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(54) **GRAVIMETRIC VAPOR CHAMBER AND HEAT PIPE CHARGING UTILIZING RADIANT HEATING**

GRAVIMETRISCHE DAMPFKAMMER- UND WÄRMEROHRAUFLADUNG UNTER VERWENDUNG
VON STRAHLUNGSHEIZUNG

CHAMBRE DE VAPEUR GRAVIMÉTRIQUE ET CALODUC UTILISANT LE CHAUFFAGE RADIANT

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Description

BACKGROUND OF THE DISCLOSURE

[0001] Electronic devices generate thermal energy during use. The thermal energy can be removed from the housing of the device by conducting or radiating the thermal energy through an exhaust or opening in the device housing. As electronic devices become more portable, the devices are becoming lighter and smaller, concentrating the thermal energy in a smaller volume and constricting airflow through the devices. Modern portable electronics require more efficient transport of the thermal energy.

[0002] Vapor chamber thermal management devices utilize a vaporization and condensation cycle to transport thermal energy from a higher temperature region, such as near a processor, to a lower temperature region, such as near an exhaust or a fan. Vapor chambers contain a working fluid that vaporizes and condenses to transport heat, and the vapor pressure in the chamber affects the vaporization and condensation temperature. US 2018/106553 A1 describes that the present application discloses a thermal ground plane that is charged by laser welding a cover on an aperture. Prior to sealing, the thermal ground plane is filled with a quantity of a working fluid, and the device is heated until the working fluid is boiling in the cavity. Accordingly, the cavity is filled with the working fluid and with a saturated vapor of the working fluid. When the saturated vapor has displaced other gases, the cavity is laser welded shut.

[0003] US 2007/062036 A1 describes a method of filling and sealing a predetermined quantity of working fluid within a hollow metal casing of a heat-dissipating device such as a heat pipe or a vapor chamber-based heat spreader includes the following steps: filling a working fluid into the hollow metal casing through an open end thereof until the hollow metal casing is full of the working fluid; pumping a portion of the working fluid out of the hollow metal casing until the predetermined quantity of working fluid is left in the hollow metal casing; and sealing the open end of the hollow metal casing. By this method, a vacuum condition is accordingly formed inside the heat pipe due to removal of the portion of the working fluid from the heat pipe and the air contained in the heat pipe is effectively removed.

[0004] US 2017/138672 A1 describes that a solid working medium filling device for heat pipe with double process ports includes a working medium tank, an upper cover, an inert gas source and a vacuum molecular pump set. The upper cover is arranged on an upper side of the working medium tank, a process port in the upper cover is in communication with the inert gas source and the vacuum molecular pump set respectively. A heat pipe to be filled includes two process ports, in which a main process port is a vacuumizing port and an inert gas passage port as well as a working medium filling port; and an auxiliary process port is a vacuumizing port as well as a port

for inert gas passage. Size of an exhaust passage of the heat pipe and the process tank is doubled, exhausting and vacuumizing are smooth and the filling range can be enlarged as required. SUMMARY The invention is set out in the appended set of claims.

[0005] In the first alternative of the invention, a method of manufacturing a thermal management device includes the features of claim 1.

[0006] In the second alternative of the invention, a method of manufacturing a thermal management device includes the features of claim 6.

[0007] In some embodiments, a system for manufacturing a thermal management device includes a fixture, a mass-weighing device, and a radiant heat source. The fixture supports a body of the thermal management device, and the mass-weight device is configured to measure the mass of the body supported by the fixture. The radiant heat source is positioned to direct radiant thermal energy toward the fixture to radiantly heat the body.

[0008] This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.

[0009] Additional features and advantages of embodiments of the disclosure will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by the practice of such embodiments. The features and advantages of such embodiments may be realized and obtained by means of the instruments and combinations particularly pointed out in the appended claims. These and other features will become more fully apparent from the following description and appended claims or may be learned by the practice of such embodiments as set forth hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] In order to describe the manner in which the above-recited and other features of the disclosure can be obtained, a more particular description will be rendered by reference to specific embodiments thereof which are illustrated in the appended drawings. For better understanding, the like elements have been designated by like reference numbers throughout the various accompanying figures. While some of the drawings may be schematic or exaggerated representations of concepts, at least some of the drawings may be drawn to scale. Understanding that the drawings depict some example embodiments, the embodiments will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

FIG. 1 is a perspective view of an electronic device having a thermal management device therein, according to at least one embodiment of the present disclosure;

FIG. 2 is a front cross-sectional view of a conventional vapor chamber during charging;

FIG. 3 is a front cross-sectional view of an unsealed vapor chamber during charging, according to at least one embodiment of the present disclosure;

FIG. 4 is a front cross-sectional view of a sealed vapor chamber, according to at least one embodiment of the present disclosure;

FIG. 5 is a flowchart illustrating a method of charging a thermal management device, according to at least one embodiment of the present disclosure;

FIG. 6 is a flowchart illustrating another method of charging a thermal management device, according to at least one embodiment of the present disclosure;

FIG. 7 is a flowchart illustrating yet another method of charging a thermal management device, according to at least one embodiment of the present disclosure;

FIG. 8-1 is a side cross-sectional view of a radiantly heated thermal management device, according to at least one embodiment of the present disclosure;

FIG. 8-2 is a graph illustrating the relationship of temperature and mass of a working fluid during charging of a thermal management device, according to at least one embodiment of the present disclosure; and
FIG. 9 is a front cross-sectional view of a plurality of thermal management devices in a low-pressure environment during charging, according to at least one embodiment of the present disclosure.

DETAILED DESCRIPTION

[0011] This disclosure generally relates to devices, systems, and methods for thermal management. More particularly, the present disclosure relates to charging a vapor chamber thermal management device with a working fluid. In some embodiments, a vapor chamber thermal management device according to the present disclosure has an opening that allows the chamber to be open to the surrounding environment. A working fluid is positioned in the chamber in a liquid form, and the body of the thermal management device is heated to vaporize a portion of the working fluid. The mass of the body and working fluid is measured as the working fluid vaporizes, and the opening of the chamber is sealed when the mass of the working fluid reaches the desired value.

[0012] In some embodiments, the body is radiantly heated such that the heat source does not apply a force to the body and disturb the mass measurements. For example, conductive heating can include one or more cables, wires, tubes, or pipes connected to the body of the thermal management device. The conductive heating elements can either apply a force toward the scale (e.g., weigh the body down on the scale) or apply a force away from the scale (e.g., support the body above the scale), which will alter the mass measurements and may result in lower performance vapor chambers.

[0013] In some embodiments, the body and working

fluid are placed in a low-pressure environment, lowering the vaporization temperature of the working fluid. For example, the body and working fluid can be placed on a scale in a bell jar, and a vacuum pump can remove air from the bell jar to lower pressure in the bell jar. As the pressure decreases, the working fluid will boil at a lower temperature. For example, the working fluid may boil at room temperature. In other examples, the working fluid may boil above room temperature and below the vaporization temperature at standard pressure.

[0014] FIG. 1 is a perspective view of an embodiment of an electronic device 100. The electronic device 100 may include a first portion 102 and a second portion 104 movably connected to one another by a hinge 106. In some embodiments, the first portion 102 of the electronic device 100 may include a display 108 to present visual information to a user and the second portion 104 of the electronic device 100 may include one or more input devices 110, such as a trackpad, a keyboard, etc., to allow a user to interact with the electronic device 100. In embodiments in which the computing device is a hybrid computer, the first portion 102 may include the display 108 and at least a processor 112. The first portion 102 may further include additional computer components, such as a storage device, system memory, a graphical processing unit, graphics memory, one or more communication devices (such as WIFI, BLUETOOTH, near-field communications), peripheral connection points, etc. In some embodiments, the first portion 102 may be removable from the hinge 106 and/or the second portion 104.

[0015] The electronic components of an electronic device 100, in particular the display 108, input device 110, processor 112, memory, and batteries, generate thermal energy. In some embodiments, the electronic components are cooled by a thermal management device. In the example illustrated in FIG. 1 and in other examples, it is desirable that the electronic devices be thin and light for transport, while remaining powerful and quiet during use. The thermal management device, therefore, may be robust and efficient while being quiet and occupying as little volume of the electronic device 100 as possible.

[0016] While the embodiment of an electronic device 100 illustrated in FIG. 1 is a hybrid laptop device, it should be understood that thermal management devices according to the present disclosure are relevant to any electronic device 100. In some embodiments, an electronic device 100 may be any computing device, such as a desktop computer, a tablet computer, a server, or a smartphone; a wearable device, such as a wrist- or head-mounted device; home appliances, such as cameras, televisions, radios, microwaves, or lights; home automation devices; automotive or other transportation devices; or any other electronic devices that generate thermal energy during use. In other embodiments, a thermal management device according to the present disclosure may be used with heat pumps.

[0017] FIG. 2 illustrates conventional manufacturing of a thermal management device 114. The thermal man-

agement device 114 has a body 116 defining a chamber 118 therein. The chamber 118 houses a working fluid that is a liquid 120 in a portion of the chamber 118 and a gas 122 in the remaining portion of the chamber 118. As the body 116 of the thermal management device 114 is exposed to thermal energy and increases in temperature, the working fluid converts from liquid 120 to gas 122 and moves through the chamber 118, creating an isothermic region in the thermal management device 114. The isothermic region allows the thermal management device 114 to move thermal energy generated by electrical components to another area of the electronic device to remove the thermal energy.

[0018] The amount of working fluid in the chamber 118 is critical to the effectiveness of the thermal transfer within the chamber. A chamber 118 including too little working fluid will limit the effectiveness of the state changes between liquid 120 and gas 122 by allowing too much gas 122 and adversely impacts the thermal energy transfer in the chamber 118. For example, if the liquid amount is too low then the vapor chamber "dries out" at the evaporator and overheats. Too much working fluid liquid 120 and gas 122 will similarly limit the effectiveness of the state changes between liquid 120 and gas 122 by limiting the amount of gas 122 and adversely impacts the thermal energy transfer in the chamber 118. For example, when there is too much working fluid, the liquid reduces the space available for vapor flow thus increasing the vapor's velocity which in turn increases the pressure drop across the vapor chamber. The pressure gradient creates an undesirable temperature gradient across the vapor chamber due to the fact that pressure and temperature are dependent on one another inside the vapor chamber (due to vapor-liquid equilibrium).

[0019] To control the introduction of working fluid to the chamber 118, a conventional thermal management device 114 has a fill tube 124 through which working fluid is inserted into the chamber 118. Because the thermal energy transfer of the working fluid is related to the vaporization temperature of the fluid, the vaporization temperature of the working fluid can be lowered by reducing the vapor pressure in the chamber 118. A vacuum pump 126 is conventionally attached to the fill tube 124 or other outlet of the chamber 118 to lower the pressure in the chamber 118. The conventional method of filling and then evacuating working fluid (both liquid 120 and gas 122) is imprecise and introduces error in the amount of working fluid in the thermal management device 114.

[0020] FIG. 3 is a side cross-sectional view of a body 216 of a thermal management device 214, according to some embodiments of the present disclosure. The body 216 defines a chamber 218 into which a working fluid is introduced. The working fluid is introduced as a liquid 220 that wets a wick in the chamber 218. In some embodiments, the working fluid is water. In other embodiments, the working fluid is acetone. In yet other embodiments, the working fluid is an alcohol. In further embodiments, the working fluid is a fluid that is liquid at room

temperature (i.e., 24°C) and has a vaporization temperature at or below 100°C. In at least one embodiment, the working fluid is a fluid that is liquid at room temperature and has a vaporization temperature at or below 35°C in the chamber 218. For example, the pressure inside the chamber 218 may be less than standard atmospheric pressure, reducing the vaporization temperature.

[0021] The body 216 of the thermal management device 214 can then be heated to vaporize the liquid 220 into a gas 222 and displace ambient air 230 from the chamber 218. An opening 228 at an end of the chamber 218 allows fluid to pass out of the unsealed chamber and into the atmosphere external to the body 216. As the working fluid boils and the working fluid gas 222 displaces air 230 from the chamber 218, the working fluid will begin to exit out of the opening 228 and the overall mass of the body 216 and working fluid in the body 216 will begin to decrease. When the mass of the body 216 and the working fluid reaches the desired value, the opening 228 can be closed, sealing the chamber 218.

[0022] FIG. 4 is a side cross-sectional view of a sealed body 316 of a thermal management device 314, according to some embodiments of the present disclosure. The working fluid may be a liquid 320, a gas 322, or a combination of liquid 320 and gas 322. The gas 322 may fill the chamber 318 such that the working fluid gas 322 is the only gas in the chamber 318. In other embodiments, there may be other gases in the chamber 318. For example, residual air may remain in the chamber 318, introducing nitrogen, oxygen, carbon dioxide, or other gases.

[0023] In some embodiments, the chamber 318 is sealed using a laser 332 to weld the opening 328 closed. The weld 334 may include the same material as the body 316. In other examples, the weld 334 may include or be a separate piece of material that is placed in or over the opening 328 and welded to the body 316 to hold the chamber 318 closed. In yet other examples, the weld 334 may be created by heat sources other than a laser. The opening 328 may be welded shut by a torch, or the opening 328 may be welded shut by an electrical heat source, such as in gas metal arc welding.

[0024] In other embodiments, the chamber 318 is sealed mechanically. For example, the body 316 may be mechanically deformed to close the opening 328. In some examples, the body 316 may be crimped to close the opening 328. In other examples, the body 316 may be folded to close the opening 328. In yet other examples, a separate piece may be positioned in the opening 328 to seal the chamber 318. The separate piece may be held in place by a friction fit, a press fit, a snap fit, an adhesive, a mechanical fastener (such as a clip, clamp, pin, rod, bolt), or combinations thereof.

[0025] In order to control the amount of working fluid precisely, the chamber 318 must be closed when the mass is measured at the desired amount. In order to precisely measure the mass of the body 316 and working fluid (both liquid 320 and gas 322), the body 316 and

working fluid are heated without physically contacting the body 316 or other part of the thermal management device 314.

[0026] FIG. 5 is a flowchart illustrating a method 436 of charging a thermal management device, according to some embodiments of the present disclosure. The method 436 includes radiantly heating a body of an unsealed thermal management device having a working fluid therein at 438. Radiantly heating the body allows thermal energy to be delivered to the body and the working fluid to increase in temperature without applying any physical forces to the body. Applying force to the body would alter any measurements collected by a scale or balance, and the force would, therefore, render the working fluid mass measurements inaccurate.

[0027] The method 436 further includes vaporizing at least a portion of the working fluid from a liquid phase to a gaseous phase at 440. In some embodiments, the working fluid is vaporized through the application of the radiant heat only at standard atmospheric pressure. For example, the radiant heat may increase the temperature of a water working fluid to 100°C (at sea level) and boil the water. In other examples, the radiant heat may increase the temperature of the working fluid to a temperature at or above the atmospheric saturation temperature of the working fluid. In other embodiments, the working fluid is vaporized through the application of the radiant heat in an environment with a decreased atmospheric pressure. For example, the radiant heat may increase the temperature of a water working fluid to a temperature less than 100°C, while a decreased atmospheric pressure around the body lowers the vaporization temperature, such that the temperature is sufficient to boil the water. A combination of decreasing the pressure and applying radiant heating may allow lower energy radiant heat sources to boil the working fluid or higher energy radiant heat sources to boil the working fluid fast, saving time and energy. The combination will also reduce the residual air left in the chamber.

[0028] FIG. 6 illustrates another method 536 of charging a thermal management device, according to some embodiments of the present disclosure. The method 536 includes filling a portion of a chamber with a working fluid at 542 and vaporizing at least a portion of the working fluid at 538. In some embodiments, the portion of the chamber is filled with water. In other embodiments, the portion of the chamber is filled with acetone. In yet other embodiments, the portion of the chamber is filled with an alcohol.

[0029] In some embodiments, at least 1% of the chamber is filled with the working fluid. For example, a liquid may be introduced to the chamber that only occupies 1% of the volume of the chamber in liquid form before any of the working fluid is in a gaseous state. In other embodiments, at least 10% of the chamber is filled with the working fluid. For example, filling 10% of the volume of the chamber with a working fluid liquid provides enough liquid to displace the remaining volume of gas. In yet

other embodiments, at least 50% of the chamber is filled with the working fluid, and in further embodiments, at least 100% of the chamber is filled with the working fluid. For example, the working fluid may be introduced in a combination of liquid and gas that displaces all prior fluids from the chamber.

[0030] Vaporizing at least a portion of the working fluid at 538 includes increasing the temperature and/or lowering a vapor pressure of the chamber to vaporize the liquid portion of the working fluid into a gas. In some embodiments, the working fluid is vaporized through the application of the heat only at standard atmospheric pressure. For example, the heat may increase the temperature of a water working fluid to 100°C (at sea level) and boil the water. In other embodiments, the working fluid is vaporized through the application of the heat in an environment with a decreased atmospheric pressure. For example, the heat may increase the temperature of a water working fluid to a temperature less than 100°C, while a decreased atmospheric pressure around the body lowers the vaporization temperature, such that the temperature is sufficient to boil the water. A combination of decreasing the pressure and applying heating may allow lower energy heat sources to boil the working fluid or higher energy heat sources to boil the working fluid fast, saving time and energy.

[0031] In some embodiments, the heat source is a radiant heat source. For example, the heat source may be a heat lamp, a laser, or other heat source that emits thermal energy without conduction of the heat to the body of the thermal management device. In other embodiments, the heat source is a conductive heat source, such as heating coils, a fluid bath, a heat gun, or other heat source that applies a substance of elevated temperature to the body of the thermal management device. In yet other embodiments, the heat source is an inductive heat source. For example, a magnetic field may be applied to the body of the thermal management device to generate heat in the body and increase the temperature of the body and working fluid.

[0032] The method 536 further includes weighing the body and the working fluid during the vaporization of the working fluid at 544. In some embodiments, weighing the body and working fluid includes positioning the body and working fluid on a scale. In other embodiments, weighing the body and working fluid includes positioning the body and working fluid on a support fixture positioned on a scale. For example, the body may be supported in an upright orientation with the opening at the top of the body. The liquid may thereby be retained at the bottom of the chamber in the body, while the gas displaces out the opening at the top.

[0033] FIG. 7 illustrates yet another method 636 of charging a thermal management device, according to some embodiments of the present disclosure. The method 636 includes vaporizing at least a portion of a working fluid from a chamber of the thermal management device at 646 and weighing a body and working fluid during the

vaporization at 648.

[0034] Vaporizing at least a portion of the working fluid at 646 includes increasing the temperature and/or lowering a vapor pressure of the chamber to vaporize the liquid portion of the working fluid into a gas. In some embodiments, the working fluid is vaporized through the application of the heat only at standard atmospheric pressure. For example, the heat may increase the temperature of a water working fluid to 100°C (at sea level) and boil the water. In other embodiments, the working fluid is vaporized through the application of the heat in an environment with a decreased atmospheric pressure. For example, the heat may increase the temperature of a water working fluid to a temperature less than 100°C, while a decreased atmospheric pressure around the body lowers the vaporization temperature, such that the temperature is sufficient to boil the water. A combination of decreasing the pressure and applying heating may allow lower energy heat sources to boil the working fluid or higher energy heat sources to boil the working fluid fast, saving time and energy.

[0035] The method 636 further includes weighing the body and the working fluid during the vaporization of the working fluid at 648. In some embodiments, weighing the body and working fluid includes positioning the body and working fluid on a scale. In other embodiments, weighing the body and working fluid includes positioning the body and working fluid on a support fixture positioned on a scale. For example, the body may be supported in an upright orientation with the opening at the top of the body. The liquid may thereby be retained at the bottom of the chamber in the body, while the gas displaces out the opening at the top.

[0036] The method 636 then includes closing the chamber to seal the working fluid in the chamber 650. In some embodiments, the chamber is closed using a laser to weld the opening closed. The weld may include the same material as the body. In other examples, the weld may include or be a separate piece of material that is placed in or over the opening and welded to the body to hold the chamber closed. In yet other examples, the weld may be created by heat sources other than a laser. The opening may be welded shut by a torch, or the opening may be welded shut by an electrical heat source, such as in gas metal arc welding.

[0037] In other embodiments, the chamber is closed mechanically. For example, the body may be mechanically deformed to close the opening. In some examples, the body may be crimped to close the opening. In other examples, the body may be folded to close the opening. In yet other examples, a separate piece may be positioned in the opening to seal the chamber. The separate piece may be held in place by a friction fit, a press fit, a snap fit, an adhesive, a mechanical fastener (such as a clip, clamp, pin, rod, bolt), or combinations thereof.

[0038] FIG. 8-1 is a side view of an embodiment of radiantly heating a body 716 of a thermal management device 714. The body 716 has a chamber 718 with an

opening 728. A working fluid liquid 720 is positioned in the chamber 718, and, as the working fluid liquid 720 vaporizes into a working fluid gas 722, a scale 754 or other mass-weighting device measures changes in the mass of the body 716, the working fluid, and the fixture 752 holding the body 716 upright. As the body 716 and the fixture 752 are of a fixed mass, the scale 754 measures the changes in the working fluid.

[0039] In some embodiments, the scale 754 has 0.01 gram precision. In other embodiments, the scale 754 has 1.0 milligram precision. For example, a thermal management device for cooling the electronic components of a hybrid laptop, such as described in relation to FIG. 1, may contain between 0.5 grams and 2.0 grams of working fluid. Therefore, measuring the removal of the working fluid through vaporization may have a precision at least an order of magnitude greater.

[0040] In some embodiments, the scale 754 measures the mass with a scale frequency in a range having an upper value, a lower value, or upper and lower values including any of 1 Hertz (Hz), 5 Hz, 10 Hz, 50 Hz, 100 Hz, 1000 Hz, or any values therebetween. For example, the scale frequency may be greater than 1 Hz. In other examples, the scale frequency may be less than 1000 Hz. In yet other examples, the scale frequency may be between 1 Hz and 1000 Hz. In further examples, the scale frequency may be between 5 Hz and 100 Hz. In at least one example, the scale frequency is about 10 Hz. Larger volume chambers may have a larger amount of working fluid, and the mass of the working fluid may change more slowly proportionately to the total mass. Smaller volume chambers, such as those used in wearable devices, may have smaller amounts of working fluid, and the mass may change more quickly proportionately to the total mass. A higher scale frequency may allow the system to measure the mass and seal the chamber with a working fluid mass closer to the target mass.

[0041] The body 716 is heated by radiant thermal energy 756 directed at a surface of the body 716 by one or more heat sources 758. In some embodiments, the body 716 is reflective to the wavelength of the radiant heat source 758, and a non-reflective surface is applied to the body 716 to assist in the absorption of the radiant thermal energy 756. For example, a body 716 of a thermal management device 714 made from titanium alloy may present a reflective surface. A coating with known emissivity can be applied to the surface to make the surface less reflective or matte. In at least one embodiment, a black coating may be applied to absorb more of the radiant thermal energy 756.

[0042] In some embodiments, the radiant heating of the body 716 can be monitored during heating. For example, a sensor 759 may be applied to the surface being heated. In other examples, a thermal imaging camera may image the thermal energy of the body 716 to capture the surface temperature of different areas of the body 716. In at least one example, an infrared imaging camera may be used to image the surface temperature of the

body 716 during heating.

[0043] FIG. 8-2 is an example relationship between the heating and mass-change of the thermal management device 714 of FIG. 8-1. The temperature curve 760 shows the warming of the working fluid liquid to the vaporization temperature. Upon reaching the vaporization temperature, the temperature stops increasing as the boiling working fluid vaporizes and the gas displaces from the chamber, conducting thermal energy away. The mass curve 762 reflects the vaporizing and displacing working fluid as the working fluid converts from liquid to gas and leaves the chamber.

[0044] As described herein, the working fluid liquid may be vaporized by lowering a vapor pressure in the chamber and of the atmosphere around the body. FIG. 9 is a side cross-sectional view illustrating an embodiment of a plurality of thermal management devices 814-1, 814-2 inside a vacuum chamber 864 connected to a vacuum pump 826. The first thermal management device 814-1 may be placed on a first scale 854-1, and the second thermal management device 814-2 may be placed on a second scale 854-2. By measuring the masses of the thermal management devices 814-1, 814-2 independently, the thermal management devices 814-1, 814-2 may be sealed independently when the desired working fluid mass is attained.

[0045] One or more specific embodiments of the present disclosure are described herein. These described embodiments are examples of the presently disclosed techniques. Additionally, in an effort to provide a concise description of these embodiments, not all features of an actual embodiment may be described in the specification. It should be appreciated that in the development of any such actual embodiment, as in any engineering or design project, numerous embodiment-specific decisions will be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one embodiment to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

[0046] The articles "a," "an," and "the" are intended to mean that there are one or more of the elements in the preceding descriptions. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements. Additionally, it should be understood that references to "one embodiment" or "an embodiment" of the present disclosure are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. For example, any element described in relation to an embodiment herein may be combinable with any element of any other embodiment described herein. Numbers, percentages, ratios, or other values stated herein are intended to in-

clude that value, and also other values that are "about" or "approximately" the stated value, as would be appreciated by one of ordinary skill in the art encompassed by embodiments of the present disclosure. A stated value should therefore be interpreted broadly enough to encompass values that are at least close enough to the stated value to perform a desired function or achieve a desired result. The stated values include at least the variation to be expected in a suitable manufacturing or production process, and may include values that are within 5%, within 1%, within 0.1%, or within 0.01% of a stated value.

[0047] A person having ordinary skill in the art should realize in view of the present disclosure that equivalent constructions do not depart from the spirit and scope of the present disclosure, and that various changes, substitutions, and alterations may be made to embodiments disclosed herein without departing from the spirit and scope of the present disclosure. Equivalent constructions, including functional "means-plus-function" clauses are intended to cover the structures described herein as performing the recited function, including both structural equivalents that operate in the same manner, and equivalent structures that provide the same function. It is the express intention of the applicant not to invoke means-plus-function or other functional claiming for any claim except for those in which the words 'means for' appear together with an associated function. Each addition, deletion, and modification to the embodiments that falls within the meaning and scope of the claims is to be embraced by the claims.

[0048] The terms "approximately," "about," and "substantially" as used herein represent an amount close to the stated amount that still performs a desired function or achieves a desired result. For example, the terms "approximately," "about," and "substantially" may refer to an amount that is within less than 5% of, within less than 1% of, within less than 0.1% of, and within less than 0.01% of a stated amount. Further, it should be understood that any directions or reference frames in the preceding description are merely relative directions or movements. For example, any references to "up" and "down" or "above" or "below" are merely descriptive of the relative position or movement of the related elements.

[0049] The described embodiments are to be considered as illustrative and not restrictive. The scope of the disclosure is, therefore, indicated by the appended claims rather than by the foregoing description. Changes that come within the meaning and range of equivalency of the claims are to be embraced within their scope.

Claims

1. A method of manufacturing a thermal management device, the method comprising:
radiantly heating (438) an unsealed chamber (218) of the thermal management device (214) that is filled

with a working fluid (220, 222), further comprising weighing (648) the thermal management device (714) and working fluid (720, 722) while radiantly heating the unsealed chamber (718).

2. The method of claim 1, radiantly heating (438) the unsealed chamber (718) including directing a heat lamp (758) at a body (716) of the thermal management device (714). 5
3. The method of claim 1, further comprising measuring a temperature of the thermal management device while radiantly heating the unsealed chamber. 10
4. The method of claim 3, measuring the temperature including imaging the thermal management device with a thermal camera. 15
5. The method of claim 3, measuring the temperature of the thermal management device including measuring a surface temperature of a coating with known emissivity on the thermal management device. 20
6. A method of manufacturing a thermal management device, the method comprising: 25
 - vaporizing (646) a working fluid (320, 322) from a chamber (318) in a body (316) of a thermal management device (314);
 - weighing (648) the body and working fluid during vaporization; and
 - closing (650) the chamber to seal the working fluid in the body. 30
7. The method of claim 6, vaporizing (646) the working fluid (320, 322) including radiantly heating the body (316). 35
8. The method of claim 6, weighing (648) the body (316) and working fluid (320, 322) including measuring a mass of the body and working fluid with at least a 0.01 g resolution. 40
9. The method of claim 6, weighing (648) the body (316) and working fluid (320, 322) including measuring a mass of the body and working fluid with at least a 10 Hertz frequency. 45
10. The method of claim 6, closing (650) the chamber (318) including welding a portion (334) of the body (316). 50
11. The method of claim 6, closing (650) the chamber (318) including directing a laser (332) at a portion (334) of the body (316). 55
12. The method of claim 6, vaporizing (646) the working fluid (320, 322) including heating the body (316) to

an atmospheric saturation temperature of the working fluid.

13. The method of claim 6, further comprising closing (650) the chamber (316) when the working fluid (320, 322) in the chamber is at a vaporization temperature of the working fluid.

14. The method of claim 13, vaporizing (646) the working fluid (320, 322) including lowering an ambient air pressure.

Patentansprüche

1. Verfahren zum Herstellen einer Wärmeverwaltungs-
vorrichtung, wobei das Verfahren umfasst:
Strahlungsbeheizen (438) einer unversiegelten
Kammer (218) der Wärmeverwaltungs-
vorrichtung (214), die mit einem Arbeitsfluid (220, 222) gefüllt
ist, weiter umfassend Wiegen (648) der Wärme-
verwaltungsvorrichtung (714) und des Arbeitsfluids
(720, 722), während die unversiegelte Kammer
(718) strahlungsbeheizt wird.
2. Verfahren nach Anspruch 1, wobei Strahlungsbehei-
zen (438) der unversiegelten Kammer (718) bein-
hältet, eine Wärmelampe (758) auf einen Körper
(716) der Wärmeverwaltungs-
vorrichtung (714) zu richten.
3. Verfahren nach Anspruch 1, weiter umfassend Mes-
sen einer Temperatur der Wärmeverwaltungs-
vorrichtung, während die unversiegelte Kammer strah-
lungsbeheizt wird.
4. Verfahren nach Anspruch 3, wobei Messen der Tem-
peratur beinhaltet, die Wärmeverwaltungs-
vorrichtung mit einer Wärmebildkamera abzubilden.
5. Verfahren nach Anspruch 3, wobei Messen der Tem-
peratur der Wärmeverwaltungs-
vorrichtung beinhaltet, eine Oberflächentemperatur einer Beschichtung
mit bekanntem Emissionsgrad auf der Wärme-
verwaltungsvorrichtung zu messen.
6. Verfahren zum Herstellen einer Wärmeverwaltungs-
vorrichtung, wobei das Verfahren umfasst:

Verdampfen (646) eines Arbeitsfluids (320, 322)
aus einer Kammer (318) in einem Körper (316)
einer Wärmeverwaltungs-
vorrichtung (314);
Wiegen (648) des Körpers und des Arbeitsfluids
während Verdampfung; und
Schließen (650) der Kammer, um das Arbeits-
fluid in dem Körper zu versiegeln.
7. Verfahren nach Anspruch 6, wobei Verdampfen

(646) des Arbeitsfluids (320, 322) beinhaltet, den Körper (316) strahlungszubeheizen.

8. Verfahren nach Anspruch 6, wobei Wiegen (648) des Körpers (316) und des Arbeitsfluids (320, 322) beinhaltet, eine Masse des Körpers und des Arbeitsfluids mit zumindest einer Auflösung von 0,01 g zu messen. 5
9. Verfahren nach Anspruch 6, wobei Wiegen (648) des Körpers (316) und des Arbeitsfluids (320, 322) beinhaltet, eine Masse des Körpers und des Arbeitsfluids mit zumindest einer Frequenz von 10 Hertz zu messen. 10
10. Verfahren nach Anspruch 6, wobei Schließen (650) der Kammer (318) beinhaltet, einen Abschnitt (334) des Körpers (316) zu schweißen. 15
11. Verfahren nach Anspruch 6, wobei Schließen (650) der Kammer (318) beinhaltet, einen Laser (332) auf einen Abschnitt (334) des Körpers (316) zu richten. 20
12. Verfahren nach Anspruch 6, wobei Verdampfen (646) des Arbeitsfluids (320, 322) beinhaltet, den Körper (316) auf eine atmosphärische Sättigungstemperatur des Arbeitsfluids zu erwärmen. 25
13. Verfahren nach Anspruch 6, weiter umfassend Schließen (650) der Kammer (316), wenn das Arbeitsfluid (320, 322) in der Kammer bei einer Verdampfungstemperatur des Arbeitsfluids ist. 30
14. Verfahren nach Anspruch 13, wobei Verdampfen (646) des Arbeitsfluids (320, 322) beinhaltet, einen Umgebungsdruck zu senken. 35

Revendications

1. Procédé de fabrication d'un dispositif de gestion thermique, le procédé comprenant :
le chauffage par rayonnement (438) d'une chambre non scellée (218) du dispositif de gestion thermique (214) qui est remplie d'un fluide de travail (220, 222), comprenant en outre le pesage (648) du dispositif de gestion thermique (714) et du fluide de travail (720, 722) tout en chauffant par rayonnement la chambre non scellée (718). 45
2. Procédé selon la revendication 1, le chauffage par rayonnement (438) de la chambre non scellée (718) incluant le fait de diriger une lampe chauffante (758) au niveau d'un corps (716) du dispositif de gestion thermique (714). 50
3. Procédé selon la revendication 1, comprenant en outre la mesure d'une température du dispositif de 55

gestion thermique tout en chauffant par rayonnement la chambre non scellée.

4. Procédé selon la revendication 3, la mesure de la température incluant l'imagerie du dispositif de gestion thermique avec une caméra thermique.
5. Procédé selon la revendication 3, la mesure de la température du dispositif de gestion thermique incluant la mesure d'une température de surface d'un revêtement avec une émissivité connue sur le dispositif de gestion thermique.
6. Procédé de fabrication d'un dispositif de gestion thermique, le procédé comprenant :

la vaporisation (646) d'un fluide de travail (320, 322) depuis une chambre (318) dans un corps (316) d'un dispositif de gestion thermique (314) ; le pesage (648) du corps et du fluide de travail pendant la vaporisation ; et la fermeture (650) de la chambre pour sceller le fluide de travail dans le corps.
7. Procédé selon la revendication 6, la vaporisation (646) du fluide de travail (320, 322) incluant le chauffage par rayonnement du corps (316).
8. Procédé selon la revendication 6, le pesage (648) du corps (316) et du fluide de travail (320, 322) incluant la mesure d'une masse du corps et du fluide de travail avec une résolution d'au moins 0,01 g.
9. Procédé selon la revendication 6, le pesage (648) du corps (316) et du fluide de travail (320, 322) incluant la mesure d'une masse du corps et du fluide de travail avec une fréquence d'au moins 10 Hertz.
10. Procédé selon la revendication 6, la fermeture (650) de la chambre (318) incluant le soudage d'une partie (334) du corps (316).
11. Procédé selon la revendication 6, la fermeture (650) de la chambre (318) incluant le fait de diriger un laser (332) au niveau d'une partie (334) du corps (316).
12. Procédé selon la revendication 6, la vaporisation (646) du fluide de travail (320, 322) incluant le chauffage du corps (316) à une température de saturation atmosphérique du fluide de travail.
13. Procédé selon la revendication 6, comprenant en outre la fermeture (650) de la chambre (316) lorsque le fluide de travail (320, 322) dans la chambre est à une température de vaporisation du fluide de travail.
14. Procédé selon la revendication 13, la vaporisation (646) du fluide de travail (320, 322) incluant l'abais-

sement d'une pression d'air ambiant.

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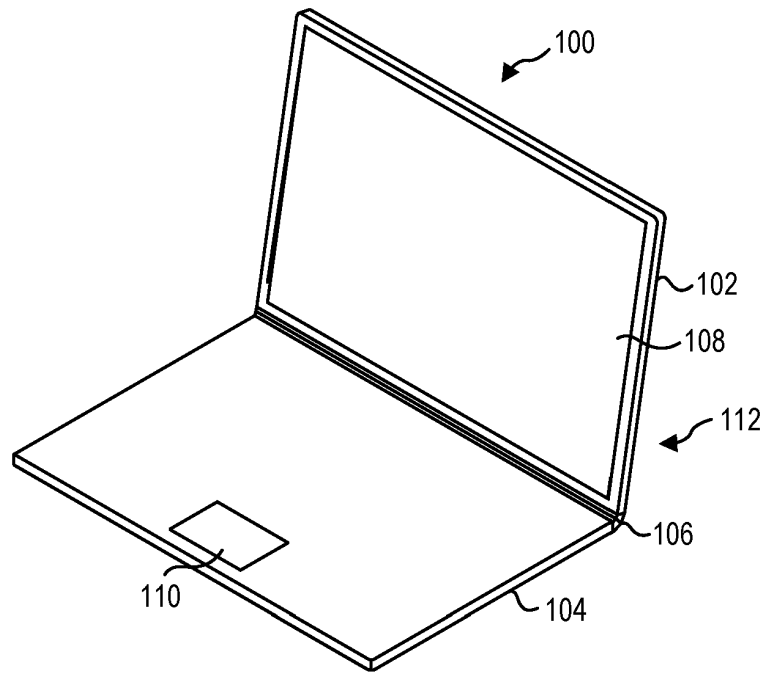


FIG. 1

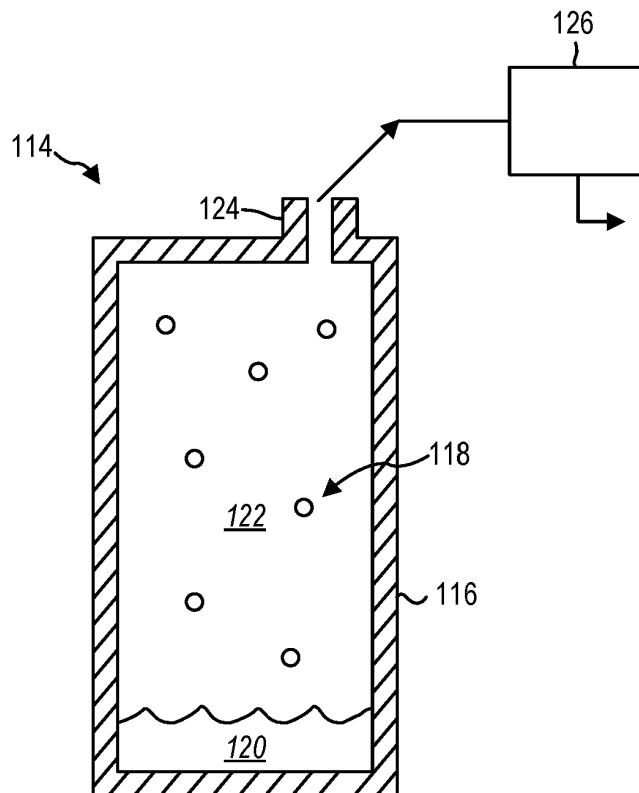


FIG. 2

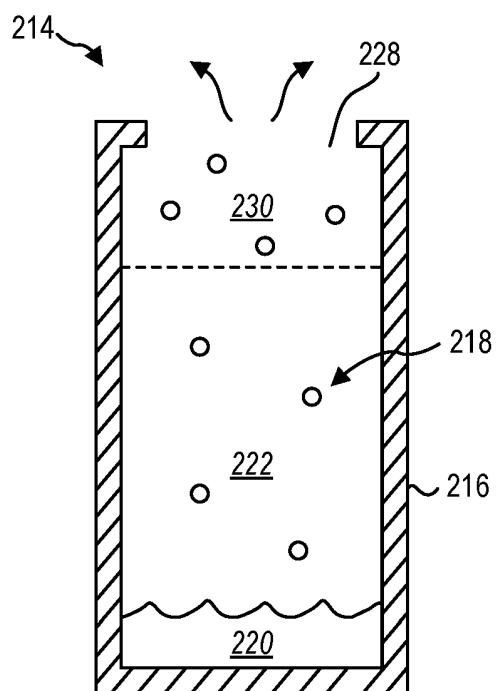


FIG. 3

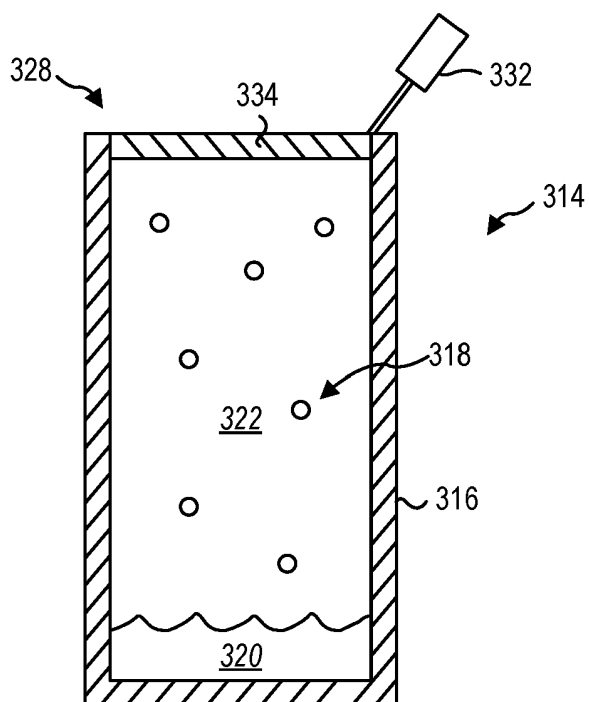


FIG. 4

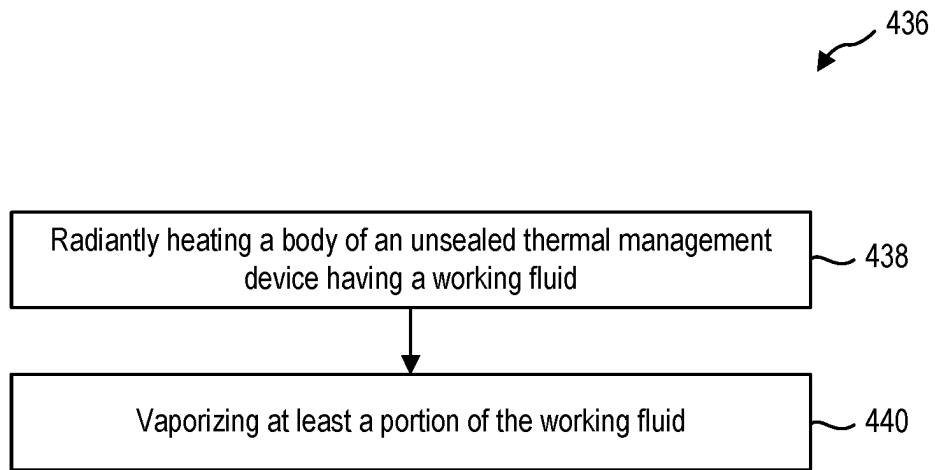


FIG. 5

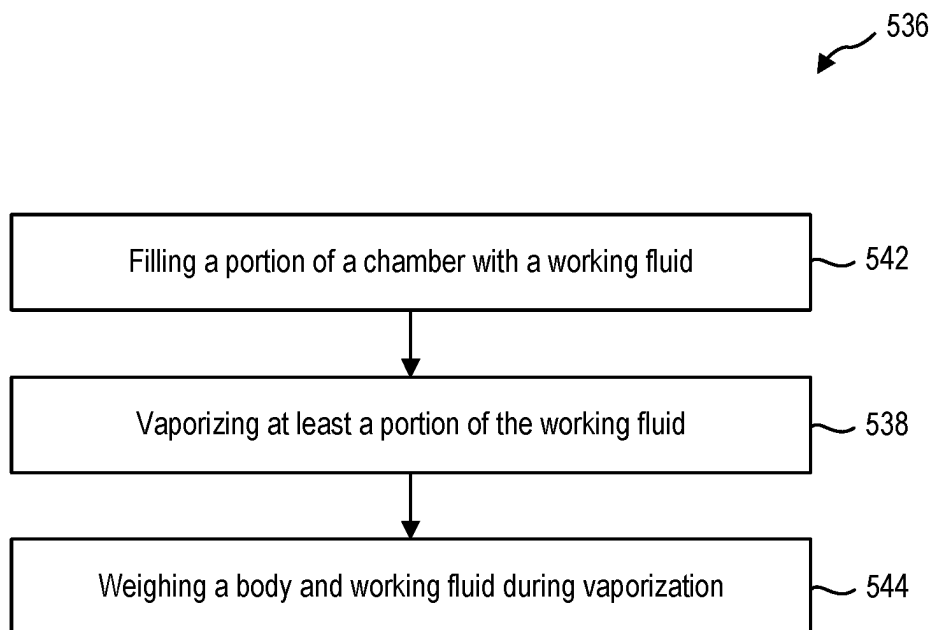


FIG. 6

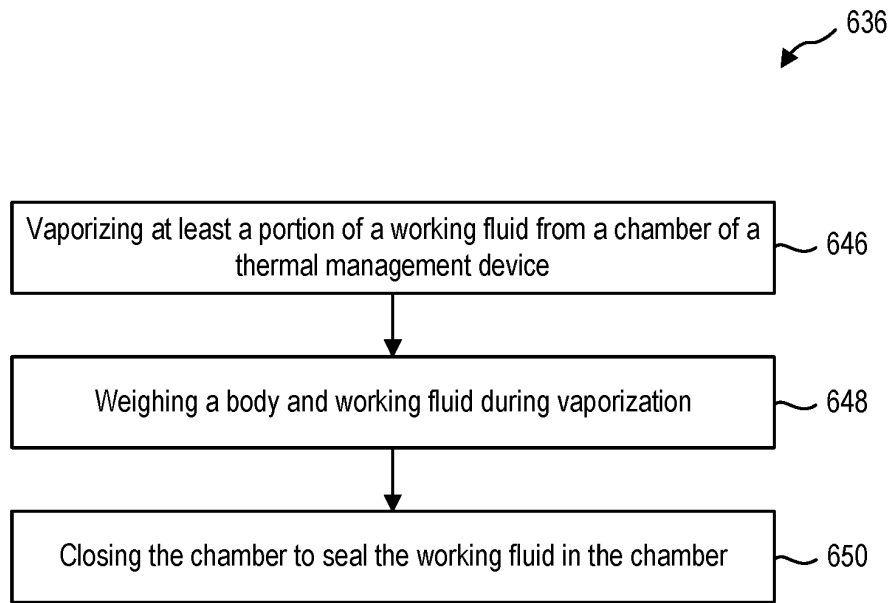


FIG. 7

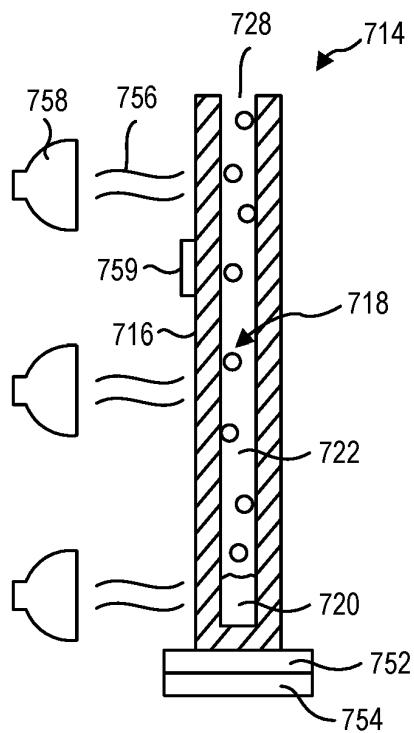


FIG. 8-1

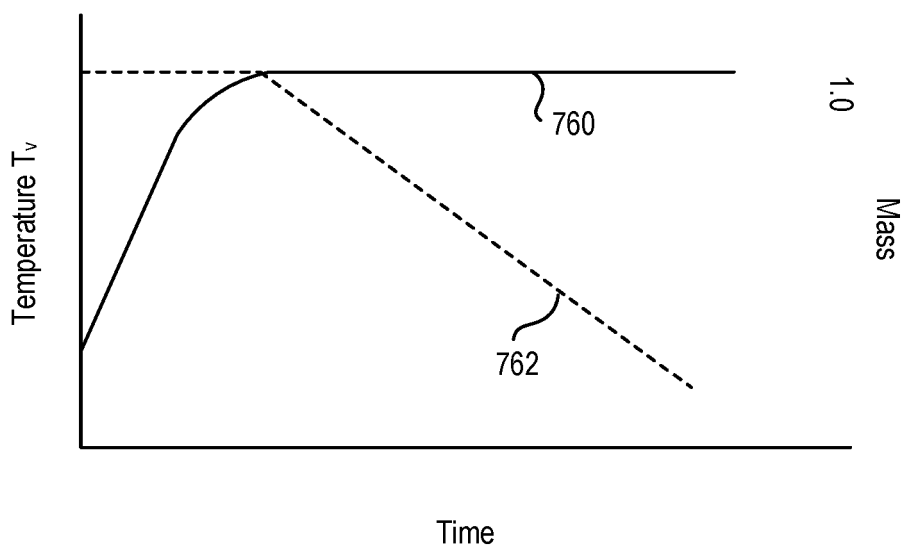


FIG. 8-2

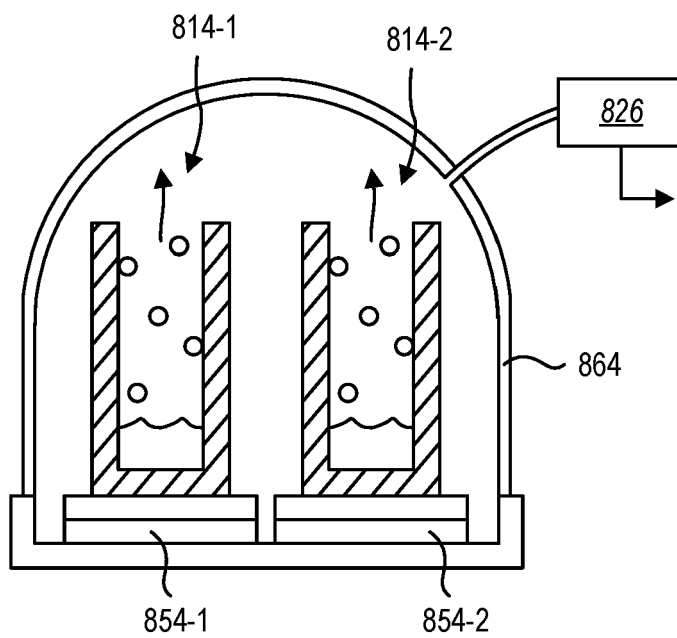


FIG. 9

REFERENCES CITED IN THE DESCRIPTION

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