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(71) Applicant: **CGG SERVICES SAS** [US/FR]; 27 Avenue Carnot, 91341 Massy Cedex (FR).

(72) Inventors: **CLERC, Laurent**; 10300 Town Park Drive, Houston, TX 77072 (US). **BLANC, Jean-yves**; 27 Avenue Carnot, 91341 Massy Cedex (FR).

(74) Agent: **KUELBS, Kevin, A.** et al.; Osha Bergman Watanabe & Burton LLP, 1100 Louisiana Street, Suite 4900, Houston, TX 77002 (US).

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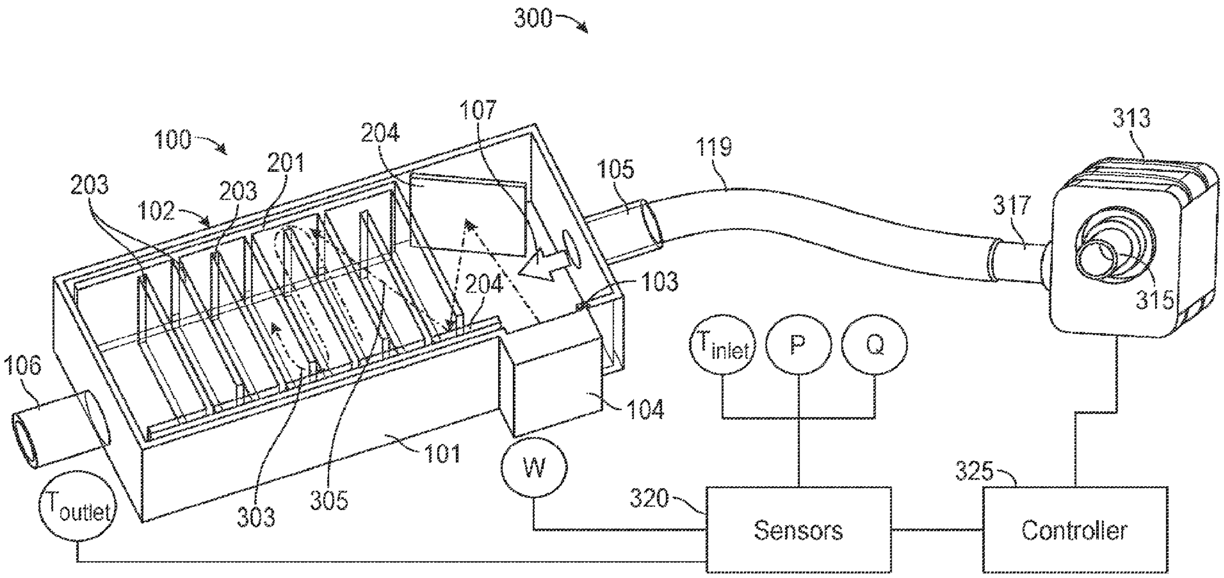

FIG. 3

(57) Abstract: A device for cooling an electronic component includes a casing enclosing a cavity, an inlet orifice, an outlet orifice, a radiative opening, and a reflective surface. The inlet orifice and the outlet orifice are hydraulically connected by the cavity. The cavity receives a cooling fluid from the inlet orifice and directs the cooling fluid to the outlet orifice. The radiative opening is disposed between the cavity and the electronic component and permits transmission of radiation from the electronic component to the cooling fluid in the cavity. The reflective surface is disposed in the cavity and reflects the radiation in the cavity.

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METHODS AND SYSTEMS FOR FLUID ASSISTED RADIATIVE COOLING

BACKGROUND

[0001] In general, electronic components generate heat while operating. This heat may, in turn, detrimentally impact the performance of the electronic components by increasing their electrical resistance, causing electronic component burnout, or effecting similar forms of equipment failure. To alleviate the detrimental effects of the generated heat, it is becoming increasingly common to use a cooling fluid to absorb heat from electronic components and redistribute the heat to a separate location away from the electronic components for further dissipation. For example, by passing a cooling fluid over, near, or around an electronic component such that heat is transferred from the electronic component to the cooling fluid via conduction, convention, or a combination thereof.

SUMMARY

[0002] 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.

[0003] Embodiments disclosed herein relate to a device for cooling an electronic component. The device includes a casing enclosing a cavity, an inlet orifice, an outlet orifice, a radiative opening, and a reflective surface. The inlet orifice and the outlet orifice are hydraulically connected by the cavity. The cavity receives a cooling fluid from the inlet orifice and directs the cooling fluid to the outlet orifice. The radiative opening is disposed between the cavity and the electronic component and permits transmission of radiation from the electronic component to the cooling fluid in the cavity. The reflective surface is disposed in the cavity and reflects the radiation in the cavity.

[0004] Embodiments disclosed herein further relate to a method for cooling an electronic component. The method includes attaching the electronic component that radiatively emits heat to a device. The device includes a casing enclosing a cavity, an inlet orifice and an outlet orifice hydraulically connected by the cavity, a radiative opening disposed between the cavity and the electronic component, and a reflective surface disposed in the cavity that reflects the radiation in the cavity. The cavity receives a cooling fluid from the inlet orifice and directs the cooling fluid to the outlet orifice. The radiative opening permits transmission of radiation from the electronic component to the cooling fluid in the cavity. The method further includes transporting the cooling fluid into the casing through the inlet orifice with a pump. In addition, the method includes transferring heat via radiation from the electronic component to the cooling fluid. The radiation is reflected within the cavity by the reflective surface and absorbed by the cooling fluid. The method also includes directing the directing the cooling fluid out of the casing with the outlet orifice.

[0005] Embodiments disclosed herein further relate a system. The system includes a pump, a device for cooling an electronic component, and a controller. The device includes a casing enclosing a cavity, an inlet orifice, an outlet orifice, a radiative opening, and a reflective surface. The inlet orifice and the outlet orifice are hydraulically connected by the cavity. The cavity receives a cooling fluid from the inlet orifice and directs the cooling fluid to the outlet orifice. The radiative opening is disposed between the cavity and the electronic component and permits transmission of radiation from the electronic component to the cooling fluid in the cavity. The reflective surface is disposed in the cavity and reflects the radiation in the cavity. The cooling fluid is pumped through into the inlet orifice, through the cavity, and out the outlet orifice by the pump. The controller is electrically coupled to the pump and controls operation of the pump.

[0006] Any combinations of the various embodiments and implementations disclosed herein can be used in a further embodiment, consistent with the disclosure. Other aspects and advantages of the claimed subject matter will be apparent from the following description and the claims.

BRIEF DESCRIPTION OF DRAWINGS

[0007] Specific embodiments of the disclosed technology will now be described in detail with reference to the accompanying figures. Like elements in the various figures are denoted by like reference numerals for consistency. The sizes and relative positions of elements in the drawings are not necessarily drawn to scale. For example, the shapes of various elements and angles are not necessarily drawn to scale, and some of these elements may be arbitrarily enlarged and positioned to improve drawing legibility.

[0008] Figure 1 depicts a device and an electronic component in accordance with one or more embodiments disclosed herein.

[0009] Figure 2 depicts a device and an electronic component in accordance with one or more embodiments disclosed herein.

[0010] Figure 3 depicts a system in accordance with one or more embodiments disclosed herein.

[0011] Figure 4 depicts a device and two electronic components in accordance with one or more embodiments disclosed herein.

[0012] Figure 5 depicts a device coupled to electronic boards each containing an electronic component in accordance with one or more embodiments disclosed herein.

[0013] Figure 6 depicts a method for radiatively cooling an electronic component using a cooling fluid in accordance with one or more embodiments disclosed herein.

DETAILED DESCRIPTION

[0014] In the following detailed description of embodiments of the disclosure, numerous specific details are set forth in order to provide a more thorough understanding of the disclosure. However, it will be apparent to one of ordinary skill in the art that the disclosure may be practiced without these specific details. In other instances, well-known features have not been described in detail to avoid unnecessarily complicating the description.

[0015] Throughout the application, ordinal numbers (*e.g.*, first, second, third, etc.) may be used as an adjective for an element (*i.e.*, any noun in the application). The use of ordinal numbers is not intended to imply or create any particular ordering of the elements nor to limit any element to being only a single element unless expressly disclosed, such as using the terms "before," "after," "single," and other such terminology. Rather, the use of ordinal numbers is to distinguish between the elements. By way of an example, a first element is distinct from a second element, and the first element may encompass more than one element and succeed (or precede) the second element in an ordering of elements. Furthermore, while certain electronic components are referred to in the singular to simplify discussion of embodiments of the invention, those skilled in the art will appreciate that any individual electronic component may be replaced with a multitude of electronic components in advanced embodiments of the invention.

[0016] In addition, throughout the application, the terms "upper" and "lower" may be used to describe the position of an element of the invention. In this respect, the term "upper" denotes an element disposed above a corresponding "lower" element in a vertical direction, while the term "lower" conversely describes an element disposed below a corresponding "upper" element in the vertical direction. Similarly, the term "inner" refers to an orientation closer to a center of an object than a corresponding "outer" orientation.

[0017] In general, embodiments of the invention are directed towards a heat exchanger device ("device") for cooling electronic systems with a cooling fluid ("fluid"). Electronic systems generate heat as they operate. That heat needs to be removed to ensure that the electronic components contained in the electronic systems remain in the temperature range for which they were designed.

[0018] In typical data processing centers, the heat is removed from the electronic systems by running a fluid through the systems (e.g., a gas such as air, a liquid, or a combination of both a gas and a liquid) and relying on conduction or convection. A multiphase fluid (i.e., combination of both a gas and liquid) may occur if, for example, the fluid experiences a phase change.

[0019] The fluid is used to remove the heat away from the electronic equipment to an external location where the heat can be exchanged with another fluid, or directly dissipated in the environment.

[0020] The efficiency, redundancy, and maintainability of that process generally depends on the fluid used (e.g., its mass, electrical properties, chemical properties, and thermal properties), the amount of fluid and flow required, and the amount of energy and complexity of the system necessary to circulate that fluid.

[0021] High performance computing (HPC) centers contain a large number of electronic systems, e.g., for seismic data processing. Improving the efficiency, redundancy, and operational flexibility of the cooling systems is a desirable outcome for HPC centers (e.g., for data processing).

[0022] For example, U.S. Patent No. 10,257,963 (filed April 18, 2017, and titled "Methods and system for oil immersion cooling") and U.S. Patent No. 10,349,555 (also filed April 18, 2017, and also titled "Methods and system for oil immersion cooling"), which are incorporated by reference herein in their entirety, disclose examples of systems designed to improve one or more of the elements described above. In general, embodiments disclosed herein can operate with, or be used to improve and augment, the systems described in the aforementioned patents.

[0023] Embodiments disclosed herein relate to a novel approach to removing the heat produced by an electronic component (or, more simply a component or a component of an electronic system) by absorbing, to a volume of a fluid, the energy radiated by the electronic component rather than relying on traditional conduction and/or convection at the fluid-electronic component interface. Methods and systems for fluid assisted radiative cooling described herein are especially efficient when applied to electronic components where heat has been converted to radiation (specifically, thermal radiation).

[0024] All forms of matter emit radiation. Standard wave properties such as wavelength and frequency are often attributed to radiation. Thus, radiation can be viewed with respect to the electromagnetic spectrum. An intermediate portion of the electromagnetic spectrum with wavelengths spanning from approximately 0.1 μm to

100 μm is often termed "thermal radiation" because these wavelengths can be caused by and affected by the temperature of associated matter (e.g., thermal state of an object). This range includes a portion of the electromagnetic spectrum considered ultraviolet and all of the wavelengths generally designated as the visible spectrum and infrared (IR) spectrum. Herein, discussion of radiation refers to thermal radiation unless otherwise specified.

[0025] In general, radiation is both emitted (i.e., emission) by a body or volume of matter and incident upon the body or volume of matter (i.e., irradiation). Radiation received or incident upon a body or volume of matter (i.e., irradiation) can be absorbed, transmitted, or reflected by the body or volume of matter where the fractions of irradiation that are absorbed, transmitted, and reflected must sum to one. That is, all incident radiation on an object or volume of matter (i.e., irradiation) is either absorbed, transmitted, or reflected. For example, for a given object, 50% of irradiation may be reflected, 30% may be absorbed, and 20% may be transmitted by the object. Reflection is the process of irradiation being redirected away from a body or volume of matter (e.g., away from its surface) without an effect on the body or volume of matter. A medium that experiences no transmission may be considered opaque. Similarly, a medium that predominantly transmits radiation may be considered transparent.

[0026] For emission, the magnitude of radiation can vary with both wavelength (spectral dependence) and direction (directional dependence). The relative fractions of absorption, transmission, and reflection of irradiation on a body or volume of matter can also have a spectral and directional dependence. Thus, some mediums may be considered transparent or opaque (or some combination) based on the wavelength and direction of irradiation. For example, glass made of caesium idodide may transmit infrared radiation over a wide spectrum (e.g., 0.25 μm to 55 μm) whereas glass made of sapphire may transmit a much smaller band of infrared radiation (e.g., 0.17 μm to 5 μm) and otherwise be opaque. As another example, materials such as aluminum, gold, and silver are often considered highly reflective of infrared radiation.

[0027] For gases and semitransparent solids (e.g., glass), emission of radiation from the matter is often deemed a volumetric phenomenon whereas for most other solids and liquids radiation emission is considered a surface phenomenon. Similarly, for many solids the fractional distribution of absorption, transmission, and reflection is a surface phenomenon (again, with a spectral and directional dependence). Thus, in some instances, properties such as emission, transmission, reflection, and absorption of an object can be altered by changing the properties of its surface. For example, coating an object in, or depositing a small layer of, a given material (e.g., gold) can make an object that is otherwise very absorptive to a given range of radiation (e.g., infrared) reflective at that range of radiation.

[0028] Initially, Figure 1 depicts a heat exchanger device (100) ("device," "exchanger") for fluid assisted radiative cooling in accordance with one or more embodiments. In one aspect, the device is as hollowed-out device used to contain a fluid (e.g., cooling fluid). The shape of the exchanger may be a function of the space available in the enclosure where the electronic components reside. That is, in general, and an electronic component may exist or otherwise function inside a space or enclosure such as a cabinet or rack. As will be described, the device (100) and an electronic component can be removably attached to each other. As such, the device (100) is shaped to reside within the working environment of the electronic component, e.g., within a rack.

[0029] The device (100) consists of a casing (101) that can contain a fluid. The hollowed-out part of the exchanger (100) is called a cavity (102). In other words, the casing (101) can be considered a shell that defines an internal volume referenced herein as a cavity (102). The cavity (102) is only open to the exterior through two sets of communication ports. The first set of communication ports consists of one or more openings (103) through to the cavity (102) and sized to match the size of the area exchanging heat with the electronic component(s) (104). The openings (103) allow for the radiation to exit the electronic component(s) (104) and enter the cavity (102). The openings (103) may be equipped with a physical barrier insulating the fluid from the electronic component (104) as long as it is transparent to the radiation wavelength. The second set of communication ports consist of two or more pipes or accesses (105, 106) allowing the fluid to enter and exit the cavity (102). An external circulation device that can be but not limited to, a pump or a fan, is used to circulate the fluid through the pipes depending on the nature of the fluid.

[0030] The cavity can be equipped with reflective surfaces turned to the wavelength of the radiation emanating from the electronic component (104) and designed to reflect and contain that radiation inside the cavity (102). The cavity (102) can also contain surfaces that may or may not be transparent to radiation to guide the circulation of the fluid in the cavity, as described in greater detail below.

[0031] In one or more embodiments, the fluid inside the cavity (102) is tuned to absorb the wavelength of the radiation emanating from the electronic component (104), either as a natural characteristic or because it is enhanced with particles, nano-particles, or other fluids tunned to absorb the proper wavelength(s). The fluid may be a liquid, or a gas, or even experience a change in phase in the cavity (102) as it absorbs energy (i.e., by absorbing radiation, radiative heat transfer). The fluid may be dielectric if the interface with the electronic component (104) is exposed to electrical connections (e.g., no physical barrier insulating the fluid from the electronic component), or not, if the interface contains the liquid but allows for the radiative process to occur.

[0032] Further, in one or more embodiments, the flow of fluid (107) ("fluid flow"), as depicted with an arrow in Figure 1, is tuned to enable maximum absorption of radiative heat in the cavity (102) and adequate removal of the heat. In general, transfer of heat occurs in the volume of the fluid contained by the cavity (102) through absorption of radiation emitted by the electronic component (104). There may also be some amount of additional transfer from conduction at the interface of the fluid and electronic component(s) and also at the cavity (102) walls and surfaces. Some of the internal surfaces of the casing (101) may be tuned to absorb radiative energy and increase heat transfer through conduction with the fluid.

[0033] The heat is removed through the flow of fluid (107) from the input pipe(s) (105) to the output pipe(s) (106). The reflective cavity (102) and the surfaces it contains to manage radiative emissions together with the fluid circulating in it and tunned to absorb the radiated heat are considered innovative aspects of embodiments disclosed herein.

[0034] Keeping with Figure 1, in greater detail, the device (100) includes a casing (101) that encloses a cavity (102). That is, the casing (101) defines or encloses an internal volume. The device (100) can take a variety of shapes as required to attach with and reside near an electronic component (104). Figure 1 depicts the casing (101) as being a substantially rectangular shape having a length (L) along a longitudinal axis (108) of the casing (101), a height (H), and a width (W). Remaining examples of the casing (101) presented herein are also rectangular being defined with a length (L), width (W), and height (H), however, as discussed, the shape of the device (100) or casing (101) need not be limited to this shape.

[0035] The casing (101) may be formed of a material such as one or more plastics (*e.g.*, polypropylene, polyethylene, polycarbonate, or equivalent polymers), or a metal such as aluminum, brass, steel, an alloy, or equivalent material. The casing (101) may be formed in two separate pieces that are fused or adhered together (*e.g.*, by welding, using screws, bolts, or adhesives, etc.), or alternatively formed as a single, integral element by processes such as injection molding or 3D printing.

[0036] By way of nonlimiting examples, the electronic component (104) may be one or more computing hardware devices such as a microprocessor, a processing unit such as a Central Processing Unit (CPU) and/or a Graphics Processing Unit (GPU), a storage medium (*e.g.*, a Hard Disk Drive (HDD), a Solid State Drive (SDD), or Random Access Memory (RAM)), and/or a communication device (*e.g.*, ethernet, Wi-Fi, or other Local Area Network (LAN) or Wide Area Network (WAN) interconnects) such as a transceiver or networking card that serves to transmit and receive signals. However, the above description of the electronic component (104) is not intended to limit the type of electronic component (104) to be cooled using, at least, radiative heat transfer to a cooling fluid, and, thus, the electronic component (104) as described herein may further encompass various other electrically powered devices, equipment, and/or hardware known to a person having ordinary skill in the art.

[0037] In general, the electronic component (104) generates a heat load as it operates. If a sufficiently large heat load is developed by the electronic component (104), the electronic component (104) may be detrimentally impacted, such as the electronic component (104) becoming de-soldered, or hardware burnout occurring due to the large heat load. Furthermore, during extreme heat loads, an enclosure of the electronic component (104) (*e.g.,* a processor housing) may melt, as electronic component housings may be formed of a plastic material. Thus, to avoid the above detrimental situations, it is advantageous to remove or reduce the heat load produced by the electronic component (104). To remove the heat from the electronic component (104) radiation emitted by the electronic component is absorbed by a fluid flowing through the cavity (102) of the device (100). In some instances, the flow of fluid (107) can also remove heat generated by the electronic component (104) by the heat transport mechanisms of conduction and convection.

[0038] The device (100) and an electronic component (104) can be removably attached to one another. The electronic component (104) is attached to the device (100) at a radiative opening (103) in the casing (101). That is, the opening (103) permits the transmission of radiation (at least at the relative thermal wavelengths) from the electronic component (104) to the cavity (102). In one or more embodiments, the opening (103) includes a physical barrier such as glass that prevents fluid circulating through the cavity (102) to contact the electronic component (104). In such a case it is emphasized that the physical barrier is selected to allow the transmission of the radiation emitted by the electronic component (104) to the cavity (102). In other embodiments, a physical barrier is not provided between the electronic component (104) and cavity (102) at the radiative opening (103). In these cases, a seal or gasket can be disposed at an interface of the electronic component (104) and the casing (101) around the radiative opening (103) to prevent the loss or leaking of the cooling fluid from the radiative opening (103). That is, regardless of whether the radiative opening (103) includes a physical barrier or not, the radiative opening (103) is configured to transmit radiation from the electronic component (104) and prohibit the transport or transmission of the cooling fluid through the radiative opening (103). As will be described below with reference to Figure 4, the device (100) can be connected to more than one electronic component (104) and have more than one radiative opening (103). Radiative opening(s) (103) are comprised by the first set of communication ports.

[0039] In one or more embodiments, the electronic component (104) is removably attached to the device (100) or casing (101) of the device by way of a detachable mount (not shown). The detachable mount may be embodied as an adhesive, such as thermal paste, that includes an adhesive base material such as an epoxy mixed with a thermally-conductive filler such as aluminum particles. Alternatively, the detachable mount may comprise a structural element such as a bracket, clip, or clamp retained to the electronic component (104) and the device (100) by way of screws, bolts, or similar structural mechanisms. Furthermore, the detachable mount may, in one or more embodiments, comprise both an adhesive layer and a structural element in order to securely attach the electronic component (104) and device (100).

[0040] As stated above, the second set of communication ports includes two or more pipes or accesses (105, 106) allowing the fluid to enter and exit the cavity (102). Figure 1 depicts an inlet orifice (105) and an outlet orifice (106) disposed on the lateral sides (109) of the casing (101) such that fluid flow (107) within the cavity is predominantly along the longitudinal axis (108). In some embodiments, more than one inlet (105) and/or outlet (106) are provided. Further, one or more of the inlet (105) and the outlet (106) can be disposed on of the longitudinal sides (110) of the casing (101). For example, an inlet (105) can be disposed on a lateral side (109) while the outlet is located on a longitudinal side (110). In some embodiments, both the inlet (105) and the outlet (106) are located on the same side of the casing (101), whether the side is considered a lateral side (109) or a longitudinal side (110). The flow of fluid (107) from the inlet (105), through the cavity (102), and out of the outlet (106) may be directed using one or more channels and/or baffles.

[0041] In one or more embodiments, the device (100) further includes one or more reflective surfaces. The reflective surfaces are configured to reflect, within the cavity (102), the radiation emitted by the electronic component (104). In some embodiments, one or more internal walls or surfaces of the casing (101) are reflective to the radiation (e.g., by material selection for the casing or using a coating or deposition of a reflective material). In some embodiments, and as described below, various reflective surfaces are disposed within the cavity (102) to promote the reflection of incident radiation.

[0042] Thus, radiation emitted from the electronic component (104) enters the cavity (102) of the device (100) and can reflect within the device (100) until eventually being absorbed by the fluid. Absorption of the radiation by the fluid raises the temperature of the fluid and the heat (energy, radiation) of the electronic component (104) is carried out of the device by the fluid exiting through the outlet (106). In one or more embodiments, the fluid is a dielectric fluid such as mineral oil, for example, that absorbs heat from the electronic component (104) attached to the casing (101).

[0043] In one or more embodiments, the fluid is tuned to absorb the wavelength of the radiation emanating from the electronic component (104), either as a natural characteristic or because it is enhanced with particles, nano-particles, or other fluids tunned to absorb the proper wavelength(s). For example, in one or more embodiments, solids that are substantially opaque to the thermal radiation emitted by the electronic component (104) are suspended in the fluid. Examples of such solids may include polycarbonate spheres and carbon spheres or nanotubes. In general, the solids are selected in terms of both size, density, and solids loading such that the solids are entrained by the fluid flow and follow the fluid flow. In other embodiments, a radiation absorbing dye is injected into the fluid or, in some instances used as the fluid (i.e., radiation absorption is a characteristic of the fluid), to enhance absorption of the radiation emanating from the electronic component (104) to the fluid as the fluid flows through the device. For example, a cyanine dye may be used to enhance absorption of radiation in the near infrared spectrum.

[0044] Figure 2 depicts a view of the cavity (102) of another embodiment of the device (100). As seen in Figure 2, in one or more embodiments, one or more reflective surfaces (201) are disposed within the cavity (102), e.g., on or near some internal surfaces of the casing (101). The reflective surfaces are configured to reflect, within the cavity (102), the radiation emitted by the electronic component (104). The cavity (102) may contain additional reflective surfaces (204), also configured to reflect radiation emitted by the attached electronic component (104), where the additional reflective surfaces (204) can direct radiation emitted by the electronic component (104) to other portions of the cavity (102). An example of a radiation path is given later with reference to Figure 3.

[0045] Continuing with Figure 2, in one or more embodiments, the cavity (102) further contains a series of baffles (203) ("baffles"). In one or more embodiments, each baffle extends substantially across the width of the cavity (102), leaving a small gap for the fluid to transfer into the next pass of baffles (203). In turn, the elongated fluid flow path created by the baffles (203) increases the amount of time for the cooling fluid to absorb heat from the electronic component (104).

[0046] In general, the baffles (203) can direct the path of the fluid flow (107) and increase the residence time of the fluid in the cavity (102). An example of a fluid path is given later with reference to Figure 3. In one or more embodiments, the baffles (203) are configured to be transparent to the radiation emitted by the electronic component (104).

[0047] The cavity (102) may be partitioned into a baffle portion (205) and a non-baffle portion (206). An example of such a partitioning is shown in Figure 2, where the baffles (203) only span the baffle portion (205) of the cavity. Further, the baffles (203) can be designed or specified according to a given inter-baffle spacing (207), baffle width, and baffle height. In one or more embodiments, the baffle height is less than the height of the casing (H) (or, at least the height of the cavity) such that a gap (208) exits between the baffles (203) and a side of the casing (101).

[0048] One or more of the baffles (203), reflective surfaces (201) and additional reflective surfaces (204) can be inserted into (or otherwise attached to) the casing (101) or can be integrally formed with the casing (101). As an example, the reflective surfaces (201) and baffles (203) can be formed as an independent element or apparatus and then inserted (e.g., with an interference fit) into the cavity (102) of the casing (101). As another example, in some implantations, the baffles (203) are integral to the casing (101) (e.g., the cavity (102) being formed around the baffles through a milling process).

[0049] Figure 3 depicts a radiative cooling system (300) that uses the heat exchanging device (100), in accordance with one or more embodiments. As seen, the radiative cooling system includes a pump (313) with a pump inlet (315) and a pump outlet (317), which respectively form entrance and egress orifices for the cooling fluid flowing through the pump (313). For its part, the pump (313) may include an impeller (not shown) protected by a housing, and the impeller actuates in order to generate motion in a fluid that flows through the pump (313). Alternatively, the pump (313) may be replaced with a fan, propeller, or similar fluid agitation devices suitable for creating a controllable fluid flow.

[0050] The pump inlet (315) is in hydraulic connection with a source of the fluid. The pump outlet is connected, e.g., using a conduit (319), to the inlet (105) of the device (100). The conduit (319) is a tube, pipe, or duct that serves to direct the fluid flow of the cooling fluid to the device (100). The conduit (319) may be formed of a metal such as stainless steel or brass, or alternatively of an elastomer such as polyurethane. To attach the conduit (319) to the device (100) and the pump outlet (317), each of the device (100) and the pump outlet (317) may be formed with internal threads. Similarly, the conduit (319) may have complimentary threaded ends such that the conduit (319) is screwed into the device (100) and the pump outlet (317). Alternatively, in cases where the conduit (319) is formed of an elastically deforming material, the conduit (319) may be adhered to the device (100) and the pump outlet (317) by compressive force provided by the conduit (319) itself. Other attachment methods may alternatively be used, such as adhesives or a pipe clamp, without departing from the nature of this disclosure. Another conduit, as described above, may be attached to the device outlet (106) to transport the fluid elsewhere, e.g., an external heat exchanger or a heat sink.

[0051] The pump (313) actuates to forcefully direct the fluid to and through the device (100). The fluid follows a fluid path (303). In one or more embodiments, and as seen in Figure 3, the fluid path (303) can follow one or more channels formed by the baffles (203). For example, the fluid path (303) may wind successively through the baffles as depicted. Figure 3 also depicts a radiation path (305) of radiation emitted by the electronic component (104). As seen, radiation enters the cavity through the radiation opening (103) and is initially reflected by an additional reflective surface (204) disposed in a non-baffle portion (206) of the device (100). The additional reflective surface

(204) redirects the radiation toward the baffle portion (205) of the device where the radiation is reflected by the reflective surfaces (201) and transmitted through the baffles (203) until eventually being absorbed by the fluid.

[0052] In one or more embodiments, the radiative cooling system (300) further includes a set of sensors (320). In some instances, one or more sensors of the set of sensors (320) are disposed on or within the device (100) such that the set of sensors (320) may be considered part of the device (100). The set of sensors (320) can measure one or more properties of the fluid at various locations in the system (300) or device (100). For example, the set of sensors (320) can contain a first temperature sensor (T_{inlet}) and second temperature sensor (T_{outlet}) disposed proximate the inlet (105) and outlet (106) of the device (100), respectively. The first and second temperature sensors (T_{inlet}, T_{outlet}) can be used to determine a change in temperature of the fluid as a result of circulating through the device (100). The change in temperature can further be used to determine an amount of energy or heat removed from the electronic component (104) by the fluid. The set of sensors (320) may further include a pressure sensor (P) and a flow rate sensor (Q) disposed at one or more locations in the cavity (102). These sensors can be used to determine the thermophysical state of the fluid (e.g., if the fluid is saturated) and the efficiency of the pump (e.g., determine frictional losses of the fluid in the device). Additionally, the set of sensors (320) can include a power meter or power sensor (W) that measures the power consumed by the electronic component (104). Measurements of the power sensor (W) can, in turn, be used to determine a cooling efficiency of the device (100) and/or inform operational parameters of the system (300) such as power directed to the pump (313) or a frequency of the pump (313).

[0053] In one or more embodiments, the radiative cooling system (300) includes a controller (325) in electrical communication with, at least, the set of sensors (320) (if present) and the pump (313). The controller (325) can both determine and command operational parameters to the pump (313). As an example, the controller (325) can direct the pump (313) to alter the flow rate of the fluid based on one or more of: a change in power consumption by the electronic component (104); an observed decrease or increase (e.g., above a threshold) in the change in temperature across the device

(100); and an observed decrease or increase (e.g., above a threshold) of the temperature of the fluid at the outlet (106).

[0054] The pump (313) can be connected to the controller (325) by way of a data cable, or wire, where the controller (325) issues operating commands to the pump (313) that instruct the pump (313) to initiate, re-initiate, or cease its actuation. Alternatively, the pump (313) may be continuously powered by the electronic component (104), and the controller (325) removed from the radiative cooling system (300) to simplify the design thereof. Additional cables can be included in the radiative cooling system (300), such as a power or data cable (not shown) connected to the electronic component (104), without departing from the nature of this specification.

[0055] As described herein, the controller (325) may be embodied as a processor, a microcontroller, an integrated circuit, or similar logic processing electronic components capable of forming and issuing the operating commands. In some embodiments, the operating commands are issued by the controller (325) when a temperature at the location of the electronic component (104) exceeds a predetermined temperature threshold. The temperature of the location of the electronic component (104) may be provided by the electronic component (104) itself by way of internal thermistors (not shown), which are resistors with a variable resistance dependent on the external temperature or using a temperature sensor in the set of sensors (320) disposed proximate the electronic component (104). Thus, in some instances, the electronic component (104) may determine its temperature based upon the resistance generated by the thermistors (not shown) and provide the temperature to the controller (325).

[0056] As discussed, the fluid is tuned to absorb the wavelength of the radiation emanating from the electronic component (104), either as a natural characteristic or because it is enhanced with particles (e.g., suspended solids), nano-particles, or other fluids (e.g., dyes) tunned to absorb the proper wavelength(s). As such, the tuned fluid is considered part of the radiative cooling system (300).

[0057] Figure 4 depicts another embodiment of the heat exchanging device (100) where the device (100) is attached to two heat-generating electronic components, namely, an electronic component (104) as previously described and another electronic component

(404). As seen in Figure 4, the fluid enters the inlet (105) and winds along a fluid path (303) though a series of baffles (203) in the cavity and exits through the outlet (106). The electronic component (104) and the another electronic component emit radiation through respective radiation openings (103) into the cavity (102). The radiation is initially reflected off additional reflective surfaces (204) and then subsequently reflected within the cavity (102) by the reflective surfaces (201), as depicted by the radiation path (305) and the another radiation path (405) corresponding to the electronic component (104) and the another electronic component (404), respectively. Radiation emitted by the electronic component (104) and the another electronic component (404) is reflected within the cavity until absorbed by the fluid, raising the temperature of the fluid.

[0058] Figure 5 depicts an external view of a heat exchanging device (100), as described herein according to one or more embodiments. In Figure 5, the device (100) is attached to two electronic boards (505) each containing at least one heat-generating electronic component (504). The heat-generating electronic components (504) of the electronic boards are placed at radiation openings (103) of the device (100) such that radiation emitted by the electronic components (504) can enter the cavity (102) of the device for eventual absorption and removal by a fluid circulating through the device (100). The electronic boards (505) can be, for example, printed circuit boards. Each electronic board (505) retains electrically powered elements on one of its surfaces that are interconnected by a conductive layer. In the case of Figure 5, the electronic boards (505) provide one example of an electronic system comprising a plurality of electronic components (504) as described herein.

[0059] Turning to Figure 6, Figure 6 depicts a method 600 for cooling an electronic component with a heat exchanger device that may be used to realize a radiative cooling system. Thus, steps of Figure 6 may be performed using a device and system as discussed above in relation to Figures 1-2, 4-5 and Figure 3, respectively, but are not limited thereto. Further, multiple steps of Figure 6 may be performed as a single action, or one step may comprise multiple actions by devices or electronic components described herein.

[0060] The method 600 initiates with step 610, where an electronic component is attached at a radiative opening of a device. The electronic component radiatively emits heat. In accordance with one or more embodiments, the device includes a casing that encloses a cavity, an inlet orifice, and an outlet orifice. The inlet orifice and outlet orifice are hydraulically connected by the cavity and the cavity is configured to receive a cooling fluid from the inlet orifice and direct the cooling fluid to the outlet orifice. The radiative opening is configured to permit transmission of radiation from the electronic component to the cooling fluid in the cavity. The device can further include a reflective surface disposed in the cavity that reflects the radiation in the cavity.

[0061] Step 620 comprises transporting the cooling fluid into the casing (i.e., within the cavity) through the inlet orifice. In some embodiments, transport or circulation of the cooling fluid is effectuated by actuating a pump to forcefully direct the cooling fluid into the inlet orifice. In particular, when the pump is actuated, the pump draws cooling fluid from a source and passes the fluid to a conduit connected to the inlet orifice. The cooling fluid is tuned to absorb a wavelength of the radiation emanating from the electronic component, either as a natural characteristic or because it is enhanced with particles (e.g., suspended solids), nano-particles, or other fluids (e.g., dyes) tuned to absorb the proper wavelength(s). As discussed below, the fluid flow (e.g., actuated by the pump) within the casing absorbs heat from the electronic component and actively removes the absorbed heat from the device by carrying and redistributing the heat to a separate location away from the device (e.g., an external heat exchanger or heat sink).

[0062] In step 630 heat is transferred via radiation from the electronic component to the cooling fluid. In general, the radiation enters the cavity through the radiative opening and is reflected within the cavity by the reflective surface within the cavity until absorbed by the cooling fluid. In some embodiments, the cooling fluid may pass though a series of baffles within the cavity to increase the residence time of the cooling fluid in the device further promoting absorption of radiation by the cooling fluid.

[0063] In step 640, the cooling fluid is directed out of the casing with an outlet orifice of the casing. In particular, and as discussed above, a conduit can extend from the outlet of the device to carry the cooling fluid to a separate location such as an external heat exchanger or heat sink. Thus, after the cooling fluid has absorbed energy via radiative heat transfer, the energy (heat) generated by the electronic component, the cooling fluid is directed to the outlet orifice.

[0064] Although only a few example embodiments have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the example embodiments without materially departing from this invention. For example, although the disclosure describes the use of a single pump connected to a conduit or manifold in hydraulic communication with the heat exchanging device, additional pumps (each connected to an additional conduit or manifold) may be used with the device to increase the cooling fluid flow rate or create additional cooling fluid flows. Furthermore, the pump and the controller may be connected to an uninterruptible power supply or a backup power supply such that fluid flow is maintained even if the attached electronic component is not powered. Alternatively, the pump and the controller may be integrated with and powered by the electronic component itself in order to compact the design of the overall system. In addition, many modifications will be appreciated by those skilled in the art to adapt a particular instrument, situation, or material to embodiments of the disclosure without departing from the essential scope thereof. Thus, all such modifications are intended to be included within the scope of this disclosure.

[0065] Embodiments of the present disclosure may provide at least one of the following advantages: a use of radiative heat transfer to remove heat from an electronic component, where such heat transfer is used in replacement of or in addiction to heat transfer via conduction and/or convection; and an increased amount of heat removed from an electronic component. As discussed, in typical data processing centers, heat is removed from the electronic systems by running a fluid through the systems (e.g., a gas such as air, a liquid, or a combination of both a gas and a liquid) and relying on conduction or convection. Embodiments disclosed herein improve upon conventional fluid-based cooling systems by further removing heat from heat-generating electronic components by using the fluid to absorb radiation emitted by the electronic components and transporting the absorbed heat away with the fluid. Heat can be removed principally by radiation or in conjunction with existing conduction and/or convention based methods and systems. That is, embodiments disclosed herein are cost effective as they can be integrated with existing cooling systems.

[0066] Although only a few example embodiments have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the example embodiments without materially departing from this invention. Accordingly, all such modifications are intended to be included within the scope of this disclosure as defined in the following claims.

CLAIMS

What is claimed is:

1. A device for cooling an electronic component, the device comprising:
   a casing enclosing a cavity;
   an inlet orifice and an outlet orifice hydraulically connected by the cavity, wherein the cavity is configured to receive a cooling fluid from the inlet orifice and direct the cooling fluid to the outlet orifice;
   a radiative opening disposed between the cavity and the electronic component and configured to permit transmission of radiation from the electronic component to the cooling fluid in the cavity; and
   a reflective surface disposed in the cavity that reflects the radiation in the cavity.

2. The device of claim 1, further comprising a series of baffles disposed in the cavity.

3. The device of claim 2, wherein the baffles are substantially transparent to the radiation.

4. The device of claim 2 or 3, wherein the baffles of the series of baffles are oriented such that a fluid flow path of the cooling fluid is directed to wind in successive passes within the cavity.

5. The device of any one of claims 2 to 4, further comprising an additional reflective surface disposed in the cavity that directs radiation from the electronic component toward the baffles.

6. The device of claim 1, wherein the cavity is partitioned into a baffle portion and a non-baffle portion, and the device further comprises a series of baffles contained in the baffle portion.

7. The device of any one of claims 1 to 6, wherein the radiative opening comprises a medium that is transparent to the radiation and prevents contact between the cooling fluid and the electronic component.

8. The device of any one of claims 1 to 7, wherein the reflective surface comprises a reflective coating deposited on at least one internal surface of the cavity.

9. The device of any one of claims 1 to 8, further comprising at least one sensor configured to measure one or more of a temperature, a pressure, and a flow rate at a location in the cavity.

10. A method for cooling an electronic component, the method comprising:

attaching the electronic component to a device, wherein the electronic component radiatively emits heat, the device comprising:

a casing enclosing a cavity,

an inlet orifice and an outlet orifice hydraulically connected by the cavity, wherein the cavity is configured to receive a cooling fluid from the inlet orifice and direct the cooling fluid to the outlet orifice,

a radiative opening disposed between the cavity and the electronic component and configured to permit transmission of radiation from the electronic component to the cooling fluid in the cavity, and

a reflective surface disposed in the cavity that reflects the radiation in the cavity;

transporting, with a pump, the cooling fluid into the casing through the inlet orifice;

transferring heat via radiation from the electronic component to the cooling fluid, where the radiation is reflected within the cavity by the reflective surface and absorbed by the cooling fluid; and

directing the cooling fluid out of the casing with the outlet orifice.

11. The method of claim 10, further comprising suspending particles in the cooling fluid, wherein the particles absorb the radiation.

12. The method of claim 10 or 11, further comprising:

receiving sensor data from at least one sensor disposed in or proximate to the cavity and configured to measure one or more of a temperature, a pressure, and a flow rate at a location in the cavity;

determining operation of the pump based on the sensor data; and

operating the pump according to the determined operation.

13. A system, comprising:

a pump;

a device for cooling an electronic component, the device in hydraulic communication with the pump, the device comprising:

a casing enclosing a cavity,

an inlet orifice and an outlet orifice hydraulically connected by the cavity, wherein the cavity is configured to receive a cooling fluid from the inlet orifice and direct the cooling fluid to the outlet orifice, wherein the cooling fluid is pumped through into the inlet orifice, through the cavity, and out the outlet orifice by the pump,

a radiative opening disposed between the cavity and the electronic component and configured to permit transmission of radiation from the electronic component to the cooling fluid in the cavity, and

a reflective surface disposed in the cavity that reflects the radiation in the cavity; and

a controller electrically coupled to the pump and configured to control operation of the pump.

14. The system of claim 13, wherein the device further comprises a series of baffles disposed in the cavity.

15. The system of claim 14, wherein the device further comprises an additional reflective surface that directs radiation from the electronic component toward the baffles and wherein the baffles are substantially transparent to the radiation.

16. The system of claim 14 or 15, wherein the baffles are oriented such that a fluid flow path of the cooling fluid is directed to wind in successive passes within the cavity.

17. The system of claim 13, wherein:

the cavity is partitioned into a baffle portion and a non-baffle portion,

the device further comprises a series of baffles contained in the baffle portion, and

the radiative opening is in the non-baffle portion.

18. The system of any one of claims 13 to 17, wherein the radiative opening comprises a medium that is transparent to the radiation and prevents contact between the cooling fluid and the electronic component.

19. The system of any one of claims 13 to 18, wherein the reflective surface comprises a reflective coating deposited on at least one internal surface of the casing.

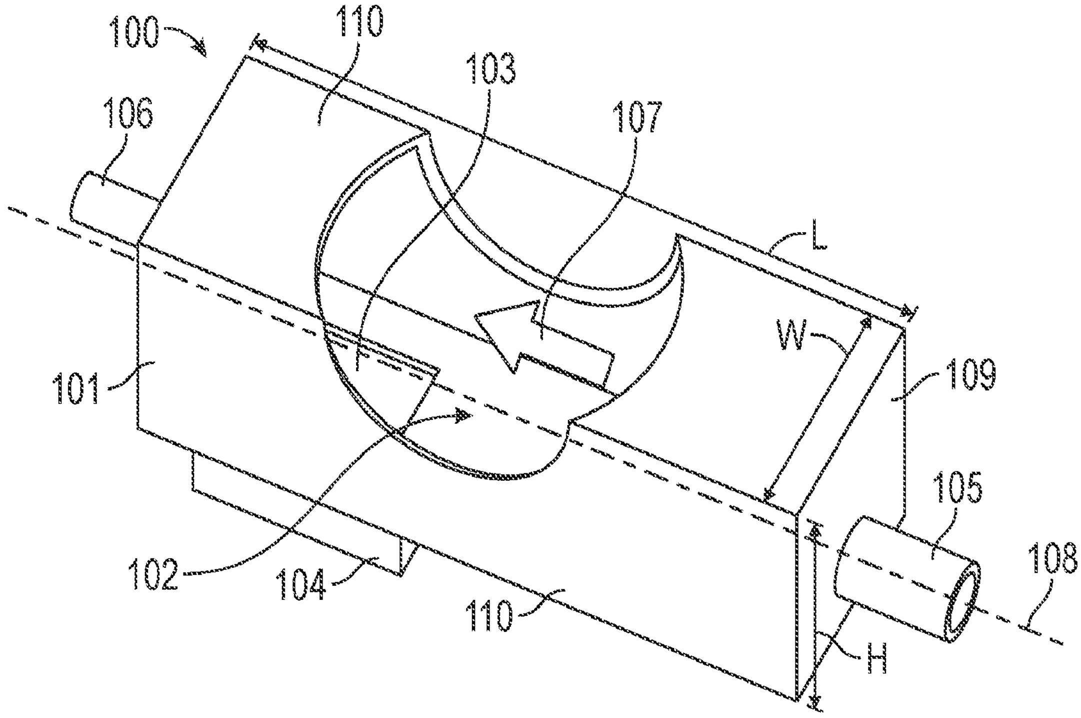
20. The system of any one of claims 13 to 19, further comprising:

at least one sensor configured to measure one or more of a temperature, a pressure, and a flow rate at a location in the cavity;

wherein the at least one sensor is in electrical communication with the controller,

wherein the controller receives sensor data from the at least one sensor, and

wherein operation of the pump is determined by the controller based on the sensor data.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106
107
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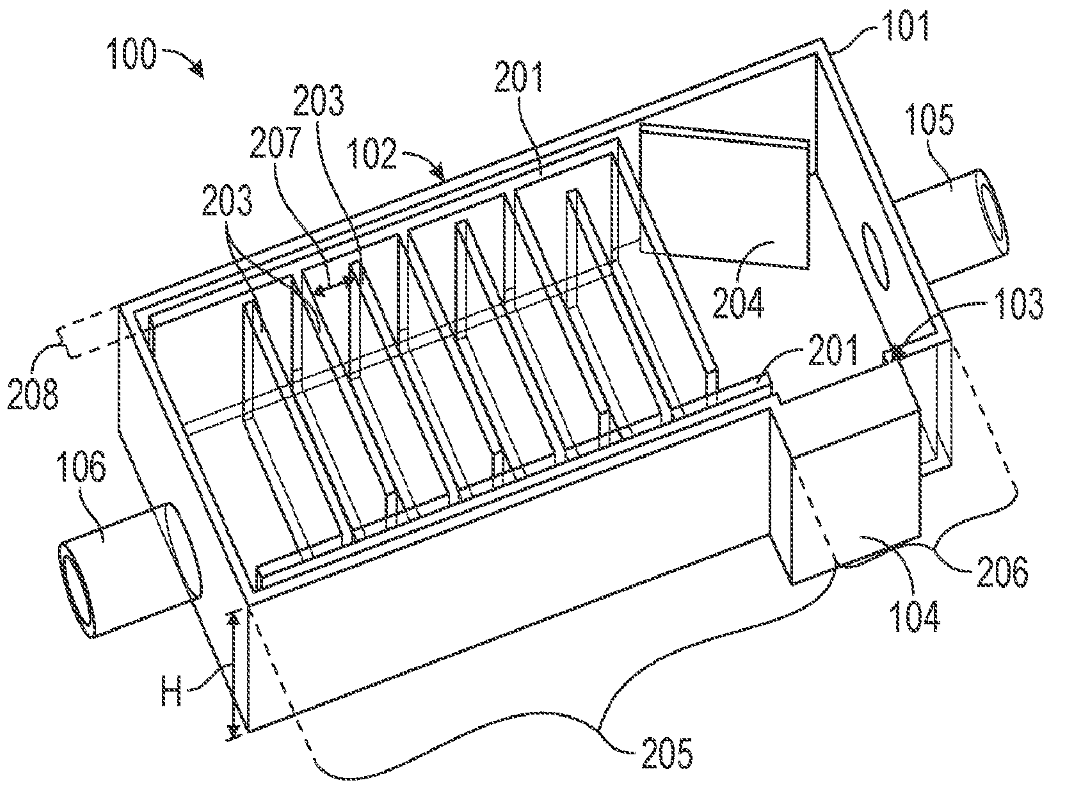
101
109
105
108
102
104
110
H

FIG. 1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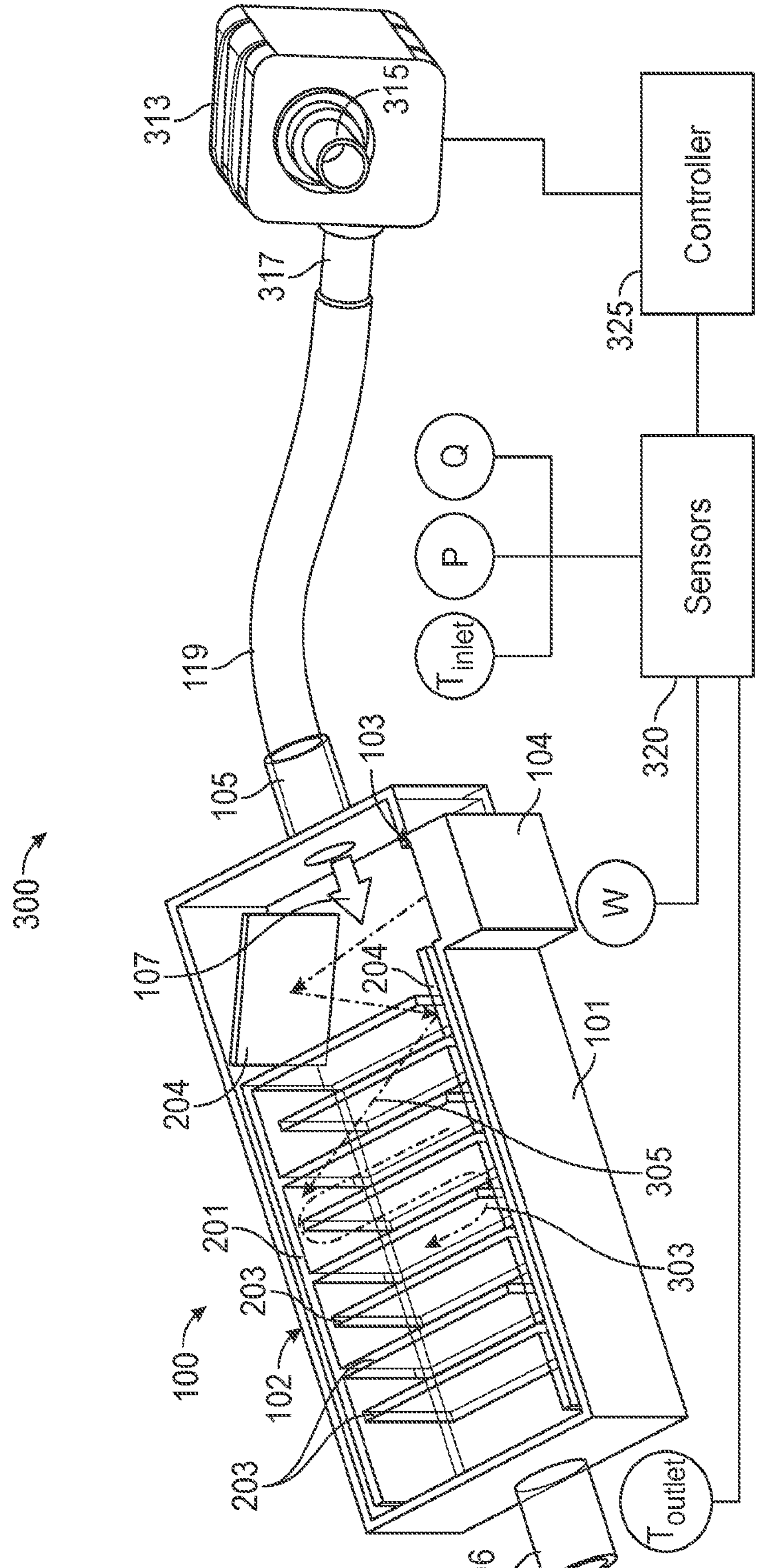
H
205

FIG. 2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315
317
119
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325
Q
P
T_{inlet}
Sensors
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204
101
305
201
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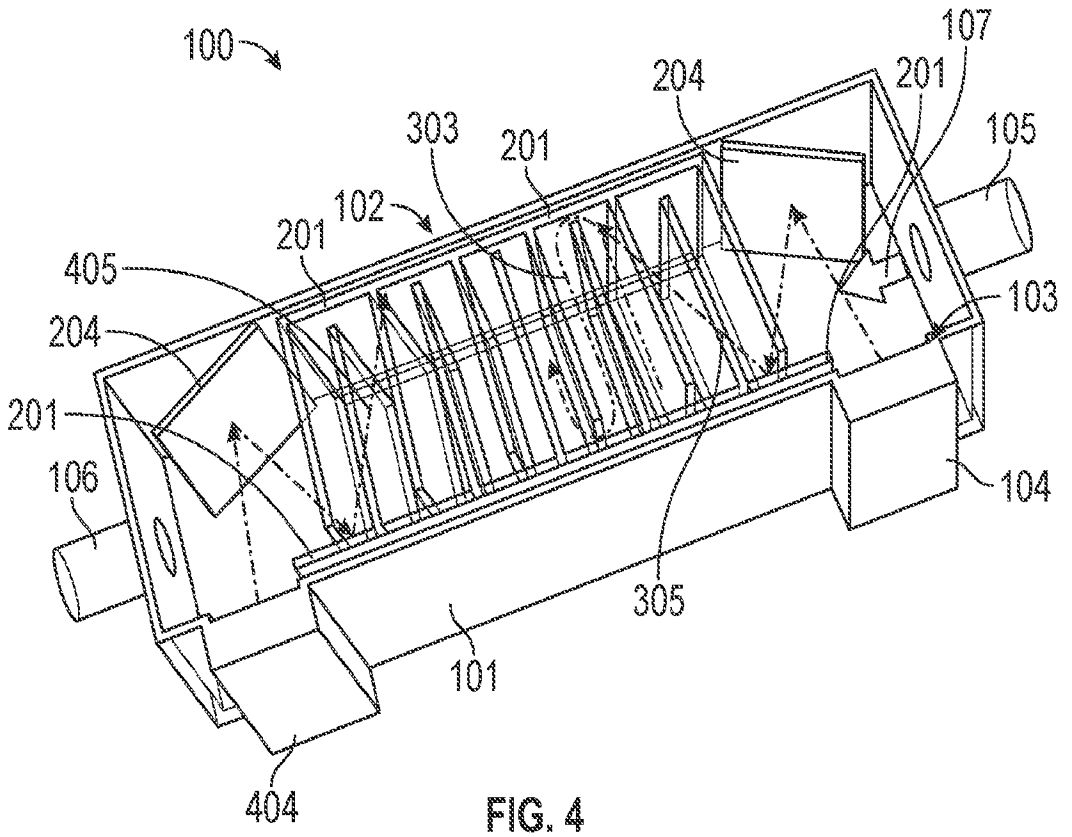
203
100
102
203
T_{outlet}
106

FIG. 3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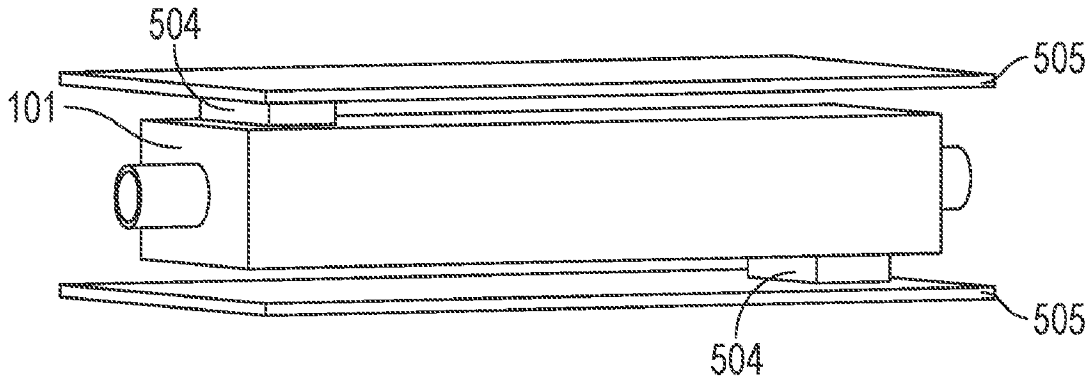
404

FIG. 4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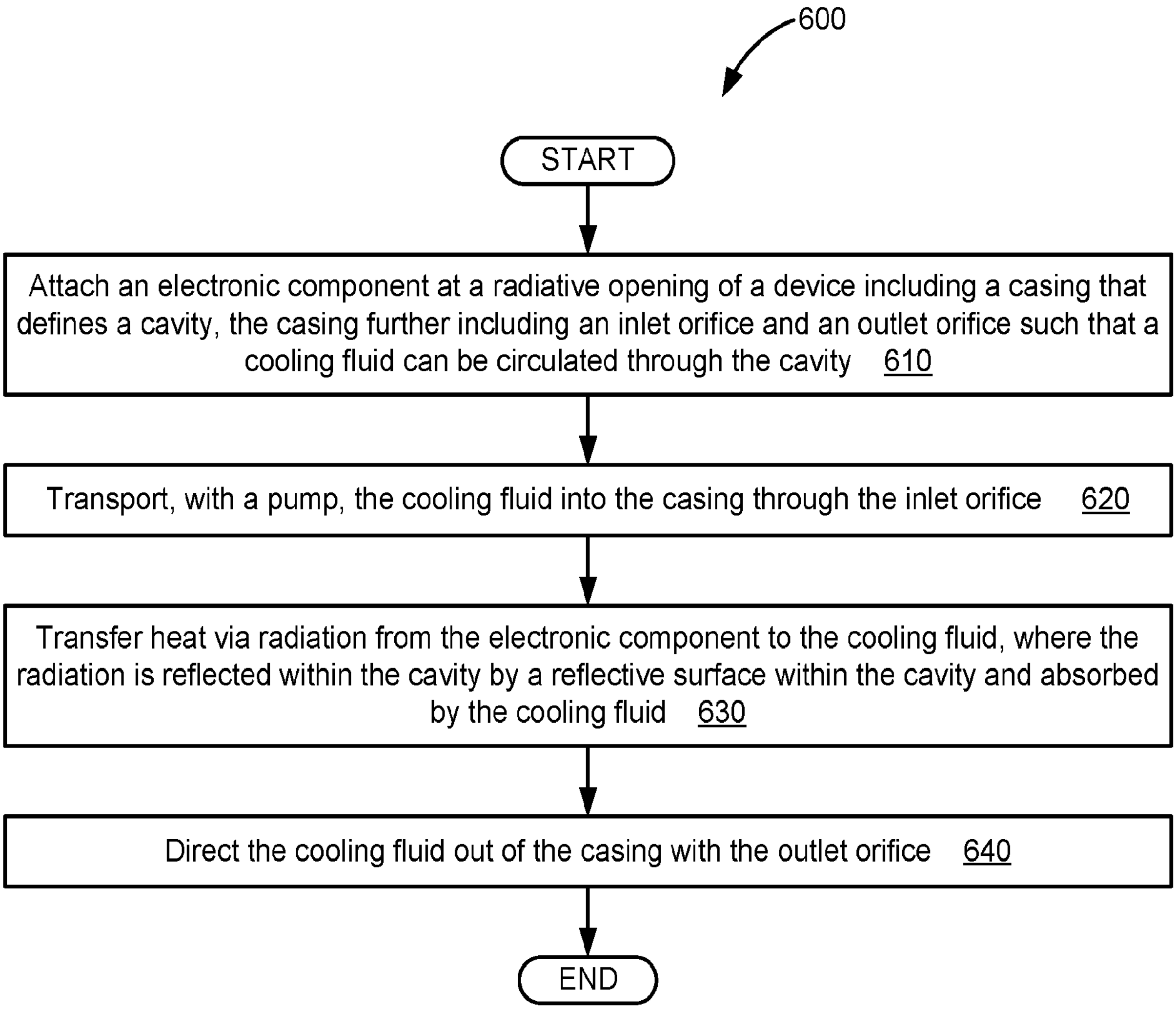
505
101
505
504

FIG. 5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START
Attach an electronic component at a radiative opening of a device including a casing that defines a cavity, the casing further including an inlet orifice and an outlet orifice such that a cooling fluid can be circulated through the cavity 610
Transport, with a pump, the cooling fluid into the casing through the inlet orifice 620
Transfer heat via radiation from the electronic component to the cooling fluid, where the radiation is reflected within the cavity by a reflective surface within the cavity and absorbed by the cooling fluid 630
Direct the cooling fluid out of the casing with the outlet orifice 640
END

FIG. 6