

A HEAT TRANSFER DEVICE

FIELD OF INVENTION

The present invention relates broadly to a heat transfer device for maintaining a temperature of a device under test with heat generating capability at a prescribed temperature.

BACKGROUND

Typically, all high-performance electronic devices are subjected to a 100% functional test prior to being shipped by a manufacturer. For example, high power microprocessor devices are typically subjected to a classification test to determine an effective operating speed of the devices. During the classification test, it is important to keep a temperature of a die of the microprocessor device at a single prescribed temperature while the power of the device is varied from about 0% to about 100% of the power rating in a predetermined test sequence.

To maintain the die at the prescribed temperature during testing, equipments known as thermal control units (TCUs) have been designed. Generally, a heating process is achieved by installing a heater in the TCU. To achieve a cooling process, the TCU is coupled to a closed loop system whereby a cold medium is delivered through the TCU to remove heat generated by test devices such as microprocessors. The cold medium can either be single phase flow or two phase flow. A single phase flow medium can remove heat by forced convection without changing its state.

Chilled water TCU technology using the single phase flow is commonly used in microprocessor testing. It is found that the power densities in packaged microprocessor devices have approached levels of about 50 W/cm² to about 100 W/cm². As the levels of the microprocessor device power densities increase, it is possible that the single phase flow technology would reach its limits in terms of testing microprocessors at lower temperatures.

Hence, there is a need to provide a new TCU which addresses at least one of the above-mentioned problems.

SUMMARY

According to a first aspect of the invention, there is provided a heat transfer device for maintaining a temperature of a device under test with heat generating capability at a prescribed temperature, the heat transfer device comprising; an inlet flow-duct, an outlet flow-duct; a conductor block comprising a plurality of through-holes, the through-holes receiving a fluid from the inlet flow-duct and delivering the fluid to the outlet flow-duct; and inserts disposed in the respective through-holes for reducing a cross-sectional area of the respective through-holes to improve heat transfer efficiency, wherein the inserts disposed in the respective through-holes are arranged such that each insert is not restricted to a fixed position with respect to a center of the cross-sectional area of the respective through-holes.

The inserts may be substantially longitudinal and may be disposed in the respective through-holes such that longitudinal axes of the respective inserts are substantially parallel to the through-holes.

The inlet and outlet flow-duct may be secured to opposite ends of the conductor block to form a heat transfer (HT) module, wherein heat transfer mainly occurs in the HT module.

The HT module may be disposed inside a housing, and the heat transfer device may further comprise a valve disposed on the housing for removing air inside the housing and creating a partial vacuum environment around the HT module, wherein the partial vacuum environment facilitates suspension of the HT module in the housing, provides heat transfer insulation between the HT module and the housing for preventing condensation on the housing.

The conductor block may be substantially T-shaped and comprises a stem portion and a branch portion, the branch portion comprising the plurality of through-holes and the stem portion comprising a surface contacting the device under test.

The inlet flow-duct and the outlet flow-duct may be secured to opposite ends of the branch portion of the conductor block for facilitating fluid flow through the through-holes.

The heat transfer device may further comprise a heater layer disposed on a surface of the branch portion of the conductor block opposite the surface of the stem portion of the conductor block contacting the device under test.

The heater layer may be secured to the conductor block with a heater fixture, wherein a vacuum seal is disposed between the conductor block and the heater fixture.

The heat transfer device may further comprise a temperature sensor disposed in the conductor block for measuring the temperature of the device under test.

The heat transfer device may further comprise a controller coupled to the temperature sensor for maintaining the temperature of the device under test at the prescribed temperature.

The controller may maintain the temperature of the device under test at the prescribed temperature by controlling power supply to the heater layer and/or by controlling the fluid flow.

In operation, fluid may enter the through-holes in a substantially saturated liquid state, transitions into a substantially gaseous state under conversion of heat from the device under test, and exits the through-holes in a substantially gaseous state.

The housing may be made of high strength materials for providing structural rigidity and withstanding high pressure spikes inside the housing.

The housing may be made of materials with high thermal conductivity for preventing localized condensation on the housing.

The through-holes may be aligned in a plurality of rows and columns in the conductor block.

The heat transfer device may comprise one or more insert elements, each insert element threading through two or more of the through-holes.

The inserts may be made of materials with high thermal conductivity for enhancing effective heat transfer.

The conductor block may be of a single integral component made of a material with high thermal conductivity for providing effective heat transfer.

The inlet flow-duct, outlet flow-duct and heater fixture may be made of materials with low thermal conductivity for preventing condensation on respective top channel sections of the inlet flow-duct, outlet flow-duct and heater fixture.

Also disclosed herein is a heat transfer device for maintaining a temperature of a device under test with heat generating capability at a prescribed temperature, the heat transfer device comprising an inlet flow-duct; an outlet flow-duct; a conductor block comprising a plurality of through-holes, the through-holes receiving a fluid from the inlet flow-duct and delivering the fluid to the outlet flow-duct; and wherein the conductor block, inlet flow-duct and outlet flow-duct form a heat transfer (HT) module and the HT module is disposed inside a housing, and the heat transfer device further comprises a valve disposed on the housing for removing air inside the housing and creating a partial vacuum environment around the HT module, wherein the partial vacuum environment facilitates suspension of the HT module in the housing, provides heat transfer insulation between the HT module and the housing for preventing condensation on the housing.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

Figure 1 shows a schematic drawing of a cross-sectional view of a heat transfer device in the form of a thermal control unit (TCU).

Figure 2 shows a schematic drawing of a cross-sectional view of the heat transfer (HT) module of the TCU of Figure 1.

Figure 3 shows a schematic drawing of another cross-sectional view of the heat transfer device in the form of TCU.

Figure 4 shows a schematic drawing of a cross-sectional top view of the HT module of the TCU of Figure 1.

Figure 5 shows a schematic drawing of the HT module of the TCU of Figure 1 placed in contact with a tested device.

DETAILED DESCRIPTION

The example embodiments described herein provide a new thermal control unit employing a two phase flow process. A two phase flow medium experiences a change in state from liquid to vapour to remove heat by latent heat of vaporization.

Figure 1 shows a schematic drawing of a cross-sectional view of a heat transfer device in the form of a thermal control unit (TCU) 100. The TCU 100 comprises a housing 102, which comprises a housing base 104 and a main housing body 106 respectively. A check valve 108 is attached to the main housing body 106.

A heat transfer (HT) module 110 is disposed in the housing 102. The main housing body 106 is placed on top of the HT module 110 and the housing base 104 is placed below the HT module 110. A portion of the HT module 110 protrudes the housing base 104. A surface 112 of the HT module 110 is exposed to the surrounding

environment of the TCU 100. The HT module 110 is designed for fast thermal response involving fast raising and lowering of temperatures and maintaining at a single set temperature during device testing. Therefore, it is important that the HT module 110 is properly insulated. The design of the HT module 110 takes into consideration of an intrusion of environment heat flux. The heat transfer between the environment and the HT module 110 can be advantageously negated and a controlled vicinity surrounding the HT module 110 can be advantageously achieved.

In electronic cooling, any presence of water in any form is highly undesirable. As the TCU 100 operates in an open environment under the existence of water vapours, condensation on the surfaces of the TCU 100 is an issue. To prevent condensation on the housing 102 of the TCU 100, the HT module 110 is insulated. Air that is contained inside the TCU 100 is drawn out using the check valve 108. By drawing out the air inside the TCU 100, a partial vacuum environment is created within the interior of the TCU 100. With partial vacuum in the TCU 100 being an excellent insulator, the surface temperature of the housing 102 facing the surrounding environment is kept above dew point temperature, which is a factor of relative humidity and ambient temperature. Condensation on the surfaces of HT module 110 can also be advantageously prevented. In addition, during heating processes, the partial vacuum region also functions as an insulator to prevent any heat loss by the HT module 110.

Despite the condensation prevention method as described above, the housing 102 of the TCU 100 may not be entirely free of condensation. Condensation may still occur due to localized cold regions on the housing 102 due to localized heat transfer between the HT module 110 and the housing 102. Therefore, a high conductivity material is used for manufacturing the housing 102 of the TCU 100 to ensure good spreading of heat that prevents any localized cold regions where condensation may occur. In one example implementation, an aluminium alloy is used, but it will be appreciated that other high-thermal conductivity materials may be used in different implementations.

To minimize localized cold regions on the housing 102, it is preferred that any direct contact between the HT module 110 and the housing 102 is avoided or minimized. This can be achieved in the example embodiment by suspending the HT module 110

inside the housing 102. Vacuum seals 116 made of insulation materials of low thermal conductivity are used to fill the gaps 122 between the housing 102 and the HT module 110 to reduce remaining heat transfer between the HT module 110 and the housing 102, thus achieving minimization of localized cold regions effects. The vacuum seals 116 advantageously prevent any possible air flow from the surrounding environment into the TCU 100. The partial vacuum region in the TCU 100 also advantageously provides a suction effect to hold the vacuum seals 116 in place. Due to the partial vacuum region above the HT module 110, the pressure difference vertically across the HT module 110 can cause the HT module 110 to be lifted within the housing 102 under the atmospheric pressure acting on the external surface 112 of the HT module 110, thus suspending the HT module 110 inside the housing 102. Hard stoppers 114 made of insulation material are clamped between the HT module 110 and the main housing body 106 to reduce heat transfer thus minimizing localized cold areas and to align the HT module 110 to the housing 102. In example implementations, low-thermal conductivity metals such as stainless steel or high strength plastic such as polycarbonate are used for the hard stoppers 114, but it will be appreciated that other low-thermal conductivity materials may be used in different implementations.

To ensure an airtight environment within TCU 100, the housing 102 is properly sealed in the example embodiment. Vacuum seals 120 are inserted between the housing base 104 and the main housing body 106 and between the conductor block 202 and the heater fixture 210 to prevent air leaks into the TCU 100. In the event where faulty equipment along the process line causes a high pressurised fluid flow into the HT module 110, the housing 102 is designed to act as reinforcement to the HT module 110. To withstand the pressure spikes during operation, the housing 102 is manufactured with a high strength material that provides structural rigidity. In one example implementation, an aluminium alloy is used, but it will be appreciated that other high strength materials may be used in different implementations.

Figure 2 shows a schematic drawing of a cross-sectional view of the HT module 110 of the TCU 100 in Figure 1. The HT module 110 comprises a conductor block 202, an inlet flow-duct 205 and an outlet flow-duct 206, a heater in the form of a heater layer 208 and a heater fixture 210. The conductor block 202 is substantially T-shaped with a branch portion in the form of an upper portion 203 having a larger width than a stem

portion in the form of a lower portion 204. To facilitate effective heat transfer, the conductor block 202 is manufactured with materials which are good conductors of heat and manufactured as a single integral component. In one example implementation, a copper alloy is used, but it will be appreciated that other high-thermal conductivity materials may be used in different implementations.

To minimize heat transfer through an intrusion of environmental heat flux and to prevent condensation at respective top channel sections 228, 230 and 232 of the inlet flow-duct 205, the outlet flow-duct 206 and the heater fixture 210 that are exposed to the open space environment, the inlet flow-duct 205, the outlet flow-duct 206 and the heater fixture 210 are manufactured with materials which are poor conductors of heat. For example, low-thermal conductivity metals such as stainless steel or high strength plastic such as polycarbonate may be used.

The inlet flow-duct 205 and the outlet flow-duct 206 are disposed at opposite ends of the upper portion 203 of the conductor block 202. The inlet flow-duct 205 and the outlet flow-duct 206 are secured to the upper portion 203 of the conductor block 202 using respective fasteners 212 on the inlet flow-duct 205 and the outlet flow-duct 206. The upper portion 203 of the conductor block 202 is enclosed by the inlet flow-duct 205 and the outlet flow-duct 206. As appreciated by a person skilled in the art, the problem of condensation as mentioned above does not occur on the conductor block 202, the inlet flow-duct 205 and the outlet flow-duct 206 as they are enclosed in the partial vacuum environment within the TCU 100.

The heater layer 208 is disposed on a surface 209 of the upper portion 203 of the conductor block 202 opposite to the surface 112 of the lower portion 204 of the conductor block 202. The heater layer 208 is secured to the upper portion 203 of the conductor block 202 by the heater fixture 210 using fasteners 214 and vacuum seal 120. In the example embodiment, the heater layer 208 is a commercially available flat-type resistance heater, but it will be appreciated that other heater layer designs may be used in different implementations. The vacuum seal 120 is disposed between the conductor block 202 and the heater fixture 210. The heater fixture 210 is manufactured with materials which are good insulators of heat to minimize heat transfer. In example implementations, low-thermal conductivity metals such as stainless steel or high strength

plastic such as polycarbonate are used, but it will be appreciated that other low-thermal conductivity materials may be used in different implementations. Seals 216 are disposed between the upper portion 203 of the conductor block 202 and the inlet flow-duct 205 and the outlet flow-duct 206 to prevent leakage of fluid. The seals 216 are made of materials which are tolerable under both high and low temperatures. In example implementations, viton or silicone are used, but it will be appreciated that other low-thermal conductivity materials may be used in different implementations.

A temperature sensor in the form of a spring-loaded thermocouple 218 is disposed in a cavity 220, which is substantially in the centre of the conductor block 202. The spring-loaded thermocouple 218 is coupled to an external controller 222. The spring-loaded thermocouple 218 measures temperatures of a device under test 502 and feeds back the temperature measurements to the controller 222. The controller 222 also monitors and controls fluid flow through the HT module 110, in particular the pressure, temperature and flow rate, and also controls a power supply to the heater 208 layer for maintaining the temperature of the device under test 502 at a prescribed temperature. The controller 222 is coupled to a power supply/controller 224 and a reservoir/controller 226. The power supply/controller 224 for controlling the power supply to the heater layer 208 is coupled to the heater layer 208. The reservoir/controller 226 for facilitating the fluid flow is coupled to the inlet flow-duct 205 and the outlet flow-duct 206.

Figure 3 shows a schematic drawing of another cross-sectional view of the heat transfer device in the form of TCU 100. As shown in Figure 3, the conductor block 202 of the HT module 110 comprises a plurality of through-holes in the form of channels 302 on the upper portion 203 of the conductor block 202. The channels 302 are aligned in a plurality of rows and columns at two sides of the thermocouple 218 disposed in the cavity 220 of the conductor block 202.

Two factors affecting the performance of heat transfer at the conductor block 202 of the TCU 100 are effective heat transfer to fluid through the conductor block 202 and the amount of fluid delivered through the channels 302 of the conductor block 202. Flow boiling in channels offers very high heat transfer capabilities. To increase heat transfer coefficient of fluid flow, it is preferred that the channels 302 have a smaller D_h , where D_h

is the hydraulic diameter. However, a smaller D_h poses a problem in manufacturing the conductor block 202 with the channels 302 through conventional machining.

A longitudinal insert e.g. a wire 304 is inserted into the channels 302 of the conductor block 202 to obstruct a portion of flow area in every channel 302 to reduce a cross-sectional area of the channels 302. Consequently, a smaller D_h is attained. As such, the total heat transfer coefficient of the fluid going through the channels 302 increases, which advantageously provides a more effective heat removal by the fluid. Given the flexibility to control the hydraulic diameter D_h of the channels 302 by using e.g. wires 304, an increase in the diameter of the channels 302 is advantageously provided which results in an ease of manufacturing the conductor block 202. Therefore, conventional machining can be used to manufacture the conductor block 202 of the TCU 100, without forsaking the basic functions of allowing effective heat removal and maintaining a prescribed temperature during testing. The inserts, e.g. wires 304, disposed in the respective channels 302 are arranged such that each insert is not restricted to a fixed position with respect to a center of the cross-sectional area of the respective channels 302. To further enhance the effectiveness of heat transfer, the inserts, e.g. wires 304, are made of a high thermal conductivity material. In example implementations, the inserts e.g. wires 304 may be provided as copper or aluminium alloy wires, but it will be appreciated that other high-thermal conductivity materials may be used in different implementations.

The diameter of the through-holes and the wires are preferred to be within the range of 0.2mm to 3mm. As will be appreciated by a person skilled in the art, within 0.2-3mm, the flow channel is typically referred to as a mini-channel, which is currently most suitable for the technique of the example embodiment of using inserts to substantially reduce the cross-sectional area. In TCU 100, the diametral ratio of the wire to the through-holes is preferred to be within the range of more than 0.7, leading to a reduction in cross-sectional area of more than 50 percent and in hydraulic diameter of more than 70 percent. For the same pressure gradient applied, the consequential reduction in flow rate is more than 85 percent.

Figure 4 shows a schematic drawing of a cross-sectional top view of the HT module 110 of the TCU 100 of Figure 1. One end of the insert e.g. wire 304 is inserted

into one end of a channel 302, is pulled out from an opposite end of the same channel 302 and is inserted to an adjacent end of an adjacent channel 302 in a same row. As shown in Figure 4, for each row of the channels 302 at each side of the thermocouple 218 (Figure 3) disposed in the cavity 220 (Figure 3) of the conductor block 202, the threading of the insert e.g. wire 304 begins at a starting point 402, which is furthest away from the thermocouple 218 (Figure 3) and ends at an ending point 404, which is adjacent to the thermocouple 218 (Figure 3). It will be appreciated by the person skilled in the art that the threading method and/or pattern are not limited to that as described in this embodiment. Both ends of the insert e.g. wire 304 are fixed at the starting point 402 and the ending point 404 by e.g. welding. The channels 302 and the insert e.g. wire 304 are enclosed by the inlet flow-duct 205 and the outlet flow-duct 206.

Figure 5 shows a schematic drawing of the HT module 110 of the TCU 100 in Figure 1 placed in contact with a device under test 502. The device under test 502 is mounted on a mounting stage 504. By either moving the device under test 502 upwards or moving the HT module 110 downwards, the device under test 502 is brought into contact with the surface 112 of the conductor block 202 for testing. A positive contact between the device under test 502 and the surface 112 of the conductor block 202 is achieved by means of actuators (not shown). The connections between the device under test 502 and the exposed surface 112 during testing are not shown.

The device under test 502 has heat generating capability. To maintain the temperature of the device under test 502 at the prescribed temperature during a cooling process, heat that is transferred from the device under test 502 to the conductor block 202 by conduction is removed by a cold medium fluid passing through the channels 302 of the conductor block 202 by convection. The fluid in a substantially saturated liquid state is delivered into the inlet flow-duct 205 as indicated by arrow 506. The fluid flows through the channels (302 of Figure 3) of conductor block 202 in a direction as indicated by arrow 508. The fluid within the channels (302 of Figure 3) experiences a change of state from a substantially saturated liquid state to a substantially gaseous state during the heat transfer process. The fluid in a substantially gaseous state is delivered out of conductor block 202 through the outlet flow-duct 206 as indicated by arrow 510. The heat is removed from the conductor block 202 by the fluid flowing through the channels of conductor block 202 by convection. In example implementations, refrigerant gases

such as R22, R404A and CO₂ are used, but it will be appreciated that fluids may be used in different implementations.

To raise a temperature of the device under test 502 during a heating process, the heater layer 208 is switched on to supply heat to the device under test 502. Heat supplied is transferred from the conductor block 202 to the device under test 502 by conduction.

The TCU 100 as described above advantageously achieves desired test temperatures by using two phase flow process and advantageously provides rapid heating and cooling. The TCU 100 as described above has a simple design which advantageously provides an ease of fabrication and assembly. All components of the TCU 100 are of simple geometry which can be manufactured without special techniques and tools. This advantageously reduces machining costs. The compactness of the design of the TCU 100 also makes it easy to integrate into test handler systems.

Further, the design of the TCU 100 has encompassed a wide range of considerations for its durability and reliability. For example, rapid heating and cooling, which can cause fatigue in materials affecting its overall performance, can be minimized through a proper material selection. A structural layout of the TCU 100 is designed with safety features to ensure rigidity to withstand any high pressure spikes. Hence, the design of the TCU 100 is advantageously reliable.

In addition, the TCU 100 is designed to be coupled with a cooling system to achieve the desired results and to be used in test handler systems which require applications of heating and cooling of test devices.

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. A heat transfer device for maintaining a temperature of a device under test with heat generating capability at a prescribed temperature, the heat transfer device comprising:
 - an inlet flow-duct;
 - an outlet flow-duct;
 - a conductor block comprising a plurality of through-holes, the through-holes receiving a fluid from the inlet flow-duct and delivering the fluid to the outlet flow-duct; and
 - inserts disposed in the respective through-holes for reducing a cross-sectional area of the respective through-holes to improve heat transfer efficiency,wherein the inserts disposed in the respective through-holes are arranged such that each insert is not restricted to a fixed position with respect to a center of the cross-sectional area of the respective through-holes.
2. The heat transfer device as claimed in claim 1, wherein the inserts are substantially longitudinal and are disposed in the respective through-holes such that longitudinal axes of the respective inserts are substantially parallel to the through-holes.
3. The heat transfer device as claimed in claims 1 or 2, wherein the inlet and outlet flow-ducts are secured to opposite ends of the conductor block to form a heat transfer (HT) module, wherein heat transfer mainly occurs in the HT module.
4. The heat transfer device as claimed in any one of the preceding claims, wherein the HT module is disposed inside a housing, and the heat transfer device further comprises a valve disposed on the housing for removing air inside the housing and creating a partial vacuum environment around the HT module, wherein the partial vacuum environment facilitates suspension of the HT module in the housing, and provides heat transfer insulation between the HT module and the housing for preventing condensation on the housing.

5. The heat transfer device as claimed in any one of claims 1 to 4, wherein the conductor block is substantially T-shaped and comprises a stem portion and a branch portion, the branch portion comprising the plurality of through-holes and the stem portion comprising a surface contacting the device under test.

6. The heat transfer device as claimed in claim 5, wherein the inlet flow-duct and the outlet flow-duct are secured to opposite ends of the branch portion of the conductor block for facilitating fluid flow through the through-holes.

7. The heat transfer device as claimed in claims 5 or 6, further comprising a heater layer disposed on a surface of the branch portion of the conductor block opposite the surface of the stem portion of the conductor block contacting the device under test.

8. The heat transfer device as claimed in claim 7, wherein the heater layer is secured to the conductor block with a heater fixture, wherein a vacuum seal is disposed between the conductor block and the heater fixture.

9. The heat transfer device as claimed in any one of claims 1 to 8, further comprising a temperature sensor disposed in the conductor block for measuring the temperature of the device under test.

10. The heat transfer device as claimed in any one of claims 1 to 9, further comprising a controller coupled to the temperature sensor for maintaining the temperature of the device under test at the prescribed temperature.

11. The heat transfer device as claimed in any one of claims 1 to 10, wherein the controller maintains the temperature of the device under test at the prescribed temperature by controlling power supply to the heater layer and/or by controlling the fluid flow.

12. The heat transfer device as claimed in any one of claims 1 to 11, wherein, in operation, fluid enters the through-holes in a substantially saturated liquid state, transitions into a substantially gaseous state under conversion of heat from the device under test, and exits the through-holes in the substantially gaseous state.

13. The heat transfer device as claimed in claim 4, wherein the housing is made of high strength materials for providing structural rigidity and withstanding high pressure spikes inside the housing.

14. The heat transfer device as claimed in claims 4 or 13, wherein the housing is made of materials with high thermal conductivity for preventing localized condensation on the housing.

15. The heat transfer device as claimed in any one of claims 1 to 14, wherein the through-holes are aligned in a plurality of rows and columns in the conductor block.

16. The heat transfer device as claimed in any one of claims 1 to 15, comprising one or more insert elements, each insert element threading through one or more of the through-holes.

17. The heat transfer device as claimed in any one of claims 1 to 14, wherein the inserts are made of materials with high thermal conductivity for enhancing effective heat transfer.

18. The heat transfer device as claimed in any one of claims 1 to 15, wherein the conductor block is of a single integral component made of a material with high thermal conductivity for providing effective heat transfer.