Technology Review:

Innovative Cold Plate Designs, 2007-2012

Qpedia continues its review of technologies developed for electronics cooling applications. We are presenting selected patents that were awarded to developers around the world to address cooling challenges. After reading the series, you will be more aware of both the historic developments and the latest breakthroughs in both product design and applications.

We are specifically focusing on patented technologies to show the breadth of development in thermal management product sectors. Please note that there are many patents within these areas. Limited by article space, we are presenting a small number to offer a representation of the entire field. You are encouraged to do your own patent investigation. Further, if you have been awarded a patent and would like to have it included in these reviews, please send us your patent number or patent application.

In this issue our spotlight is on innovative cold plate designs. There is much discussion about its deployment in the electronics industry, and these patents show some of the salient features that are the focus of different inventors.

Microchannel Heat Sink,
EP 1 808 892 A2 Mohinder, B., et al.

The heat sink 20 is defined by a housing including a lid 24 and a base 26, the base 26 being a flat cold plate having a top surface and a bottom surface and parallel micro-channels 28 all extending the same distance and each having a base-width bw and a base-height bh into the top surface of the base.

A manifold plate 30, having a top face and a bottom face to define a manifold-thickness mt, is disposed with the bottom face overlying the micro-channels 28 and having spaced edges 32 extending between opposite ends 34. The lid 24 has a periphery engaging the base and an interior shoulder 36 engaging the ends 34 of the manifold plate 30 to define a recessed surface 38 within the periphery and in engagement with the top face of the manifold plate 30. The edges 32 of the manifold plate 30 define an inlet edge 32 and an outlet edge 32 each spaced from the shoulder 36 to define an inlet plenum between the inlet edge 32 and the shoulder 36 and an outlet plenum between the outlet edge 32 and the shoulder 36. An inlet conduit 40 extends into the lid 24 for fluid flow into the inlet plenum and

PATENT NUMBER	TITLE	INVENTORS	DATE OF AWARD
EP 1 808 892 A2	MICROCHANNEL HEAT SINK	Mohinder, B., et al.	Sep. 1, 2007
EP 2 151 653 A2	HEAT EXCHANGER HAVING WINDING MICRO-CHANNELS	Valenzuela, Javier	Aug. 8, 2008
US 2012/0097374 A1	MAINTAINING THERMAL UNIFORMITY IN MICRO-CHANNEL COLD PLATES WITH TWO-PHASE FLOWS	Altman, David	Apr. 26, 2012

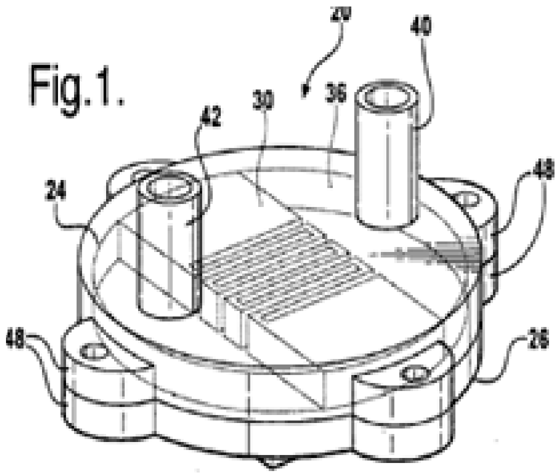


Fig.1.

an outlet conduit 42 extends into the lid 24 for fluid flow out of the outlet plenum.

The manifold plate 30 presents inlet manifold channels 44 extending into the inlet edge 32 and outlet manifold channels 46 extending into the outlet edge 32 with each manifold channel terminating in spaced relationship to the opposite edge 32. The inlet manifold channels 44 alternate with the outlet manifold channels 46 to define rectangular cells with X indicating flow into the channels 44, 46 and O indicating flow out of the channels 44, 46 as shown in Figure 4. As a result of this flow arrangement, the pressure drop is low because the flow contracts as the flow enters the micro-channels 28 and expands as the flow reverses and flows out of the micro-channels 28. A wall-thickness wt is defined or exists between the manifold channels 44, 46 with the inlet manifold channels 44 interleaved with the outlet manifold channels 46 from the outlet edge 32. The manifold channels 44, 46 have a manifold-width mw and a manifold-height mh equal to the manifold-thickness mt.

As will be appreciated, the manifold channels 44, 46 extend transversely across the micro-channels 28 in the base whereby coolant flows from the inlet conduit 40 and into the inlet plenum and into the inlet manifold channels 44 where the flow is forced downward into the micro-channels 28 where the coolant is re-directed up into the outlet manifold channels 46 and out into the outlet plenum for exit out of the outlet conduit 42 to convey heat from a heat source 22 engaging the exterior of the base, In order to obtain the maximum operating efficiency, the a base-width bw of the micro-channels 28 is maintained in the range of forty (40) microns to one hundred (100) microns, the base-height bh into the base of the micro-channels 28 in the range of two hundred (200) microns to four hundred (400) microns, the manifold-height through the manifold-thickness of the manifold channels 44, 46 in the range of one thousand (1000) microns to three thousand (3000) microns, and the manifold-width mw of the manifold channels 44, 46 in the range of three hundred and fifty (350) microns to one thousand (1000) microns. Additionally, the micro-channel 28 wall-thickness is fifty (50) microns. In further perfection, the heat presenting area of the heat source 22 has a ratio to the active heat transfer area of the bottom surface of the base covered by the micro-channels 28 between seven tenths (0.7) and one (1).

The invention, therefore, provides a method of transferring heat from a heat source 22 to a coolant fluid by flowing coolant into inlet manifold channels 44 extending into an inlet edge 32 of a manifold where the flow is forced downward into parallel and spaced micro-channels 28 extending across the manifold channels 44, 46 and re-directing the coolant up into and out of outlet manifold channels 46 extending into an outlet edge 32 of the manifold and interleaved with the inlet manifold channels 44, and by maintaining a base-width bw of the micro-

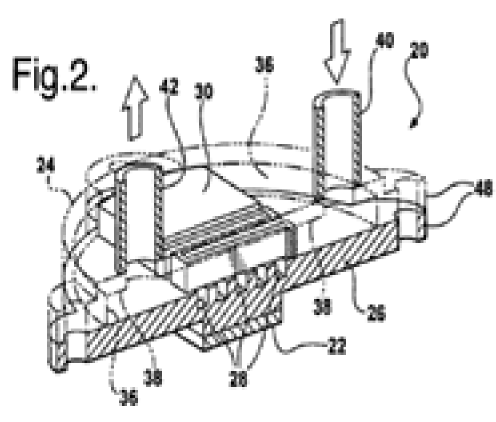
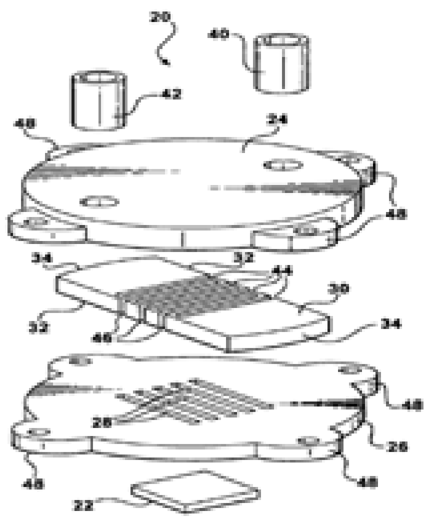


Fig.2.



channels 28 in the range of forty (40) microns to one hundred (100) microns, maintaining a base-height bh of the micro-channels 28 in the range of two hundred (200) microns to four hundred (400) microns, maintaining a manifold-height mh through of the manifold channels 44, 46 in the range of one thousand (1000) microns to three thousand (3000) microns, and maintaining a manifold-width mw of the manifold channels 44, 46 in the range of three hundred and fifty (350) microns to one thousand (1000) microns.

Heat Exchanger Having Winding Micro-Channels, EP 2 151 653 A2, Valenzuela, Javier

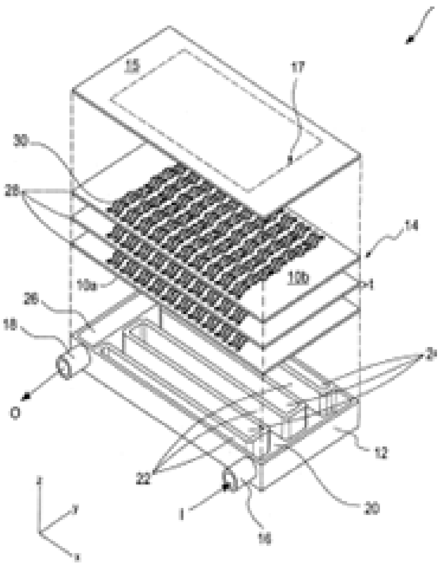
This invention relates generally to an apparatus for cooling a heat producing device and, more specifically, to a heat exchanger having winding micro-channels for use in large-area cold plates.

Liquid cooled heat exchangers are generally characterized as having macro-channels, mini-channels, or micro-channels, depending on the size of the channels. The term 'micro' is applied to devices having the smallest hydraulic diameters, generally between ten to several hundred micrometers, while 'mini' refers to diameters on the order of one to a few millimeters, and 'macro' channels are the largest in size, generally greater than a few millimeters.

There are two primary types of prior art micro-channel cold plates: parallel flow and normal flow. As the name implies, parallel flow micro channel cold plates have the liquid flowing through the heat transfer passages in a direction parallel to the surface being cooled. In contrast, normal flow micro channel cold plates (NCP) have the liquid flowing through the heat transfer passages in direction normal to the surface being cooled. The parallel flow cold plates have geometries similar to that of the finned cold plate except that the dimensions are scaled down by an order of magnitude. For example, the channel width in a micro-channel cold plate is typically less than 500 microns. Because of the high pressure drop in the micro-channels, the size of the parallel flow micro-channel cold plates is typically less than about 1to 2 cm on a side. Even at these small sizes, the pressure drop can be too large for some applications. The pressure drop can be reduced by subdividing the micro-channel into several sections and providing alternating inlet and outlet manifolds along the length of the cold plate.

The embodiments disclosed herein relate to a heat exchanger having winding micro-channels for use in large-area cold plates. The term "large-area cold plate" as used herein refers to heat exchangers used for transferring heat between a surface and a fluid where the cold plate surface dimensions are larger than about 2 x 2 centimeters. Although the present application will make reference to large-area applications, the micro-channel design may find use in other applications, particularly those having extremely low flow per unit area where there is a desire to increase the pressure drop to assist in flow distribution and to avoid gas blockage. As also used herein, the term "winding" is used to mean a twisting, serpentine, sinuous path, or the like, which may have a curvature or be angular, and which creates a non-linear path between an inlet and an outlet.

A winding micro-channel heat exchanger 10 includes a manifold 12, a heat transfer member 14 having winding micro-channels 30, and a cover plate 15, is illustrated. In use, heat is transferred to, and/

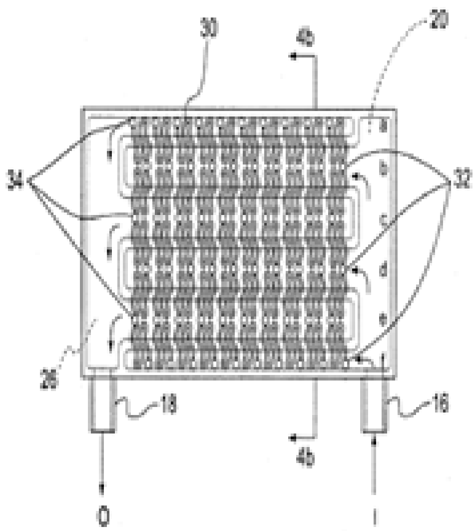


or from, the heat exchanger 10 over the portion of the cover plate that is enclosed by the dashed line 17, which corresponds to the portion of the heat exchanger 10 that includes winding micro-channels 30, as described in more detail below. In the heat exchanger 10 of the present embodiment, the functions of distributing and collecting the fluid over the active heat transfer area 17 and transferring the heat between the fluid and the active heat transfer area 17 are achieved by two separate components: the manifold 12 and the heat transfer member 14, respectively. This separation in functions allows the selection of the flow passage geometry in each component to the benefit of their respective functions.

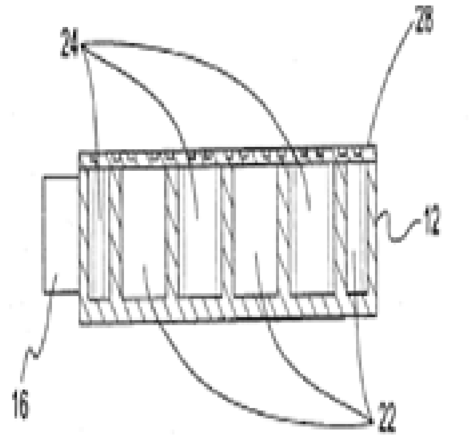
Heat transfer member 14 includes one or more layers 28, each having a plurality of winding micro-channels 30 formed therein. The present description is made with respect to a single exemplary micro-channel 30. Additional channels may be identical to the exemplary micro-channel, as in the present embodiment, or may be varied. For example, the channels may be mirror images, or may have different geometries, as described in greater detail below.

In the present embodiment, a bonded stack of three layers 28 is illustrated, which may be varied according the needs of the particular application, as would be known to those of skill in the art. Each layer 28 is generally planar and includes a first surface 10a and a second surface 10b, opposite the first surface. Micro-channels 30 may be formed in the second surface, for example by etching, such that the micro-channels have a depth that is less than the thickness "t" of their corresponding layer. The micro-channels may be formed by alternate methods as would be known to those of skill in the art, and may have a depth equal to the corresponding layer in some embodiments. Unlike the prior art, parallel flow micro-channels; the winding micro-channels 30 of the present invention are characterized by having an aspect ratio close to unity (i.e., the depth of the micro-channels is comparable to the width).

The micro-channels 30 also each include a nonlinear flow axis 36. The non-linear flow axis 36 may include one or more undulations 38 that cause the flow to change directions, as well as one or more pairs of bends 40a, 40b that cause the flow to reverse



direction. A reference line "CL" bisects the length of the channel 30 through the approximate center between the inlet opening 32 and outlet opening 34. The portion of the channel 30 disposed between the line "CL" and the inlet opening 32 is referred to as the inlet side (Is), and the portion of the channel disposed between the line "CL" and the outlet opening 34 is referred to as the outlet side (OS) in the following description. It will be understood that the line "CL" is provided for reference purposes only and is not part of the heat exchanger design. The fluid flow is reversed in that the first bend 40a reverses the direction of the fluid flow from traveling from the inlet side (Is) toward the outlet side as represented by arrow A, to a direction traveling from the outlet side (OS) toward the inlet side of the channel as represented by arrow B. Likewise, the second bend 40b reverses the direction of the fluid that is now flowing toward the inlet side (arrow B), and re-directs the fluid flow back toward the outlet side (arrow C) of the channel. So that the flow of fluid ultimately reaches the outlet side and outlet opening 34, for each bend that changes the direction of flow toward the inlet side Is of the channel there is a corresponding bend that changes the flow back toward the outlet side (OS) of the channel. In addition to the one or more pair of reversing bends 40a, 40b, the winding micro-channel 30 may also include one or more undulations 38 that change the direction of the fluid flow, but which do not reverse the direction of the fluid flow. In the present embodiment the undulations 38 have a smaller amplitude than that of the bends 40a, 40b. These smaller amplitude undulations 38 change the local direction of the fluid flow without reversing the overall direction so that the flow continues in the same overall direction the fluid was traveling before reaching the undulation. It will be appreciated that the number and size of the bends and undulations can be varied depending upon the particular application, and the micro-channels may include both bends and undulations or include just bends or just undulations.



The heat transfer layers 28 each have a plurality of inlet openings 32 and corresponding outlet openings 34 arranged in substantially parallel rows a, b, c, d, e, and f through each layer, each opening extending from the first surface 10a through to the second surface 10b. Each winding micro-channel 30 is in fluid communication with at least one of the inlet openings 32 and at least one of the corresponding outlet openings 34. Each of the inlet openings 32 and outlet openings 34, in turn, is in fluid communication with corresponding inlet channels 22 and outlet channels 24 of the manifold 12. In the present embodiment, each micro-channel 30 may share their inlet openings and/or outlet openings, although the micro-channels may alternately have independent inlet openings and outlet openings. During use, fluid is provided from the manifold 12 and flows into the inlet openings 32 and into each of the micro-channels 30. The fluid then flows through the micro-channels 30 and out of each of the outlet openings 34 which return the fluid to the manifold 12.

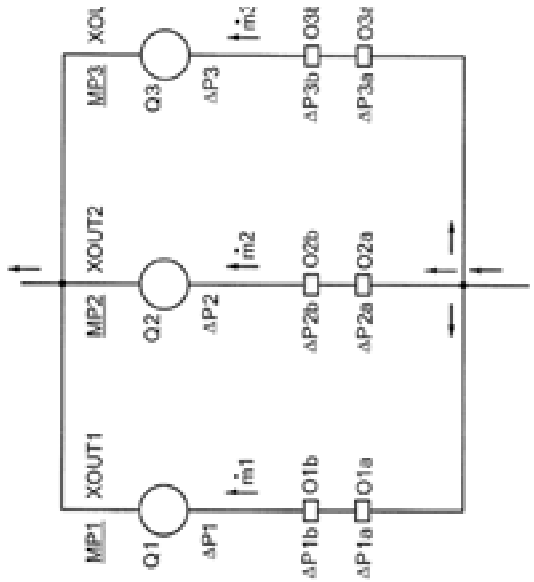
Maintaining Thermal Uniformity in Micro-Channel Cold Plates with Two-Phase Flows,
US 2012/0097374 A1, Altman, David

Micro-channel cold plates utilizing phase-change heat removal have emerged as a viable technique for coping with increased dissipation density in semiconductor devices. However, the increased pressure loss associated with micro-channels necessitates shortening of flow paths and forces flow path parallelism to achieve optimal thermal and hydraulic performance.

Conventional implementations of parallel micro-channel phase-change cooling schemes for spatially varying thermal loads have design specific flow arrangements, which limit applicability and increase complexity. U.S. Pat. No. 7,218,519 to Prasher et al., which is incorporated herein by reference, discloses micro-channel cold plates having channels designed with a priori knowledge of high and low heat load locations. Thus, the cold plates disclosed by Prasher are limited to particular board layouts with integrated circuits, such as microprocessors, in given locations. Thus, Prasher discloses a cold plate that is limited to one particular board layout.

It is known that for micro-channel cold plates an increase in vapor percent in a flow path due to a higher heat load results in an increased pressure drop, which reduces the mass flow rate of the coolant. Pressure and temperature determine a change in phase from liquid to vapor, i.e., the boiling point of a liquid. A subcooled liquid, also referred to as a compressed liquid, is a liquid at a temperature lower than the saturation temperature at a given pressure. Liquid flashing occurs when a saturated liquid stream undergoes a reduction in pressure to below the vapor pressure, creating vapor without external heat addition. Flashing can occur in response to pressure drops. Two-phase cooling in cold plates refers to a coolant in liquid and gas states.

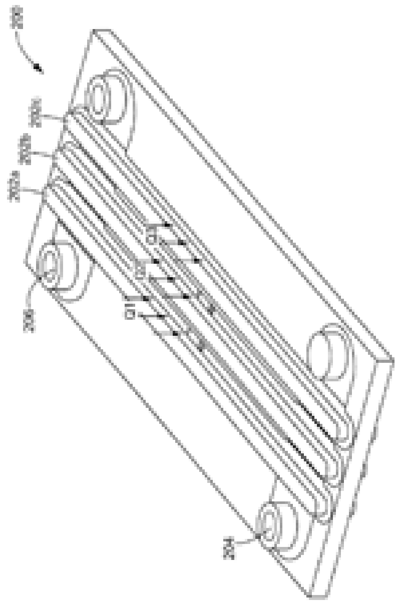
In general, exemplary embodiments of the invention provide a cold plate with enhanced cooling



performance by minimizing the reduction of coolant flow in parallel flow paths caused by differing vapor percent in the paths due to uneven spatial and/or temporal heat loading on the cold plate. Exemplary embodiments of the invention provide micro-channel cold plates having parallel paths and spaced orifices to facilitate balanced coolant flow in the hydraulically parallel paths in the presence of varying heat loads.

A first orifice is sized such that, under nominal balanced flow conditions, the pressure drop incurred will not cause flashing. A second orifice is sized to flash the subcooled liquid to a two-phase flow. If the heat load on a given parallel path decreases, the resultant increase in liquid flow through that path causes flashing through the first orifice, which results in a two-phase mixture being supplied to the second orifice. This causes an increase in the pressure drop at the first orifice and a significant increase in the pressure drop at the second orifice. The increased pressure losses through the orifices offsets the reductions in downstream pressure drop due to the reduced exit quality for preventing misdistribution of flow. The presence of the flashing orifice can provide the added benefit of improved thermal performance and increased heat flux dissipation capability.

Shown is the first, second, and third flow paths MP1, MP2, MP3, all of which are hydraulically parallel.



Each path MP1, MP2, MP3 has a respective pressure drop ΔP1, ΔP2, ΔP3, heat load Q1, Q2, Q3, and mass flow rate mdot1, mdot2, mdot3. The outlet of each path has a respective vapor quality xout1, xout2, xout3.

The first path MP1 includes a first orifice O1 a and a second orifice O1 b spaced a given distance from the first orifice. In the illustrated embodiment, the orifices O1 a, O1 b are located on an inlet side of the flow path MP1. The second and third paths MP2, MP3 similarly have respective first orifices O2 a, O3 a and second orifices O2 b, O3 b. The first and second orifices O1 a, O1 b of the first flow path MP1 can be considered a first set of orifices, the first and second orifices O2 a, O2 b of the second flow path can be considered a second set of orifices and so on. In general, these orifices can be located close to, or far from, the heat sources of interest, as required for a specific design.

If the first path heat load Q1 is greater than the second and third path heat loads Q2, Q3, slight increases in the second and third path mass flow rates mdot2, mdot3, induce flashing across the first orifices, which results in increased pressure drops ΔP2 a,b, ΔP3 a,b across the first and second orifices O2 a,b, O3 a,b in the second and third paths MP2, MP3. This offsets the lower pressure drop ΔP2,3 in the micro-channels due to reduced heating.