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(54) **ELECTRODE AND CIRCUITRY DESIGN FOR CORROSION PROTECTION IN LIQUID COOLING SYSTEM**

(71) Applicant: **Cisco Technology, Inc.**, San Jose, CA (US)

(72) Inventors: **Vipulkumar K. PATEL**, Breinigsville, PA (US); **Chun Chih CHEN**, Hsinchu City (TW); **Huan Chun CHEN**, New Taipei City (TW); **Glen Michael J. BROOKS**, San Jose, CA (US)

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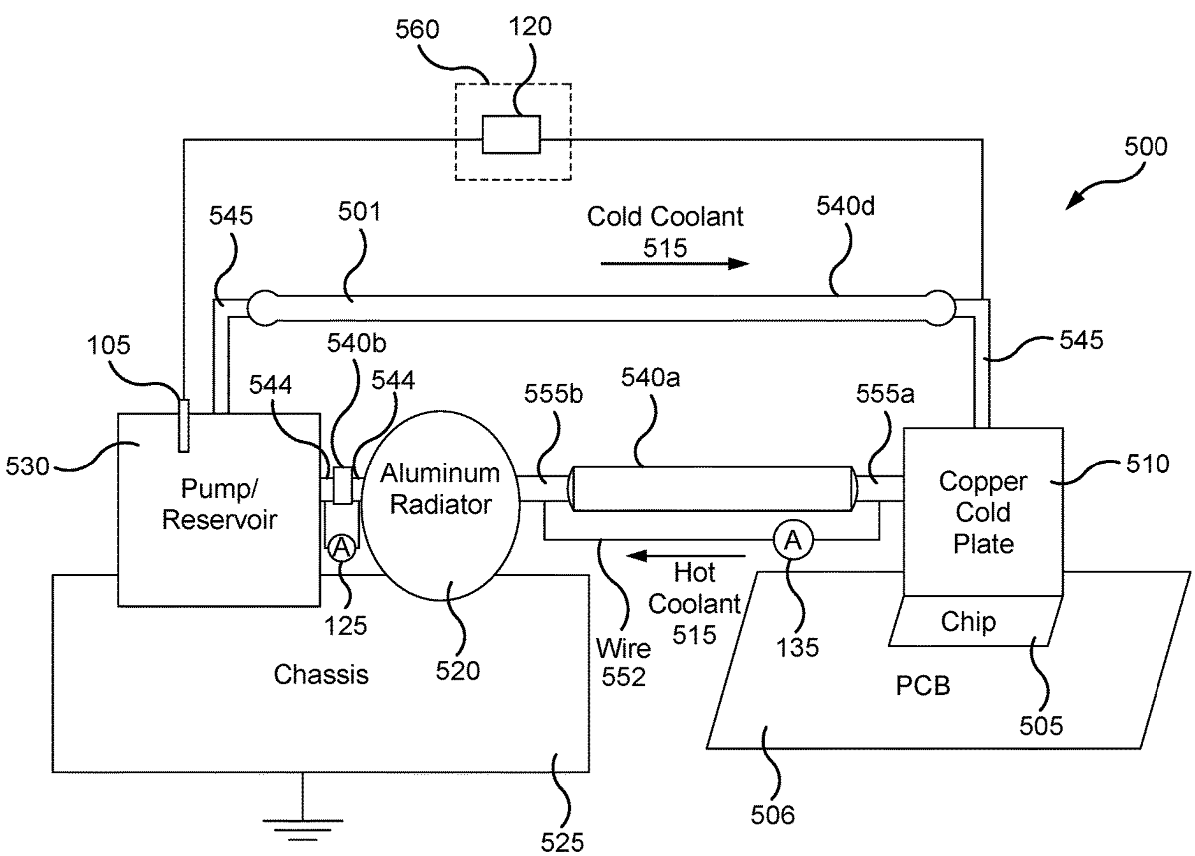
(57) **ABSTRACT**

Embodiments herein describe liquid cooling systems and methods that measure a current between an inert counter electrode and a non-inert heat exchange component. This current can result in corrosion. The liquid cooling system can then apply a voltage (e.g., a reverse bias) that causes current to flow from the counter electrode to the non-inert heat exchange components. The embodiments herein can be used if the liquid cooling system includes heat exchange components that are made of the same non-inert metal or includes heat exchange components made of different metals.



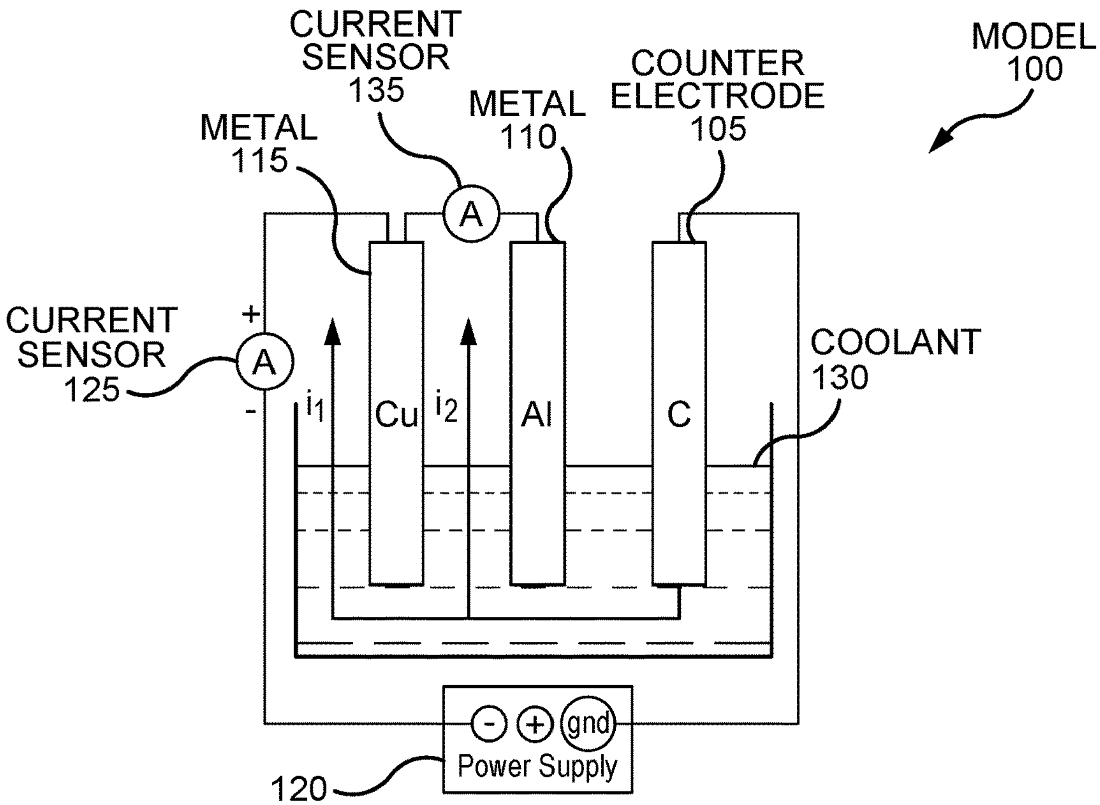

MODEL
100
CURRENT
SENSOR
135
METAL
115
METAL
110
COUNTER
ELECTRODE
105
A
CURRENT
SENSOR
125
+
A
-
i_1
Cu
i_2
Al
C
COOLANT
130
- + gnd
Power Supply
120

FIG. 1

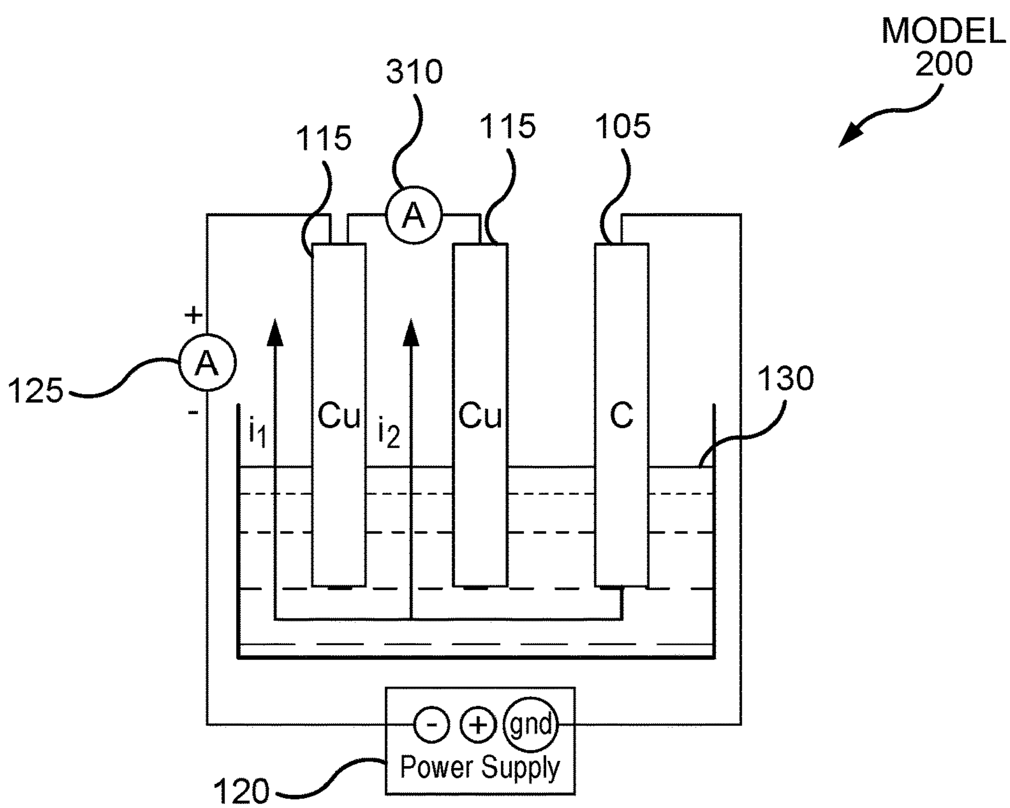

MODEL
200
310
115
115
105
A
+
A
125
-
i_1
Cu
i_2
Cu
C
130
- + gnd
Power Supply
120

FIG. 2

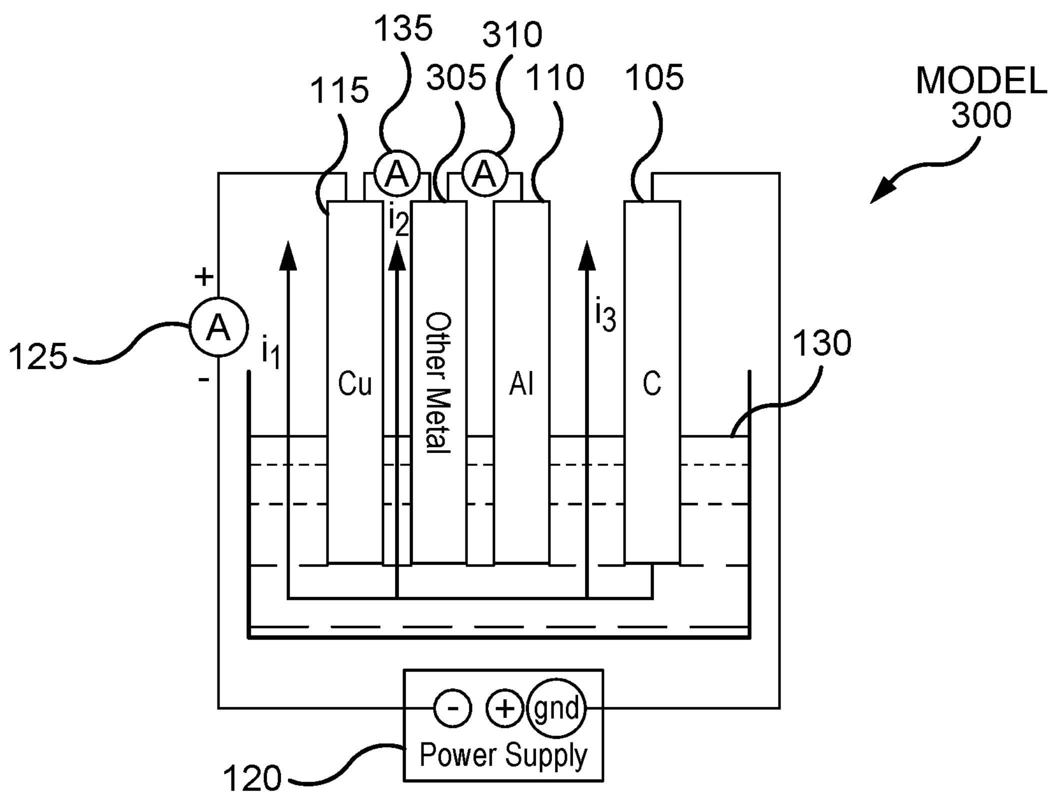

135
310
115
305
110
105
MODEL
300
A
A
i_2
+
A
125
i_1
-
Cu
Other Metal
Al
i_3
C
130
-
+
gnd
Power Supply
120

FIG. 3

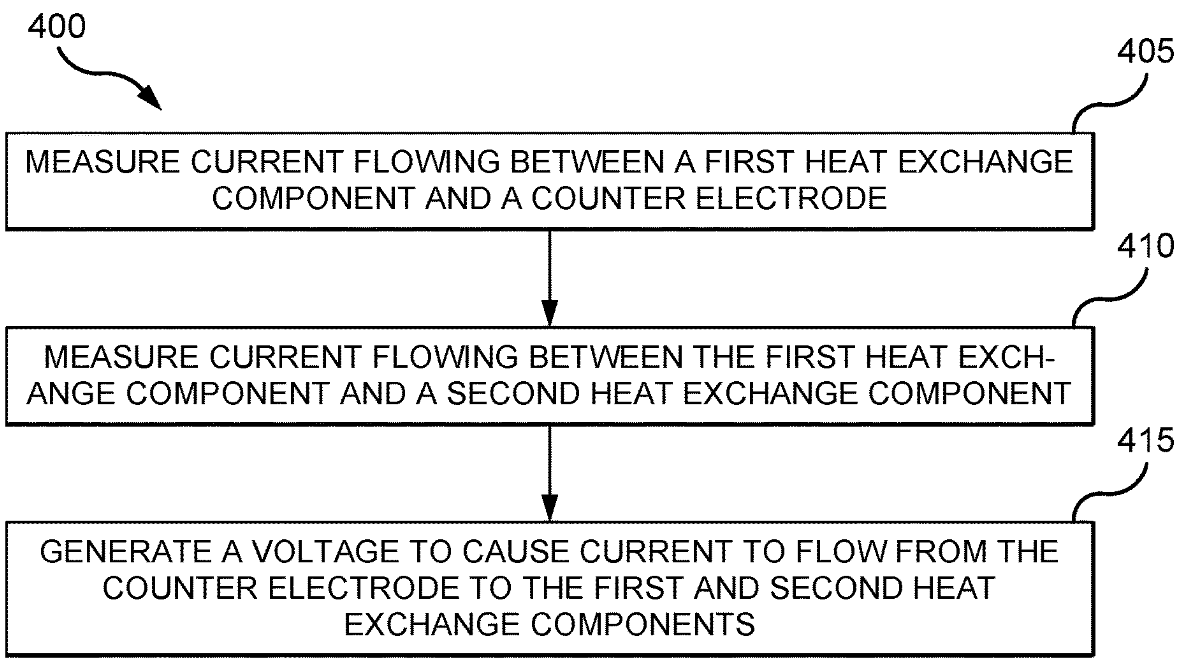

400
405
MEASURE CURRENT FLOWING BETWEEN A FIRST HEAT EXCHANGE COMPONENT AND A COUNTER ELECTRODE
410
MEASURE CURRENT FLOWING BETWEEN THE FIRST HEAT EXCH-ANGE COMPONENT AND A SECOND HEAT EXCHANGE COMPONENT
415
GENERATE A VOLTAGE TO CAUSE CURRENT TO FLOW FROM THE COUNTER ELECTRODE TO THE FIRST AND SECOND HEAT EXCHANGE COMPONENTS

FIG. 4

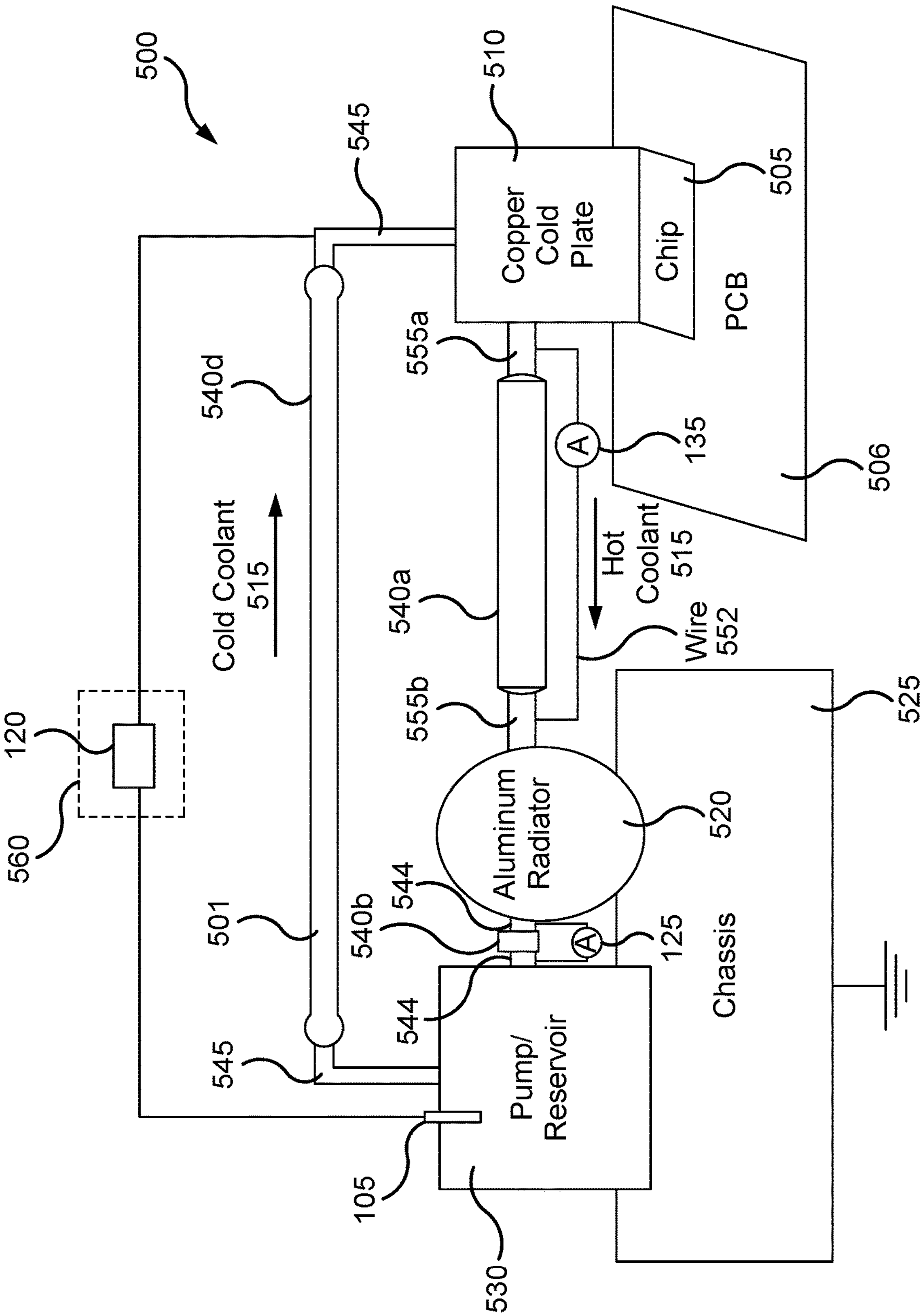

500
545
510
Copper
Cold
Plate
Chip
505
PCB
555a
540d
135
506
Cold Coolant
515
Hot
Coolant
515
540a
Wire
552
120
560
555b
525
Aluminum
Radiator
520
501
540b
544
125
Chassis
544
545
Pump/
Reservoir
105
530

FIG. 5

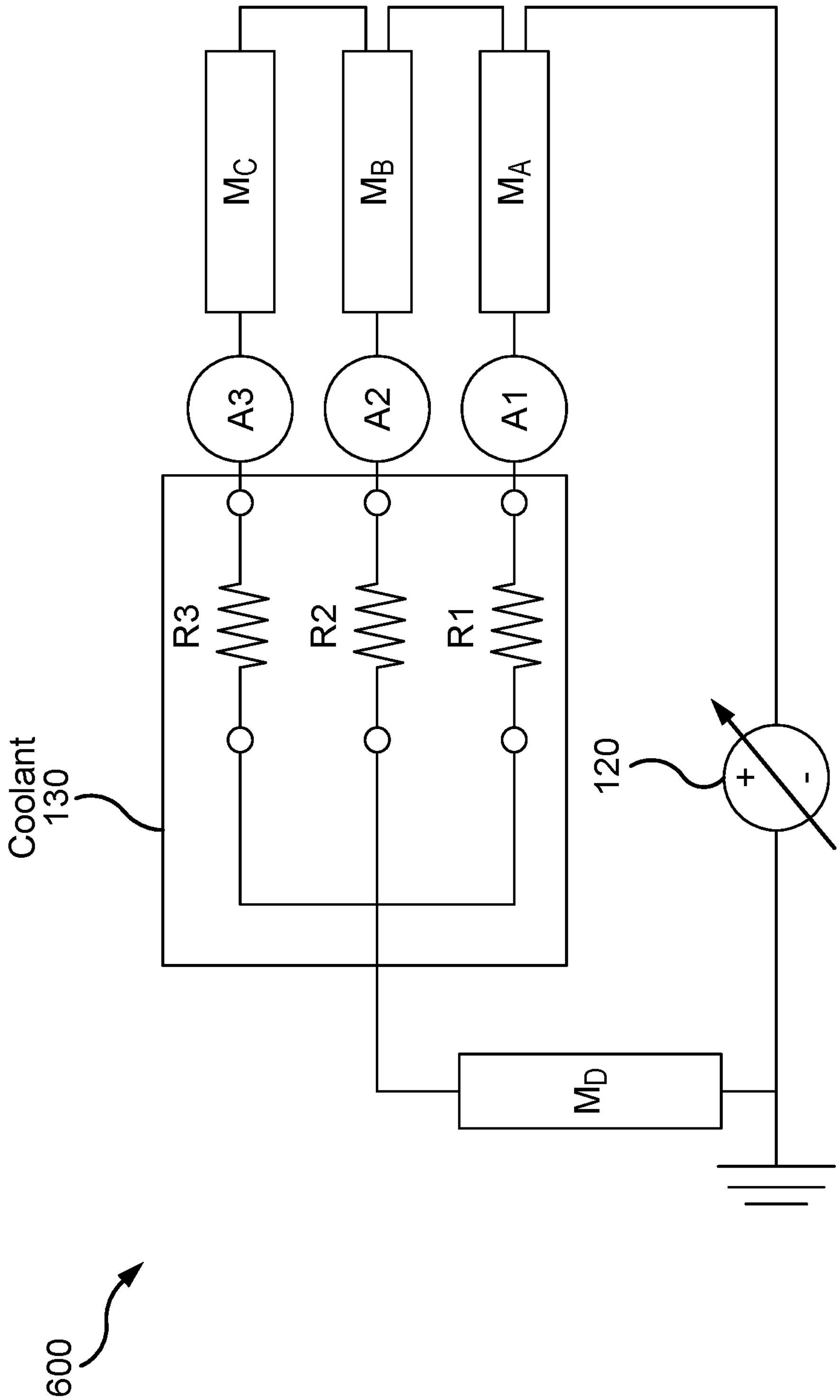


FIG. 6

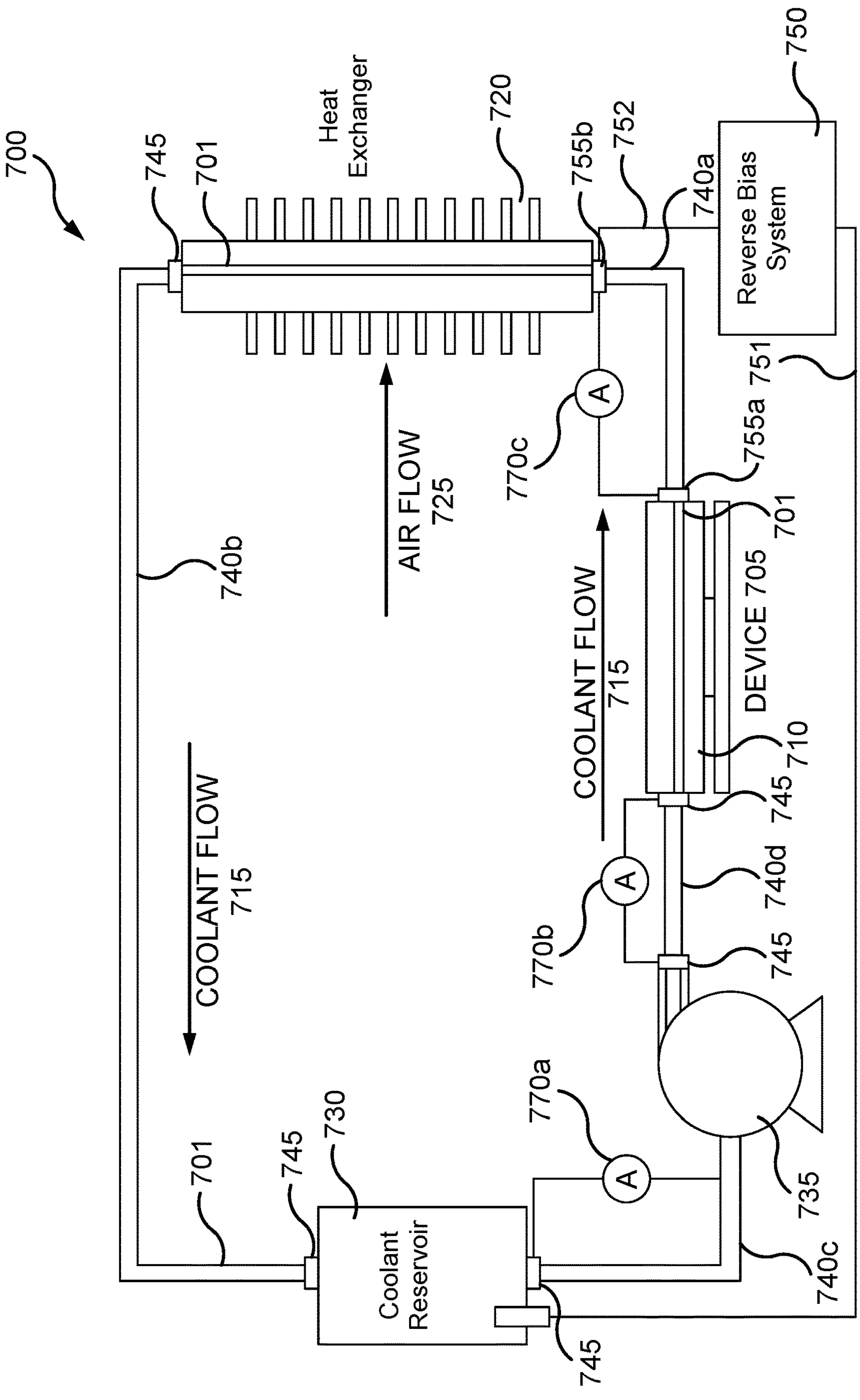

700
745
701
Heat Exchanger
720
755b
752
740a
750
Reverse Bias System
751
A
770c
755a
701
AIR FLOW
725
COOLANT FLOW
715
DEVICE 705
710
745
740b
A
740d
770b
745
COOLANT FLOW
715
770a
A
730
701
745
Coolant Reservoir
735
740c
745

FIG. 7

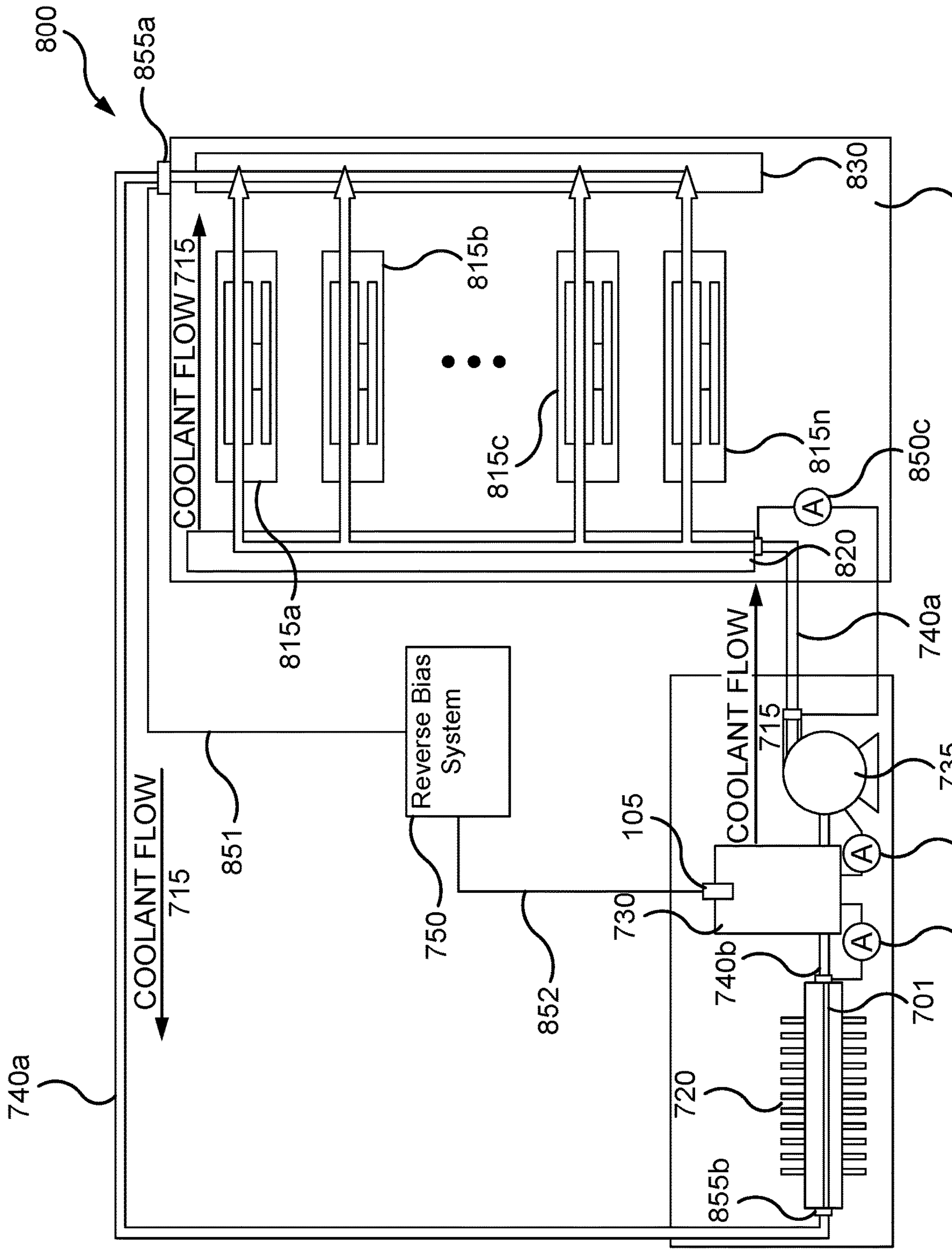

800
855a
830
810
815b
COOLANT FLOW 715
815c
815n
850c
820
815a
740a
Reverse Bias System
851
750
852
COOLANT FLOW
715
105
730
735
850b
850a
740b
701
720
855b
COOLANT FLOW
715
740a
A

FIG. 8

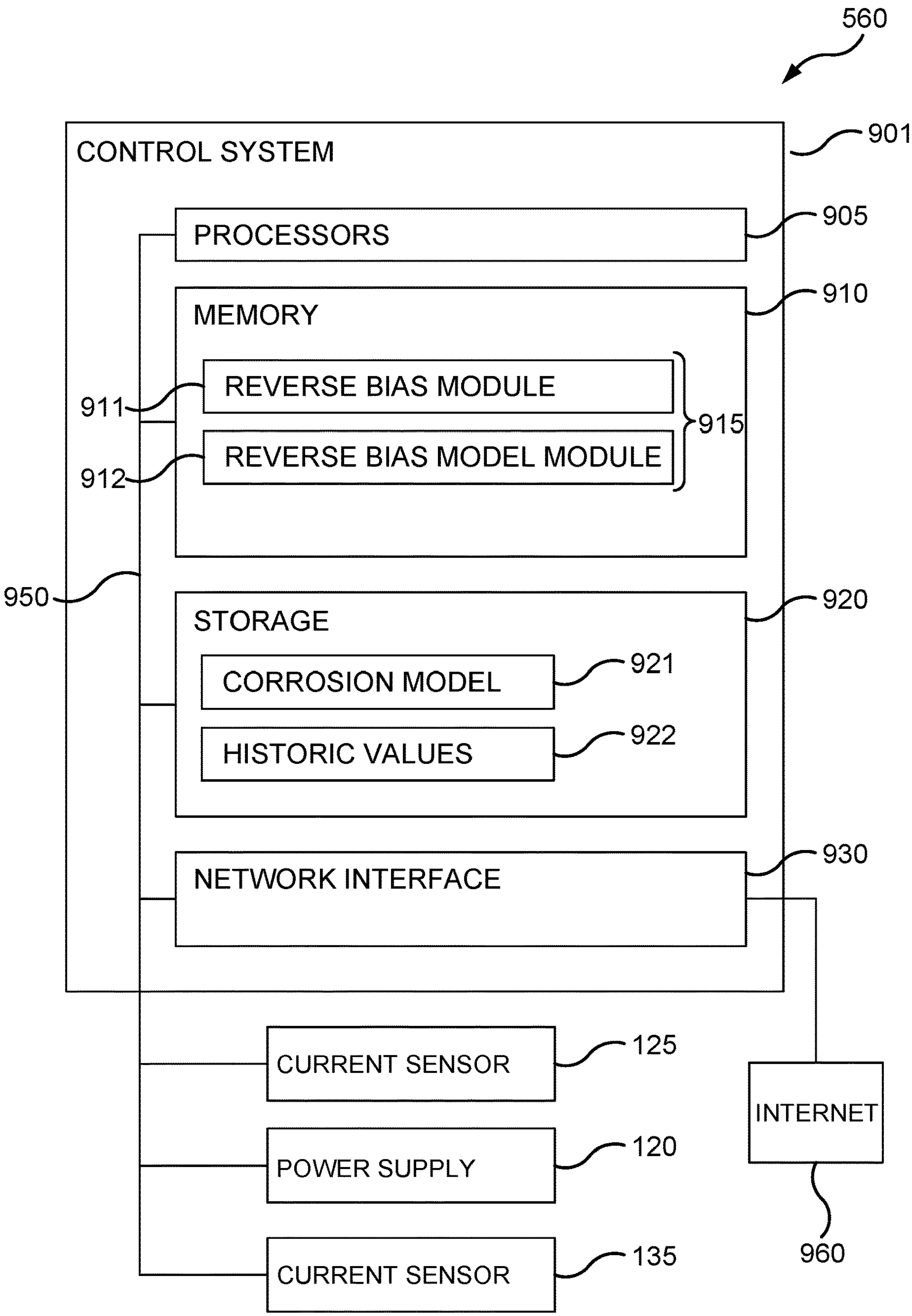

560
CONTROL SYSTEM
901
PROCESSORS
905
MEMORY
910
REVERSE BIAS MODULE
REVERSE BIAS MODEL MODULE
911
912
915
950
STORAGE
920
CORROSION MODEL
921
HISTORIC VALUES
922
NETWORK INTERFACE
930
CURRENT SENSOR
125
POWER SUPPLY
120
CURRENT SENSOR
135
INTERNET
960

FIG. 9

ELECTRODE AND CIRCUITRY DESIGN FOR CORROSION PROTECTION IN LIQUID COOLING SYSTEM

TECHNICAL FIELD

[0001] Embodiments presented in this disclosure generally relate to preventing corrosion in liquid cooling systems. More specifically, embodiments disclosed herein use a counter electrode to reduce corrosion.

BACKGROUND

[0002] As computer systems and the associated electronic devices increase in power and complexity, the heat output of these systems also increases. While traditional air flow based cooling systems provide some levels of cooling, liquid cooling systems are increasingly found to provide more direct and efficient cooling paradigms for high powered and high heat producing electronic devices. While development in liquid cooling systems has improved, the related efficiencies and costs of installing and maintaining liquid cooling systems remains challenging.

[0003] For example, liquid cooling systems are typically more expensive in time and resource usage compared to the traditional airflow systems. One of the primary causes of the time and resource costs in liquid cooling systems relates to ensuring that liquid coolant in the systems is at appropriate levels in the system and not leaking from the system. Much of this required maintenance and need for liquid replacement and system inspection is due to corrosion that occurs in the liquid cooling systems. Reducing or preventing corrosion in the liquid cooling systems remains a challenge.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] So that the manner in which the above-recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate typical embodiments and are therefore not to be considered limiting; other equally effective embodiments are contemplated.

[0005] FIGS. **1-3** illustrates models of liquid cooling systems that include counter electrodes, according to embodiments described herein.

[0006] FIG. **4** is a flowchart for mitigating corrosion in a liquid cooling system using a counter electrode, according to one embodiment.

[0007] FIG. **5** illustrates a liquid cooling system with a counter electrode, according to one embodiment.

[0008] FIG. **6** illustrates an equivalent circuitry for the cooling system in FIG. **5**, according to one embodiment.

[0009] FIG. **7** illustrates a closed loop liquid cooling system, according to one embodiment.

[0010] FIG. **8** illustrates on open loop liquid cooling system, according to one embodiment.

[0011] FIG. **9** illustrates a block diagram of a reverse bias system, according to one embodiment.

[0012] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements disclosed in one embodiment may be beneficially used in other embodiments without specific recitation.

DESCRIPTION OF EXAMPLE EMBODIMENTS

Overview

[0013] One embodiment presented in this disclosure is a liquid cooling system that includes a first heat exchange component comprising a first non-inert metal, a counter electrode comprising an inert material, piping configured to carry a liquid coolant where the first heat exchange component and the counter electrode contact the liquid coolant, a sensor configured to measure a current flowing, or a voltage, between the first heat exchange component and the counter electrode, and a control system coupled to the sensor and configured to control a power supply electrically connected to the first heat exchange component and the counter electrode to generate a voltage that reduces or prevents current from flowing between the first heat exchange component and the counter electrode.

[0014] One embodiment presented in this disclosure is a method that includes measuring current flowing between, or a voltage between, a first heat exchange component and a counter electrode in a liquid cooling system where the first heat exchange component includes a first non-inert metal and the counter electrode includes an inert material. Further, the first heat exchange component and the counter electrode contact a liquid coolant in the liquid cooling system. The method also includes generating a voltage to reduce or prevent current from flowing between the first heat exchange component and the counter electrode.

Example Embodiments

[0015] As described above, liquid cooling systems provide effective cooling to high heat producing electronic devices. However, liquid cooling systems have several intrinsic problems related to the corrosion of the various components in the system over time. Corrosion on the heat exchange components in a liquid cooling system can occur from at least two sources: galvanic corrosion when different types of metals are used in the liquid cooling system, and oxidation. The embodiments herein can be used to minimize or eliminate both types of corrosions by using a counter electrode made from an inert material (e.g., gold, platinum, graphite, silver, etc.).

[0016] Some solutions to counteract the corrosion have been implemented to limited success in liquid cooling systems. For example, a corrosion inhibitor may be added to the liquid coolant to slow corrosion; however, these corrosion inhibitors and the related thermal conductivity of the liquid coolant in liquid cooling systems often degrades over time. This degradation may be caused by a degradation of corrosion inhibitors in liquid coolants, temperature induced degradation, or by oxidation in the liquid. This degradation, in turn, requires the liquid to be refilled or replaced frequently, which increases maintenance costs of the liquid cooling system.

[0017] The systems and methods described herein can be used with a coolant that includes a liquid inhibitor and coolant that does not. If the coolant includes a liquid inhibitor, the embodiments herein can greatly extend the life of the corrosion inhibitor, and thus, reduce maintenance costs. If the coolant does not include the liquid inhibitor, the embodiments herein can still mitigate corrosion, although perhaps not as well or as long as a coolant that includes liquid inhibitor. In any case, the embodiments herein describe a liquid cooling system that measures currents between the counter electrode and metallic heat exchange components. This current can result in both galvanic corrosion and oxidation. The liquid cooling system can then apply a voltage (e.g., a reverse bias) to reduce or eliminate both galvanic corrosion and oxidation. This control system can be used if the liquid cooling system includes heat exchange components that are the same metal (in which case there is no galvanic corrosion, although there may still be oxidation) or includes heat exchange components of different metals, in which case there can be both galvanic corrosion and oxidation.

[0018] FIGS. **1-3** illustrates models of liquid cooling systems that include counter electrodes, according to embodiments described herein. FIG. **1** illustrates a model **100** of a liquid cooling system that includes two different types of metal that are electrically connected to a counter electrode **105**. For example, metal **110** (e.g., aluminum in this example) can represent the material of a first heat exchange component in the liquid cooling system, while metal **115** (e.g., copper in this example) represents the material of a second heat exchange component in the liquid cooling system. The counter electrode **105**, the metal **110**, and the metal **115** contact a coolant **130** of the liquid cooling system.

[0019] Because the metals **110** and **115** are different types of non-inert metals (e.g., aluminum and copper), there can be galvanic corrosion on these metals. In some cases, corrosion is most significant in liquid cooling systems with differing materials due to galvanic corrosion. For example, a cold plate made be made of metal **110** while a radiator is made from metal **115**, and as such, may experience large amounts of galvanic corrosion. Homogenous systems, such as copper only based liquid cooling systems avoid this problem of galvanic corrosion, but may have greater fabrication costs, relatively heavy in weight, and suffer from low production yields in manufacturing.

[0020] The model **100** also illustrates a power supply **120**, a first current sensor **125**, and a second current sensor **135**. One output of the power supply **120** (e.g., the ground output) is coupled to the counter electrode **105** while another output (e.g., the negative output) is coupled to the metal **115**. However, this is just one example of coupling the metal **115** and the counter electrode **105** to the power supply **120**.

[0021] The first current sensor **125** is disposed in the current path between the metal **115** and the counter electrode **105**. In this example, the current sensor **125** is disposed between the metal **115** and the power supply **120** but could also be disposed between the power supply **120** and the counter electrode **105**.

[0022] The second current sensor **135** is disposed in the current path between the metal **115** and the metal **110**.

[0023] A control system (discussed in detail in FIG. **9**) can monitor the current measured by the first current sensor **125** and the second current sensor **135** and control the power supply **120** to generate a voltage that prevents or reduces galvanic corrosion and oxidation. To do so, in one embodiment, the voltage supply generates a reverse bias that causes the current through the metal **115** (i.e., i_1) and the current though the metal **110** (i.e., i_2) to flow in the same direction. That is, the power supply **120** generates a voltage bias that causes current to flow from the counter electrode **105** to the metal **110** and **115** as shown in FIG. **1**. Doing so can reduce or prevent galvanic corrosion, as well as oxidation. By adding the counter electrode **105**, the surface reactions on the metals **110** and **115** are converted to electrochemical reactions which do not cause corrosion.

[0024] Further, the model **100** illustrates electrically connecting the metal **115** to the metal **110** so that the metal **115** and the metal **110** are at the same voltage potential. However, the metals **110** and **115** may not be connected serially, but rather in parallel with the counter electrode **105** which is shown in FIG. **6**.

[0025] Electrically connecting the metals **110** and **115** to each other represents electrically connecting two heat exchange components (made from different metals) to each other using, e.g., a conductive wire. This is shown in more detail in FIG. **5** below. In another embodiment, because the metals **110** and **115** have the same voltage potential, the power supply **120** could have been coupled to the metal **110** (rather than the metal **115**) and the system would function the same to prevent corrosion assuming the same current direction. In one embodiment, wiring that connects the metals **110** and **115** can be a conductive tubing system, such as metal, or an extra connection if non-conductive tubing if used in the cooling system.

[0026] FIG. **2** illustrates a model **200** of a liquid cooling system that includes two heat exchange components made from the same metal **115**. For example, the two heat exchange components could be a cold plate and a radiator formed using the same metal **115**. The two heat exchange components represented by the two instances of metal **115** are connected in the same manner to each other, and to the counter electrode **105**, as in FIG. **1**. That is, the metals **115** are at the same voltage potential, while one of the metals **115** is connected to the counter electrode **105** through the power supply **120**.

[0027] Like above, a control system can monitor the current measured by the first current sensor **125** and the second current sensor **135** and control the power supply **120** to generate a voltage that causes the currents through both metals **115** (i.e., i_1 and i_2) to flow in the same direction. Put differently, current flows from the counter electrode **105** to both the metals **115**. In this case, doing so can reduce or prevent oxidation. There would be no galvanic corrosion in this instance since the two metals **115** are the same. Thus, the model **200** illustrates that the control system described herein can be used in a liquid cooling system that has any number of heat exchange components made from the same metal. In one embodiment, wiring that connects the metals **115** can be a conductive tubing system, such as metal, or an extra connection if non-conductive tubing if used in the cooling system.

[0028] Further still, the control system could be used if the liquid cooling system had only one non-inert heat exchange component and a counter electrode, although most liquid cooling systems have multiple metallic heat exchange components.

[0029] FIG. **3** illustrates a model **300** of a liquid cooling system that includes three heat exchange components made from three different types of non-inert metals. For example, a radiator may be made from metal **115**, a cold plate may be made from metal **110**, and a pump tank may be made from metal **305**. As shown, the three metals **110**, **115**, and **305** are connected to each other by respective current sensors to measure the current flowing between them. One of the metals (metal **115** in this case) is coupled to the counter electrode **105** via the power supply **120**.

[0030] Like above, a control system can monitor the current measured by the current sensor **125**, the second current sensor **135**, and a third current sensor **310** and control the power supply **120** to generate a voltage that causes the current through the metal **115** (i.e., i_1), the current through metal **305** (i.e., i_2), and the current through metal **110** (i.e., i_3) to flow in the same direction. Put differently, current flows from the counter electrode **105** to the metals **110**, **115**, and **305**. Doing so can reduce or prevent galvanic corrosion, as well as oxidation. Thus, the model **300** illustrates that the control system described herein can be used in a liquid cooling system that has any number of heat exchange components made from any number of different non-inert metals. In one embodiment, wiring that connects the metals **110**, **115**, and **305** can be a conductive tubing system, such as metal, or an extra connection if non-conductive tubing if used in the cooling system.

[0031] FIG. **4** is a flowchart of a method **400** for mitigating corrosion in a liquid cooling system using a counter electrode, according to one embodiment. At block **405**, a first current sensor (e.g., the current sensor **125** in FIGS. **1-3**) measures current flowing between a first heat exchange component and a counter electrode. The first heat exchange component can be made from a non-inert metal (e.g., copper, aluminum, etc.) while the counter electrode is made from an inert material (e.g., graphite, gold, platinum, silver, etc.).

[0032] At block **410**, a second current sensor (e.g., the current sensor **135** in FIGS. **1-3**) measures current flowing between the first heat exchange component and a second heat exchange component. The second heat exchange component can be made from a non-inert metal (e.g., copper, aluminum, etc.) which can be the same material as the first heat exchange component, or a different material.

[0033] At block **415**, a power supply generates a voltage to cause current to flow from the counter electrode to the first and second heat exchange components. In one embodiment, the power supply provides a reserve biased voltage which generates current that flows in the same direction in the first and second heat exchange components. Alternatively, there may be no current flowing through one of the heat exchange components while current does flow from the counter electrode to the other heat exchange component. Doing so can reduce or prevent one of, or both of, galvanic corrosion and oxidation.

[0034] In another embodiment, voltage sensing rather than current sensing can be used.

[0035] Although method **400** describes using a counter electrode to reduce corrosion for two heat exchange components made from a non-inert metal, the method **400** can be expanded to any number of heat exchange components, whether they are made from the same metal (as shown in FIG. **2**) or different metals (as shown in FIGS. **1** and **3**). Further, the heat exchange components may be electrically connected via current sensors.

[0036] FIG. **5** illustrates a liquid cooling system **500** with a counter electrode **105**, according to one embodiment. The system **500** includes a reverse bias system **560** to prevent corrosion in the system **500**. The system **500** also includes a coolant pump system such as pump/reservoir **530** and aluminum radiator **520** mounted on a grounded chassis **525**. In some examples, the aluminum radiator **520** is an air cooled aluminum radiator. The pump/reservoir **530** receives a coolant **501** from the aluminum radiator **520** via a pipe **540***b* connected to each respective component via fittings **544**. The pump/reservoir **530** stores the coolant and provides the coolant **501** in a cold state to copper cold plate **510** via a pipe **540***d*. The pipe **540***d* is connected to the pump system and the copper cold plate **510** via fittings **545**.

[0037] The copper cold plate **510** provides heat exchange/cooling to a chip **505** mounted on a printed circuit board (PCB) **506**. As the coolant **501** flows along direction **515** into the copper cold plate **510**, the coolant is heated such that the coolant **501** flows from the copper cold plate **510** to the aluminum radiator **520** via a pipe **540***a*. The pipe **540***a* is connected to the copper cold plate **510** via fitting **555***a* and aluminum radiator **520** via fitting **555***b*. The reverse bias system **560** is electronically connected at one end to the fitting **545** of the cold plate **510** and at a second end to the counter electrode **105**.

[0038] System **500** can be modeled by the model **100** in FIG. **1**. For example, the aluminum radiator **520** can correspond to the metal **110** in FIG. **1** while the copper cold plate **510** corresponds to the metal **115** in FIG. **1**. As discussed in FIG. **1**, the heterogeneous usage of metal materials such as aluminum and copper in the system **500** causes galvanic corrosion in the system **500**. Galvanic corrosion causes a galvanic current in the system **500** and may be calculated or estimated using the Nernst equation to define the thermodynamic relationship between a galvanic current and the related corrosion/etching in the system. In some examples, as temperature of the system **500** increases during operation, the galvanic corrosion also increases. The reverse bias system **560** receives measurements from the current sensor **125** (coupled between the radiator **520** and the reservoir **530** which includes the counter electrode **105**) and the current sensor **135** (coupled between the cold plate **510** and the radiator **520**) to measure the galvanic currents and includes the power supply **120** to apply an external reverse bias voltage to the system **500**. In some examples, the current sensor **125** measures the galvanic current between a first heat exchange component and the counter electrode **105** disposed in the pump/reservoir **530**. For example, the current sensor **125** is positioned to measure the galvanic current across the fittings **545** of the copper cold plate **510** and the counter electrode **105**. The reverse bias system **560** then applies the reverse bias voltage via the power supply **120** to reduce or prevent the galvanic current. Moreover, reducing the galvanic current can also prevent oxidation on the heat exchange components in the system **500**, such as the aluminum radiation **520** and the copper cold plate **510**.

[0039] In one embodiment, the reverse bias system **560** determines, based on a corrosion model for the liquid cooling system and the galvanic currents measured by the current sensors **125** and **135**, a corrosion status of the liquid cooling system at a first time. In some examples, the corrosion status includes an amount of corrosion present in the system based on the material properties of the coolant and the measure galvanic current. The reverse bias system **560**, using the corrosion status and the galvanic current, determines a reverse bias voltage to prevent corrosion in the liquid cooling system. For example, the reverse bias system **560** may determine a reverse bias voltage that would bring the corrosion rate to 0 µg/day.

[0040] FIG. **5** also illustrates a wire **552** (along which the current sensor **135** is disposed) that electrical connects the copper cold plate **510** to the aluminum radiator **520** so that these two heat exchange components are at substantially the same voltage potential. In this example, the wire **552** is coupled to the fitting **555***a* of the cold plate **510** and the fitting **555***b* of the radiator **520**, but can be coupled anywhere so long as the wire **552** enables these two components to be at the same voltage potential. If other non-inert heat exchange components are present which also contact the coolant, then an additional wire can be used to connect that component with the radiator **520** and the cold plate **510**. For example, if the reservoir **530** is made from a non-inert metal (which could be aluminum, copper, or some other metal), it too can be susceptible to corrosion. In that case, a wire can be added to the system **500** to connect the reservoir **530** to the aluminum radiator **520** or the copper cold plate **510** (and add another current sensor). However, the reservoir **530** could be made from an inert material (e.g., plastic or rubber) in which case it would not be susceptible to galvanic corrosion or oxidation, and as such, it would not prevent corrosion to electrically couple the reservoir **530** to the radiator **520** or the cold plate **510**.

[0041] While FIG. **5** illustrates disposing the counter electrode **105** within the reservoir **530**, this is just one suitable location. The counter electrode **105** can be disposed in any location of the system **500** so long as the counter electrode **105** is brought in contact with the coolant. For example, the counter electrode **105** could be disposed in a large tube through which the coolant flows. In one embodiment, the counter electrode only connects to the heat exchange components by wire.

[0042] FIG. **6** illustrates an equivalent circuit **600** for the cooling system in FIG. **5**, according to one embodiment. The circuit **600** includes the current sensors **A1**-**A3** and the power supply **120** which can form the reverse bias system **560**. The circuit **600** illustrates that the power supply **120** is coupled at one end to M_D which represent the counter electrode **105**. FIG. **6** also includes M_A which represents the cold plate **510**, MB which represents the aluminum radiator **520** and M_C which represents any other or additional non-inert material that may be coupled in series (e.g., the pump or reservoir **530**).

[0043] In another embodiment, there may be multiple M_A's connected in parallel in implementations that have multiple copper cold plates **510**. For example, the PCB **506** can support four chips **505** with four copper cold plates **510** for cooling the four chips **505**.

[0044] FIG. **6** also illustrates resistances R**1**-R**3** that represents the conductivity of the coolant in the liquid cooling system. The metals M_{A-C} can have different resistance values R**1**-R**3** to the counter electrode M_D. Regardless of the different resistances R**1**-R**3**, using the control techniques above, the reverse bias system can apply a reverse bias voltage via the power supply **120** to reduce or prevent the galvanic current. Moreover, reducing the galvanic current can also prevent oxidation on the heat exchange components in the system.

[0045] FIG. **7** illustrates a closed loop liquid cooling system **700**, according to one embodiment. The system **700** is referred to a closed loop system since a liquid coolant **701** flows through each component of the system **700** in a closed loop. The embodiments described herein do not require that the various liquid cooling systems are arranged in closed loops. (For example, an open loop liquid cooling system is described in more detail in relation to FIG. **8**.) The system **700** provides cooling to various electronic components in the system by circulating the liquid coolant **701** from heat producing electronic components to heat radiating components.

[0046] For example, the system **700** includes device **705** which produces heat. In some examples, the device is in integrated circuit (IC) chip (e.g., an application-specific integrated circuit (ASIC) chip) or other type of electronic/heat producing device which produces heat at a level that requires external cooling. For example, the device **705** may produce an amount of heat that would degrade a performance of the device **705** without heat mitigation via a cooling system associated with the device **705**.

[0047] To provide heat mitigation or cooling to the device **705**, the system **700** includes component **710** attached to the device **705** or otherwise positioned to provide heat exchange between the device **705** and the liquid coolant **701**. The component **710** may include any type of heat exchanger which provides heat exchange and cooling to the device **705**. In some examples, the component **710** is a cold plate which includes tubing embedded in a heat conductive material in the component **710**, where the liquid coolant **701** flows through the tubing and absorbs heat from the device **705** via the heat conductive material. In some examples, the liquid coolant **701** flows as heated coolant from the component **710** to a component **720** where the liquid coolant **701** exchanges or radiates the heat absorbed at the component **710** into the component **720**.

[0048] The component **720** may include any type of heat exchanger or radiator which provides for heat exchange/absorption from heated liquid coolant. For example, the component **720** may include a radiator, such as an air cooled aluminum radiator, which radiates heat from the component **720** to an airflow **725** which flows across and through various subcomponents of the component **720** (e.g., radiator fins etc.). The component **720** provides the liquid coolant **701**, as a cooled coolant back to recirculation components of the system **700**. For example, the liquid coolant **701** flows into a coolant reservoir **730** and is recirculated into the component **710** by a coolant pump system such as a coolant pump **735**. The coolant pump **735** provides the liquid coolant **701** along the coolant flow **715** from the component **710** to the component **720**, the coolant reservoir **730** and any other additional components typical to a liquid cooling system.

[0049] The liquid coolant **701** flows between the various components via conduits, tubing, or pipes such as pipe **740***a*, pipe **740***b*, pipe **740***c*, and pipe **740***d*. In some examples, the pipes **740***a*-**740***d* are plastic piping or piping formed from other inert or non-reactive and non-conductive materials. The pipes are connected to the various components via fittings **745**, fitting **755***a*, and fitting **755***b*. For example, the fitting **755***a* connects the pipe **740***a* to the component **710** and the fitting **755***b* connects the pipe **740***a* to the component **720**. In some examples, the fittings **745**, **755***a*, and **755***b* are formed from metallic or conductive materials, such that the fitting serve as electrical contacts as described in more detail herein.

[0050] While shown in FIG. **7** in a circular arrangement, the various components of system **700** may be positioned in various arrangements in relation to the other components of the system. Additionally, the components of the system **700** may be collocated on a structure (e.g., located on a single chassis or other base structure) or may be located at different locations. Moreover, the reverse bias system **560** discussed in FIG. **5** may be collocated with other components of the system **700** or remote from the component **710**. In some examples, the reverse bias system **560** is positioned on a chassis or base structure independent of either the chassis or component **710**. The reverse bias system **560** is connected to the system **700** via connection **751** to the counter electrode **105** and via connection **752** to the fitting **755***b*. The reverse bias system **560** can receive current measurements from the current sensors **770***a-c* and applying an external reverse bias voltage to prevent corrosion in the liquid cooling system, as described in more detail above. Additionally, although not shown, any components in the system **700** that are made from a non-inert material (e.g., are susceptible to corrosion) that contact the coolant may be connected electrically to each other so that these components have the same voltage potential.

[0051] FIG. **8** illustrates on open loop liquid cooling system **800**, according to one embodiment. The system **800** includes the liquid coolant **701**, the component **720**, coolant reservoir **730**, and coolant pump **735** which pumps the liquid coolant **701** through the system **800** along the coolant flow **715**. In the system **800**, cooling heat exchanges is provided to a plurality of heat producing electronic devices via a manifold system **810**. The manifold system **810** includes a supply manifold **820** which provides liquid coolant received via the pipe **740***a* to arrangements **815***a*-**815***n*. In some examples, each of the arrangements **815***a*-**815***n* includes a component and a device (e.g., the component **710** and the device **705**). In some examples, the liquid coolant **701** flows from the supply manifold **820** through a plurality of copper cold plates (or other copper heat exchangers) in the arrangements **815***a*-**815***n* and heated liquid coolant **701** flows into the return manifold **830**. The heated liquid coolant flows from the return manifold **830** the component **720** via the pipe **740***a*. The system **800** also includes the reverse bias system **560**, where the reverse bias system **560** is connected to fitting **855***a* via a connection **851** and to the counter electrode **105** via a connection **852**. The arrangement of system **800** in FIG. **8** is shown in a circular arrangement; however, the various components of the system **800** may be collocated or positioned in remote locations.

[0052] As described above, the liquid cooling systems, systems **700** and **800**, are subject to various levels of corrosion which often causes several issues in the systems. For example with reference back to FIG. **7**, the liquid coolant **701** may cause galvanic and other corrosion in any metallic components with which the coolant contacts or interacts. These corrosion sources may include any of component **710**, component **720**, coolant reservoir **730**, the coolant pump **735**, and the pipes **740** (if metallic). In some examples, as the system **700** corrodes, the corroded materials collect in the liquid coolant **701** which in turn lowers a heat exchange efficiency and thermal performance of the liquid coolant **701**. For example, the liquid coolant **701** with large amounts of corroded material in suspended in the liquid will not exchange heat with the component **710** and component **720** at a same efficiency as a liquid coolant **701** without corroded materials. Additionally, corroded materials may cause clogs, blockages, or other reduced flow issues such that the liquid coolant **701** along the coolant flow **715** requires a higher energy output from the coolant pump **735** and provides lower amounts of exchange between the component **710**, component **720** and the liquid coolant **701**.

[0053] In some examples, corrosion in the system **700** also degrades the structural integrity of the metallic components, including component **710**, component **720**, and the fittings **745**, **855***a*, and **855***b*. This degradation may cause the various components to decrease in performance. For example, the components **710** and **720** may not exchange heat as efficiently as designed. Additionally, the structural degradation may cause leaks to form in the system **700**. For example, leaks may form in any of the components **710** and **720** and the fittings **745**, **755***a*, and **755***b*. Leaks of the liquid coolant **701** require for the leaks to be repaired and for coolant to be refilled which increases the overall maintenance costs of the system **700**.

[0054] To prevent or reduce corrosion in the system **700**, the system may include several corrosion mitigation measures. For example, the system **700** may include metallic interactions with the liquid coolant **701**. For example, the component **710**, the component **720**, and the various fittings may all be formed from a single metallic material, such as copper. In example where all of metallic interactions with the liquid coolant are copper, corrosion in the system **700** is reduced since there is no galvanic corrosion; however, copper is relatively heavy compared to other suitable materials (e.g., aluminum). This increased weight in limits the feasibility of fabricating and installing the system **700**. Further, even if the components are the same metal, there are still susceptible to corrosion via oxidation.

[0055] In some examples, lighter weight heterogeneous materials may be used. For example, a mixture of copper components and aluminum components may be used in the system **700**, which reduces the weight of the system **700**. In some examples, the various aluminum components may include protective layers, such as an aluminum oxide layer between the liquid coolant **701** and the components themselves. For example, the component **720** may be an aluminum radiator that includes an aluminum oxide layer between the liquid coolant **701** and an aluminum body of the radiator. In some examples, the protective layers reduce corrosion in the system, but corrosion may still occur through protective layers and the thermal conductivity of the protective layers is lower than the surrounding materials.

[0056] Another example corrosion resistance measure includes increasing a resistance of the liquid coolant **701**, such that corrosion via galvanic reactions is reduced. In some examples, corrosion inhibitors reduce corrosion, but increases maintenance costs and requires frequent liquid exchange or refill in order to keep the corrosion inhibitor at optimum levels in the liquid coolant **701**. While each of the above solutions provide some measure of corrosion preventing in the system **700**, corrosion may still be present in the system **700**.

[0057] To provide efficient and effective corrosion prevention in the systems discussed in any of the figures above, the systems can include a reverse bias system such as reverse bias system **560** and current sensors **850***a-c*. As already described above, the reverse bias system **560** provides for corrosion prevention in the system by applying an external reverse bias. The reverse bias system described herein can be used to mitigate both galvanic corrosion and oxidation, or only galvanic corrosion in systems that are not susceptible to oxidation, or only oxidation in systems that are not susceptible to galvanic corrosion.

[0058] FIG. **9** illustrates a block diagram of a reverse bias system, according to one embodiment. The reverse bias system **560** may include a control system **901** embodied as computer or other electronic device which executes the functions of the reverse bias system **560** discussed above, and can perform the methods, including method **400** described herein. The control system **901** is shown in the form of a general-purpose computing device. The components of control system **901** may include, but are not limited to, one or more processing units or processors **905**, a system memory **910**, a storage system **920**, a bus **950** that couples various system components including the system memory **910** and storage system **920** to processors **905**, along with current sensors **125** and **135**, power supply **120**, and along with an external network interface **930**. The external network interface **930** is connected to an external network such as the internet **960**. In some embodiments, the reverse bias system **560** is distributed and includes a plurality of discrete computing devices that are connected through wired or wireless networking.

[0059] System memory **910** may include a plurality of program modules **915** for performing various functions related applying an external reverse bias voltage, described herein. The program modules **915** generally include program code that is executable by one or more of the processors **905**. As shown, program modules **915** include a reverse bias module **911** and a reverse bias model module **912**. In some examples, the program modules **915** may be distributed and/or cloud based applications/modules. Additionally, storage system **920** may include media for a corrosion model **921** and historical values **922**, and other information. The information stored in storage system **920** may be updated and accessed by the program modules **915** described herein.

[0060] Additionally various computing components may be included to perform the methods described herein. For example, bus **950** represents one or more of any of several types of bus structures, including a memory bus or memory controller, a peripheral bus, an accelerated graphics port, and a processor or local bus using any of a variety of bus architectures. In some examples, such architectures may include Industry Standard Architecture (ISA) bus, Micro Channel Architecture (MCA) bus, Enhanced ISA (EISA) bus, Video Electronics Standards Association (VESA) local bus, and Peripheral Component Interconnects (PCI) bus.

[0061] Further, the control system **901** typically includes a variety of computer system readable media. Such media may be any available media that is accessible by the control system **901**, and it includes both volatile and non-volatile media, removable and non-removable media.

[0062] System memory **910** can include computer system readable media in the form of volatile memory, such as random access memory (RAM) and/or cache memory. The control system **901** may further include other removable/non-removable, volatile/non-volatile computer system storage media. In some examples, storage system **920** can be provided for reading from and writing to a non-removable, non-volatile magnetic media (not shown and typically called a "hard drive"). Although not shown, an optical disk drive for reading from or writing to a removable, non-volatile optical disk such as a CD-ROM, DVD-ROM or other optical media can be provided. In such instances, each can be connected to bus **950** by one or more data media interfaces.

[0063] As depicted and described above, system memory **910** may include at least one program product having a set (e.g., at least one) of program modules **915** that are configured to carry out the functions of embodiments of the invention. The control system **901** may further include other removable/non-removable volatile/non-volatile computer system storage media. In some examples, storage system **920** may be included as part of system memory **910** and may typically provide a non-volatile memory for the networked computing devices, and may include one or more different storage elements such as Flash memory, a hard disk drive, a solid state drive, an optical storage device, and/or a magnetic storage device.

[0064] In the current disclosure, reference is made to various embodiments. However, the scope of the present disclosure is not limited to specific described embodiments. Instead, any combination of the described features and elements, whether related to different embodiments or not, is contemplated to implement and practice contemplated embodiments. Additionally, when elements of the embodiments are described in the form of "at least one of A and B," or "at least one of A or B," it will be understood that embodiments including element A exclusively, including element B exclusively, and including element A and B are each contemplated. Furthermore, although some embodiments disclosed herein may achieve advantages over other possible solutions or over the prior art, whether or not a particular advantage is achieved by a given embodiment is not limiting of the scope of the present disclosure. Thus, the aspects, features, embodiments and advantages disclosed herein are merely illustrative and are not considered elements or limitations of the appended claims except where explicitly recited in a claim(s). Likewise, reference to "the invention" shall not be construed as a generalization of any inventive subject matter disclosed herein and shall not be considered to be an element or limitation of the appended claims except where explicitly recited in a claim(s).

[0065] As will be appreciated by one skilled in the art, the embodiments disclosed herein may be embodied as a system, method or computer program product. Accordingly, embodiments may take the form of an entirely hardware embodiment, an entirely software embodiment (including firmware, resident software, micro-code, etc.) or an embodiment combining software and hardware aspects that may all generally be referred to herein as a "circuit," "module" or "system." Furthermore, embodiments may take the form of a computer program product embodied in one or more computer readable medium(s) having computer readable program code embodied thereon.

[0066] Program code embodied on a computer readable medium may be transmitted using any appropriate medium, including but not limited to wireless, wireline, optical fiber cable, RF, etc., or any suitable combination of the foregoing.

[0067] Computer program code for carrying out operations for embodiments of the present disclosure may be written in any combination of one or more programming languages, including an object oriented programming language such as Java, Smalltalk, C++ or the like and conventional procedural programming languages, such as the "C" programming language or similar programming languages. The program code may execute entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user's computer through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider).

[0068] Aspects of the present disclosure are described herein with reference to flowchart illustrations and/or block diagrams of methods, apparatuses (systems), and computer program products according to embodiments presented in this disclosure. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer program instructions. These computer program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the block(s) of the flowchart illustrations and/or block diagrams.

[0069] These computer program instructions may also be stored in a computer readable medium that can direct a computer, other programmable data processing apparatus, or other device to function in a particular manner, such that the instructions stored in the computer readable medium produce an article of manufacture including instructions which implement the function/act specified in the block(s) of the flowchart illustrations and/or block diagrams.

[0070] The computer program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other device to cause a series of operational steps to be performed on the computer, other programmable apparatus or other device to produce a computer implemented process such that the instructions which execute on the computer, other programmable data processing apparatus, or other device provide processes for implementing the functions/acts specified in the block(s) of the flowchart illustrations and/or block diagrams.

[0071] The flowchart illustrations and block diagrams in the Figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods, and computer program products according to various embodiments. In this regard, each block in the flowchart illustrations or block diagrams may represent a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function(s). It should also be noted that, in some alternative implementations, the functions noted in the block may occur out of the order noted in the Figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustrations, and combinations of blocks in the block diagrams and/or flowchart illustrations, can be implemented by special purpose hardware-based systems that perform the specified functions or acts, or combinations of special purpose hardware and computer instructions.

[0072] In view of the foregoing, the scope of the present disclosure is determined by the claims that follow.

We claim:

1. A liquid cooling system comprising:

a first heat exchange component comprising a first non-inert metal forming a first electrode;

a second heat exchange component comprising a second non-inert metal forming a second electrode;

a counter electrode comprising an inert material;

piping configured to carry a liquid coolant, wherein the first and second heat exchange components and the counter electrode contact the liquid coolant;

a first sensor configured to measure a current flowing, or a voltage, between the first heat exchange component and the counter electrode;

a second sensor configured to measure a current flowing, or a voltage, between the first heat exchange component and the second heat exchange component; and

a control system coupled to the first and second sensors and configured to control a power supply electrically connected to the first heat exchange component and the counter electrode to generate a voltage that reduces or prevents at least one of galvanic corrosion or oxidation.

2. The liquid cooling system of claim **1**, wherein the power supply generates a voltage that causes current to flow from the counter electrode to the first and second heat exchange components.

3. The liquid cooling system of claim **1**, wherein the second non-inert metal is different from the first non-inert metal.

4. The liquid cooling system of claim **3**, wherein the first heat exchange component is copper and the second heat exchange component is aluminum.

5. The liquid cooling system of claim **1**, wherein the first heat exchange component is a cold plate configured to thermally couple to an integrated circuit and the second heat exchange component is a radiator.

6. The liquid cooling system of claim **1**, further comprising:

a third component coupled to, or part of, the piping and contacting the liquid coolant, wherein the third component is electrically connected to the first heat exchange component or the second heat exchange component such that the first and second heat exchange components, and the third component are at a same voltage potential.

7. The liquid cooling system of claim **6**, wherein the third component comprises a third non-inert metal that is different from the first and second non-inert metals.

8. The liquid cooling system of claim **6**, wherein at least two of the first heat exchange component, the second heat exchange component and the third component are the same material.

9. The liquid cooling system of claim **1**, wherein the voltage is a reverse bias and the first heat exchange component is coupled to a negative output of the power supply and the counter electrode is coupled to a ground output of the power supply.

10. The liquid cooling system of claim **1**, further comprising:

a reservoir for storing the liquid coolant, wherein the counter electrode is disposed in the reservoir such that the counter electrode contacts the liquid coolant in the reservoir.

11. A method comprising:

measuring, using a first sensor, current flowing between, or a voltage between, a first heat exchange component and a counter electrode in a liquid cooling system, wherein the first heat exchange component comprises a first non-inert metal and the counter electrode comprises an inert material, wherein the first heat exchange component and the counter electrode contact a liquid coolant in the liquid cooling system;

measuring, using a second sensor, current flowing between, or a voltage between, the first heat exchange component and a second heat exchange component in the liquid cooling system, wherein the second heat exchange component comprises a second non-inert metal, wherein the second heat exchange component contacts the liquid coolant; and

generating a voltage to reduce or prevent at least one of galvanic corrosion or oxidation based on measurements from the first and second sensors.

12. The method of claim **11**, wherein the voltage causes current to flow from the counter electrode to the first and second heat exchange components.

13. The method of claim **11**, wherein second non-inert metal is different from the first non-inert metal.

14. The method of claim **13**, wherein the first heat exchange component is copper and the second heat exchange component is aluminum.

15. The method of claim **11**, wherein the first heat exchange component is a cold plate thermally coupled to an integrated circuit and the second heat exchange component is a radiator.

16. The method of claim **11**, wherein the liquid cooling system comprises a third component contacting the liquid coolant, wherein the third component is electrically connected to the first heat exchange component or the second heat exchange component such that the first and second heat exchange components, and the third component are at a same voltage potential.

17. The method of claim **16**, wherein the third component comprises a third non-inert metal that is different from the first and second non-inert metals.

18. The method of claim **11**, wherein the generated voltage is a reverse bias.

19. The method of claim **18**, wherein the first heat exchange component is coupled to a negative output of a power supply that generates the voltage and the counter electrode is coupled to a ground output of the power supply.

20. The method of claim **11**, wherein the liquid cooling system comprises a reservoir for storing the liquid coolant, wherein the counter electrode is disposed in the reservoir such that the counter electrode contacts the liquid coolant in the reservoir.

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