 26 of polymer, a fluorinated plasma is chosen to open layer 28, and the process is continued with an oxygen plasma. Some ducts 10 emerge on balls 26, whereas others do not.

Ducts 10 are then obtained, which connect face 6 to balls 26.

If layer 32 is thin, it is advantageous to make ducts with a tapered shape, enabling greater robustness of the structure formed from ducts 10 to be obtained.

In FIG. 5I, a top view of the object obtained in this step can be seen, where each of apertures 34 is extended by a duct 10. At the base of certain ducts 10 balls 26 are visible.

In a subsequent step balls 26 are eliminated. This elimination is obtained by dissolution in a bath. In the case of silica balls, this is a hydrofluoric acid-based bath, and in the case of polystyrene balls a hydrochloric acid bath. The final object obtained is visible in FIG. 5J. Only the balls exposed by the production of ducts 10 are dissolved, and the other balls remain inaccessible.

In order to protect the barrier layer it may be arranged to deposit, before the ball layer, a layer 28 of DLC as is visible in FIG. 6; the balls are not then in contact with the barrier layer.

As previously described, it may be desirable to locate structured areas 16. In FIG. 7A an example of such a structure can be seen. Structured areas 16 are separated by unstructured areas 18.

This location may be obtained by positioning on layer 32 masks over the areas which it is not desired to structure. Balls 30 which are not covered by a mask are eliminated by means of an excimer-type laser, collectively and simultaneously. This type of laser has a resolution of the
order of several micrometres, which enables structured areas measuring at least some ten micrometres to be located.

0133. The steps of production of ducts 10 and of cavities 8 are similar to those described above.

0134. Distance d1 between two areas is between 50 μm and 500 μm, and width d2 of a structured area is between 10 μm and 50 μm.

0135. In Fig. 7B a top view of the structure of Fig. 7A can be seen. The outline of cavities 8 is represented in dotted lines, together with that of balls 30 which are buried.

0136. The device according to the present invention may be applied to diphasic thermal exchangers, diphasic thermosiphons, heat pipes and, more generally, to thermal exchangers involving a change of phase.

1-17. (canceled)

18. A thermal exchange device comprising:
   a first face configured to be in contact with a source of heat to be dissipated; and
   a second face configured to be in contact with a cooling liquid;
   wherein the device further comprises, all the way through it, between the first and second faces, multiple cavities of average radius, in which:
   the cavities are isolated from one another in a fluid manner by walls, wherein each cavity emerges in the second face through at least one duct, wherein a length of each duct is greater than the average radius of the ducts, wherein the transverse dimension of the duct in an area of the connection with the cavity is such that it forms a restriction between the cavity and the duct, and wherein the second face is pierced with apertures formed by the ducts, and in which
   the second face has properties of better wettability in relation to the cooling liquid, such that a contact angle of the liquid is less than 90° and a contact angle between the liquid and the inner surfaces of the ducts and cavities is greater than or equal to that between the liquid and the second face.

19. A thermal exchange device according to claim 18, in which the ducts have a maximum diameter between 0.1D1 and D1, and in which a number of ducts n is defined such that n=0.5×(D1/D2)².

20. A thermal exchange device according to claim 18, in which
   \[V_{\text{total ducts}} = P/P_{\text{atm}} \times V_{\text{cavity}},\]
   wherein \(V_{\text{total ducts}}\) is the volume formed by the sum of the volumes of each of the ducts penetrating into a cavity, \(V_{\text{cavity}}\) is the volume of a cavity, \(P\) is the absolute pressure of the cooling liquid, and \(P_{\text{atm}}\) is the atmospheric pressure.

21. A device according to claim 18, in which the walls separating the cavities have a minimum thickness of between 0.1 times and 0.2 times the average diameter of the cavities, and the apertures formed in the second face are separated by a smaller distance compared to the diameter of the apertures.

22. A thermal exchange device according to claim 18, in which the ducts have a tapered shape, in which the smaller base is located in the area of the connection with the cavities.

23. A thermal exchange device according to claim 18, including a matrix in which the cavities and the ducts are produced and a layer deposited on the second face, wherein the matrix has a lower wettability in relation to the liquid and the layer has a better wettability in relation to the liquid.

24. A thermal exchange device according to claim 18, including areas with apertures formed by the ducts emerging in the second face, as structured areas, and areas without apertures, as unstructured areas.

25. A thermal exchange device according to claim 24, in which the structured areas have a side measuring between 10 μm and 50 μm, wherein the areas are separated from one another by a distance of between 50 μm and 500 μm.

26. A method for production of a thermal exchange device according to claim 18, in which the cavities are obtained by depositing discrete elements on a substrate, by burying the discrete elements in a layer of material forming the matrix of the thermal exchange device, to produce in the matrix of ducts until reaching the discrete elements, and to eliminate the discrete elements.

27. A method for production of a thermal exchange device according to claim 26, including:
   a) depositing on a substrate of a barrier layer;
   b) depositing a layer of discrete elements of greater average diameter, configured to demarcate the cavities;
   c) depositing a layer on and between the discrete elements of greater average diameter, wherein the layer is configured to form the matrix of the device;
   d) depositing discrete elements of smaller average diameter on the layer forming the matrix;
   e) depositing a continuous layer on and between the discrete elements of smaller average diameter;
   f) removing the discrete elements of smaller average diameter revealing apertures in the areas of which the layer forming the matrix is exposed;
   g) producing ducts in the layer forming the matrix in the area of the apertures until reaching the discrete elements of greater average diameter;
   h) eliminating the discrete elements of greater average diameter.

28. A method for production of a thermal exchange device according to claim 26, in which the discrete elements are made of silica or polymer, or polystyrene, and the discrete elements are eliminated by dissolution of the discrete element by chemical attack.

29. A method for production of a thermal exchange device according to claim 27, in which the discrete elements of smaller average diameter have an average diameter less than or equal to the average diameter of the discrete elements of larger diameter.

30. A method for production of a thermal exchange device according to claim 27, further including reducing the size of the discrete elements of greater average diameter before the c) depositing and/or reducing, or dry etching, the size of the discrete elements of smaller average diameter before the e) depositing.

31. A method for production of a thermal exchange device according to claim 27, in which the layer deposited in the c) depositing has better wettability in relation to the cooling liquid, or silica.

32. A method for production of a thermal exchange device according to claim 27, in which the material forming the matrix is hydrogenated amorphous carbon.

33. A method for production of a thermal exchange device according to claim 27, further including, before the b) depositing, depositing a preliminary layer of material forming the matrix.

34. A method for production of a thermal exchange device according to claim 27, further including installing a mask on the stack before the f) removing the discrete elements of smaller diameter, so as to allow the discrete elements of smaller average diameter to be removed only in the area of the unmasked areas.

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