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(54) APPARATUS AND METHODS FOR MANAGING THE TEMPERATURE OF A SUBSTRATE IN A HIGH VACUUM PROCESSING SYSTEM

(75) Inventors: **Todd Arthur Luse**, Kings Park, NY (US); **Roger Fremgen**, East Northport, NY (US); **William J. Miller**, Huntington, NY (US); **Adrian Celaru**, Massapequa, NY (US)

Correspondence Address:
WOOD, HERRON & EVANS, LLP
2700 CAREW TOWER, 441 VINE STREET
CINCINNATI, OH 45202

(73) Assignee: **VEECO INSTRUMENTS INC.**, Woodbury, NY (US)

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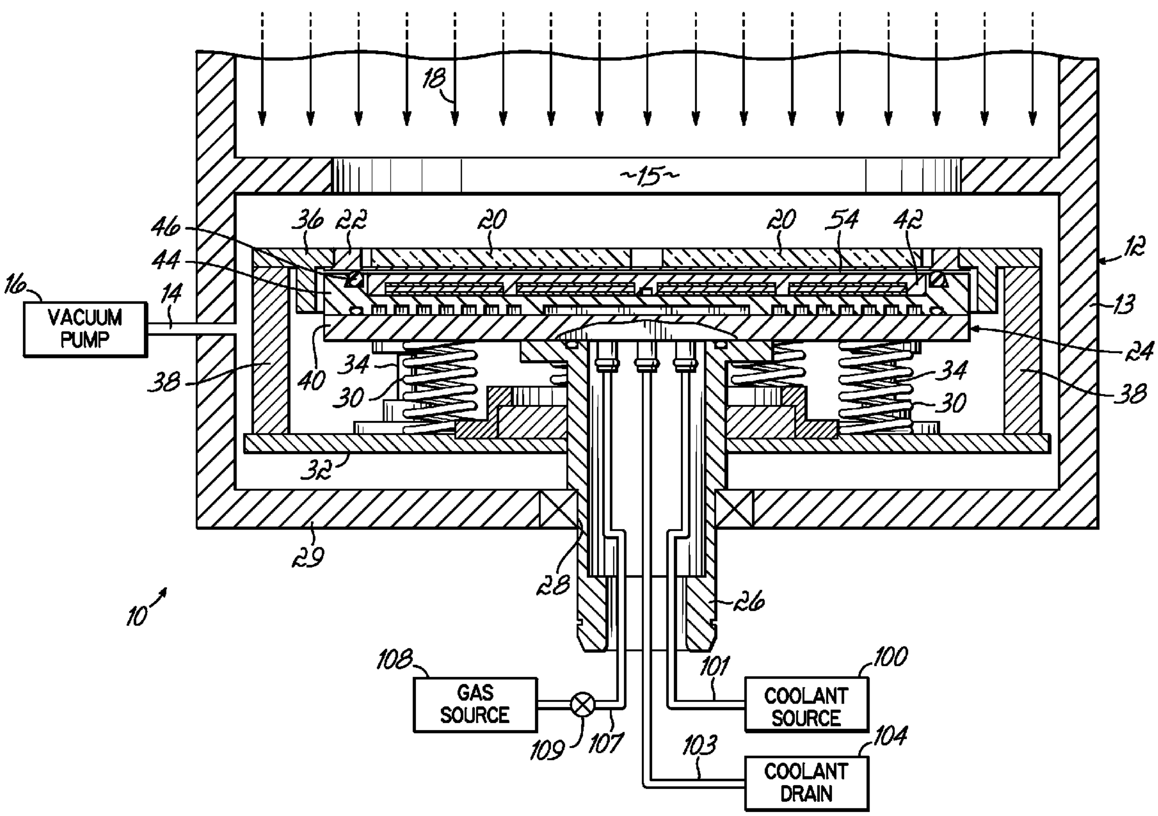
(57) **ABSTRACT**

Apparatus and methods for improving the control of the temperature of a supported member, such as a substrate, in high vacuum processing systems, such as ion beam etch (IBE) systems. The apparatus includes thermoelectric devices that transfer heat from a support member supporting the supported member to a liquid-cooled heat exchange member to regulate the temperature of the support member. The method includes cooling the support member with thermoelectric devices that transfer the heat to the liquid-cooled heat exchange member.



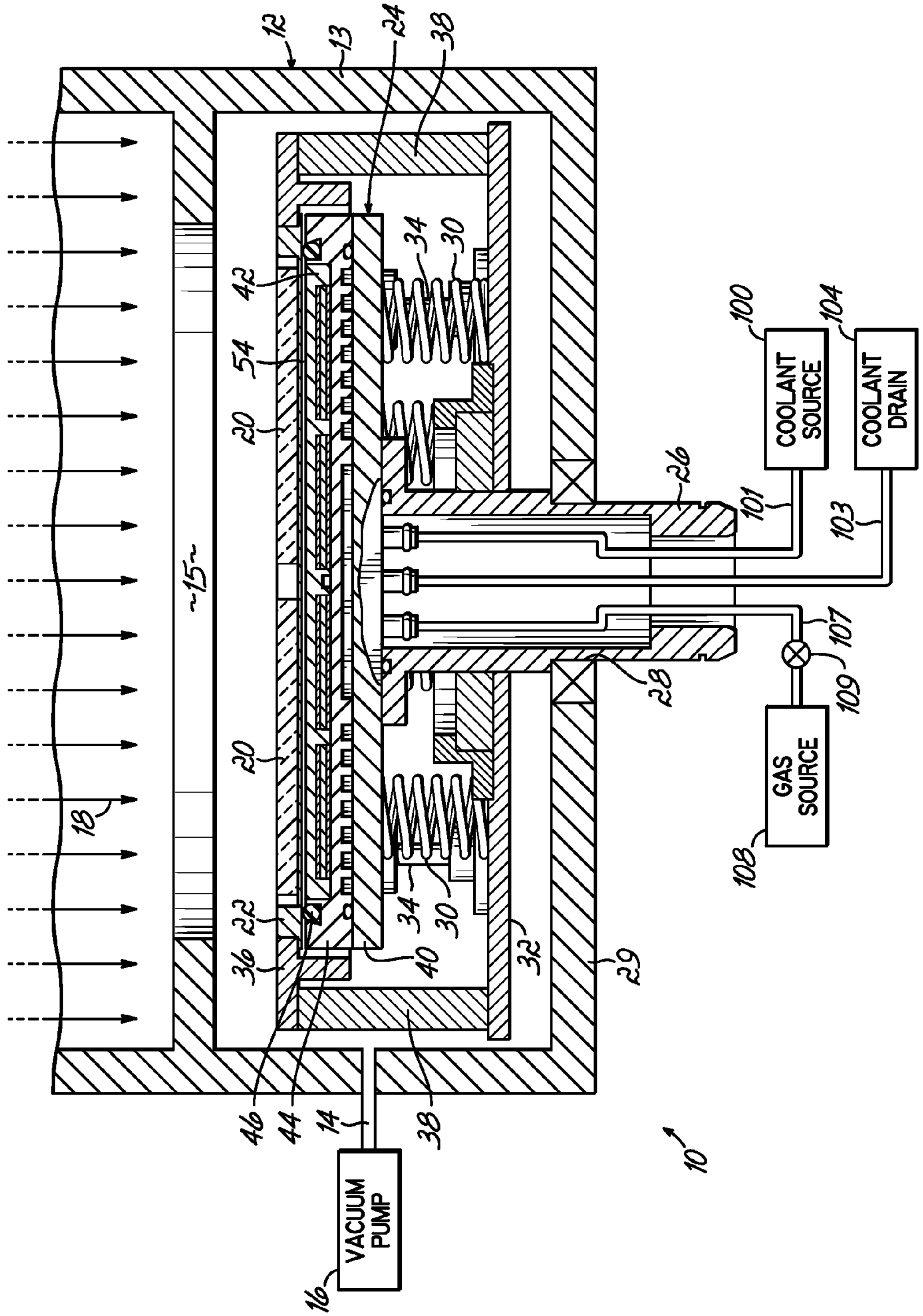


FIG. 1

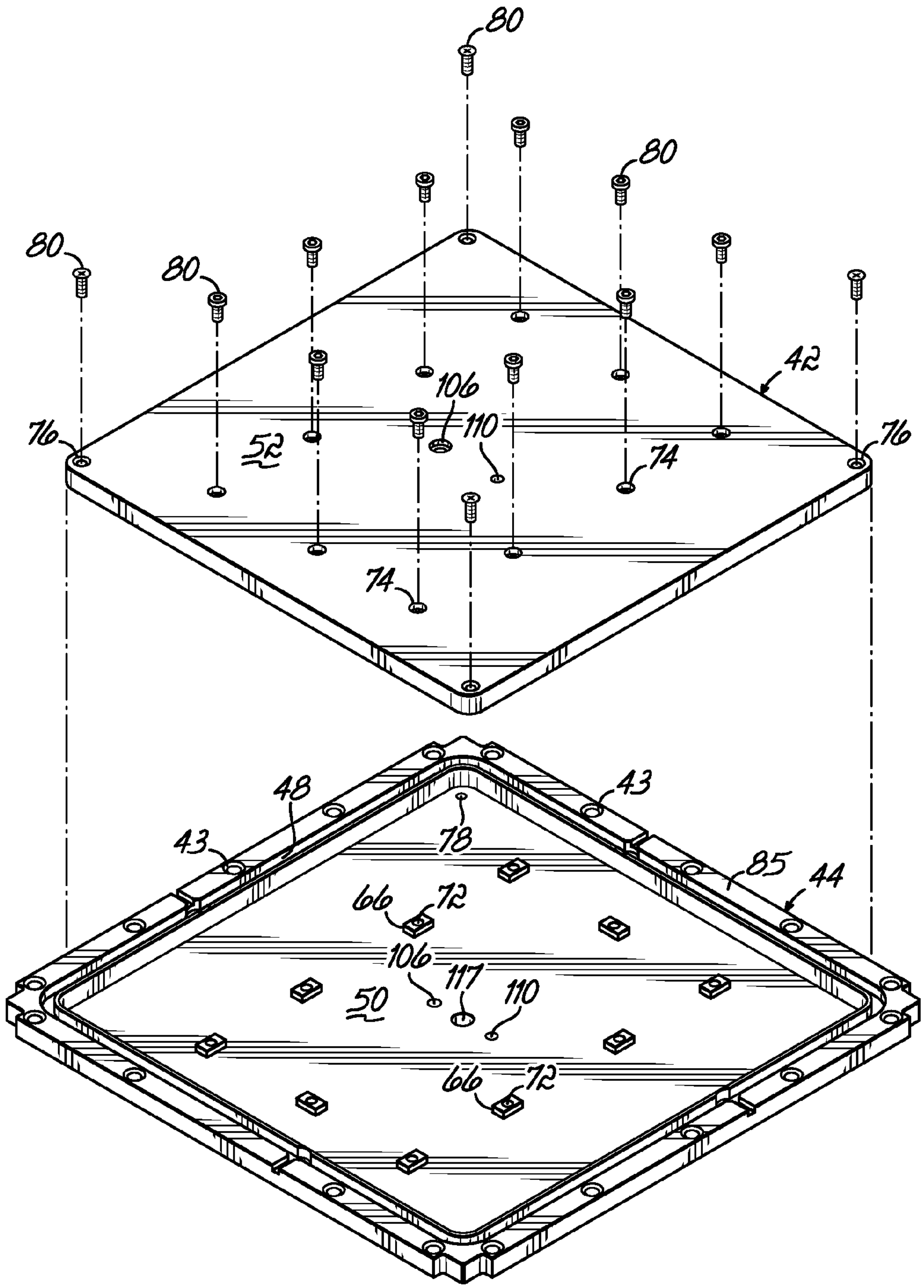

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FIG. 2

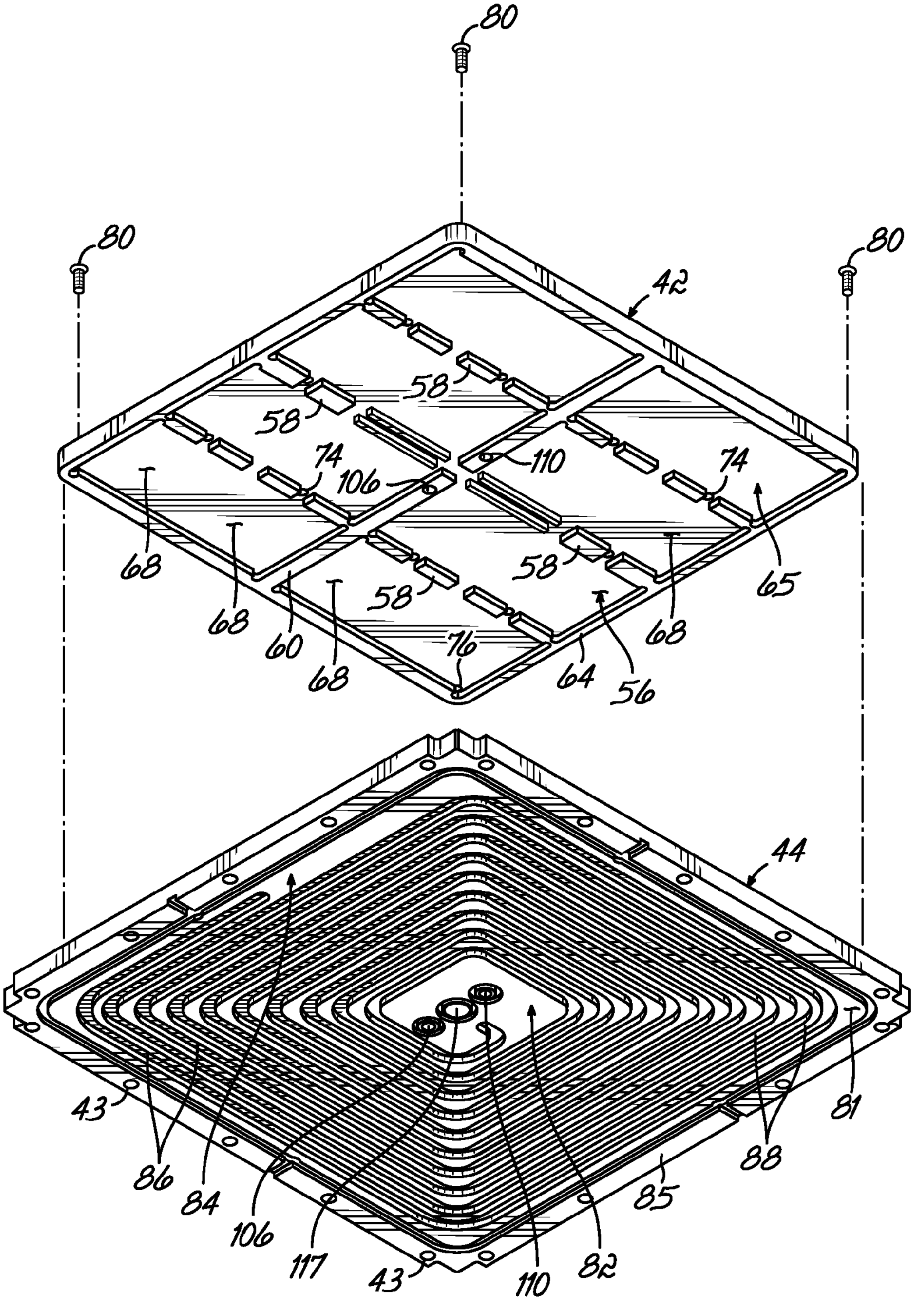
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FIG. 3

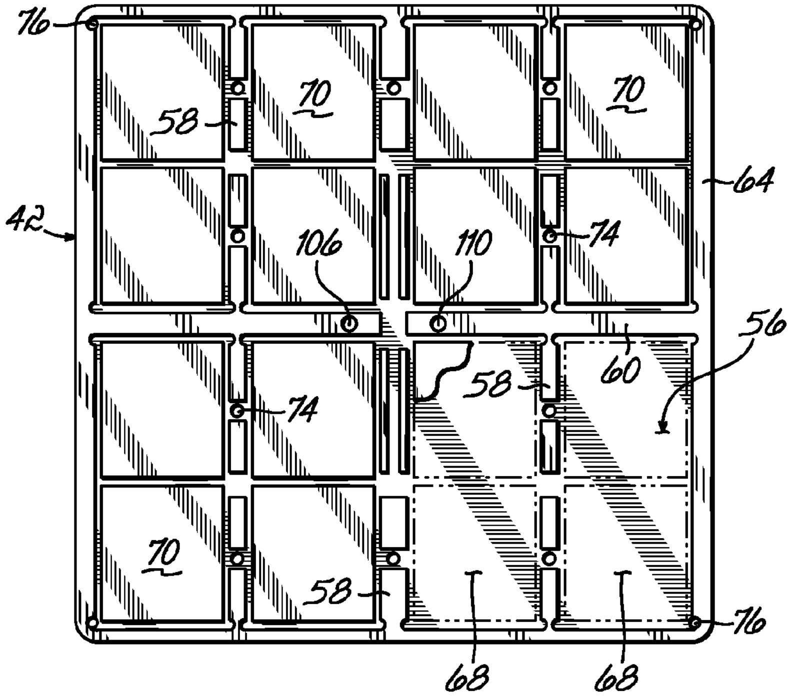

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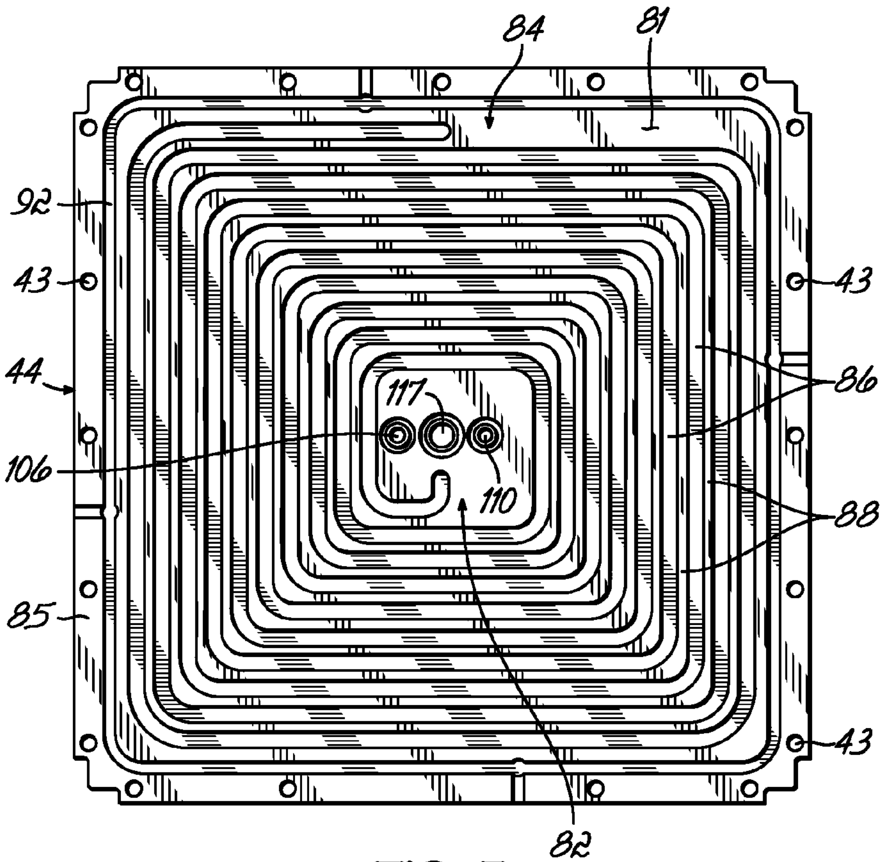
FIG. 4



84
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92
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FIG. 5

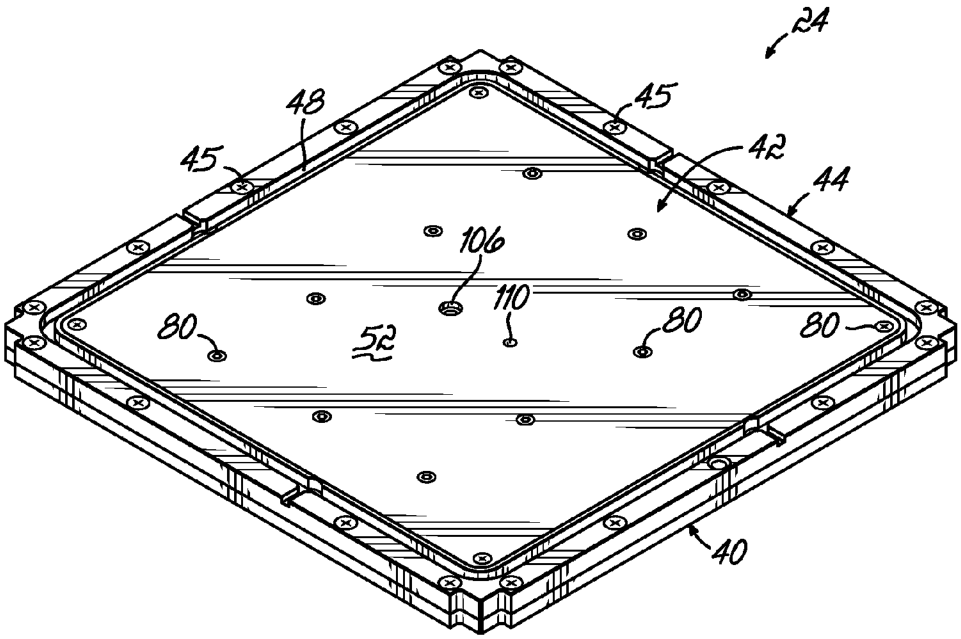

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FIG. 6

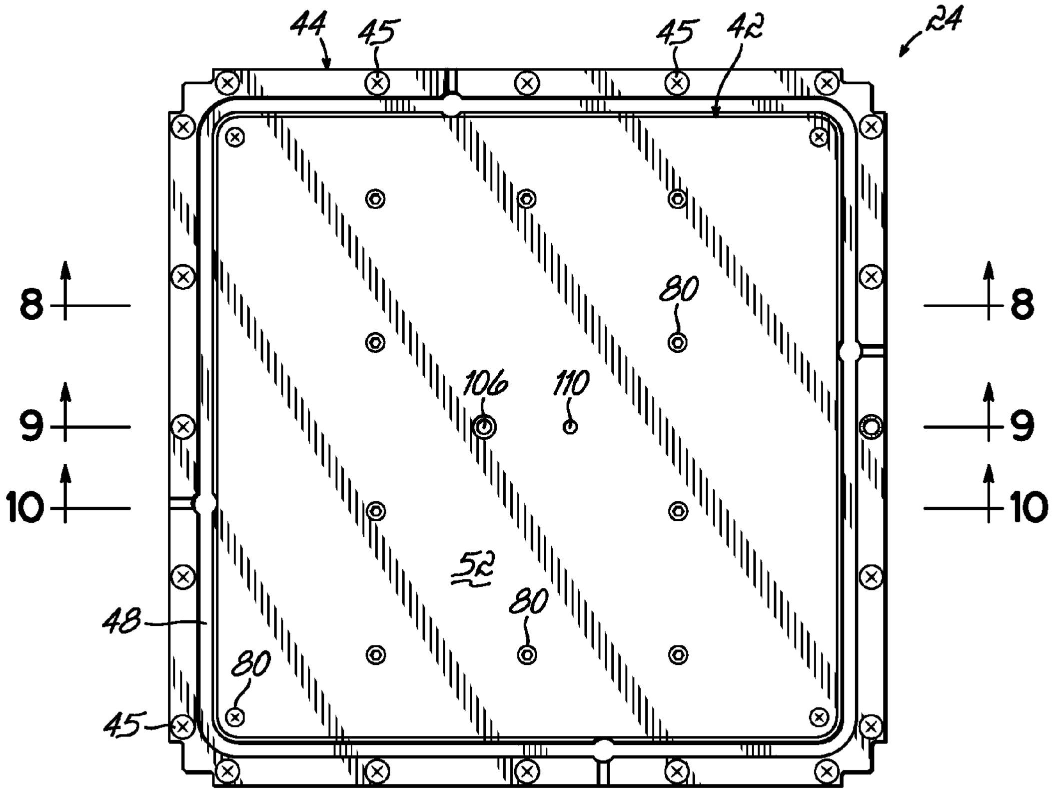

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FIG. 7

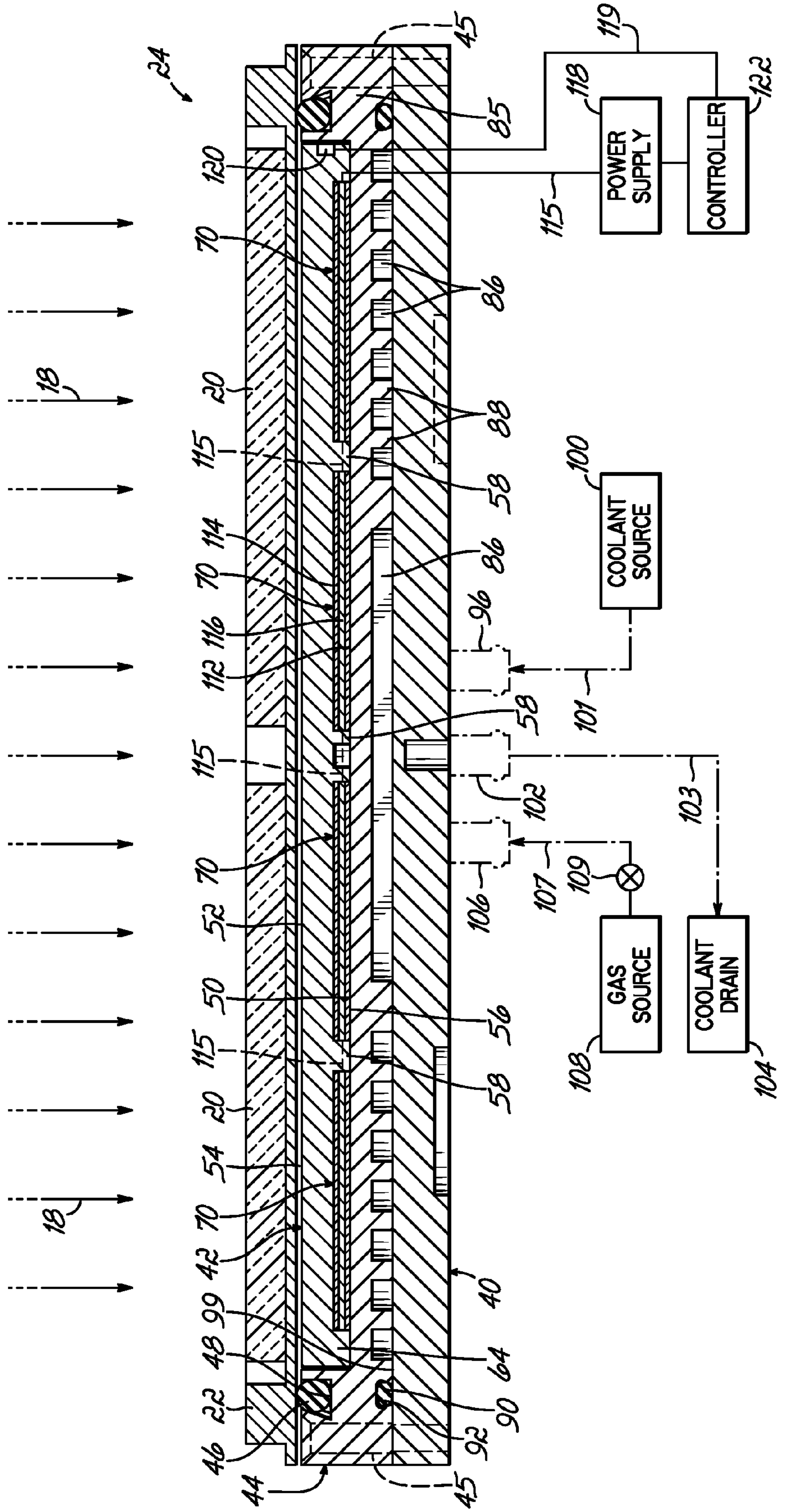
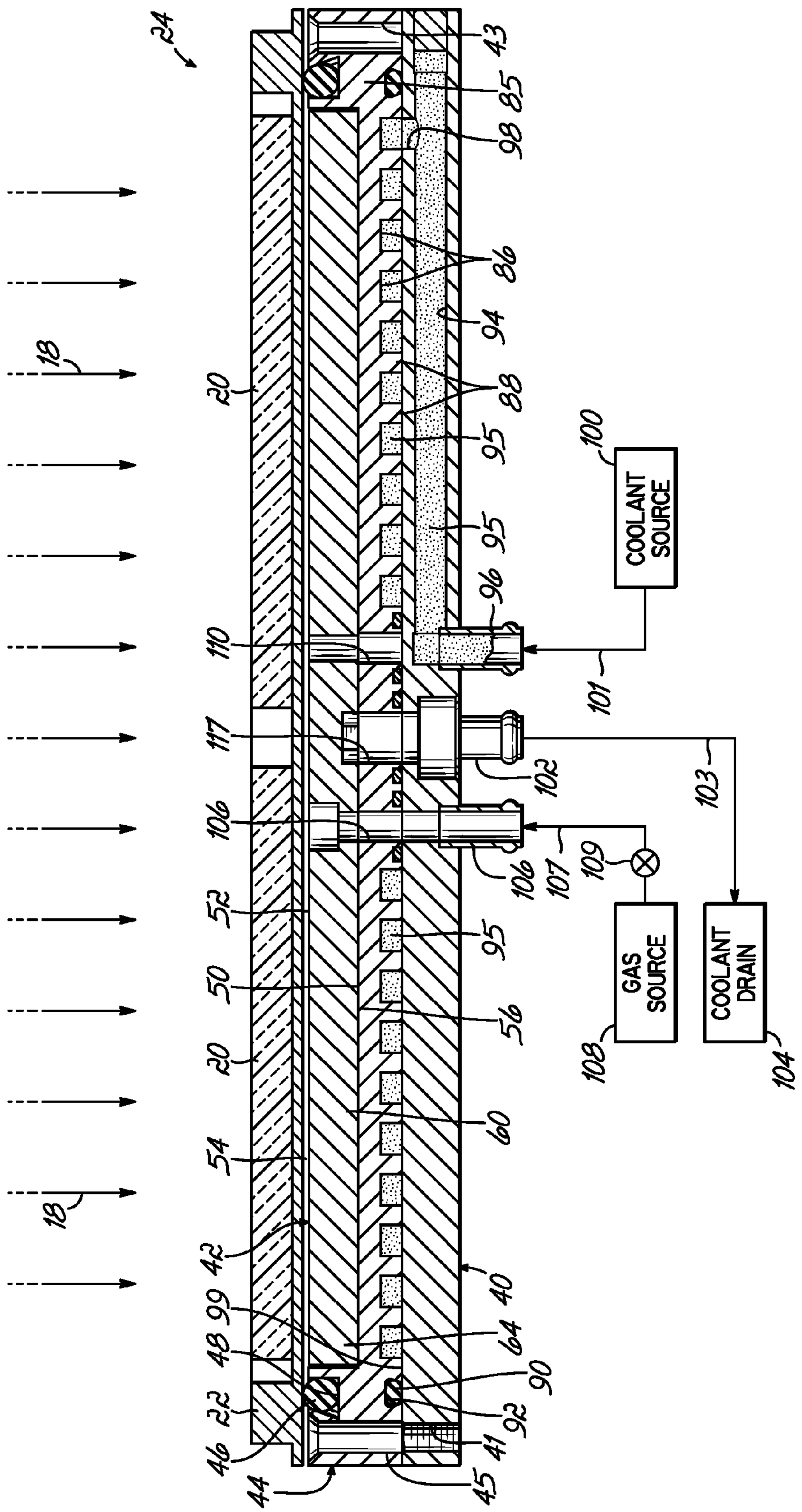

POWER SUPPLY
CONTROLLER
COOLANT SOURCE
GAS SOURCE
COOLANT DRAIN

FIG. 8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GAS SOURCE
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COOLANT DRAIN
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FIG. 9

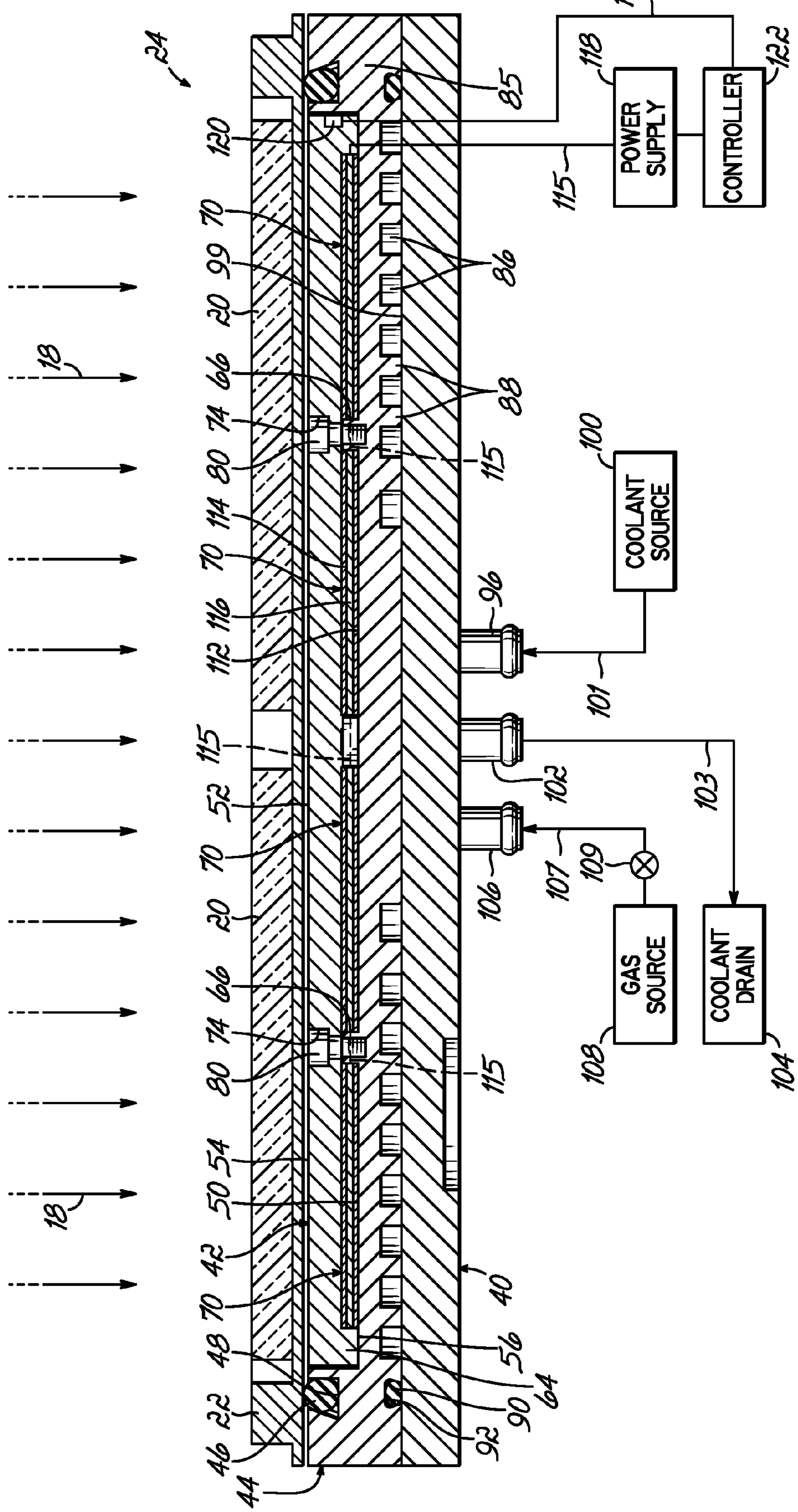
POWER SUPPLY
CONTROLLER
COOLANT SOURCE
GAS SOURCE
COOLANT DRAIN

FIG. 10

APPARATUS AND METHODS FOR MANAGING THE TEMPERATURE OF A SUBSTRATE IN A HIGH VACUUM PROCESSING SYSTEM

FIELD OF THE INVENTION

[0001] The invention relates generally to high vacuum processing systems and methods and, in particular, to apparatus and methods for controlling a temperature of a supported member, such as a substrate or one or more substrates supported on a pallet, during ion beam processing in a high vacuum processing system.

BACKGROUND OF THE INVENTION

[0002] Substrates are supported in vacuum chambers of high vacuum processing systems for treatment by processes such as ion beam etching, reactive ion etching, and plasma etching that remove a material layer from the substrates, processes such as ion beam deposition, physical vapor deposition, and chemical vapor deposition that deposit a material layer on the substrates, and other processes that modify a substrate surface property. In such surface treatment processes, the substrate rests on, or is secured to, a substrate support fixture, such as a platen, a chuck, or an electrode. During processing, a large amount of thermal energy is being transferred to the processed substrate, particularly in ion beam etch systems. At the same time, the processed substrate must be kept at, or below certain temperature levels. Therefore, the thermal energy must be transported from the substrate support fixture and dumped outside of the system. Therefore, the overall product throughput of the system is significantly limited by the cooling capacity of the support fixture. Beam-induced heating restricts the maximum etch rate that can be obtained for temperature-sensitive substrate materials, such as substrates fabricated from a polymer or organic resists coating a substrate.

[0003] The fabrication of thin film magnetic heads for magnetic storage devices requires high rate, high precision ion beam etching processes. Other processes, such as reactive ion etching, for forming thin film magnetic heads are tolerant of considerably higher etch rates than ion beam etching, but lack the precision of ion beam etching processes. Although the development of ion beam etching systems with higher achievable etch rates may have significant commercial importance, substrate cooling must be improved to accommodate the higher etching rates.

[0004] Heat conduction between a substrate and a conventional substrate holding fixture using backside heat transfer gas cooling is relatively inefficient in a near vacuum or other low pressure environment quite difficult because heat does not transfer well at these pressures. For example, the conduction of heat between coextensive surfaces of a substrate fixture and the substrate is slow and inefficient because actual contact on an atomic scale between the surfaces is limited to a small fraction of the coextensive contacting areas. Gaps that separate the remaining surface areas prohibit conduction.

[0005] In addition to adequate heat transfer, the substrate holding fixture must also easily clamp and release the substrate without damaging or contaminating the substrate and a high vacuum seal must be maintained between a sealing media and the vacuum chamber while the substrate is clamped to restrict escape of the heat transfer gas. The lack of heat transfer efficiency can be compensated by reducing the temperature of the substrate holding fixture to a much lower value than required at the substrate. Substrate holding fixtures may be cooled by circulating a chilled thermally conductive liquid, such as pure chilled water introduced at a temperature just above the liquid's freezing point, through narrow flow passages in the substrate fixture.

[0006] Despite the cooperation of these cooling techniques, conventional substrate fixtures cannot prevent substrate temperatures from being significantly elevated during a high power ion beam etching process. Many temperature-sensitive materials may be damaged at temperatures exceeding about 70° C. Consequently, the current of the impinging ion beam may be limited by the ability to cool the substrate when executing an ion beam etching process. Lower substrate temperatures may be obtained by adding a common freezing-point additive, such as ethylene glycol or propylene glycol, to the thermally conductive liquid. However, use of these freezing-point additives greatly increases the viscosity of the circulated liquid, which decreases the ability to flow the thermally conductive liquid through the narrow flow passages in the substrate fixture.

[0007] A different, but related, substrate temperature control problem is that the etch rate of certain materials, such as gallium nitride, is very temperature sensitive. As a result, the substrate temperature must be carefully controlled during ion beam etching processes for controlling the etch rate. In particular, the substrate temperature should be controlled to within a few degrees Celsius during the etch process and between different runs processing different substrates or groups of substrates. This level of temperature control is difficult to achieve using gas-assisted cooling because the substrate temperature cannot be precisely raised or lowered in correlation with variations in the process.

[0008] What is needed, therefore, are apparatus and methods improving the control of substrate temperature in high vacuum processing systems, such as ion beam etch (IBE) systems, that overcome these and other disadvantages of conventional thermally-controlled substrate fixtures used in high vacuum processing equipment and conventional methods for controlling the temperature of substrate fixtures.

SUMMARY OF THE INVENTION

[0009] The present invention is directed generally to apparatus and methods for improving the control of the temperature of a supported member, such as a substrate or a pallet carrying one or more substrates, in high vacuum processing systems, such as ion beam etch (IBE) systems. In accordance with an embodiment of the invention, an apparatus is provided for controlling the temperature of a supported member exposed to a treatment that heats the substrate. The apparatus comprises a first member having a surface configured to support the supported member and a second member coupled with the first member. The first member receives heat from the supported member transferred to the surface and the second member includes a channel configured for a flow of a temperature control liquid. A supply passageway extends through the first and second members to communicate with a heat transfer gas space defined between the surface of the first member and the supported member. Thermoelectric devices are disposed between the first and second members. Each of the thermoelectric devices has a first side contacting the first member proximate to the surface and a second side contacting the second member proximate to the liquid-carrying channel. The thermoelectric devices transfer heat between the first and second sides to regulate the temperature of the first member and, thereby, the temperature of the supported member.

[0010] In accordance with another embodiment of the invention, a method for controlling the temperature of a supported member comprises exposing the supported member to an ion beam that heats the supported member, transferring heat from the supported member with a backside gas in a heat transfer gas space between a backside of the substrate and a surface of a support member. The method further comprises cooling the support surface with a plurality of thermoelectric devices that transfer the heat from the support member to a heat transfer member and cooling the heat transfer member with a flow of a thermally conductive liquid.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and, together with a general description of the invention given above and the detailed description of the embodiments given below, serve to explain the principles of the invention.

[0012] FIG. **1** is a cross-sectional view of a portion of a high vacuum processing system incorporating a substrate fixture in accordance with an embodiment of the invention.

[0013] FIG. **2** is a top perspective view of a cap plate and a heat exchange plate of the substrate fixture of FIG. **1** shown disassembled for clarity.

[0014] FIG. **3** is a bottom perspective view of the cap plate and heat exchange plate of the substrate fixture of FIG. **1** shown disassembled for clarity.

[0015] FIG. **4** is a bottom view of the heat exchange plate of FIGS. **2** and **3** shown with the thermoelectric coolers present.

[0016] FIG. **5** is a bottom view of the cap plate of FIGS. **2** and **3**.

[0017] FIG. **6** is a top perspective view of the substrate fixture of FIG. **1**.

[0018] FIG. **7** is a top view of the substrate fixture of FIG. **6** in which the substrate-supporting pallet is omitted for clarity.

[0019] FIG. **8** is a cross-sectional view taken generally along line **8-8** in FIG. **7** and in which the substrate-supporting pallet is positioned on the substrate fixture.

[0020] FIG. **9** is a cross-sectional view taken generally along line **9-9** in FIG. **7** and in which the substrate-supporting pallet is positioned on the substrate fixture.

[0021] FIG. **10** is a cross-sectional view taken generally along line **10-10** in FIG. **7** and in which the substrate-supporting pallet is positioned on the substrate fixture.

DETAILED DESCRIPTION

[0022] With reference to FIG. **1**, a high vacuum processing system **10** in the form of an ion beam etch system includes a vacuum chamber or vessel **12** having a vacuum-tight chamber wall **13**, which is only partially shown, that encloses an evacuated processing space **15**. A port **14** with a lumen extending through the chamber wall **13** places the processing space **15** in communication with a vacuum pump **16**. The vacuum pump **16** includes suitable components with a pumping capacity effective for evacuating the processing space **15** of the vacuum vessel **12** to a vacuum pressure suitable for processing one or more substrates **20** with an ion beam **18** of charged particles. The charged particles in the ion beam **18** may be positive ions generated by an ion source (not shown) from an ionizable working gas and accelerated toward the substrates **20**. Bombardment of the substrates **20** by the ion beam **18** processes the substrates **20** to achieve an intended beneficial result. Among other beneficial results, the ion beam **18** may be used to remove material from the surface of the substrates **20** by an etching process. The substrates **20**, which are secured in fixed spatial relationship with a pallet **22** by cooperating clamp members (not shown), are positioned spatially inside the processing space **15** at a location exposed to the ion beam **18**.

[0023] A substrate chuck or fixture **24** supports the pallet **22** and the substrates **20** carried on the pallet **22** in the processing space **15** inside the vacuum vessel **12**. The substrate fixture **24** is mounted to a tubular access column **26** extending through a sealed opening **28** in an end region **29** of the chamber wall **13**. An upper end of the access column **26** has a sealed engagement with the substrate fixture **24**. The access column **26** encloses a lumen through which electrical and fluid utilities are routed to the substrate fixture **24**.

[0024] The substrate fixture **24** is biased by biasing elements having the form of compression springs **30** that are compressed between the substrate fixture **24** and a support plate **32** inside the processing space **15**. The support plate **32** is mounted to the access column **26**. The compression springs **30** exert a force biasing the substrate fixture **24** in a direction away from the end region **29** of the chamber wall **13**. Each of a plurality of actuators (not shown), which may comprise bi-directional pneumatic cylinders, includes a piston moving a rod **34** mechanically coupled with the substrate fixture **24**. Motion of the rods **34** moves the substrate fixture **24** relative to the pallet **22** and against the biasing force of the compression springs **30** to provide a clearance between the pallet **22** and substrate fixture **24**. A transfer mechanism (not shown) is inserted into the clearance between the pallet **22** and substrate fixture **24** to lift or otherwise remove the pallet **22** during exchanges of processed and unprocessed substrates **20**.

[0025] The substrate fixture **24** is located inside the inner perimeter of a frame **36**. Spanning between the frame **36** and support plate **32** are stanchions **38** that space the support frame **36** from support plate **32**. Frame **36** includes stationary lift arms (not shown) disposed at the notched or scalloped corners of the substrate fixture **24**, which are best visible in FIG. **6**, and projecting inwardly from the inner perimeter of the frame **36**. When the substrate fixture **24** is lowered toward the support plate **32**, the corners of the pallet **22** contact the lift arms so that the pallet **22** is lifted from the support fixture **24** to provide the necessary clearance between the pallet **22** and substrate fixture **24**.

[0026] With reference to FIGS. **2-10**, the substrate fixture **24** includes a base member or base plate **40**, a support member or cap plate **42**, and a heat exchange member or heat exchange plate **44** disposed between the base plate **40** and the cap plate **42**. The base plate **40** and heat exchange plate **44** are secured together as an assembly by fasteners **45** (FIG. **9**) coupled with threaded openings **41** (FIG. **9**) in base plate **40** and extending through clearance openings **43** in heat exchange plate **44**. An O-ring **46** (FIGS. **8-10**) is seated in an

O-ring groove **48** (FIG. **2**) extending peripherally about the perimeter of the cap plate **42** and circumscribes a recessed upper surface or side **50** of the heat exchange plate **44**. The O-ring **46** sits in the O-ring groove **48** such that the O-ring **46** is partially raised above an upper surface or side **52** of the cap plate **42**. The pallet **22** contacts the O-ring **46** to peripherally seal and define a heat transfer gas space **54** (FIGS. **8-10**) as a gap between the underside of the pallet **22** and the upper side **52** of the cap plate **42**. The invention contemplates that a single substrate (not shown) may be processed without the assistance of pallet **22** as the intermediate supported member supported by the cap plate **42**. In the absence of pallet **22**, the supported member supported by the cap plate **42** may be a single substrate that directly contacts the O-ring **46** to peripherally seal and define the heat transfer gas space **54**.

[0027] A lower surface or side **56** of the cap plate **42**, which is disposed opposite to upper side **52**, includes a grid of ribs comprising a plurality of narrow spacers or ribs **58** and a thin spacer or rib **60** having a discontinuity near the center of cap plate **42**. Ribs **58** are arranged in a plurality of rows and a thin rib **60** is arranged to bisect the rows of ribs **58**. Projecting from the lower side **56** of cap plate **42** is a rim **64** that extends about the periphery of the cap plate **42** and encircles a recess **65**. The ribs **58**, **60** lend structural support to the cap plate **42**.

[0028] Posts **66** project from the upper side **50** of the heat exchange plate **44** toward the lower side **56** of cap plate **42**. The ribs **58**, **60** and posts **66** cooperate with rim **64** to define a grid of partitions that compartmentalize recess **65** into a plurality of, for example, sixteen individual compartments **68**. Each of the individual compartments **68** is dimensioned to receive a corresponding one of a plurality of thermoelectric devices **70** (FIG. **4**), although the invention does not require that each compartment **68** be filled with a thermoelectric device **70**. Centrally-located ribs **58** may be bifurcated into closely-spaced parallel upright members and the ribs **58** are segmented by grooves to provide wireways for routing wires **115** (FIG. **8**) to the thermoelectric devices **70**. Threaded openings **72** in posts **66** are registered with countersunk clearance openings **74** in the cap plate **42**. Additional registered pairs of countersunk clearance openings **76** and threaded openings **78** are provided in the cap plate **42** and heat exchange plate **44**, respectively. Small fasteners **80** extending through registered openings **72**, **74** and registered openings **76**, **78** operate to secure the assembled cap plate **42** and heat exchange plate **44** together.

[0029] The upper side **52** of the cap plate **42** is generally planar so that the heat transfer gas space **54** (FIGS. **8-10**) has a substantially uniform height inside the perimeter circumscribed by O-ring **46** (FIGS. **8-10**). The compartments **68** are arranged such that the thermoelectric devices **70** are disposed in a plane substantially parallel to the upper side **52** of the cap plate **42**.

[0030] A lower surface or side **81** of the heat exchange plate **44**, which is disposed opposite to upper side **50**, includes a central liquid region **82**, a peripheral liquid region **84** near the perimeter of the heat exchange plate **44**, a liquid channel **86** coupling the liquid regions **82**, **84**, and a rim **85** that circumscribes the liquid regions **82**, **84** and liquid channel **86**. The liquid channel **86** is defined by a thin-walled partition **88** carried by the lower side **81** of heat exchange plate **44**. The partition **88** contacts the base plate **40** so that the liquid channel **86** is partially closed by an upper surface or side **99** of the base plate **40**. An O-ring **90** (FIGS. **8-10**), which is stationed in an O-ring groove **92** extending about the rim **64** of the heat exchange plate **44** and is compressed between the upper side **99** of base plate **40** and the heat exchange plate **44**, seals with the rim **85** of the base plate **40**.

[0031] A liquid passageway **94** in the base plate **40** couples a liquid inlet **96**, which is defined by a fitting, with a liquid outlet **98**. The liquid outlet **98** emerges from the upper side **99** of the base plate **40** to communicate with the peripheral liquid region **84** of the heat exchange plate **44**. Liquid channel **86** winds helically about the central liquid region **82** for directing a coolant or thermally conductive liquid **95** of a pre-selected temperature between the base plate **40** and the heat exchange plate **44**. The liquid inlet **96** is coupled by a conduit **101** with an external coolant source **100**. Another liquid passageway (not shown) in the base plate **40** communicates with the peripheral liquid region **84** and is coupled by a drain passage **102** with a conduit **103** extending to a coolant drain **104**. The coolant drain **104** either disposes of the elevated-temperature thermally liquid **95** heated by flow through liquid channel **86** or cools the elevated-temperature thermally liquid **95** for recirculation. Alternatively, the thermally conductive liquid **95** may be circulated in the opposite direction from the central liquid region **82** to the peripheral liquid region **84**. The thermally conductive liquid **95** flowing through the liquid channel **86** may be chilled pure water at 5° C. to 10° C. supplied from a chiller unit integrated into coolant source **100**, although the invention is not so limited.

[0032] Extending through the base plate **40**, cap plate **42**, and heat exchange plate **44** is a central inlet gas passageway **106** (FIG. **9**), which emerges on the upper side **52** of cap plate **42**. An external gas source **108** is coupled by a conduit **107** with the inlet gas passageway **106** with the heat transfer gas space **54** defined between the pallet **22** and the cap plate **42**. Pressurized backside gas, such as helium, is transferred through the inlet gas passageway **106** and exhausted from the inlet gas passageway **106** to the heat transfer gas space **54**. The gas flow is regulated by a flow control device **109**. A central outlet gas passageway **110** (FIG. **9**) extends through the cap plate **42** and heat exchange plate **44** for coupling the heat transfer gas space **54** with an exhaust conduit (not shown). The backside heat transfer gas in space **54** facilitates the transfer of heat between the pallet **22** and the cap plate **42** by mechanisms understood by a person having ordinary skill in the art.

[0033] The invention contemplates that the atmosphere of heat transfer gas in space **54** may be static while the substrates **20** are being treated by ion beam **18** or may dynamically flow through the heat transfer gas space **54**. Exemplary dynamic flow devices are described in U.S. Pat. No. 4,949,783, which is hereby incorporated by reference herein in its entirety, and are commercially available in high vacuum processing systems under the Flowcool™ trade name from Veeco Instruments Inc. (Woodbury, N.Y.).

[0034] As best shown in FIGS. **4**, **8**, and **10**, each of the thermoelectric devices **70** includes a lower support plate **112**, an upper support plate **114**, and multiple thermoelectric elements **116** extending between the lower and upper support plates **112**, **114**. The thermoelectric elements **116** consist of an array of up to several hundred dissimilar n-type and p-type semiconductors, which may be formed from p-doped and n-doped bismuth-telluride, thermally joined in parallel and electrically joined in series at both ends to form couples. The lower and upper support plates **112**, **114** may be thin ceramic wafers with a relatively high thermal conductivity that add rigidity and electrically insulate the thermoelectric elements **116**. One or both of the support plates **112**, **114** includes metallization, which is dispoed on a surface that does not confront the cap plate **42** or heat transfer plate **44**, or another circuit interface used to electrically couple the thermoelectric elements **116** with the terminals of a power supply **118**. Typically, these electrical connections are coupled with the power supply **118** by the conductors of insulated wires **115**, which constitute the positive and negative leads to the thermoelectric elements **116**. The power supplied by the power supply **118** over wires **115** is normally direct current (DC) power. The wires **115** are routed through the lumen of access column **26** and an electrical feedthrough (not shown) filling a passage **117** extending through the base plate **40** and heat transfer plate **42**.

[0035] The thickness of the thermoelectric devices **70** is selected relative to the vertical dimension of the ribs **58**, **60** and rim **64** such that, when the cap plate **42** and the heat exchange plate **44** are fastened together, the ribs **58**, **60** and rim **64** fail to contact the upper side **50** of the heat exchange plate **44** and the posts **66** fail to contact the lower side **56** of the cap plate **42**. The thermoelectric devices **70** are clamped between the cap plate **42** and heat exchange plate **44**, which constrains lateral movement of the thermoelectric devices **70** within the compartments **68**. The lower side **56** of the cap plate **42** and the upper side **50** of the heat exchange plate **44** are separated by a gap defined predominantly by recess **65** (FIG. **3**) and partially by thin gaps, which are considerably smaller and not visible in the drawings, where ribs **58**, **60** and rim **64** confront the upper side **50** of heat exchange plate **44** and where posts **66** confront the lower side **56** of cap plate **42**. These gaps interrupt potential heat transfer paths between the cap plate **42** and heat exchange plate **44** so that these members are substantially thermally isolated from each other. The fasteners **80**, which have a relatively small cross-sectional area that limit their ability to transfer heat, supply the only conductive paths between the cap plate **42** and heat exchange plate **44**. In an alternative embodiment of the invention, the fasteners **80** may be formed from a non-metal or thermal insulator characterized by a low thermal conductivity to further reduce heat transfer between the cap plate **42** and heat exchange plate **44**. An annular gap, as best shown in FIGS. **6** and **7**, is also present between the perimeter of the rim **64** of cap plate **42** and the confronting inner edge of the rim **85** of heat transfer plate **44** for further disrupting heat flow between these members.

[0036] The thermoelectric devices **70**, which operate by the Peltier effect as understood by a person having ordinary skill in the art, convert electrical energy from the power supply **118** to heat pumping energy. In particular, direct current power applied between the lower and upper support plates **112**, **114** induces pumped heat flow from the cap plate **42** through the thermoelectric elements **116** to the heat exchange plate **44** as the thermoelectric elements **116** convert electrical energy to heat pumping energy. Heat is conducted through the thermoelectric elements **116** and between the support plates **112**, **114** by charge carriers. As heat is continuously absorbed from the upper support plate **114** and transferred by the thermoelectric elements **116** to the lower support plate **112**, the upper support plate **114** defines a cold side of each thermoelectric device **70** that absorbs heat and the lower support plate **112** defines a hot side that rejects the heat.

[0037] The upper support plate **114** of each thermoelectric device **70** is in physical and thermal contact with the lower side **56** of cap plate **42** to establish a thermal interface for the absorption of thermal energy or heat from the cap plate **42** across the shared areas of thermal contact. The upper support plates **114** contact a majority of the surface area of the lower side **56** of cap plate **42** for absorbing heat from the cap plate **42**. The contacting surface area may extend across approximately 90% of the surface area of the lower side **56** of cap plate **42**. The lower support plate **112** of each thermoelectric device **70** is in physical and thermal contact with the upper side **50** of heat exchange plate **44** to establish another thermal interface for the flow of the rejected heat from the thermoelectric devices **70** to the heat exchange plate **44** across the shared areas of contact. A thermally conductive medium (not shown), such as a thermal grease or graphite pads, may be placed between the lower support plate **112** of each thermoelectric device **70** and the thermal transfer plate **44** and between the upper support plate **114** of the thermoelectric devices **70** and the cap plate **42** to act as a conductive interface and, thereby, potentially improve the thermal contact.

[0038] The properties and number of thermoelectric devices **70** may be tailored to provide a targeted reduction in the temperature of the cap plate **42**. The thermoelectric devices **70** may be selected from among the XLT series of thermoelectric coolers commercially available from Marlow Industries Inc. (Dallas, Tex.), which exhibit a durability adequate to survive a high number of continuous cycles over a broad temperature range. Although the invention is not so limited, a specific thermoelectric device **70** suitable for use in the invention is the model XLT2385 thermoelectric cooler commercially available from Marlow Industries Inc. (Dallas, Tex.), which is capable of providing a maximum temperature drop for an unloaded state of 56.5° C.-dry N_2 from the cold side to the hot side with the hot side at a temperature of 27° C. and a maximum temperature drop for an unloaded state of 64.0° C.-dry N_2 from the cold side to the hot side with the hot side at a temperature of 50° C. The thermoelectric devices **70** may comprise single stage thermoelectric devices or, alternatively, may comprise stacked or cascaded thermoelectric devices.

[0039] In use and with reference to FIGS. **1-10**, heat transfer gas is supplied to heat transfer gas space **54** and the thermally conductive liquid **95** is flowed through the liquid channel **86**. The cooling effect of the flowing thermally conductive liquid **95** in liquid channel **86** reduces the temperature of the heat exchange plate **44** and the cap plate **42**. The temperature reduction from the flowing thermally conductive liquid **95** is further communicated by the heat exchange plate **44** to the cap plate **42**. The thermoelectric devices **70** are energized by the power supply **118**, which causes heat transfer or heat flow in a direction from the cap plate **42** to the upper support plate **114** of each thermoelectric device **70** and through the thermoelectric elements **116** to the lower support plate **112**. The heat transfer through the thermoelectric devices **70** reduces the temperature of the upper support plate **114**. A temperature differential exists between the lower and upper support plates **112**, **114** that increases in a direction from the upper support plate **114** to the lower support plate **112**.

[0040] The incident ion beam **18** on the pallet **22** and the substrates **20** carried on the pallet **22** represents a heat load in that a fraction of the ion kinetic energy of each incident ion is converted to heat. The backside heat transfer gas in the heat transfer gas space **54** transfers heat away from the substrates **20** and pallet **22** to the cap plate **42**. A significant portion of the generated heat is subsequently transferred from the cap plate **42** to the upper support plate **114** of each thermoelectric device **70**, which cools the cap plate **42**. The thermoelectric devices **70** operate as temperature-modifying elements for corresponding portions of the pallet **22** to extract heat from portions of the substrates **20** to which each is closest. A portion of the heat is transferred by thermal conduction between contacting portions of the cap plate **42** and heat exchange plate **44**. The heat is subsequently transferred from the lower support plate **112** of each thermoelectric device **70** to the heat exchange plate **44** and to the thermally conductive liquid **95** flowing through the liquid channel **86**. A temperature gradient exists because of heat flow from the heated substrates **20** to the heat exchange plate **44**. The thermally conductive liquid **95**, which is warmed from its inflow temperature by the transferred heat, removes the heat from the substrate fixture **24** for external dissipation.

[0041] The temperature of the processed substrates **20** reflects the temperature of the cap plate **42**. The presence of the thermoelectric devices **70** increases the net drop in temperature across the cap plate **42** and the heat exchange plate **44** of substrate fixture **24** so that the substrates **20** are maintained at a lower temperature while exposed to the ion beam **18**. As a result, heat is more efficiently transferred away from the substrates **20**. Because of the additional incremental temperature reduction provided by the thermoelectric devices **70**, the current of the ion beam **18** in the high vacuum processing system **10** used to process the substrates **20** may be increased to increase the etching rate and system throughput. Certain temperature-sensitive materials, such as gallium nitride, may be processed in the high vacuum processing system **10** without damaging the substrates **20**. The temperature reduction of the substrate fixture **24** is achieved without adding common freezing-point additives, such as ethylene glycol or propylene glycol, to the thermally conductive liquid **95** flowing through the liquid channel **86**.

[0042] In an alternative embodiment of the invention, a drive mechanism (not shown) may be coupled with the substrate fixture **24** for rotating and/or tilting all, or part, of the substrate fixture **24** and, therefore, the substrates **20** carried on the pallet **22** relative to the ion beam **18** and chamber wall **13**. Electrical connections for the drive mechanism may be routed through the access column **26** to a drive mechanism inside the vacuum vessel **12** or the access column **26** may actively participate in the rotation and/or tilting. The electrical interface electrically coupling the thermoelectric devices **70** with the power supply **118** may comprise a slip ring (not shown) often used to provide a signal transmission path when transmitting electrical signals between a stationary structure and a structure that rotates with respect to the stationary structure. Generally, slip rings typically include conductive brushes that contact conductive bands to pass electrical current from the stationary structure to the rotating structure.

[0043] In certain embodiments of the invention, the substrate fixture **24** may include at least one temperature sensor **120** (FIG. **8**) that detects or measures the temperature of the cap plate **42** of the substrate fixture **24**. The temperature sensor **120** supplies the measured temperature as feedback signals on a continuing or intermittent basis to a temperature controller **122** (FIG. **8**) interfaced with the power supply **118** to define a temperature control unit. Alternatively, the temperature feedback signals may be supplied to another controller (not shown) associated with the high vacuum processing system **10** and interfaced with the power supply **118**. The temperature sensor **120** may be embedded in the cap plate **42**, as depicted in FIG. **8**, or may be otherwise thermally coupled with the substrate fixture **24**. Multiple temperature sensors **120** may be disposed at different locations in the substrate fixture **24** to provide distributed temperature information to the power supply **118** for ensuring temperature uniformity across the cap plate **42**. Suitable temperature sensors **120** include resistance temperature detectors, thermocouples, thermistors, and infrared devices, although the invention is not so limited. In one embodiment of the invention, the temperature sensor **120** may be a thermocouple thermally coupled with rib **60** of the cap plate **42**.

[0044] A temperature controller **122** receives the temperature information as input from the temperature sensor **120** across an insulated conductor or wire **119** that establishes a communications path. The temperature controller **112** may utilize the temperature feedback information to regulate the operating power delivered from the power supply **118** to the thermoelectric devices **70** so as to improve the ability to precisely control the temperature of the substrates **20**. The temperature controller **122** may include a programmable system, such as a microprocessor, capable of being programmed to execute instructions effective to control the temperature of the cap plate **42** of the substrate fixture **24** and the substrates **20** at one uniform temperature. In particular, the temperature controller **122** calculates control signals for the thermoelectric devices **70** and sends the calculated control signals to the power supply **118**. The power supply **118** responds to the control signals by changing the electrical current supplied to the thermoelectric devices **70**. The electrical current through the thermoelectric devices **70** is increased or decreased by the power supply **118**, as required, in relation to a difference between the measured temperature and a temperature set point established in a comparative control circuit or by a software control residing in the temperature controller **122**. Maintaining the cap plate **42** of the substrate fixture **24** at, or near, a measured temperature operates to maintain the substrates **20** below a certain temperature.

[0045] The program executed by the temperature controller **122** may provide for varying the temperature as a function of time and may include cycling the cap plate **42** of the substrate fixture **24** and the substrates **20** through ranges of temperatures during processing. The temperature controller **122** may be a proportional, a proportional-derivative (PD), a proportional-integral (PI), or a proportional-integral-derivative (PID) controller that uses feedback information from the temperature sensor **120** to control the substrate temperature based upon deviations of the measured temperature from the temperature set point. In this manner, the sensor **120** and temperature controller **122** cooperate to provide a closed loop control system.

[0046] The temperature controller **122** may also calculate and send additional control signals to the coolant source **100** to control the flow of the thermally conductive liquid **95** to liquid inlet **96** and, ultimately, liquid channel **86**. The temperature controller **122** may also control the temperature of the thermally conductive liquid **95**.

[0047] For expanded temperature control, the temperature controller **122** may be configured to switch the thermoelectric devices **70** between heating and cooling by reversing the current delivered from the power supply **118** to the support plates **112**, **114**. In this switched condition in which the temperature controller **122** is configured for bipolar operation, the thermoelectric devices **70** may be used to heat the substrate fixture **24**, for example, before venting the vacuum vessel **12** of the high vacuum processing system **10** to atmosphere. The temperature controller **122** may include a relay that permits bipolar operation.

[0048] The thermoelectric devices **70** are shown wired or otherwise electrically connected in series with the power supply **118**. Alternatively, the thermoelectric devices **70** may be wired or otherwise electrically connected in parallel with the power supply **118**. In an alternative embodiment of the invention, some of the thermoelectric devices **70** may be serially coupled to the power supply **118** for cooling the substrate fixture **24** and the remainder of the thermoelectric devices **70** may be serially coupled for heating the substrate fixture **24**. The ability to heat and cool the substrate fixture **24** improves the precision of temperature regulation. The power supply **118** is operated under the control of temperature controller **122** to regulate the currents through the thermoelectric devices **70** to maintain a desired substrate temperature for the nearest substrate **20** (or substrate portion) by heating or cooling the portion of the pallet **22** carrying the substrate **20**. The thermoelectric devices **70** may be used to establish a controlled substrate temperature above ambient temperature in some processes to volatilize etch products from the ion beam process and, thereby, increase the reactive etching rate.

[0049] Further details and embodiments of the invention will be described in the following example.

EXAMPLE AND COMPARATIVE EXAMPLE

[0050] A substrate fixture, substantially similar to substrate fixture **24**, was equipped with an array of sixteen thermoelectric devices arranged as shown in FIGS. **1-10**. The thermoelectric devices were model XLT2385 thermoelectric coolers manufactured by Marlow Industries Inc. (Dallas, Tex.). The thermoelectric coolers were operated at a one-quarter of their rated power to cool the cap plate of the substrate fixture. The temperature of the cap plate **42** was monitored using a thermocouple. An ion beam having a beam voltage of 800 volts (V) and a beam current of 1200 milliamps (mA) was directed onto a substrate supported on the cap plate. The ion beam, which delivered a beam power of 960 watts, is characterized by an etch rate of about 55 nm/min. While exposed to the ion beam, the temperature of the cap plate measured by the thermocouple was less than 50° C.

[0051] Under the same conditions and for purposes of comparison, a substrate supported by the cap plate of a substrate fixture lacking thermoelectric devices was exposed to an ion beam having a beam voltage of 700 volts and a beam current of 1100 milliamps. This ion beam, which delivered a beam power of 770 watts, is characterized by an etch rate of about 45 nm/min. While exposed to the ion beam, the observed temperature of the cap plate was approximately 70° C.

[0052] While the present invention has been illustrated by a description of various embodiments and while these embodiments have been described in considerable detail, it is not the intention of the applicants to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. Thus, the invention in its broader aspects is therefore not limited to the specific details, representative apparatus and method, and illustrative example shown and described. Accordingly, departures may be made from such details without departing from the spirit or scope of applicants' general inventive concept.

What is claimed is:

1. An apparatus for controlling the temperature of a supported member exposed to a treatment that heats the supported member, the apparatus comprising:

a support member having a surface configured to support the supported member, said support member receiving heat from the supported member transferred to said surface;

a heat transfer member coupled with said support member, said heat transfer member including a channel configured for a flow of a temperature control liquid;

a supply passageway extending through said support and heat transfer members to communicate with a heat transfer gas space defined between said surface of said support member and the supported member; and

a plurality of thermoelectric devices disposed between said support and heat transfer members, each of said thermoelectric devices having a first side contacting said support member proximate to said surface and a second side contacting said heat transfer member proximate to said channel, and each of said thermoelectric devices transferring heat between said first and second sides to regulate the temperature of said support member.

2. The apparatus of claim **1** further comprising:

at least one temperature sensor for detecting a temperature of said support member and generating electrical signals related to said detected temperature.

3. The apparatus of claim **2** further comprising:

a temperature control unit coupled to said temperature sensor for receiving said electrical signals and coupled with said thermoelectric devices, said temperature control unit adapted to regulate power delivered to said thermoelectric devices based upon said electrical signals for controlling the temperature of said support member.

4. The apparatus of claim **3** wherein said thermoelectric devices are connected in series with the temperature control unit.

5. The apparatus of claim **3** wherein said thermoelectric devices are connected in parallel with the temperature control unit.

6. The apparatus of claim **1** wherein said thermoelectric devices are positioned between said surface of said support member and said channel in said heat transfer member.

7. The apparatus of claim **1** wherein said first side of each of said thermoelectric devices is a cold side and said second side of each of said thermoelectric devices is a hot side for transferring heat from said cold side to said hot side to cool the support member.

8. The apparatus of claim **1** wherein said support and heat transfer members bound a plurality of compartments, each of said compartments receiving a corresponding one of said thermoelectric devices.

9. The apparatus of claim **8** wherein said support member comprises a peripheral rim and a grid of ribs circumscribed by said peripheral rim for defining said compartments.

10. The apparatus of claim **8** wherein said compartments are arranged such that said thermoelectric devices are disposed in a plane substantially parallel with said surface of said support member.

11. The apparatus of claim **1** further comprising:

a drain passageway communicating with said heat transfer gas space, said drain passageway permitting a flow of heat transfer gas from said supply passageway to said drain passageway.

12. The apparatus of claim **1** wherein said support member is separated from said heat transfer member by a gap that limits direct heat transfer between the first and heat transfer members.

13. The apparatus of claim **12** wherein said thermoelectric devices separate said first and heat transfer members to define the gap.

14. A method for controlling the temperature of a supported member, the method comprising:

exposing the supported member to an ion beam that heats the supported member;

transferring heat from the supported member with a backside gas in a heat transfer gas space between a backside of the supported member and a surface of a support member;

cooling the support member with a plurality of thermoelectric devices that transfer the heat from the support member to a heat exchange member; and

cooling the heat exchange member with a flow of a thermally conductive liquid.

15. The method of claim **14** further comprising:

specifying a reference temperature to which the supported member is to be cooled while exposed to the ion beam;

measuring a temperature representative of the temperature of the supported member; and

regulating the operation of the thermoelectric devices to compensate for a difference between the reference and measured temperatures.

16. The method of claim **15** wherein measuring the temperature representative of the temperature of the supported member further comprises:

measuring the temperature of the support member.

17. The method of claim **15** further comprising:

increasing the power delivered to the supported member by the ion beam; and

reducing the representative temperature to compensate for the increased delivered power.

18. The method of claim **14** further comprising:

heating the support member with the thermoelectric devices; and

venting a vacuum vessel housing the support member to atmospheric pressure.

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