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(54) **HEAT EXCHANGE DEVICE MADE OF POLYMERIC MATERIAL**

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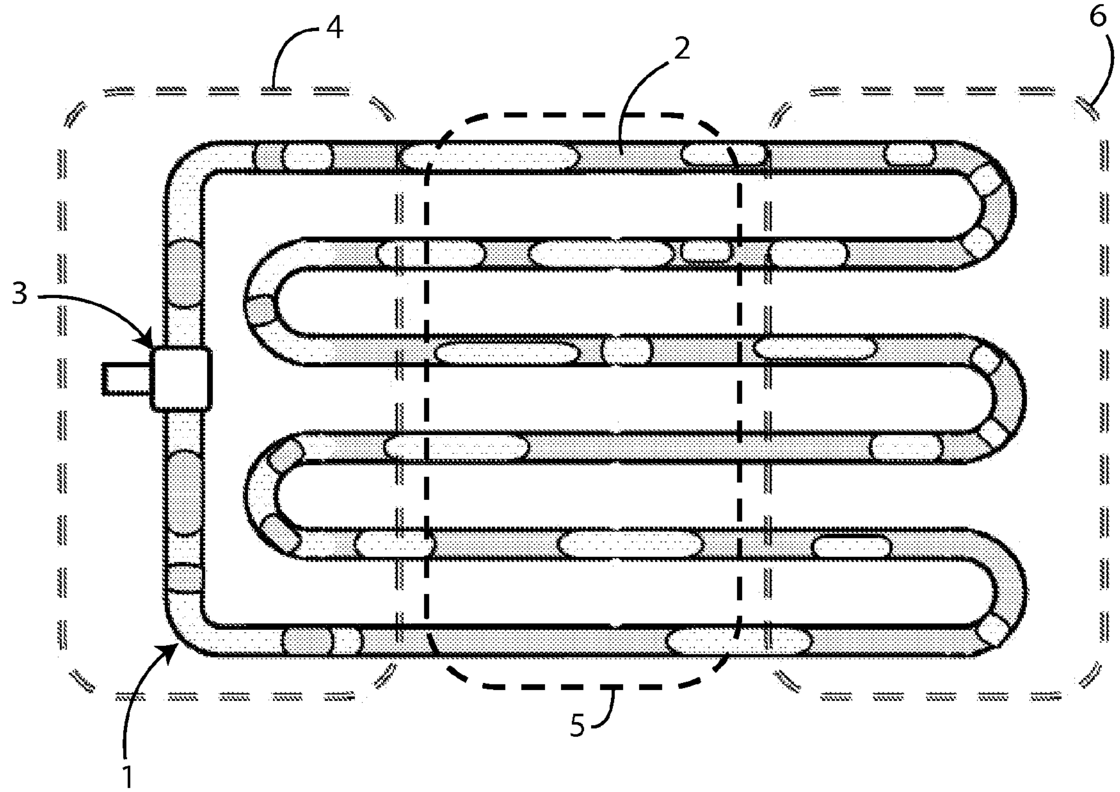
(57) **ABSTRACT**

The invention refers to a heat exchange pipe comprising a capillary pulsating heat pipe (**1**) substantially shaped so as to form substantially a closed loop wherein a working fluid (**2**) is introduced wherein at least a portion of said pulsating heat pipe (**1**) consists of polymeric material.



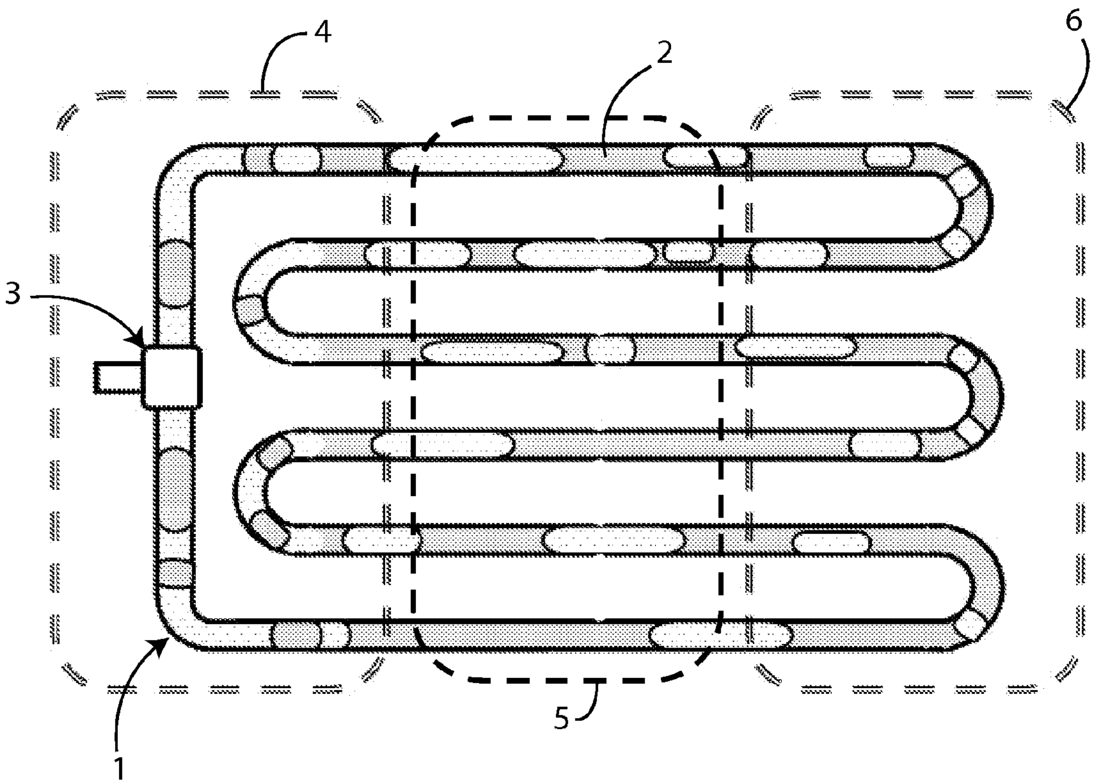


Fig. 1

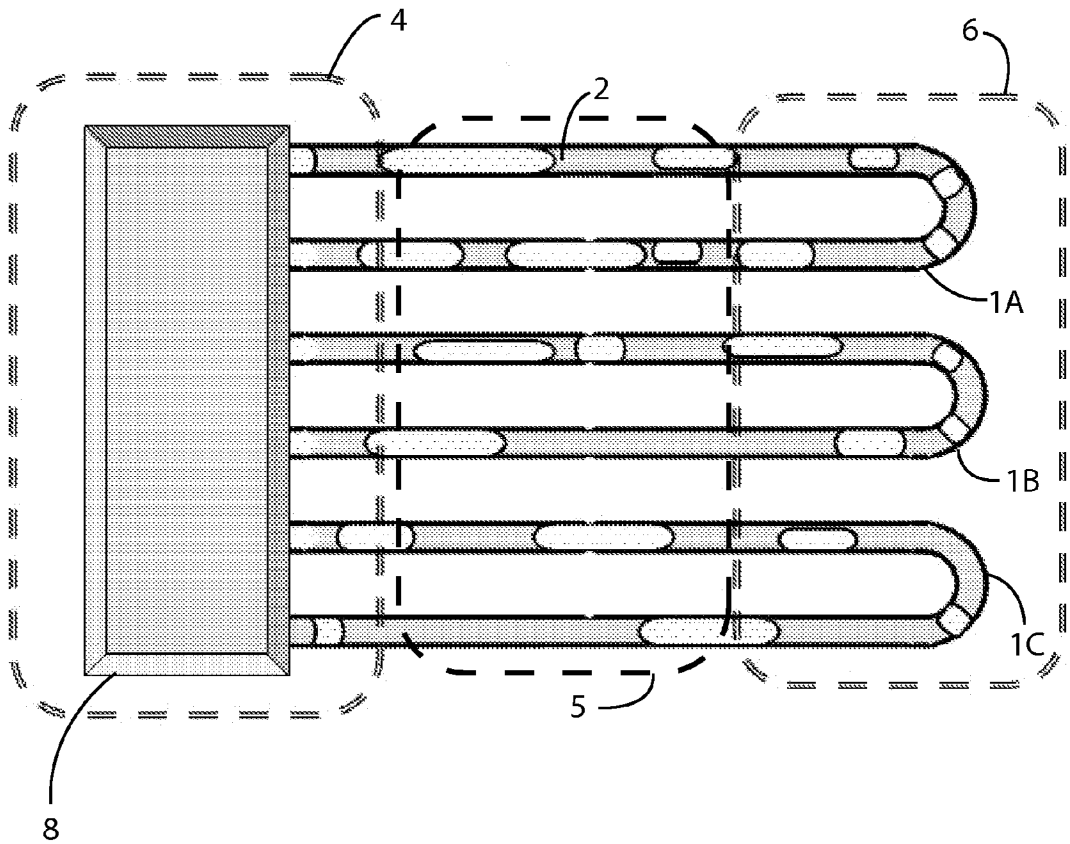


Fig. 2

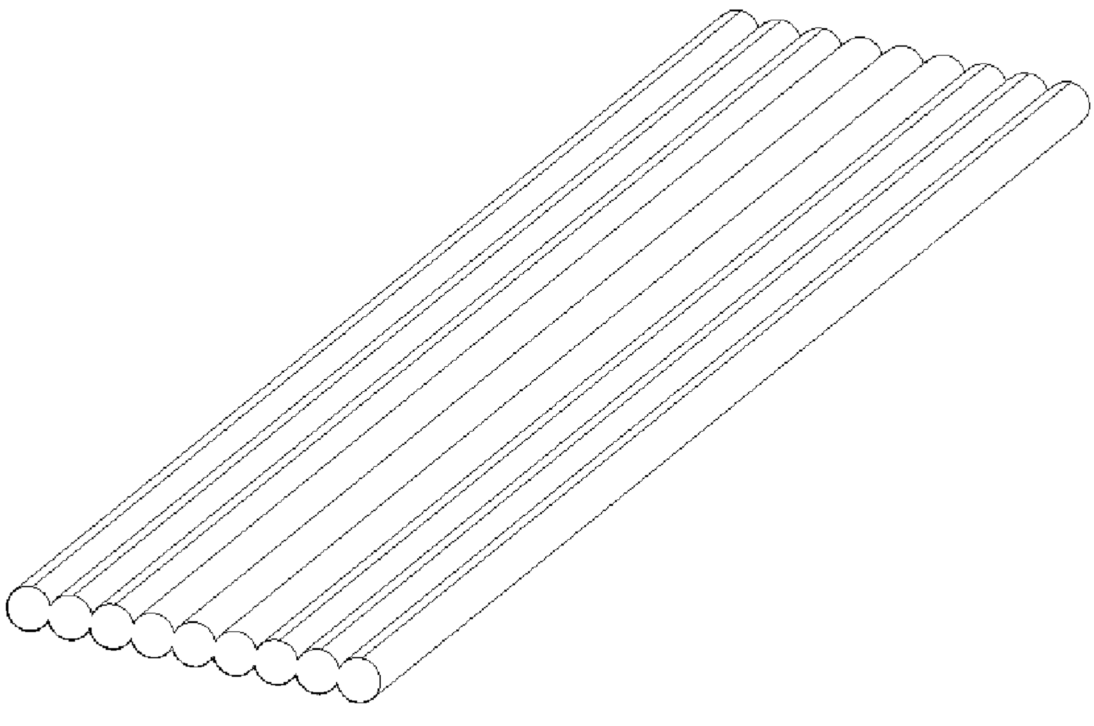


Fig. 3

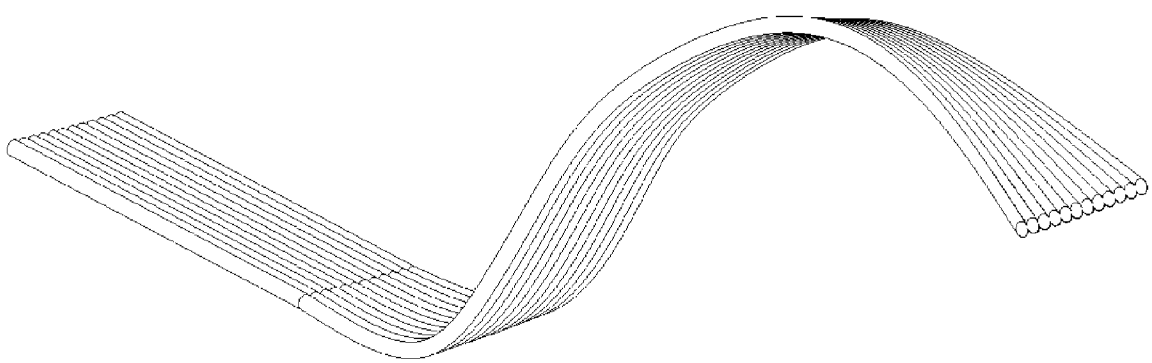


Fig. 4

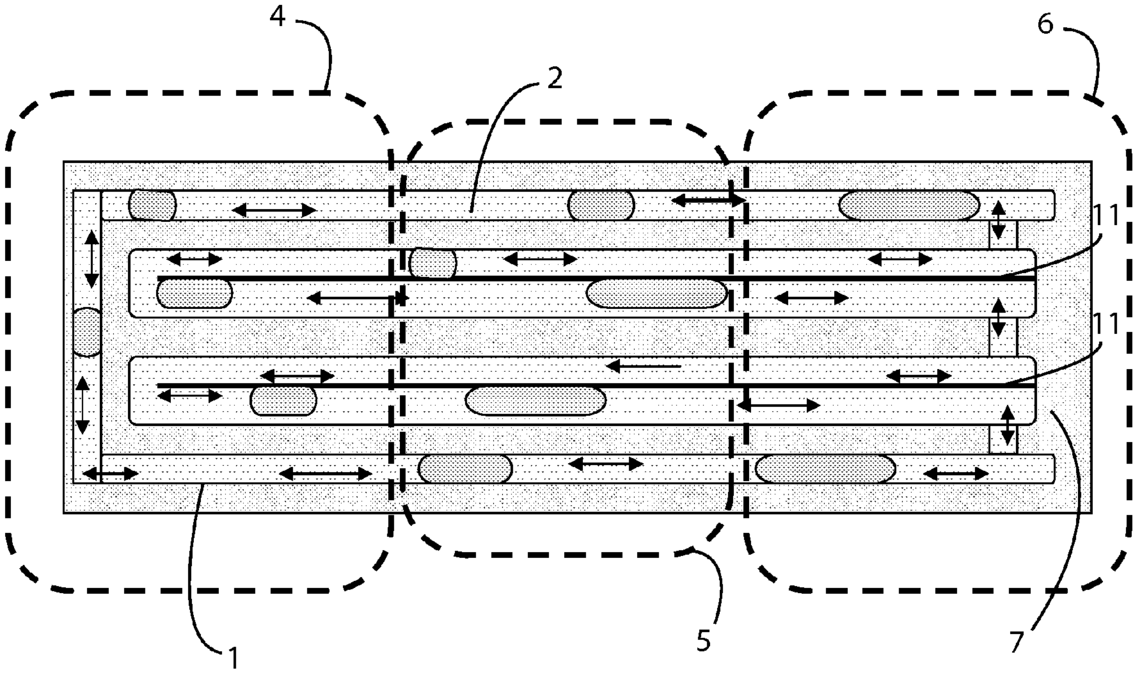


Fig. 5

HEAT EXCHANGE DEVICE MADE OF POLYMERIC MATERIAL

CROSS REFERENCE

[0001] This application claims priority to Italian application TV2008A000145 filed Nov. 14, 2008. to Italian application TV2008A000145 filed Nov. 14, 2008 is incorporated by reference herein.

BACKGROUND

[0002] The present invention is related to the field of cooling technologies for electronic, particularly micro- and nano-electronic components, and is based on an innovative heat exchange device for thermal energy handling from electronic components allowing said components to be used more efficiently and at better operating conditions in comparison to traditional heat exchange devices.

[0003] More particularly, said heat exchange device preferably comprises a pulsating heat pipe (PHP) at least a portion of which is made of polymeric material shaped so as to form a substantially closed loop into which an appropriate working or heat-transfer fluid is poured in order to allow the thermal energy from heat generating components to be dissipated.

[0004] Currently, in the field of microelectronic and opto-electronic devices an increased integration level, obtained as a consequence of dimension minimization (high density encapsulation) and performance improvement (higher frequency) of said devices, results in an increment of both device power dissipation and density with a prediction of local thermal flux dissipation up to 1000 W/cm^2.

[0005] Such a high thermal flux represents a serious challenge for current thermal control techniques designed in order that at the same time performances and reliability of said devices to be assured and in the meantime acceptable temperatures, particularly in the semiconductor field, to be maintained.

[0006] One of the most promising solutions for semiconductor coolers is represented by heat pipes (HP), offering the advantage resulting from the possibility to transport high heat quantities through reduced area crosses section.

[0007] Such heat pipes represent a valid alternative to liquid cooling provided that the same are suitable to handle thermal flux and power requirements.

[0008] A particular design of said heat tubes is represented by pulsating heat or pulsating circulation pipes (PHP) which are characterized by a very simple and easily embodied design being usually without porous matrix.

[0009] Since the late 1990's, operating characteristics and mechanisms og pulsating heat pipes have been extensively studied and the technology based thereon has found application in an increasing number of fields.

[0010] Only for exemplary purposes, it is noteworthy to point out that PHP technology has been employed on avionics device cooling resulting in a significant reduction of thermal resistance.

[0011] This technology has been used for the systems described in U.S. Pat. No. 4,921,041 to Actronics Kabushiki Kaisha, U.S. Pat. No. 5,697,428 to Actronics Kabushiki Kaisha and Hisateru Akachi and U.S. Pat. No. 6,672,373 to Idalex Technologies, Inc.

[0012] However, traditional pulsating heat pipe displays various disadvantages.

[0013] A first disadvantage consists in the fact that the pulsating heat pipe is made of linearly developed rigid metallic material thus lacking of flexibility during installation.

[0014] A second disadvantage results from the fact that the use of a metallic capillary pipe, generally made of copper, as pulsating heat pipe results in higher costs and weight.

[0015] An ulterior disadvantage is that a metallic capillary pipe is susceptible to oxidation processes and therefore to material corrosive degradation

SUMMARY

[0016] The object of the present invention is to overcome said disadvantages, by providing a heat exchange device suitable to be made according to shapes not obtainable using the traditional metallic pulsating heat pipes, in the meantime reaching a greater efficiency and better working of electronic components.

[0017] A second object is to obtain a flexible heat exchange device thus facilitating an operator at time of installation thereof.

[0018] Another object is to obtain a heat exchange device lighter than a traditional one.

[0019] An further object is to obtain a heat exchange device with improved resistance to material degradation and corrosion.

[0020] Still another object is to obtain a heat exchange device at lower cost than a traditional one.

[0021] The above objects have been obtained by providing a heat exchange device comprising a pulsating heat pipe, having sufficiently small dimensions to act as a capillary and shaped so as to form a substantially closed loop, which consists, partially or totally, of polymeric material, preferably loaded with at least one thermally conductive additive or filler, into which pipe an appropriate working fluid for thermal energy dissipation from heat generation components is poured.

[0022] Said fluid is chosen based on thermal dissipation to be obtained, optimal working temperature of the electronic device heat exchange device is installed on and chemical compatibility thereof with polymeric material pulsating heat pipe is made of.

[0023] According to a peculiar characteristic of the invention the heat exchange device comprises at least a thermal absorption/evaporation zone, at least a thermal dissipation/adiabatic condensation zone, as well as one or more zones individually interposed between said absorption zone and dissipation zone and/or between two thermal absorption/evaporation zones and/or two thermal dissipation/condensation zones.

[0024] A better explanation of the invention will be offered by means of the following detailed description and with reference to the enclosed drawings illustrating, only as an exemplary way, some preferred embodiments thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] In the drawings:

[0026] FIG. **1** shows a first embodiment of a heat exchange device, according to the invention;

[0027] FIG. **2** shows a second embodiment of the invention;

[0028] FIG. **3** shows a detail of the heat exchange device with reference to a first configuration of said device adiabatic zone;

[0029] FIG. 4 shows a detail of the heat exchange device with reference to a second configuration of said device adiabatic zone; and

[0030] FIG. 5 shows a third embodiment of the heat exchange device.

DETAILED DESCRIPTION

[0031] With particular reference to FIG. 1, according to the first described embodiment the heat exchange device comprises a capillary pulsating heat pipe 1 which comprises at least a portion of polymeric material.

[0032] It is preferable that said polymeric material is a thermally conductive polymeric material consisting of thermally conductive polymers as for example polysulfones.

[0033] It is further preferred that the polymeric material is loaded with at least one thermally conductive additive or filler, into which pipe a predetermined amount of appropriate working fluid 2 for the thermal energy dissipation from heat generation components is poured.

[0034] The capillary pulsating heat pipe is shaped so as to form a substantially closed loop having inter-connectable free ends, wherein said pipe comprises at least an opening allowing a vacuum inside of said pipe to be created and said fluid 2 to be introduced.

[0035] Alternatively, it is possible to include two openings, namely for fluid 2 inlet and vacuum generation within pipe 1, respectively.

[0036] According to the described invention it is possible to subdivide the heat exchange device in three zones: a thermal absorption/evaporation zone 4, a thermal dissipation/condensation zone 6, and an adiabatic zone 5 interposed between said two zones 4 and 6.

[0037] The thermal absorption/evaporation zone 4 contacts directly a heat generating element, as for example an electronic component (not shown).

[0038] In order the thermal resistance between the heat generating element or condensing portion and fluid 2 to be reduced, the polymer is preferably loaded with highly thermally conductive additive or filler, as for example carbon based additive or filler.

[0039] This additive or filler is chosen based on the polymer and fluid 2 compatibility thereof.

[0040] According to the invention, the percentage of additive or filler loaded in polymeric pulsating heat pipe 1 can be different for each of three zones 4, 5 and 6 of the heat exchange device.

[0041] The polymeric material used for the pulsating heat pipe 1 can consist of one or more polymeric molecule TYPES.

[0042] Said polymeric material comprises, but it is not limited to, polypropylene, polybutylene terephtalate, polyurethane, polyamide, or combination thereof.

[0043] The additive or filler can be of organic or inorganic type and have any shape, as for example spherical, cylindrical, platelet, felt or fibre or combinations thereof.

[0044] Fluid 2 to be introduced inside of heat exchange device can be alcohol, hydrofluorocarbon (HFC), water, ammonia, etc., or mixtures thereof.

[0045] The amount of fluid 2 to be introduced inside of heat exchange device is a predetermined amount which is calculated considering the evaporator partial pressure value using specific calculation codes and in many experimental embodiments it can be variable from 30 to 60% of total inner volume of said heat exchange device.

[0046] According to described example, the pulsating heat pipe 1 has a coil shape, preferably flat, with many "U" shaped portions in such way that concavities of said portions are alternatively directed toward opposite directions, and the external vertical side ends of external "U" shaped portions are connected to each other by connecting means 3.

[0047] In other words, the pulsating heat pipe ends I are connected to each other by said connecting means 3 consisting of a T-type connector in order also to allow also the fluid 2 introduction into said pipe 1.

[0048] Therefore, the fact that pipe 1 in correspondence of ends thereof is closed by connecting means 3, allows that poured fluid amount 2 can flow from thermal absorption zone 4 to thermal dissipation zone 6, passing through adiabatic zone 6, thus covering long distances within the coil.

[0049] According to the invention, in order to reduce the wettability of said adiabatic zone and thus the pressure and hydrodynamic resistance, a lining can be included inside of pulsating heat pipe 1, in correspondence of the adiabatic zone or a portion thereof.

[0050] The heat transfer is performed by means of thermal absorption from a thermal source in thermal absorption zone in order to result in the fluid vaporization and a successive condensation thereof by thermal dissipation towards a cold heat sink.

[0051] Before running the device, after vacuum inside of pulsating heat pipe 1 has been created and fluid 2 into heat pipe 1 has been poured, capillary effect results in a fluid 2 segmental distribution with liquid to vapour alternated bubbles.

[0052] The transport of liquid and vapour bubbles is the result of thermally induced pressure/density pulsations inside of said pulsating heat pipe 1 without the need of external mechanical force application for the running thereof.

[0053] When the device receives heat on the heat absorption zone 4 starts the fluid transition from liquid to vapour state. The generation of vapour bubbles acts like a pumping element for the transport of liquid parts. This pumping activity occurs in a complex motion regimen comprising oscillating, translating and vibrating activities, as a result of pressure and temperature fluctuations.

[0054] In the present description, the term "heat" means the exchanged thermal power and comprises both energy from a hot source and cooling or freezing energy.

[0055] According to the described example, like already pointed out, pipe 1 has a coil shape, but it is obvious that it can assume different shapes depending on the need. At this end, i.e. in order to be bent into a desirable shape, it is subjected to the action of a suitable bending device (not shown).

[0056] Particularly, it is possible that each zone of heat exchange device can have a desired shape regardless of other zone shapes, therefore each zone shape can be the same or different from others. For example, thermal absorption zone 4 can have a flat shape, while the others, i.e. thermal dissipation 6 and adiabatic 5 zones, can have a cylindrical shape.

[0057] According to a further example, thermal absorption zone 4 can have any desired shape aiming to an easy assembling of said heat exchange device with a thermal source. In order to further facilitate said assembling, it is possible to select a polymer suitable to thermal absorption zone 4 in order that said zone can be flexible.

[0058] It is further possible to make flexible also the other zones of the heat exchange device by choosing an appropriate polymer.

[0059] It is preferable that pulsating heat pipe **1** inner diameter is smaller or equal to 6 mm depending on electronic components or instrumentation pipe is installed on, and preferably said diameter is from 1 mm to 6 mm.

[0060] According to another embodiment, as shown in FIG. **2**, capillary pulsating heat pipe **1** comprises a plurality of pulsating capillary heat pipes **1**A, **1**B and **1**C suitable to be connected to each other by means of pulsated circulation thermal panel or manifold **8**.

[0061] According to this embodiment, each of said capillary pipes has "U" shape with the free ends connected to said manifold **8**.

[0062] This embodiment results in an interesting and important size reduction of heat exchange device.

[0063] The heat exchange device can have a thermal absorption/evaporation zone **4** and a thermal dissipation/condensation zone **5** both made of rigid highly thermally conductive material, as for example a metal.

[0064] According to the invention, it is possible that the adiabatic zone **5** of each up to now described thermal device is made of polymeric film, produced for example by extrusion, and comprises a plurality of empty, multiple, parallel and lengthwise running capillaries.

[0065] This adiabatic zone **5** can have a flat or substantially flat shape, as shown in FIG. **3** or can have one or more concave portions, as shown in FIG. **4**.

[0066] In order to have said concave portions, this adiabatic zone is made of flexible polymeric material.

[0067] According to a further embodiment, as shown in FIG. **5**, the heat exchange device comprises a plurality of tubes shaped so as to form substantially a coil, where one or more tubes are subdivided, using a suitable septum **11**, in two communicating channels in order to allow the fluid to pass from one to another channel and viceversa.

[0068] According to this embodiment the travel of said capillary tubes is obtained by removing material from a polymeric matrix **7**. Alternatively the heat exchange device can be produced by a mold melting process.

[0069] According to the same figure the flow of the vapour and liquid bubbles from thermal absorption **4** to thermal dissipation **5** zone is schematically showed.

[0070] As above pointed out, the heat exchange device can be obtained by assembling a capillary pipe plurality. This results in several advantages.

[0071] A first advantage is given from the fact that each capillary pipe can be made of different polymer and loaded with additive or filler different from that loaded in the polymers of other capillary pipes, depending on the need.

[0072] A second advantage is given from the fact that each capillary pipe can have suitable dimensions and shape as for example coil or zigzag.

[0073] Each capillary pulsating heat pipe can be produced by extrusion or pressure or injection moulding o mold melting.

[0074] A further advantage is given from the fact that, unlike a traditional heat pipe, the interior of a pulsating heat pipe does not comprise a layer of porous material to pump the fluid into the evaporator zone by capillarity.

[0075] As already pointed out, the invention finds application in numerous electronic fields, as for example mobile phones, laptops, office appliances, informatic systems, systems and apparatuses for fixed and mobile lines of telecommunications, electronic tubes and thermionic valves, semiconductors and printed circuit board, etc.

[0076] Although according to above description several characteristics and advantages of the present invention have been exposed, in addition to details of the inventive structure and function, however it is to be understood that the disclosure object configuration is offered only by an illustrative way, being possible detail modifications, especially as to shape, size and disposition of the parts within the constraints of the invention principles, to the full extent indicated by the broad general meaning of the terms according to which the appended claims are expressed.

1. Heat exchange device comprising a capillary pulsating heat pipe (**1**) substantially shaped so as to form substantially a closed loop into which a working fluid (**2**), wherein at least a portion of said pulsating heat pipe (**1**) is made of polymeric material, is introduced.

2. Heat exchange device according to claim **1**, wherein said polymeric material is a thermally conductive polymeric material; said polymeric material being consisted of thermally conductive polymers as for example polysulfones.

3. Heat exchange device according to claim **1**, wherein said polymeric material is loaded with at least a thermally conductive additive or filler.

4. Heat exchange device according to claim **1**, wherein it comprises at least a thermal absorption/evaporation zone (**4**), at least a thermal dissipation/condensation zone (**6**), as well as one or more adiabatic zones (**5**), each of which is interposed between said absorption (**4**) and dissipation (**6**) zones and/or between two thermal absorption/evaporation (**4**) and/or two thermal dissipation/condensation (**5**) zones; said thermal absorption/evaporation (**4**) zone contacting directly a heat generating element.

5. Heat exchange device according to claim **4**, wherein the percentage of additive or filler loaded in the pulsating polymeric heat pipe polymer (**1**) is different for each of heat exchange device (**4**, **5**, **6**) zones.

6. Heat exchange device according to anyone of preceding claims, wherein the fluid amount (**2**) to be introduced is a predetermined amount, preferably variable from 30 to 60% of total internal volume of said heat exchange device.

7. Heat exchange device according to anyone of claims **4**, wherein in correspondence of said adiabatic zone (**5**) or a portion thereof, in order to reduce the wettability of said adiabatic zone (**5**) or portion thereof, a lining is envisaged.

8. Heat exchange device according to claim **1**, wherein the pulsating heat pipe (**1**) inner diameter is smaller or equal to 6 mm, preferably from 1 mm to 6 mm.

9. Heat exchange device according to claim **1**, wherein the pulsating heat pipe (**1**) has a coil shape with many "U" shaped portions in such way that concavities of said portions are alternatively directed toward opposite directions and the external vertical side ends of external "U" shaped portions are connected to each other by connecting means (**3**).

10. Heat exchange device according to claim **1**, wherein said connecting means (**3**) consist of a T-type connector; said T-type connector allowing also the fluid (**2**) to be poured into the same pipe (**1**).

11. Heat exchange device according to claim **1**, wherein said pulsating heat pipe (**1**) comprises a plurality of pulsating capillary heat pipes (**1**A, **1**B, **1**C) suitable to be connected to each other by means of pulsated circulation thermal panel or manifold (**8**).

12. Heat exchange device according to claim **11**, wherein each of said capillary pipes (**1**A, **1**B, **1**C) has an "U" shape with the free ends connected to said manifold (**8**).

13. Heat exchange device according to claim **1**, wherein it comprises a plurality of tubes shaped so as to form substantially a coil, wherein one or more tubes are subdivided, using a suitable septum (**11**), in two communicating channels in order to allow the fluid to pass from one to another channel and viceversa; the travel of said tubes being obtained by removing material from a polymeric matrix (**7**).

14. Heat exchange device according to claim **1**, wherein said pulsating heat pipe (**1**) comprises a plurality of capillary pipes, each of which is made of appropriate polymer and loaded with appropriate additive or filler; each capillary pipe having suitable dimensions and shape, as for example a coil or zigzag shape.

15. Heat exchange device according to claim **14**, wherein each of said capillary pulsating heat pipes is produced by extrusion or compression or injection moulding or mold melting.

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