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(54) TWO-PHASE COOLING APPARATUS AND METHOD FOR AUTOMATIC TEST EQUIPMENT

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(57) **ABSTRACT**

A two-phase cooling apparatus for cooling an electronic assembly is disclosed. The apparatus comprises an evaporator having a single-phase inlet for receiving a single-phase liquid coolant and a two-phase outlet for discharging a two-phase coolant. A local condenser is disposed proximate the evaporator and has a two-phase inlet coupled to the evaporator outlet. The local condenser includes a single-phase liquid coolant outlet. The apparatus further includes a pump having an output coupled to the evaporator inlet, and an input coupled to the local condenser outlet.

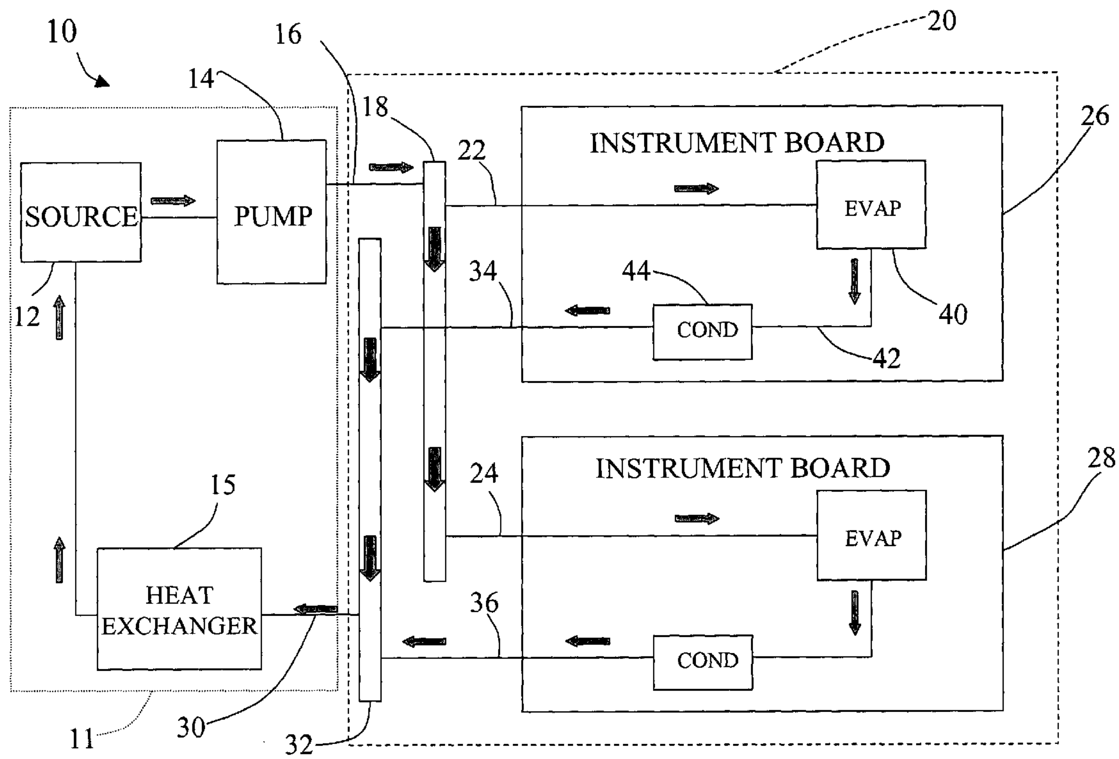


FIG. 1

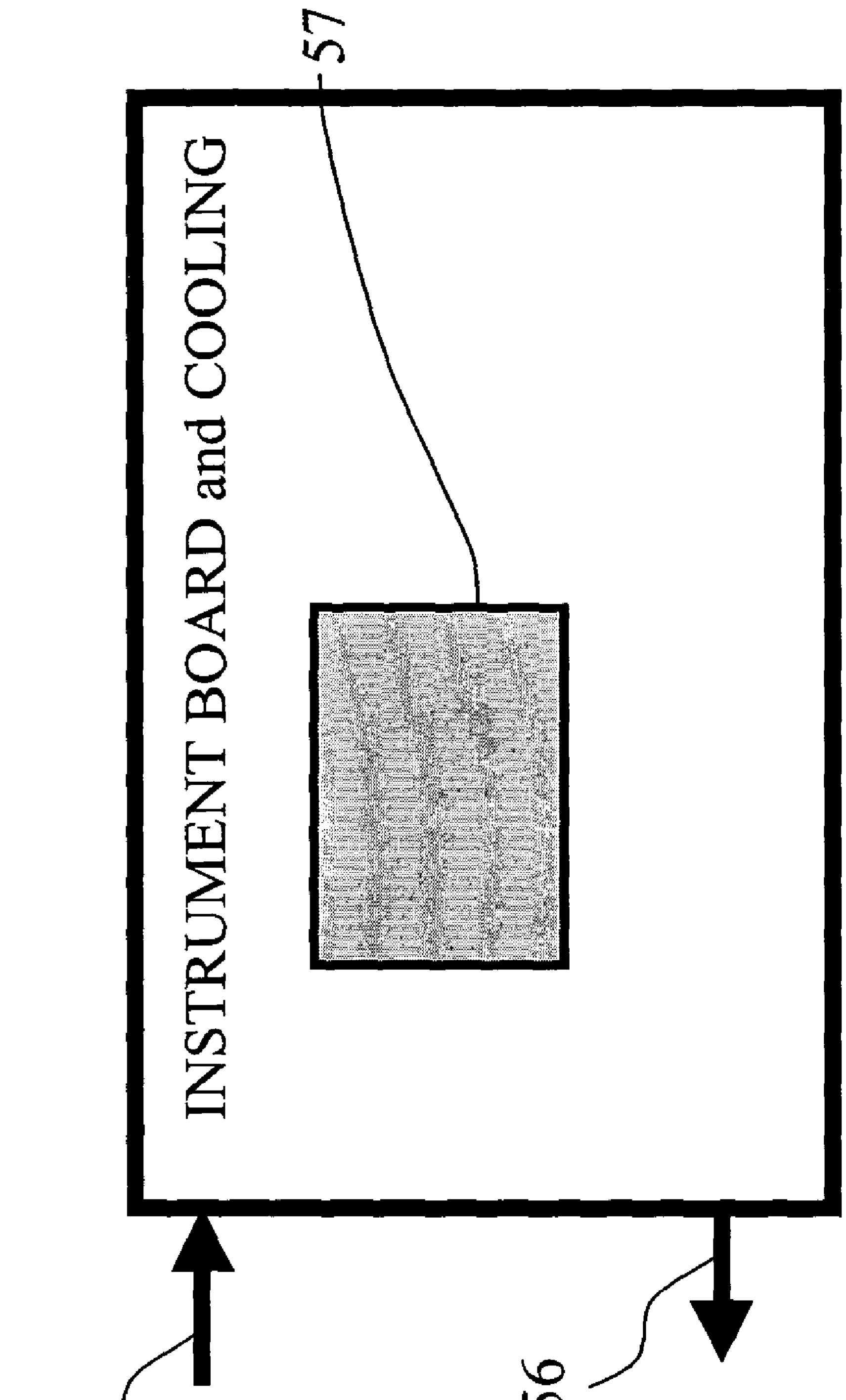
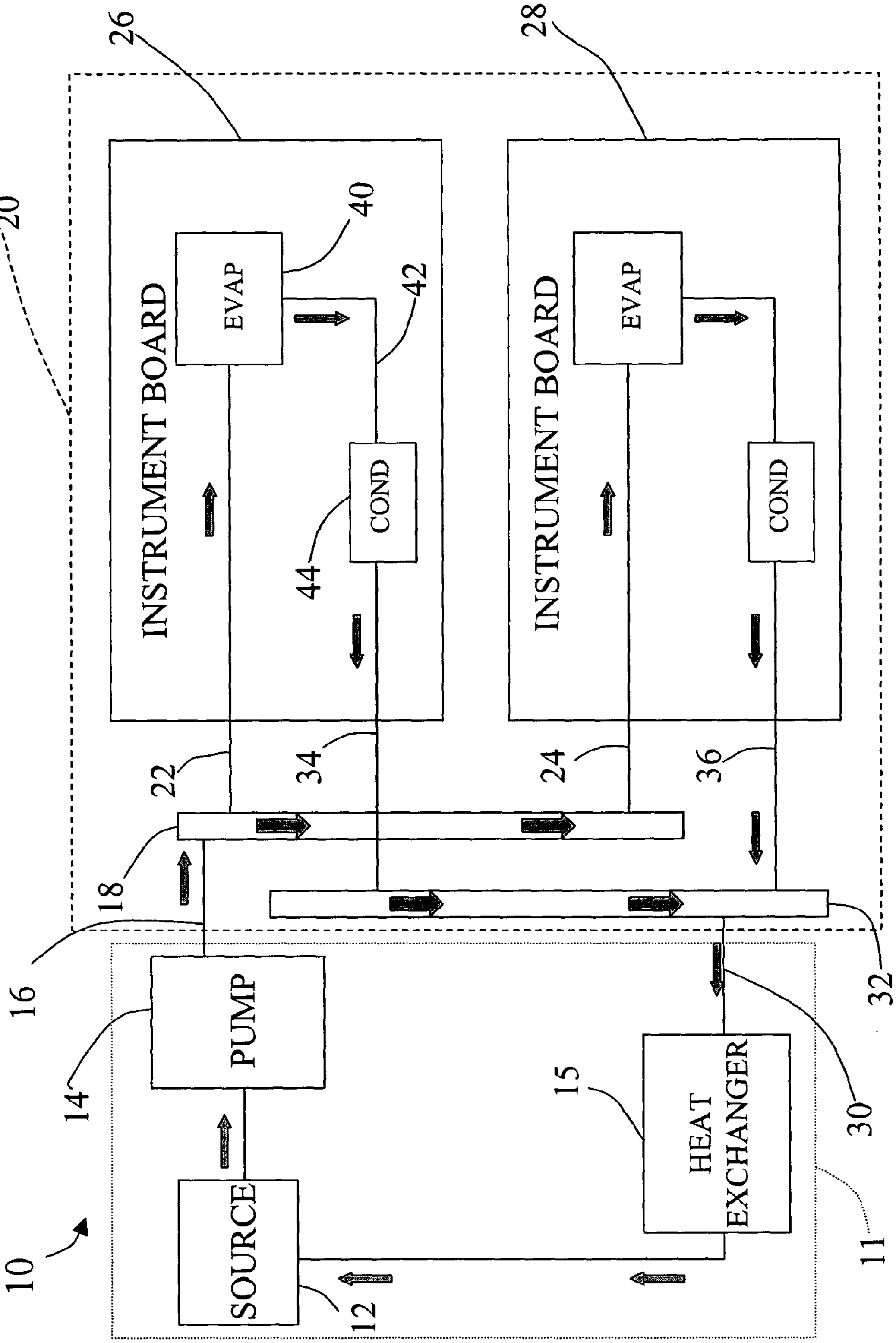


FIG. 2



26
28
20
40
42
INSTRUMENT BOARD
EVAP
COND
44
INSTRUMENT BOARD
EVAP
COND
22
34
24
36
18
16
32
PUMP
14
15
HEAT EXCHANGER
30
SOURCE
10
12
11

FIG. 3

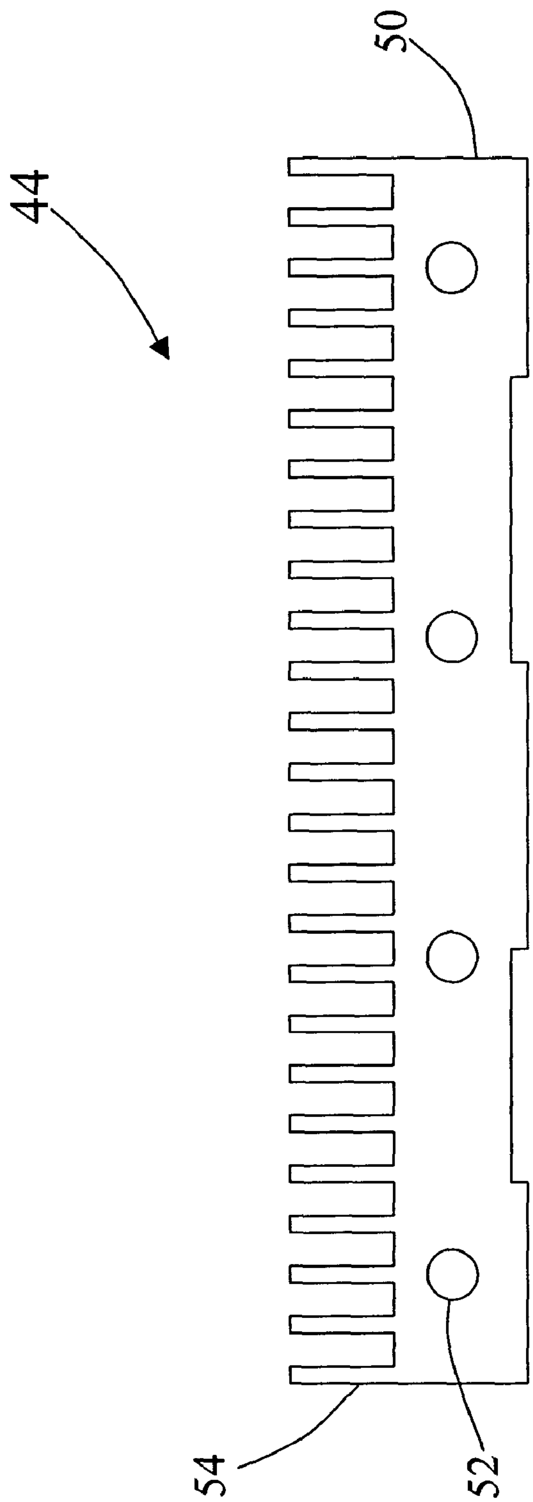


FIG. 4

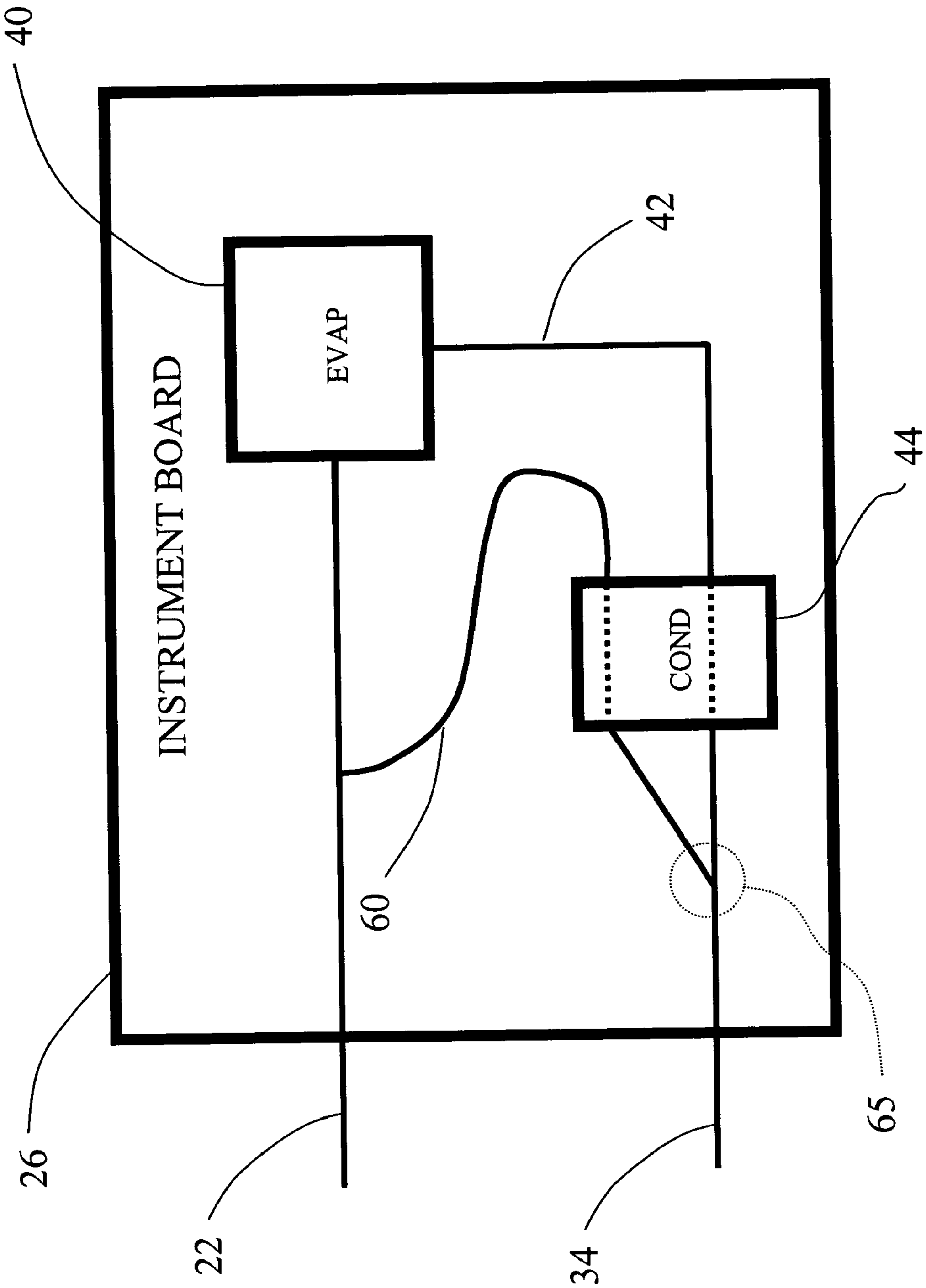


FIG. 5

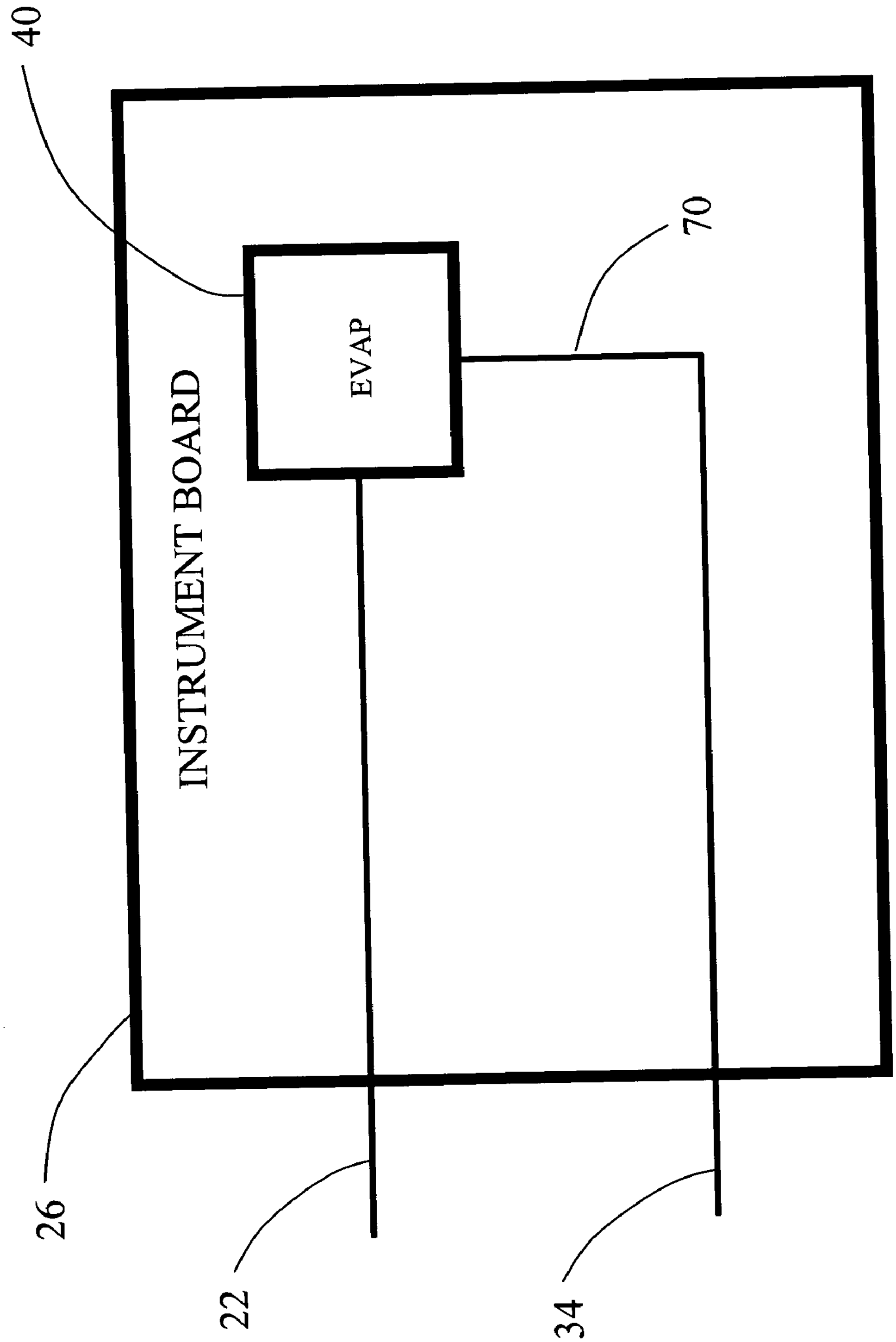
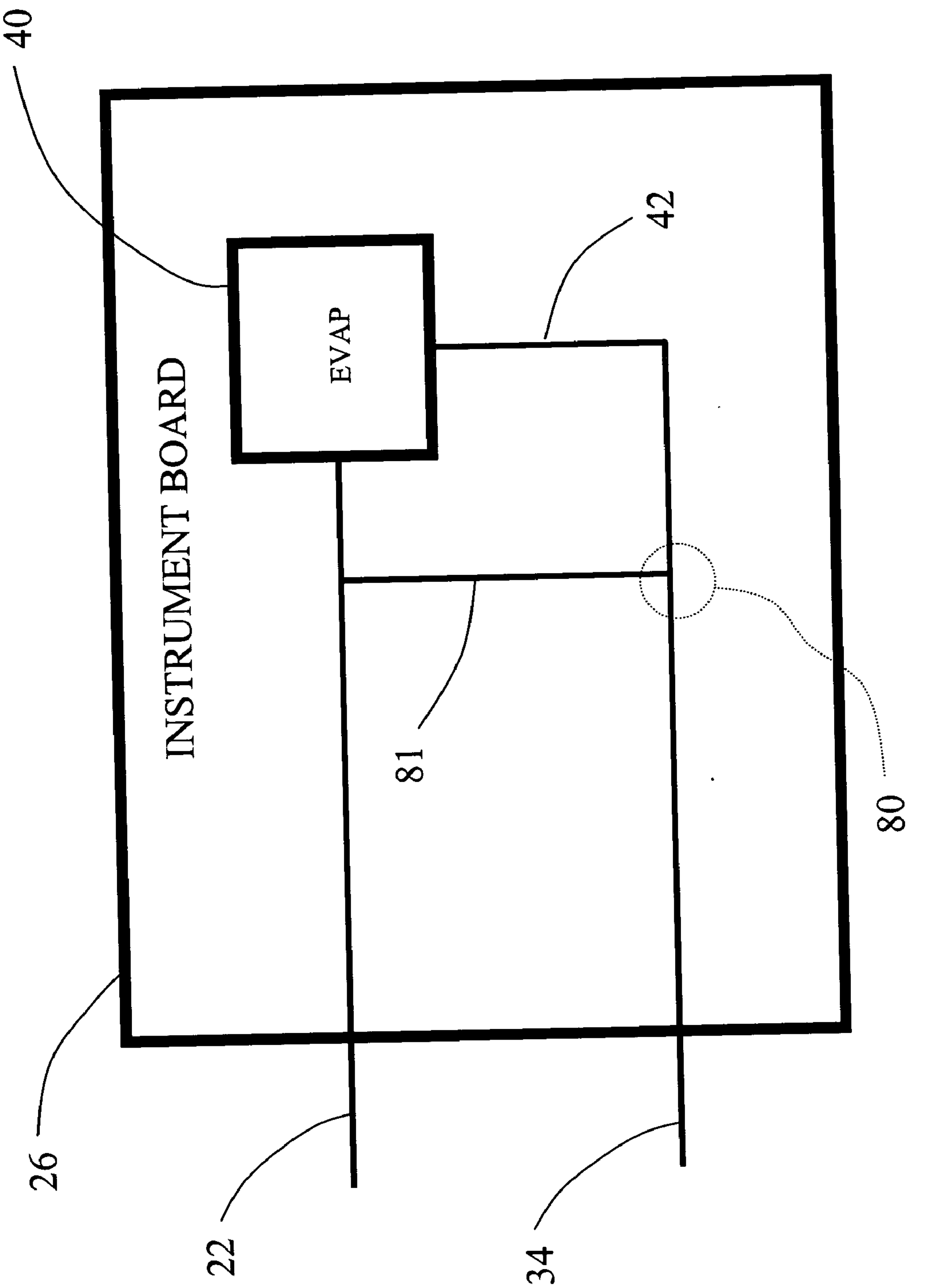


FIG. 6



TWO-PHASE COOLING APPARATUS AND METHOD FOR AUTOMATIC TEST EQUIPMENT

FIELD OF THE INVENTION

[0001] The invention relates generally to automatic test equipment, and more particularly a two-phase cooling apparatus and method for cooling electronic assemblies disposed in a semiconductor tester testhead.

BACKGROUND OF THE INVENTION

[0002] Automatic test equipment plays a pivotal role in the manufacture of semiconductor devices. The equipment, often referred to as a tester, typically provides at-speed functional verification of semiconductor devices at the wafer level and/or packaged device level. Ensuring that individual devices work properly before implementation in a higher assembly is critical to the commercial acceptance of a device.

[0003] As semiconductor devices become more complex, the ATE sub-systems required to test them correspondingly rise in complexity. Even more problematic is the rise in high-density, high-power devices. Often, high-power semiconductor devices collectively consume several hundred watts during peak operating conditions.

[0004] Conventional ATE typically employs a mainframe console or rack and a testhead. The testhead serves as a somewhat mobile housing for the channel electronics. The testhead is mobile in the sense that it may be manipulated along any one of six-degrees of freedom into a position proximate the device-under-test (DUT) to minimize signal delays between the ATE electronics and the DUT. Further, the testhead includes slots for positioning a plurality of circuit boards that mount the ATE channel electronics (often called "pin electronics"). In a sense, the testhead is a specialized card cage.

[0005] Conventional channel cards typically require some form of cooling. The art is replete with air cooled systems and liquid-cooled systems for use in semiconductor testheads. Examples of air cooling systems are found in U.S. Pat. Nos. 6,184,676, 6,078,187, 5,952,842, 5,767,690, 5,644,248, and 5,978,218. Liquid cooling systems are typically employed in the form of cold plates or modules that attach to high-power boards. Two examples are described in U.S. Pat. Nos. 6,052,284 and 6,081,428.

[0006] Conventional liquid cooling modules and cold plates are typically employed as single-phase systems. In other words, the liquid coolant remains as a liquid over the normal operating range of the system. Generally, heat is conducted from the generating component through the container wall into the liquid coolant, which then is transported by piping to a chiller where the heat is dissipated to air. In some cases, the coolant exchanges heat with temperature-controlled facility water.

[0007] While the conventional single-phase liquid cooling systems described above work well for their intended purposes, the heat transfer rate can still be too low due to the limited flow and pressure capacity of the liquid pumping systems, particularly for IC components with a relatively high heat flux. Larger coolant volume flow rates are undesirable for electronic systems striving to maintain a small footprint, since that implies much larger pumps which translates into overall larger coooling systems. Alternatively, decreasing the system pressure drop by increasing the plumbing sizes also negatively affects the system and card-cage packaging.

[0008] In an effort to provide for additional cooling capacity while maintaining a small footprint, those skilled in the art have employed two-phase cooling systems. Generally, these systems employ a low boiling point coolant that is circulated in close proximity to an electronic device. The coolant can be completely or partially vaporized (i.e. boiled) by heat dissipated by the electronic component. The coolant then travels to a remotely disposed condenser. In the condenser, the portion of the coolant that is vapor is converted back into a liquid. The liquid may further be subcooled depending on the overall cooling capacity of the condensor. The liquid is then returned to the heat-dissipating component so that the boiling/condensing cycle can be repeated.

[0009] One example of a two-phase cooling system is disclosed in U.S. Pat. No. 6,519,955 by Marsala. This system provides a plurality of locally disposed cold plates that thermally contact respective electronic assemblies. The cold plates receive a singe phase liquid coolant and distribute the coolant proximate the electronic device. As heat from the device boils off some of the coolant, the resulting two-phase mixture is discharged away from the cold plate into a remote vertically disposed vapor/liquid separator. The vertical nature of the separator enables the force of gravity to effect separation of the liquid from the vapor. The separated vapor is then directed to a remotely positioned condenser, where it is converted back to liquid. The separated liquid and converted liquid is then fed back to the pump and redistributed through the system.

[0010] While this cooling scheme appears beneficial for its intended applications, the gravity-based separation aspect is problematic for instances where the system such as automatic test equipment may lie in non-vertical orientations and the separator is mounted to the testhead. What is desired and as yet unavailable is a centralized two-phase cooling apparatus, system and method insensitive to testhead orientation. The two-phase cooling apparatus, system and method of the present invention satisfies this need.

SUMMARY OF THE INVENTION

[0011] The two-phase cooling apparatus and method of the present invention provides a cost-effective way to provide high capacity liquid cooling for a semiconductor tester testhead.

[0012] To realize the foregoing advantages, the invention in one form comprises a two-phase cooling apparatus for cooling an electronic assembly. The apparatus comprises an evaporator having a single-phase inlet for receiving a single-phase liquid coolant and a two-phase outlet for discharging a two-phase coolant. A local condenser is disposed proximate the evaporator and has a two-phase inlet coupled to the evaporator outlet. The local condenser includes a single-phase liquid coolant outlet. The apparatus further includes a pump having an output coupled to the evaporator inlet, and an input coupled to the local condenser outlet.

[0013] In another form, the invention comprises a method of cooling electronic board assemblies in automatic test equipment. The method comprises the steps of pumping a single-phase liquid coolant onto the electronic assembly; exchanging heat proximate a first electronic device on the electronic assembly with the single-phase liquid coolant, and vaporizing a portion of the single-phase liquid coolant to form a two-phase coolant; condensing the two-phase coolant back to a single-phase liquid coolant; and routing the condensed single-phase liquid coolant off the electronic assembly.

[0014] Other features and advantages of the present invention will be apparent from the following detailed description when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The invention will be better understood by reference to the following more detailed description and accompanying drawings in which

[0016] **FIG. 1** is a block diagram of a two-phase cooling apparatus;

[0017] **FIG. 2** is a block diagram of a centralized two-phase cooling system employing the two-phase cooling apparatus of **FIG. 1**;

[0018] **FIG. 3** is a cross-sectional view of a heat exchanger for use in the two-phase cooling system of **FIG. 1**;

[0019] **FIG. 4** is a block diagram similar to **FIG. 1** and illustrating a single-phase cooling path disposed in parallel with the two-phase path;

[0020] **FIG. 5** is a block diagram of an alternative embodiment of the two phase cooling system shown in **FIG. 1**; and

[0021] **FIG. 6** is a block diagram of a further alternative embodiment of the two-phase cooling system shown in **FIG. 1**.

DETAILED DESCRIPTION OF THE INVENTION

[0022] The two phase cooling apparatus, system and method described herein provides a means to selectively apply two-phase cooling to electronic assemblies such as instrument boards employed in a semiconductor tester testhead. By enabling the use of two-phase cooling in the manner described more fully below, lower cooling costs and smaller packaging would be realized by not requiring larger capacity pumps and cooling lines.

[0023] Referring first to **FIG. 1**, the system generally feeds a single phase (liquid) coolant onto one or more electronics boards either directly or within an attached cold plate, and provides for two-phase cooling (boiling or evaporation) of an electronic device **57** between the board inlet and outlet points **55** and **56**, respectively. The resulting two-phase mixture is condensed on-board, and fed back to the centralized distribution system. The following sections illustrate specific embodiments in which the on-board condensing can be achieved using a condenser, a single-phase (liquid) fluid, or by sub-cooled boiling. In all cases, the use of single-phase refers to a fluid in a liquid state but not necessarily at saturated conditions.

[0024] Referring now to **FIG. 2**, one embodiment of a centralized two-phase cooling system **11** using a local condenser is illustrated for use with automatic test equipment, generally designated **10**. The system includes a liquid coolant source **12**, such as an in-line reservoir capable of supplying a dielectric liquid (such as HFE-7100 manufactured by 3M) to a coolant pump **14**. The pump includes an outlet **16** that provides pressurized fluid to a supply manifold **18** disposed in the testhead **20** (in phantom).

[0025] Further referring to **FIG. 2**, a plurality of single-phase inlet lines **22**, **24** are distributed to spaced apart testhead slot locations (not shown) to enable selective connection to respective electronic board assemblies **26**, **28**. While only two board assemblies are shown for clarity, the testhead may include any number of boards to support whatever semiconductor device is being tested. A plurality of single-phase outlet lines **34**, **36** receive discharged single-phase coolant from the board assemblies and feed it to an outlet manifold **32**. The outlet manifold, in turn, directs the heated effluent a heat exchanger **15**. The heat exchanger couples to a facility chiller (not shown) to exchange heat between the heated effluent and a facility source of water. The output of the heat exchanger is then fed back to the coolant reservoir **12** to complete the cooling loop.

[0026] With continued reference to **FIG. 2**, each electronic board assembly **26**, **28** includes one or more electronic devices (not shown) that generate a substantial amount of heat. In order to sufficiently cool for example a particularly high-power device, an evaporator **40** is disposed in fluid communication with the single-phase coolant inlet **22** and positioned proximate the electronic device to effect two-phase heat transfer. The evaporator partially vaporizes the single-phase coolant into a two-phase fluid. A two-phase fluid line **42** couples the outlet of the evaporator to the inlet of a locally disposed condenser **44**. The output of the condenser connects to the single phase discharge line **34**. The condensor cooling source is not explicitly shown in **FIG. 2** but can be provided by any number of methods, such as those described with reference to **FIGS. 3 and 4**.

[0027] **FIG. 3** illustrates one embodiment of an air-cooled condenser **44** suitable for use with the system of **FIG. 2**. This condenser comprises a heat spreader plate **50** formed with a plurality of cooling channels **52** for the two-phase coolant coming from line **42** (**FIG. 2**). The heat dissipates off the topside surface with an array of spaced-apart cooling fins **54**. The geometric features of the condensor are sized appropriately to ensure the two-phase coolant is condensed to a single phase, a task familiar to those skilled in the art.

[0028] In operation, a plurality of electronic board assemblies are employed in the testhead, each including respective inlet and outlet cooling lines that tap into the supply and return coolant manifolds **18** and **32**. With the tester operating to stimulate and capture test signals from a device-under-test, the electronic board assemblies **26**, **28** dissipate large amounts of heat through various integrated circuit devices. This heat is transferred from the devices via the proximally located evaporators **40** to the coolant, creating a two-phase fluid mixture in the coolant line. This mixture is routed from the evaporator through the short two-phase line **42** to the condenser **44**, where the mixture returns to a single phase liquid. The liquid is then discharged through the single-phase outlet line **34** to the outlet manifold **32**, and into the heat exchanger **15** for cooling and eventually directed back to the coolant reservoir **12**.

[0029] An important aspect of this cooling scheme involves the local on-board action of condensing the two-phase fluid, and routing the resulting single-phase liquid back to the centralized cooling system **11**. By having a relatively close proximity between the point at which the two-phase fluid is condensed and the evaporator **40**, the two-phase mixture flow can be controlled to a high degree independent of any gravity effects from, for example, an inverted testhead.

[0030] With reference to **FIG. 4**, in an alternative embodiment, the instrument board **26** shown in **FIG. 2** includes the single-phase supply coolant **22** delivering liquid to the evaporator **40** and also a portion through fluid line **60** to the condensor **44**. In this case, the condenser **44** is essentially a compact liquid-to-liquid heat exchanger for which many designs exist familiar to those skilled in the art of heat exchanger design. The two-phase coolant **42** and the single-phase coolant **60** are kept separated throughout the condensor **44** and merge again at a point when both are single phase (liquid) which in this case is shown external to the condensor **44** as area **65** (in phantom), which practically can be a Tee or Wye fitting. In practice the two-phase coolant line **42** is kept very short, for instance less than one inch.

[0031] Referring now to **FIG. 5**, in a further embodiment, the instrument board **26** introduced in **FIG. 2** is again shown, but without a separate condensor. In this embodiment, sub-cooling the evaporator **40** has sub-cooled coolant entering it thereby allowing for rapid condensation of the two-phase mixture along a predetermined length of line **70**. In operation, as the two-phase fluid leaves the evaporator **40** and flows along the line **70**, the heat load and heat flux dramatically diminish and the fluid stops boiling and the vapor is condensed to a single-phase liquid state.

[0032] Referring now to **FIG. 6**, the instrument board **26** introduced in **FIG. 2** is again shown also without a separate condenser. In this embodiment, the single-phase supply coolant **22** delivers a first portion to the evaporator **40** and a second portion **81** to the two-phase mixture **42** exiting the evaporator. The blending of a sufficient amount of the single-phase coolant **81** with the evaporator discharge **42** can condense the two-phase evaporator discharge **42** resulting in a single-phase liquid **34** leaving the board **26**.

[0033] As noted above, one of the primary applications for the two-phase cooling apparatus described above involves implementation in a semiconductor tester testhead. Testheads are often oriented along several axes, and even inverted in some situations. Employing a pump **14 (FIG. 1)** in the two-phase apparatus ensures constant availability of coolant even in extreme testhead orientations.

[0034] Those skilled in the art will appreciate the many benefits and advantages afforded by the present invention. Of significant importance is the enabling of two-phase cooling for use in automatic test equipment that reduces cooling costs by increasing liquid cooling capacity. Also beneficial is the localized condensing of the two-phase fluid on the board to restore the two-phase fluid from the evaporator to a single-phase liquid over a relatively short distance. This feature addresses any potential gravity issues that might result from the testhead being oriented in an extreme manner and detrimental flow distribution effects due to mixing different streams of single-phase coolant and two-phase coolant.

[0035] While the invention has been particularly shown and described with reference to the preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A two-phase cooling apparatus for cooling an electronic assembly, the apparatus comprising:

an evaporator having a single-phase inlet for receiving a single-phase liquid coolant and a two-phase outlet for discharging a two-phase coolant;

a local condenser disposed proximate the evaporator and having a two-phase inlet coupled to the evaporator outlet, the local condenser including a single-phase liquid coolant outlet; and

a pump having an output coupled to the evaporator inlet, and an input coupled to the local condenser outlet.

2. A two-phase cooling apparatus according to claim 1 wherein:

the pump comprises a local pump disposed proximate the evaporator inlet.

3. A two-phase cooling apparatus according to claim I and further comprising:

a single-phase liquid coolant inlet line coupled to the evaporator inlet; and

a single-phase liquid coolant outlet line coupled to the local condenser outlet.

4. A two-phase cooling apparatus according to claim 3 and further comprising:

at least one single-phase coolant path disposed in parallel with the evaporator and condenser for carrying out single-phase heat transfer.

5. A method of cooling an electronic assembly, the method comprising the steps:

pumping a single-phase liquid coolant onto the electronic assembly;

exchanging heat proximate a first electronic device on the electronic assembly with the single-phase liquid coolant, and evaporating a portion of the single-phase liquid coolant to form a two-phase coolant;

condensing the two-phase coolant back to a single-phase liquid coolant; and

routing the condensed single-phase liquid coolant off the electronic assembly.

6. A method according to claim 5 and further comprising the step:

directing a portion of the single phase coolant proximate a second electronic device on the electronic assembly to effect single phase cooling for the second electronic device.

7. A two-phase cooling apparatus for cooling an electronic assembly, the apparatus comprising:

an evaporator having a single-phase inlet for receiving a single-phase liquid coolant and a two-phase outlet for discharging a two-phase coolant;

means for condensing the two-phase coolant to a single-phase coolant, the means for condensing disposed on the electronic assembly; and a remote pump having an output coupled to the evaporator inlet, and an input coupled to the means for condensing.

8. A two-phase cooling apparatus according to claim 7 wherein the means for condensing comprises:

a local condenser disposed proximate the evaporator and having a two-phase inlet coupled to the evaporator outlet, the local condenser including a single-phase liquid coolant outlet.

9. A two-phase cooling apparatus according to claim 7 wherein the means for condensing comprises:

a single-phase coolant path disposed in parallel with the evaporator, the single-phase coolant path coupled to the evaporator outlet to mix sufficient single-phase coolant with the two-phase coolant and condense the two-phase coolant to a single-phase coolant.

10. A two-phase cooling apparatus for cooling an electronic assembly, the apparatus comprising:

means for pumping a single-phase liquid coolant onto the electronic assembly;

means for exchanging heat proximate an electronic device on the electronic assembly with the single-phase liquid coolant, and evaporating a portion of the single-phase liquid coolant to form a two-phase coolant;

means for condensing the two-phase coolant back to a single-phase liquid coolant; and

means for routing the condensed single-phase liquid coolant off the electronic assembly.

11. A two-phase cooling apparatus according to claim 10 and further comprising:

means for directing a portion of the single phase coolant proximate a second electronic device on the electronic assembly to effect single phase cooling for the second electronic device.

12. A two-phase cooling apparatus according to claim 10 wherein the means for pumping comprises a remote pump.

13. A two-phase cooling apparatus according to claim 10 wherein the means for pumping comprises a local pump disposed proximate the means for exchanging heat.

14. A two-phase cooling apparatus according to claim 10 wherein the means for exchanging heat comprises an evaporator having a single-phase inlet for receiving a single-phase liquid coolant, and a two-phase coolant outlet.

15. A two-phase cooling apparatus according to claim 10 wherein the means for condensing comprises a local condenser disposed proximate the means for exchanging heat and having a two-phase inlet coupled to the means for exchanging heat, the local condenser including a single-phase liquid coolant outlet.

16. A two-phase cooling system for cooling a plurality of electronic assemblies in a semiconductor tester, the two-phase cooling system comprising:

a liquid pump having an inlet and an outlet;

an inlet manifold coupled to the pump outlet;

a plurality of cooling assemblies having respective inlets coupled to the inlet manifold, each of the cooling assemblies including

an evaporator having a single-phase inlet coupled to the cooling assembly inlet for receiving a single-phase liquid coolant and a two-phase outlet for discharging a two-phase coolant; and

a local condenser disposed proximate the evaporator and having a two-phase inlet coupled to the evaporator outlet, the local condenser including a single-phase liquid coolant outlet;

an outlet manifold coupled to the cooling assembly outlets, the outlet manifold disposed in liquid communication with the liquid pump inlet.

17. A two-phase cooling apparatus according to claim 16 wherein:

the liquid pump comprises a local pump disposed proximate the evaporator inlet.

18. A two-phase cooling apparatus according to claim 16 and further comprising:

a single-phase liquid coolant inlet line coupled to each evaporator inlet; and

a single-phase liquid coolant outlet line coupled to each local condenser outlet.

19. A two-phase cooling apparatus according to claim 16 and further comprising:

at least one single-phase coolant path disposed in parallel with each evaporator and condenser for carrying out single-phase heat transfer.

* * * * *