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(54) **SYSTEM FOR GAS PURIFICATION IN AN INDUCTION VACUUM FURNACE AND METHOD OF MAKING SAME**

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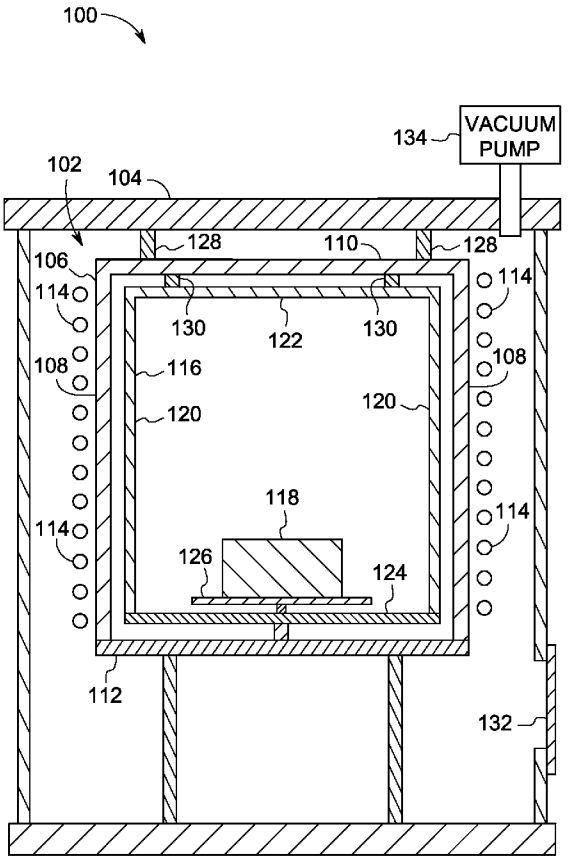
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CPC ***F27B 14/04*** (2013.01); ***F27B 14/061*** (2013.01); ***F27D 9/00*** (2013.01); *F27B 2014/0837* (2013.01)

(57) **ABSTRACT**

A system and method for removing impurities in an induction furnace cooling system is disclosed. An induction furnace for heating a workpiece includes a chamber, an induction coil positioned in the chamber to provide for heating of the workpiece when a current is provided to the induction coil, and a cooling system fluidly coupled to an interior volume of the chamber, the cooling system including a heat exchanger, a blower fluidly coupled to the heat exchanger and configured to cause a gas to flow through the heat exchanger, and a filter assembly comprising a filtering device, the filter assembly fluidly coupled to the blower and configured to remove impurities from the gas flowing through the cooling system.



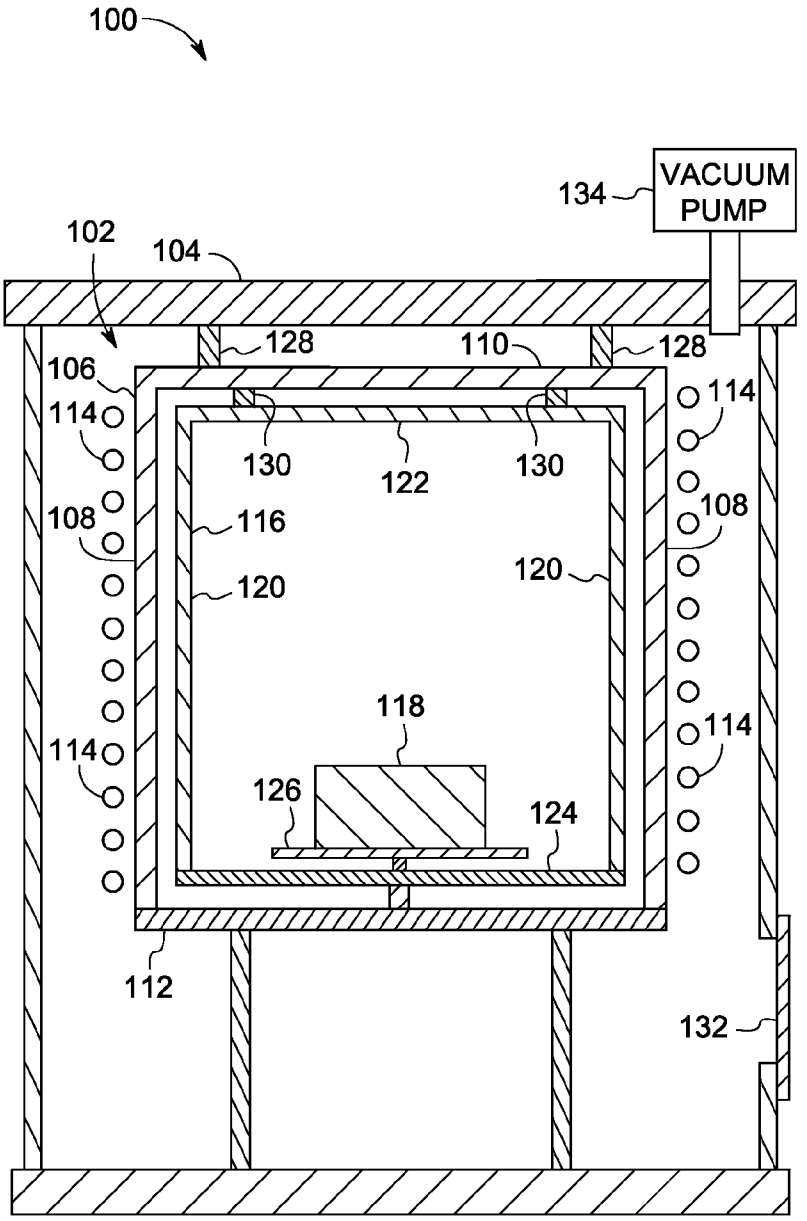

100
VACUUM PUMP
134
102
104
128
110
128
106
114
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122
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114
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116
108
120
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118
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126
124
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112
132

FIG. 1

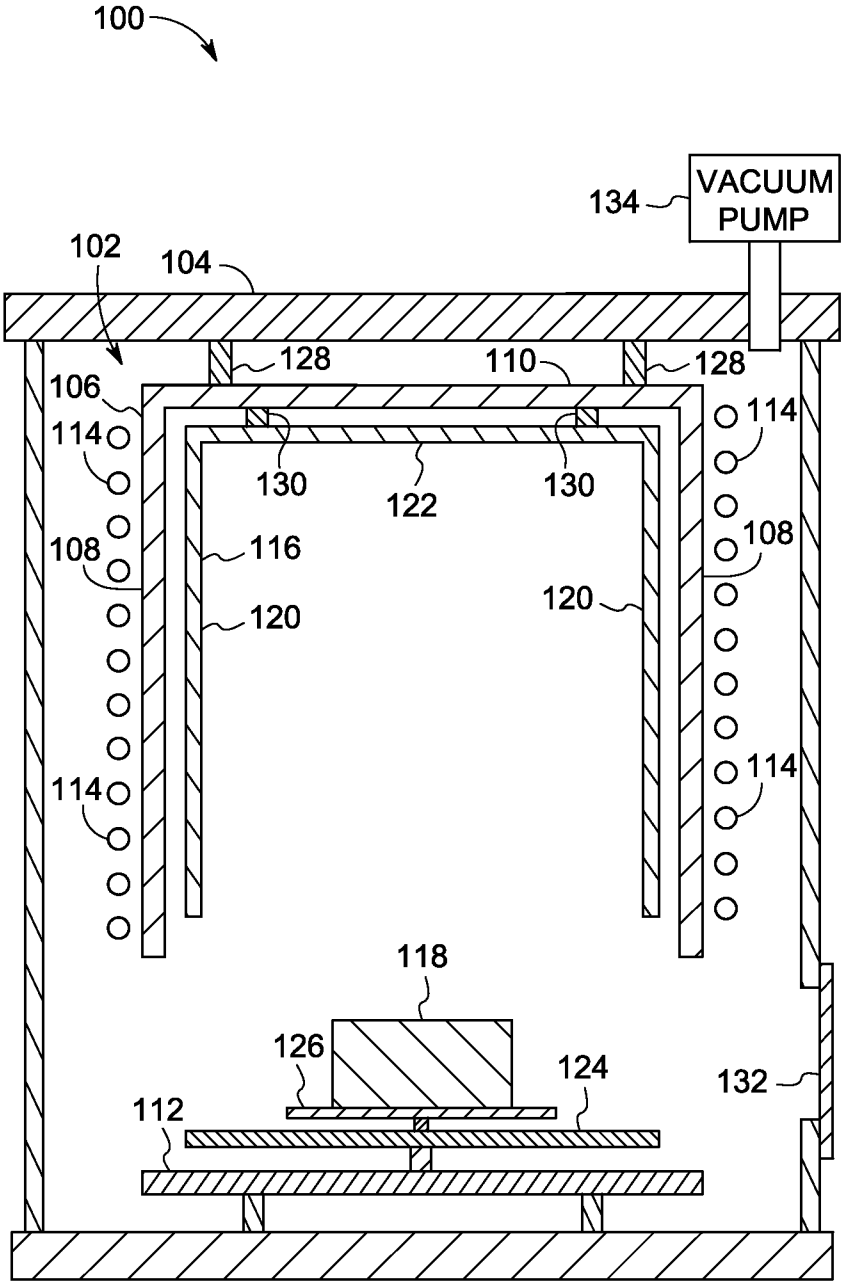

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FIG. 2

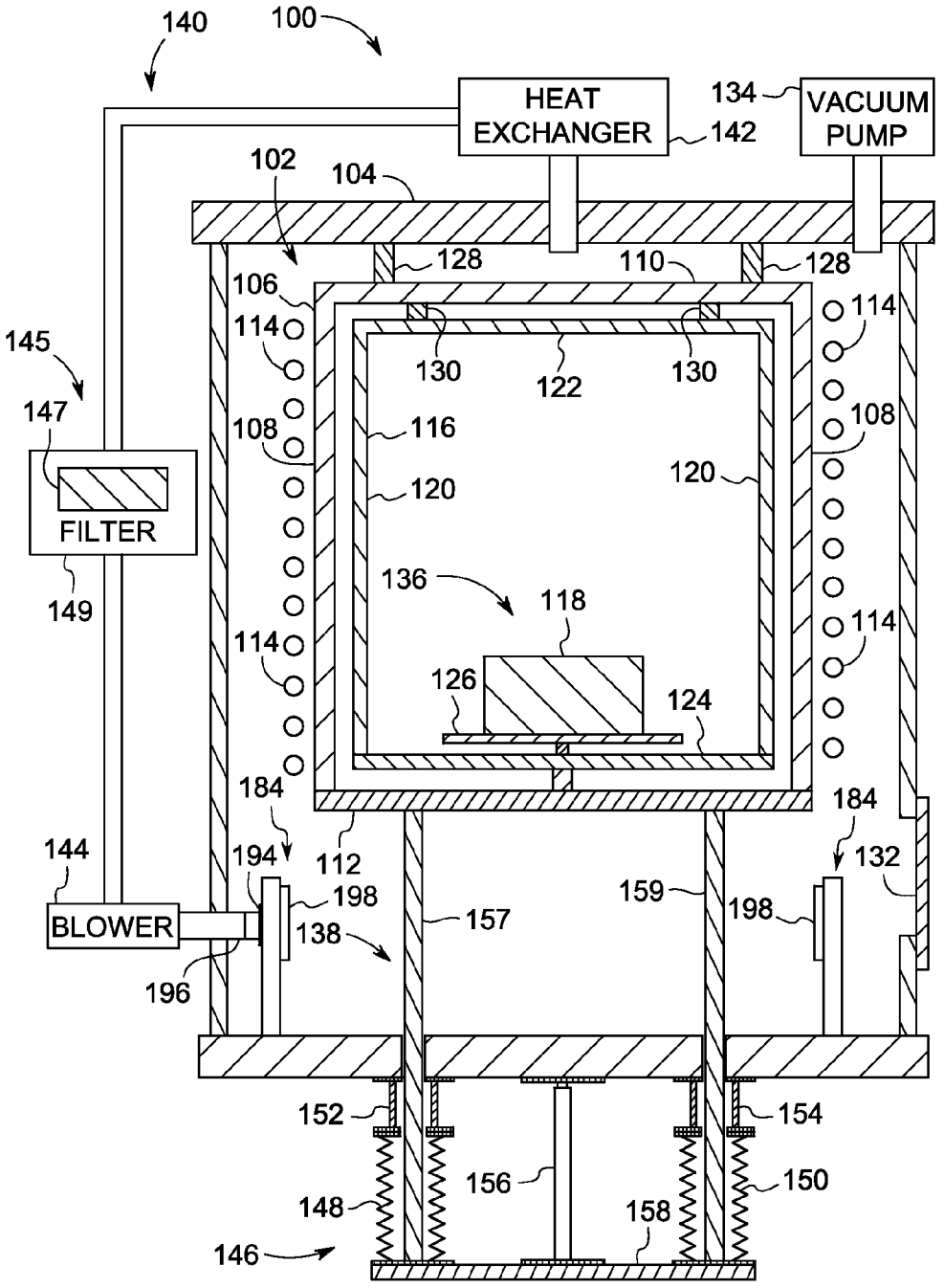

140
100
HEAT EXCHANGER
142
134
VACUUM PUMP
102
104
128
110
128
106
114
145
147
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122
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108
116
120
120
FILTER
149
136
118
114
126
124
184
184
144
194
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132
198
159
198
BLOWER
138
157
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154
156
150
148
158
146

FIG. 3

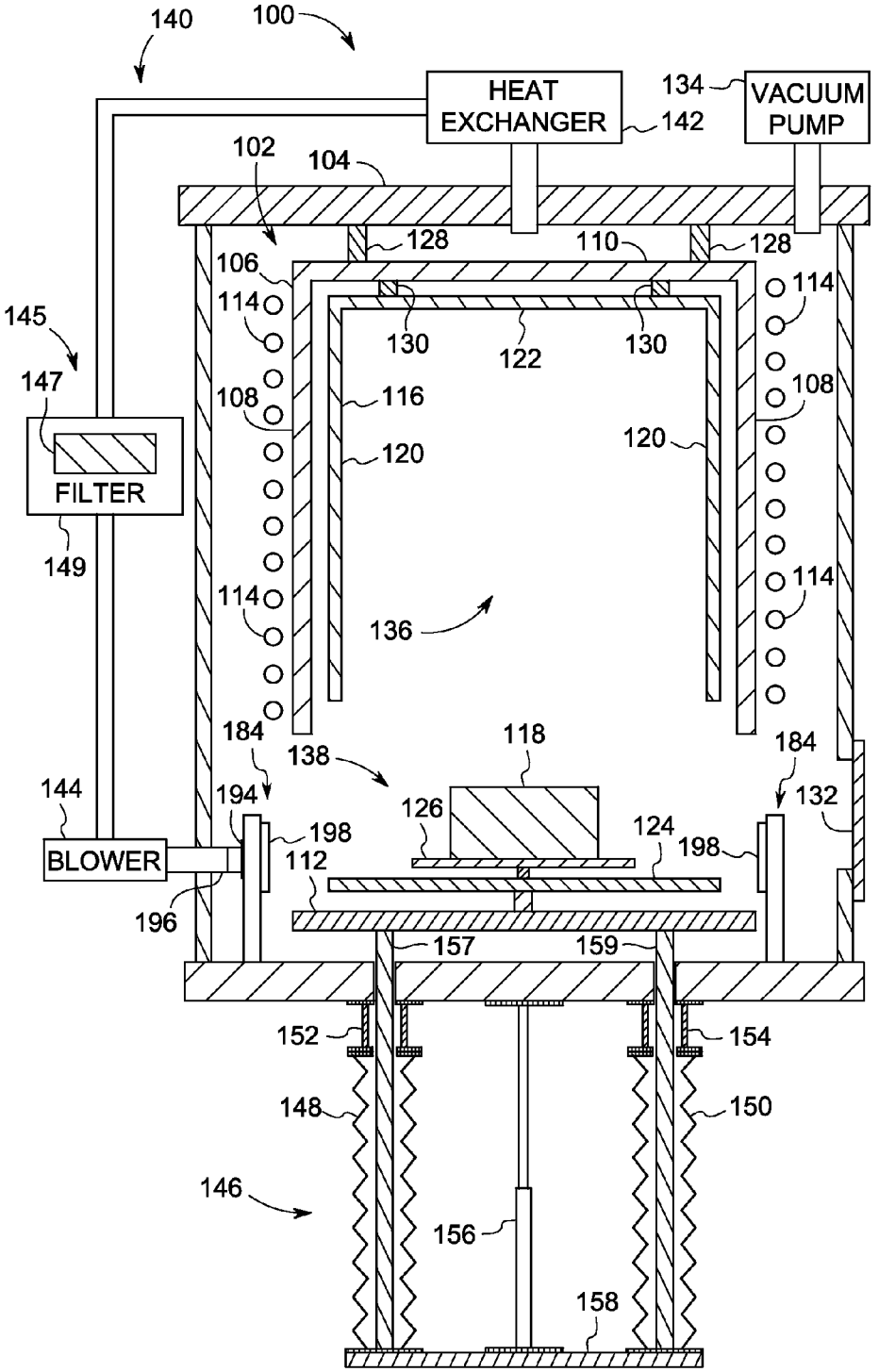

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HEAT EXCHANGER
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134
VACUUM PUMP
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104
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FILTER
149
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136
184
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118
184
144
194
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132
198
124
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BLOWER
112
196
157
159
152
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148
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146
156
158

FIG. 4

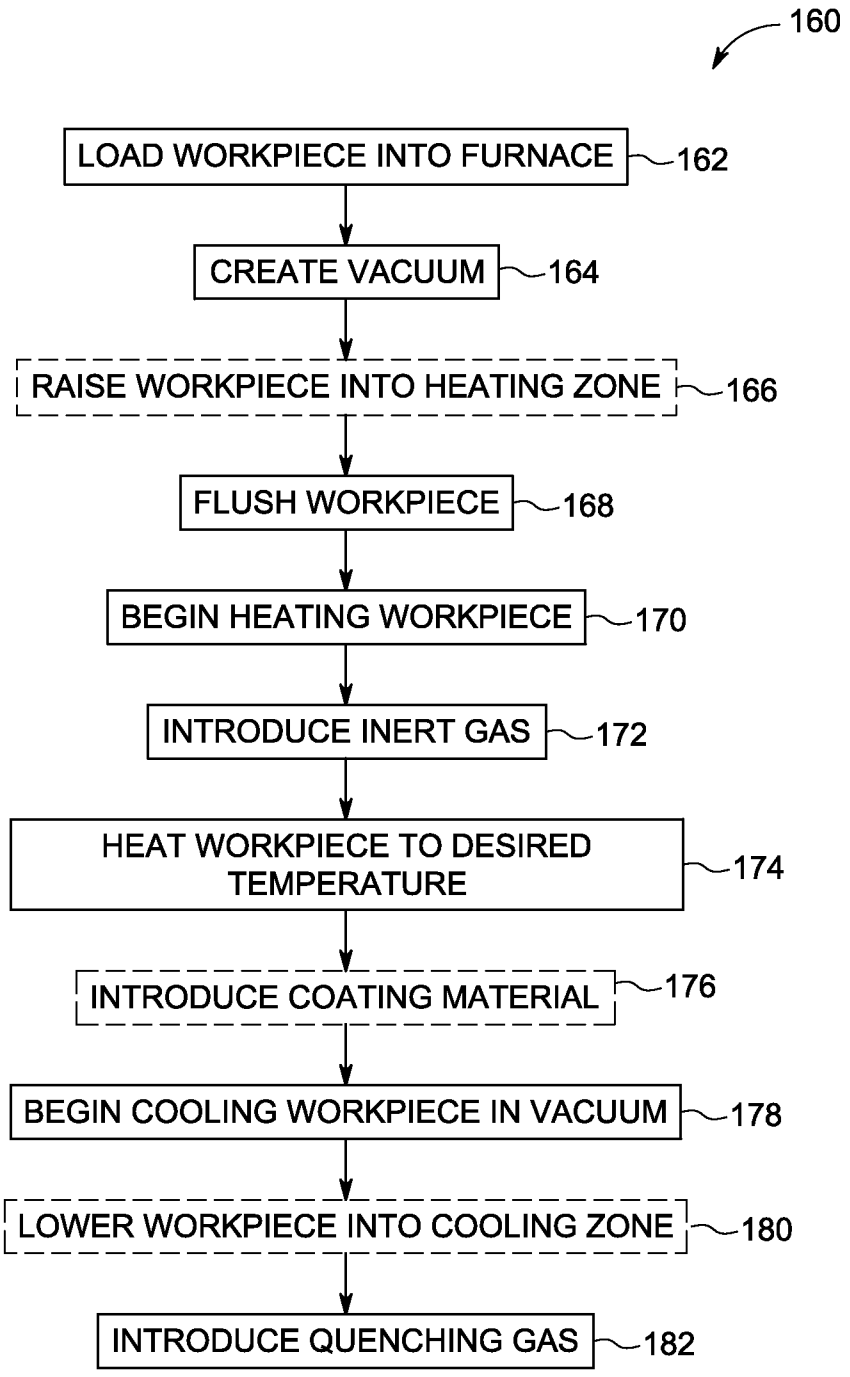

160
LOAD WORKPIECE INTO FURNACE
162
CREATE VACUUM
164
RAISE WORKPIECE INTO HEATING ZONE
166
FLUSH WORKPIECE
168
BEGIN HEATING WORKPIECE
170
INTRODUCE INERT GAS
172
HEAT WORKPIECE TO DESIRED TEMPERATURE
174
INTRODUCE COATING MATERIAL
176
BEGIN COOLING WORKPIECE IN VACUUM
178
LOWER WORKPIECE INTO COOLING ZONE
180
INTRODUCE QUENCHING GAS
182

FIG. 5

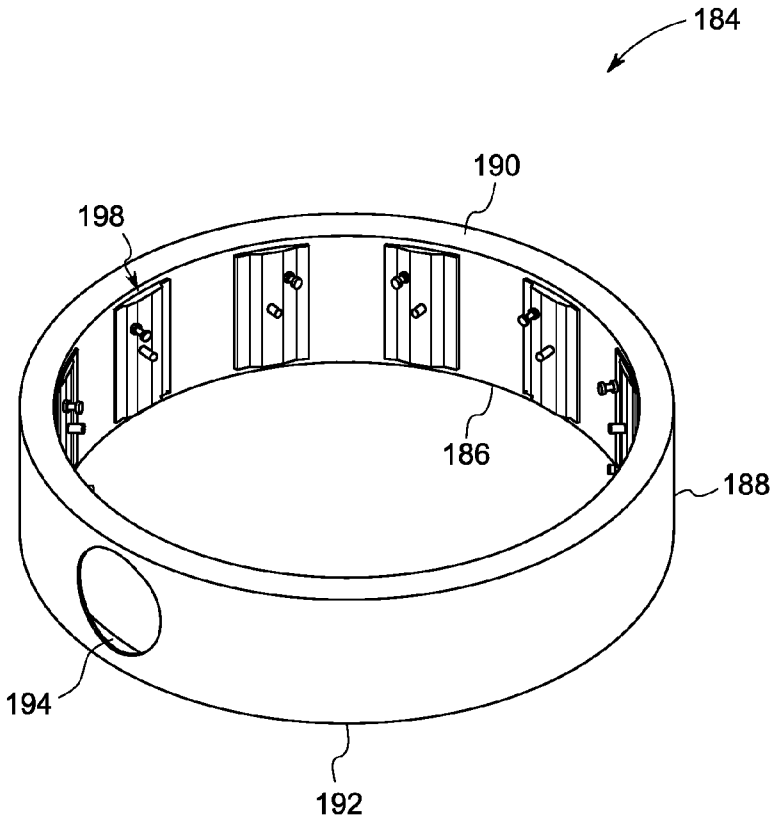


FIG. 6

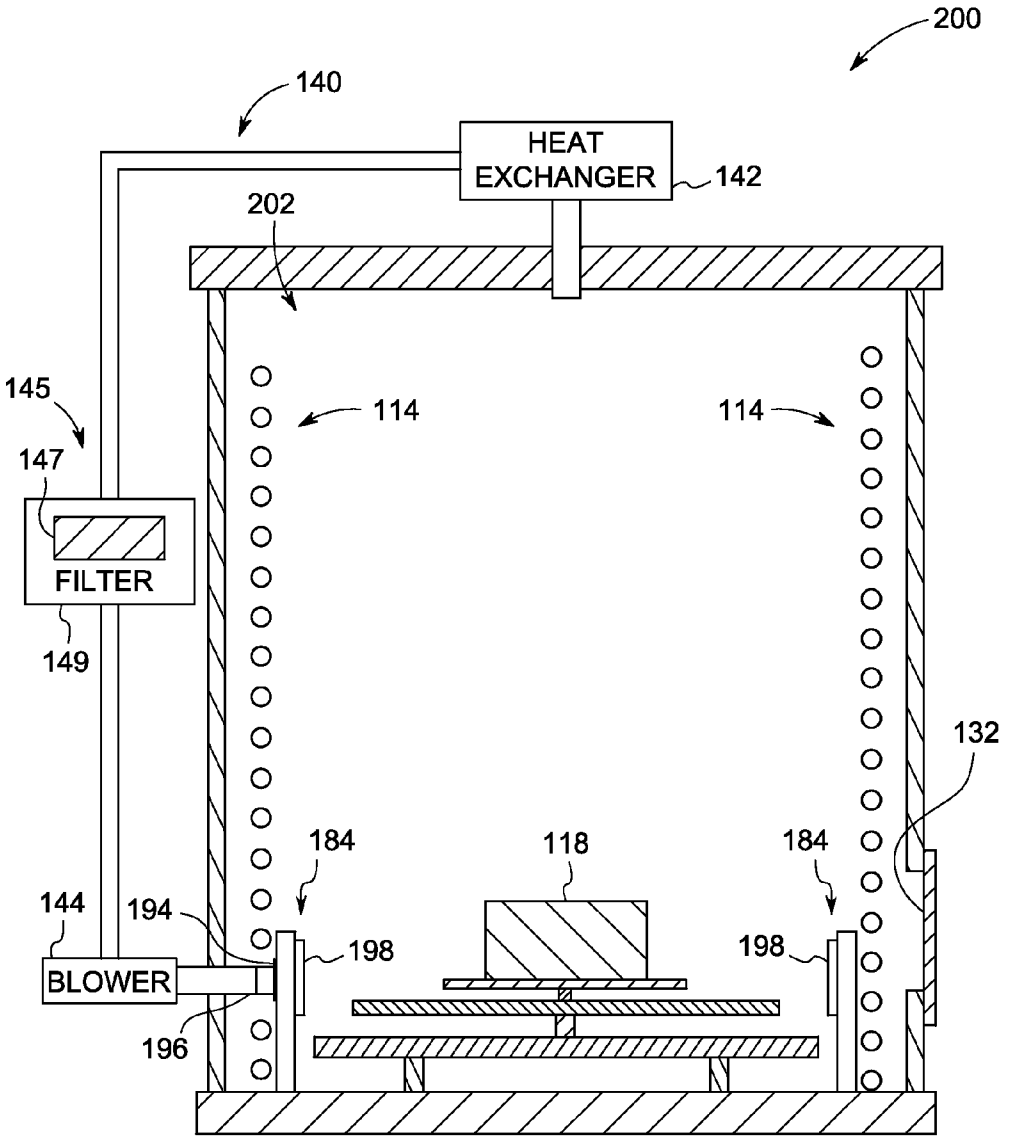

200
140
HEAT EXCHANGER
142
202
145
147
FILTER
149
114
114
132
184
118
184
144
194
198
198
BLOWER
196

FIG. 7

SYSTEM FOR GAS PURIFICATION IN AN INDUCTION VACUUM FURNACE AND METHOD OF MAKING SAME

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This is a national stage application under 35 U.S.C. §371(c) of prior-filed, co-pending, PCT application serial number PCT/US2013/039737, filed on May 6, 2013, 2013, which claims priority to U.S. Provisional Application No. 61/694,869, filed Aug. 30, 2012, the contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] Embodiments of the invention relate generally to induction furnaces for heating a workpiece in an inert atmosphere or vacuum and, more particularly, to a system for providing cooling to a workpiece in a uniform fashion, so as to reduce thermal stress in the workpiece.

[0003] Conventional induction furnaces include an induction heating system and a chamber that contains a susceptor that is susceptible to induction heating, with the chamber enclosing an inert atmosphere or vacuum therein. An electromagnetic coil sits outside the susceptor and receives high frequency alternating current from a power supply. The resulting alternating electromagnetic field heats the susceptor rapidly. The workpiece to be heated is placed in proximity to and generally within the susceptor so that when the susceptor is inductively heated by the induction heating system, the heat is transferred to the workpiece through radiation and/or conduction and convection. After a desired heating and processing of the workpiece is completed, the workpiece is then subsequently cooled in order to complete the heating/cooling cycle.

[0004] With respect to the overall time required to perform the heating/cooling cycle, it is recognized that the cooling time is a very key factor in the overall cycle time. Thus, it is desirable to be able to reduce the cooling time that is necessary for cooling the workpiece to a desired temperature. As a means for decreasing the cooling time, some prior art systems introduce an inert cooling gas that helps to increase the rate of cooling of the workpiece. A typical vacuum furnace process includes backfilling with an inert gas during the cooling phase of the cycle using a blower linked to a heat removal assembly. The faster the gas moves, the more rapid the cool down. However, this rapid gas movement can disturb dirt, dust, oil vapor and other impurities in the system and can greatly impact components susceptible to such impurities. Such contamination can negatively affect the quality and cleanliness of the parts inside the chamber/hotzone. The higher the rate of movement of the gas, the higher the chances of part contamination.

[0005] It would therefore be desirable to have an induction furnace that provides for a decrease in the cooling time of the workpiece, while removing impurities during gas cooling of the workpiece.

BRIEF DESCRIPTION OF THE INVENTION

[0006] Embodiments of the invention overcome the aforementioned drawbacks by providing an induction furnace having a filter assembly incorporated therein that removes impurities during gas cooling of a workpiece heated by the furnace.

[0007] In accordance with one aspect of the invention, an induction furnace for heating a workpiece includes a chamber, an induction coil positioned in the chamber to provide for heating of the workpiece when a current is provided to the induction coil, and a cooling system fluidly coupled to an interior volume of the chamber, the cooling system including a heat exchanger, a blower fluidly coupled to the heat exchanger and configured to cause a gas to flow through the heat exchanger, and a filter assembly comprising a filtering device, the filter assembly fluidly coupled to the blower and configured to remove impurities from the gas flowing through the cooling system.

[0008] In accordance with another aspect of the invention, an induction furnace for cooling a workpiece includes a chamber, a heating zone located within the chamber for heating the workpiece, a cooling zone located within the chamber for cooling the workpiece, and a cooling system configured to cool the chamber after the workpiece has been heated, with the cooling system further comprising a heat exchanger configured to draw hot gas from the chamber, a blower configured to blow cooled gas that has passed through the heat exchanger into the cooling zone, and a filter assembly comprising a filtering device, the filter assembly configured to remove impurities from the gas flowing through the cooling system.

[0009] In accordance with yet another aspect of the invention, a method of making an induction furnace includes providing a chamber that defines an interior volume capable of receiving a workpiece therein, positioning an induction coil within the chamber to provide for heating of the workpiece when a current is provided to the induction coil, fluidly coupling a heat exchanger to the interior volume of the chamber, fluidly coupling a blower to the interior volume of the chamber, fluidly coupling a filter to the interior volume of the chamber, to the heat exchanger, and to the blower, and configuring the filter to remove impurities from the interior volume of the chamber.

[0010] These and other advantages and features will be more readily understood from the following detailed description of embodiments of the invention that is provided in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The drawings illustrate embodiments presently contemplated for carrying out the invention.

[0012] In the drawings:

[0013] FIG. **1** is a block schematic diagram of an induction furnace according to an embodiment of the invention.

[0014] FIG. **2** is an additional diagram of the induction furnace of FIG. **1** where a workpiece is in a lowered position.

[0015] FIG. **3** is a block schematic diagram of an induction furnace according to another embodiment of the invention.

[0016] FIG. **4** is an additional diagram of the induction furnace of FIG. **3** where a workpiece is in a lowered position.

[0017] FIG. **5** is a flowchart illustrating a technique for heating and cooling a workpiece using an induction furnace according to an embodiment of the invention.

[0018] FIG. **6** is a perspective view of a cooling manifold for use with the induction furnace of FIGS. **3** and **4**.

[0019] FIG. **7** is a block schematic diagram of an induction furnace according to another embodiment of the invention.

DETAILED DESCRIPTION

[0020] Referring to FIGS. **1** and **2**, the major components of an induction furnace **100** are shown. Induction furnace **100** includes an induction heating system **102** inside a chamber **104**. Induction heating system **102** includes an insulation cylinder **106** having a side wall **108**, a top or first cover **110** for sealing one end of cylinder **106**, and a base or second cover **112** for sealing the second end of cylinder **106**. Induction heating system **102** includes a coil **114** and a power supply (not shown) that provides an alternating current that flows through coil **114** during a heating cycle. Coil **114** is wound to form a helical shape within chamber **104** about insulation cylinder **106** as shown in FIG. **1**.

[0021] Contained within insulation cylinder **106** is a susceptor **116** that is susceptible to induction heating. That is, when an alternating current flows through coil **114**, an alternating magnetic field is generated that induces eddy currents and other effects in susceptor **116** that cause the susceptor **116** to heat. The thermal energy that radiates from susceptor **116** is used to heat a workpiece **118**. Susceptor **116** is shown as being cylindrical, but other shapes can be used. Susceptor **116** is made of any material susceptible to induction heating, such as, for example, graphite, molybdenum, steel, and tungsten. Susceptor **116** is arranged within insulation cylinder **106** in chamber **104**. Insulation cylinder **106** is made from an insulative material that is not susceptible to induction heating such as, for example, fused quartz.

[0022] Susceptor **116** includes a side wall **120**, a first cover **122** for sealing one end, and a second cover **124** for sealing the other end. A tray **126** for supporting workpiece **118** to be heated is connected to second cover **124** of susceptor **116**. Although susceptor **116** is shown as having closed ends, this need not be the case. For example, the susceptor **116** can be in the form of a tube that is open at both ends or, for example, it can comprise one or more susceptor sheets. First cover **110** of cylinder **106** is coupled to chamber **104** via one or more posts **128**, which in an embodiment, is constructed of a ceramic material. First cover **122** of susceptor **116** is coupled to first cover **110** via one or more additional posts **130**.

[0023] FIG. **1** illustrates induction heating system **102** in a raised or heating position where workpiece **118** is positioned within susceptor **116** and is ready for heating according to induction furnace principles as described above. As shown in FIG. **2**, induction heating system **102** is in a lowered position where access to workpiece **118** through a door **132** of chamber **104** is possible. Induction furnace **100** also includes a vacuum pump **134** for creating a vacuum within the chamber **104**. Door **132** forms a hermetic seal when closed such that a vacuum created by vacuum pump **134** in an interior volume of chamber **104** is hermetically isolated from an ambient environment outside chamber **104**.

[0024] In operation of induction furnace **102**, the workpiece **118** is in a raised or heating position, i.e., within in a "heating zone" **136** defined by susceptor **116**, when a heating operation is being undertaken. The workpiece **118** is then moved to the lowered or cooling position, i.e., within in a "cooling zone" **138** outside of the susceptor **116**, when a cooling operation is being undertaken. Moving workpiece **118** to the cooling zone **138** after completion of the heating of workpiece **118** allows for a reduction in the primary overall furnace cycle time. That is, the time required for cooling workpiece **118** is an important factor in the overall furnace cycle time, as traditional cooling becomes increasingly inefficient at lower temperatures. According to embodiments the invention, faster cooling times are achieved at lower temperatures by dropping the parts out of the hot zone **136** and into the cool zone **138** of the vacuum chamber **104**.

[0025] According to an exemplary embodiment of the invention, induction furnace **102** is constructed so as to facilitate movement of the workpiece **118** between the heating zone **136** and the cooling zone **138** while maintaining a desired vacuum pressure within chamber **104**, and is further constructed to include elements to enhance cooling of the workpiece **118**. Referring now to FIGS. **3** and **4**, induction furnace **102** is shown as including a cooling system **140** for cooling chamber **104** after the workpiece **118** has been heated as desired. Cooling system **140** can include a heat exchanger **142**, a blower **144**, and a filter assembly **145**. Hot gas within the chamber **104** is drawn into the heat exchanger **142** and is exchanged with cooler gas, and the cooler gas is blown back into chamber **104** by blower **144**.

[0026] After completion of a heating of workpiece **118**, the second cover **124** and tray **126** are dropped using a vacuum-sealed bellows system **146** attached to second cover **112**. Bellows system **146** includes a pair of vacuum-sealed bellows **148**, **150** attached to respective coupling device **152**, **154** that are coupled to chamber **104**. A pair of cover members or supports **157**, **159** are coupled to second cover **112** and pass through coupling devices **152**, **154** to couple to bellows **148**, **150** as illustrated. In this manner, bellows **148**, **150** and coupling devices **152**, **154** surround or encircle coupling devices **152**, **154**. According to another embodiment, cover supports **157**, **159** may be directly coupled to a plate **156**, which is also coupled to bellows **148**, **150**. A linear actuator **158** such as a piston is coupled to chamber **104** external to its interior volume and is coupled to bellows **148**, **150** via plate **156**. Embodiments of the invention contemplate that linear actuator **158** may be a pneumatic or hydraulic piston, an electromechanical piston, a manual actuator, or the like. The interior volumes of bellows **148**, **150** and coupling devices **152**, **154** are fluidly coupled to the interior volume of chamber **104**. In this manner, movement of linear actuator **158** from the outside of chamber **104** allows the atmosphere and pressure inside chamber **104** to be maintained when plate **156** is moved either away from or toward chamber **104**. That is, while plate **156** is being moved away from or toward chamber **104**, bellows **148**, **150** expand or contract accordingly to maintain a separation of the inside of chamber **104** from the volume or the outside environment. Thus, workpiece **118** can be lowered from heating zone **136** to cooling zone **138** while being hermetically sealed from the outside of chamber **104**.

[0027] According to various embodiments, the movement to the cooling position or zone may be governed by a threshold time and/or temperature, and may be triggered by pressure or RGA or partial pressure, or rates of any of these. In one embodiment, the part or workpiece **118** is dropped into the cool section **138** after the part has cooled to approximately 1200° C. This effectively opens the insulated hot zone **136** and allows the cooling gas to pass across the heated parts **118**. Once the workpiece **118** drops out of the hot zone **136**, the workpiece **118** experiences improved radiative and convective cooling. The area of the cooling zone **138** within chamber **104** has unique temperature control (i.e., ability to quench from high temperature to a lower, controlled temperature), which is particularly useful for heat treating applications. Due to the multi-zone configuration of the vacuum chamber, cooling times may be greatly reduced when compared with cooling inside heating zone **136**, and faster cycle times can be met.

[0028] The filter assembly **145** is configured to hold a vacuum-compatible filtering device **147** and provide ultra-high temperature induction vacuum gas purification to the cooling system. As used herein, the term "filtering" is understood to mean that the device **147** is capable of and constructed to remove any of a number of desired impurities from the gas flowing through the cooling system, including (but not limited to) particulate matter, organics, oxygen, and/or other desired substances. For example, filtering device **147** could be configured as a charcoal filter to remove organics or a heated titanium mesh filter to remove oxygen. Filter assembly **145** is designed to allow filtering of the gas within chamber **104** while not impeding the function and cooling rate of the furnace system. The geometric design of filter assembly **145** is variable to allow for feasibility to enable high volume flow and/or high temperature filtering capability for the design and operating conditions for induction furnace **100**. In addition, while filter assembly **145** is illustrated as being downstream of heat exchanger **142** and upstream of blower **144**, embodiments of the invention contemplate coupling filter assembly **145** anywhere within system **140**. That is, filter assembly **145** may instead be positioned upstream of heat exchanger **142** or downstream of blower **144**, for example. In an embodiment where the filter assembly **145** is positioned upstream of heat exchanger **142**, the filter assembly **145** may be positioned just inside of chamber **104** (i.e., on an exterior wall of the chamber **104**)—rather than external to the chamber as is shown in FIGS. **3** and **4**.

[0029] Filter assembly **145** includes a housing **149** that may be customized or may be a housing generally available in the industry. Examples of industry-available housings include housings for bag house systems, factory automation, food processing, glass and ceramic processes, medical systems, vacuum furnaces and packaging, vacuum pumps (rotary vane, screw compressors, and piston pumps), and central vacuum systems.

[0030] According to one embodiment, filtering device may be in the form of a particle filter **147** that is an industrial filter generally available in the industry that provides various particle size filtrations. Alternatively, the particle filter **147** may be a customized filter optimized for use in the cooling process for a particular workpiece **118**. For example, the material for particle filter **147** may be selected based on a number of considerations, including chemical compatibility, outgassing, flow rate, structural stability, friability, temperature resistance, cost, and particulate capture efficiency. In one example, the filter material may be metallic wool (e.g., stainless steel wool). Other filter materials, however, are contemplated.

[0031] Filter assembly **145** is positioned, together with heat exchanger **142** and blower **144**, outside the internal volume of chamber **104** in the ambient environment to allow access thereto for maintenance and other reasons. In this manner, filter assembly **145** may be more easily accessible than if it is positioned within chamber **104**.

[0032] Referring now to FIG. **5**, and with continued reference to the furnace of FIGS. **3** and **4**, a technique **160** for heating and cooling a workpiece is illustrated according to an embodiment of the invention. As illustrated in FIG. **5**, certain steps in the technique **160** are considered to be optional, as they would only be performed when the induction furnace is of a type as shown in FIGS. **3** and **4**. These optional steps in technique **160** are shown in phantom in FIG. **5**, so as to highlight that they may not be performed in induction furnaces having a certain geometry/construction.

[0033] As shown in FIG. **5**, the technique begins at STEP **162** with loading of a workpiece **118** into the furnace **100**, such as by way of door **132**, with the piece being positioned on tray **126** when it is in a lowered position. The furnace door **132** is then closed, and the technique continues at STEP **164**, where the interior of the furnace **100** is brought to a high vacuum, such as a 10^{-7} vacuum pressure, by operation of vacuum pump **134**. The workpiece **118** is then raised into the upper hot zone chamber **136** formed by insulating cylinder **106** and susceptor **116** at STEP **166**. At STEP **168**, the workpiece **118** is flushed with argon, and the interior of the furnace **100** is subsequently brought again to a high vacuum. The workpiece then begins to be heated at STEP **170**, with an inert gas (e.g., nitrogen) then being introduced at partial pressure at STEP **172**. The workpiece **118** is heated to 200-600° C. with the flowing inert gas to expedite removal of off-gassing, and the technique then continues at STEP **174** with the furnace chamber again being returned to a high vacuum via vacuum pump **134** and heated to a desired processing temperature. A material for coating the workpiece is then introduced if desired at STEP **176**

[0034] The workpiece is begun to cool inside the vacuum at STEP **178**. According to an embodiment of the invention, the workpiece is cooled to a temperature below a cooling threshold, and the workpiece is lowered out of the heating zone **136** and into the cooling zone **138** after the threshold has been met using the vacuum sealed bellows system **146** at STEP **180**. In this manner, the vacuum pressure created inside the furnace may be maintained when moving the workpiece to the cooling zone **138**. A quenching gas such as helium, argon, or nitrogen is then injected at STEP **182**, with the gas being injected at atmospheric pressure according to one embodiment.

[0035] According to various embodiments, gas may be injected at STEP **182** at either or both of the high and low workpiece positions, as faster cooling times can be achieved at lower temperatures by dropping the workpiece out of the hot zone **136** into the cool section **138** of the vacuum chamber **104**. Thus, the process of injecting gas at STEP **182** can incorporate a repositioning of the workpiece down into the cooling zone **138** outside of susceptor **116** by lowering hot zone tray **126**. As set forth above, the lowering of the workpiece **118** down into the cooling zone **138** may be governed by a threshold time and/or temperature, and may be triggered by pressure or RGA or partial pressure, or rates of any of these. In one embodiment, the workpiece **118** is dropped into the cool section after the workpiece has cooled to approximately 1200° C., as further cooling below this threshold temperature is achieved most efficiently by passing cooling gas across the heated workpiece **118** when it is located in the cooling zone **138**. By selectively positioning the workpiece **118** in the hot zone **136** and the cooling zone **138**, the cooling time of the workpiece can be reduced greatly and faster cycle times can be met.

[0036] Since particles in chamber **104** may be disturbed and/or stirred by passing the cooling gas across the heated workpiece **118** when it is located in the cooling zone **138**, filter assembly **145** acts to filter and remove such contaminants from the circulating gas so that workpiece **118** can be cooled by the gas having all or a majority of the contaminants removed therefrom.

[0037] It is recognized that temperature uniformity within the workpiece **118** is very important during the heating and cooling of the workpiece and that, during the cooling process, the workpiece can develop thermal stress. The stress is greatly increased as the temperature difference across the workpiece grows, with the stress in the material thereof potentially causing premature failure or changes in geometry due to warpage. In applying cooling gas to the workpiece **118**, such as at STEP **182** of technique **160**, a typical vacuum furnace has a single port for gas entry, such that the side of the workpiece placed next to the location that the gas enters the hot zone will cool very quickly compared to the side that is shielded from the gas. This thermal mismatch is a source of thermal stress.

[0038] Therefore, according to one embodiment of the invention, a cooling manifold or ring **184** with multiple equally spaced ports on the gas feed side is implemented in cooling zone **138** to drive uniform gas cooling. As shown in FIGS. **3**, **4** and **6**, the cooling manifold **184** is a cylindrically shaped member that is positioned about the cooling zone **138**. A hollow interior volume of the cooling manifold **184** is defined by inner and outer walls **186**, **188** along with top and bottom walls **190**, **192**. An inlet **194** is formed on one side of cooling manifold **184** to provide a supply of gas into the interior volume thereof, with the inlet **194** having a tubing or piping **196** connected thereto that provides cooling gas from an external source, such as the blower **144**. To maintain structural integrity and non-friability (i.e., durability), the cooling manifold **184** may be manufactured from a material that is vacuum and temperature compatible.

[0039] A plurality of gas ports **198** are formed in inner wall **186**, with the gas ports being formed at a plurality of locations in the inner wall. According to an exemplary embodiment of the invention, the ports **198** are spaced around the entire circumference of the inner wall **186**, with the spacing of the ports being uniform. The exact number of ports **198** and the angular spacing therebetween is system and workload specific, with the goal of maximizing cooling uniformity. According to various embodiments of the invention, the gas ports **198** may be static holes or be louvers, for example. In the embodiment of cooling manifold **184** illustrated in FIG. **6**, the gas ports **198** are constructed as louvers that are independently operable and selectively controlled such that desired louvers can be opened and others left in a closed position. For example, louvers opposite the inlet **194** and blower **144** may be closed to improve the cooling process. The desired gas flow rate through gas ports **198** can also be controlled, with the flow rate desirably being as large as possible, up to any limits imposed by the system or workpiece (i.e., a fragile workpiece may demand reduced flow), such that the cooling time of the workpiece **118** can be minimized.

[0040] While cooling manifold **184** is shown in FIG. **6** as being constructed as a cylindrical cooling ring, it is recognized that other constructions of the cooling manifold are envisioned and considered to be within the scope of the invention. For example, cooling manifold **184** could be constructed to have a horseshoe shape, hexagon shape, or other desired shape determined to fit the requirements of cooling of a specific workpiece. Additionally, rather than the wall structure of the cooling manifold having defined inner and outer walls and top and bottom walls, it is recognized that the cooling manifold could have a tube-like construction with no defined walls, but with a pipe-like structure being used to form the cooling manifold.

[0041] Referring now to FIG. **7**, an induction furnace **200** is shown according to another embodiment of the invention. The induction furnace **200** is constructed as a vacuum furnace in which the workpiece is kept in a set position, without any sort of linear actuator (e.g., linear actuator **156** in FIGS. **3-4**) to move the workpiece between separate heating and cooling positions, and thus induction furnace **200** also does not include an insulating cylinder or susceptor (e.g., insulating cylinder **106** or susceptor **116** in FIGS. **1-4**). A cooling system **140** for cooling chamber **104** after the workpiece **118** has been heated is provided in induction furnace **200** and includes a heat exchanger **142**, a blower **144**, and a filter assembly **145**, with the filter assembly desirably being configured/constructed as described above with respect to FIGS. **4** and **5**. In operation, hot gas within the chamber **104** is drawn into the heat exchanger **142** and is exchanged with cooler gas, and the cooler gas is blown through filter assembly **145** and back into chamber **104** by blower **144**, such as through a cooling manifold **184**, although no cooling manifold is required. In the embodiment of FIG. **7**, cooling manifold **184** is formed of a non-electrically conductive material (e.g., glass manifold), such that the cooling manifold is not inductively heated when a current is provided to induction coil **114**.

[0042] Therefore, according to one embodiment of the invention, an induction furnace for heating a workpiece includes a chamber, an induction coil positioned in the chamber to provide for heating of the workpiece when a current is provided to the induction coil, and a cooling system fluidly coupled to an interior volume of the chamber, the cooling system including a heat exchanger, a blower fluidly coupled to the heat exchanger and configured to cause a gas to flow through the heat exchanger, and a filter assembly comprising a filtering device, the filter assembly fluidly coupled to the blower and configured to remove impurities from the gas flowing through the cooling system.

[0043] According to another embodiment of the invention, an induction furnace for cooling a workpiece includes a chamber, a heating zone located within the chamber for heating the workpiece, a cooling zone located within the chamber for cooling the workpiece, and a cooling system configured to cool the chamber after the workpiece has been heated, with the cooling system further comprising a heat exchanger configured to draw hot gas from the chamber, a blower configured to blow cooled gas that has passed through the heat exchanger into the cooling zone, and a filter assembly comprising a filtering device, the filter assembly configured to remove impurities from the gas flowing through the cooling system.

[0044] According to yet another embodiment of the invention, a method of making an induction furnace includes providing a chamber that defines an interior volume capable of receiving a workpiece therein, positioning an induction coil within the chamber to provide for heating of the workpiece when a current is provided to the induction coil, fluidly coupling a heat exchanger to the interior volume of the chamber, fluidly coupling a blower to the interior volume of the chamber, fluidly coupling a filter to the interior volume of the chamber, to the heat exchanger, and to the blower, and configuring the filter to remove impurities from the interior volume of the chamber.

[0045] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention

is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

What is claimed is:

1. An induction furnace for heating a workpiece, the induction furnace comprising:

a chamber;

an induction coil positioned in the chamber to provide for heating of the workpiece when a current is provided to the induction coil; and

a cooling system fluidly coupled to an interior volume of the chamber, the cooling system comprising:

a heat exchanger;

a blower fluidly coupled to the heat exchanger and configured to cause a gas to flow through the heat exchanger; and

a filter assembly comprising a filtering device, the filter assembly fluidly coupled to the blower and configured to remove impurities from the gas flowing through the cooling system.

2. The induction furnace of claim **1** wherein the filter assembly comprises a housing; and

wherein the filtering device comprises a filter material positioned within the housing and configured to remove impurities from the gas flowing through the cooling system.

3. The induction furnace of claim **2** wherein the filter material comprise one of metallic wool, charcoal, or metallic mesh, with the filter material configured to filter out at least one of particulate matter, organics, oxygen, or another desired substance.

4. The induction furnace of claim **1** wherein the filter assembly is positioned externally to an interior volume of the chamber.

5. The induction furnace of claim **1** wherein the filter assembly is positioned just within an interior volume of the chamber.

6. The induction furnace of claim **1** wherein the heat exchanger and the blower are positioned externally to an interior volume of the chamber.

7. The induction furnace of claim **1** further comprising a vacuum pump configured to create a vacuum within the chamber.

8. The induction furnace of claim **1** further comprising:

an insulation cylinder positioned within the chamber, the insulation cylinder including a bottom cover that is selectively movable between an open position and a closed position, wherein the closed position is configured to seal an interior volume of the insulation cylinder; and

a susceptor positioned within the insulation cylinder, the susceptor being inductively heated by the induction coil when a current is provided to the induction coil.

9. The induction furnace of claim **8** further comprising:

a first member coupled to the bottom cover of the insulation cylinder and extending through a wall of the chamber;

a linear actuator coupled to the first member, the linear actuator configured to selectively translate the first member to move the bottom cover of the insulation cylinder between the open and closed positions; and

a bellows system encircling a portion of the first member and configured to hermetically seal an interior volume of the chamber from an environment volume external to the chamber;

wherein the linear actuator is coupled to the wall of the chamber external to an interior volume of the chamber.

10. The induction furnace of claim **1** further comprising a cooling manifold fluidly coupled to the cooling system and constructed to surround the bottom cover when the bottom cover is positioned in the open position, the cooling manifold comprising a plurality of gas ports spaced apart so as to be positioned about the bottom cover;

wherein cooling gas received from an external source is passed through the cooling manifold and exits the plurality of gas ports so as to provide a distributed and uniform gas flow across a workpiece supported by the bottom cover.

11. An induction furnace for cooling a workpiece, the induction furnace comprising:

a chamber;

a heating zone located within the chamber for heating the workpiece;

a cooling zone located within the chamber for cooling the workpiece; and

a cooling system configured to cool the chamber after the workpiece has been heated, the cooling system comprising:

a heat exchanger configured to draw hot gas from the chamber;

a blower configured to blow cooled gas that has passed through the heat exchanger into the cooling zone; and

a filter assembly comprising a filtering device, the filter assembly configured to remove impurities from the gas flowing through the cooling system.

12. The induction furnace of claim **11** wherein the cooling system is positioned externally to an interior volume of the chamber or within an interior volume of the chamber, adjacent an exterior wall of the chamber.

13. The induction furnace of claim **12** wherein the filtering device comprises one of metallic wool, charcoal, or metallic mesh, with the filtering device configured to filter out at least one of particulate matter, organics, oxygen, or another desired substance.

14. The induction furnace of claim **11** wherein the filter assembly is positioned upstream from the blower.

15. The induction furnace of claim **14** wherein the filter assembly is further positioned downstream from the heat exchanger.

16. The induction furnace of claim **11** further comprising a susceptor positioned in the chamber and configured to be inductively heated by an induction coil when a current is provided to the induction coil, wherein an interior volume of the susceptor defines the heating zone and the cooling zone is positioned outside of the interior volume of the susceptor.

17. The induction furnace of claim **16** further comprising:

a support system coupled to a base of the susceptor, the support system extending through the wall of the chamber;

a linear actuator coupled to the support system and configured to selectively translate the support system to move the base of the susceptor to translate a workpiece tray supported by the base of the susceptor between the heating zone and the cooling zone; and

a bellows system configured to surround a portion of the support system to hermetically seal the heating and cooling zones from an environment volume external to the chamber.

18. The induction furnace of claim **11** further comprising a cooling manifold connected to the blower so as to receive cooled gas therefrom, the cooling manifold constructed to encircle the cooling zone and provide a distributed and controlled gasflow across the workpiece.

19. A method of making an induction furnace comprising:

providing a chamber that defines an interior volume capable of receiving a workpiece therein;

positioning an induction coil within the chamber to provide for heating of the workpiece when a current is provided to the induction coil;

fluidly coupling a heat exchanger to the interior volume of the chamber;

fluidly coupling a blower to the interior volume of the chamber;

fluidly coupling a filter to the interior volume of the chamber, to the heat exchanger, and to the blower; and

configuring the filter to remove impurities from the interior volume of the chamber.

20. The method of claim **19** further comprising coupling the heat exchanger, the blower, and the filter to the chamber externally to the interior volume of the chamber.

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