United States Patent

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[54] **DIFFUSION BONDING APPARATUS**
8 Claims, 9 Drawing Figs.

[52] **U.S. Cl.** **219/85,** 13/22
[51] **Int. Cl.** **B23k 11/04**
[50] **Field of Search** 219/85, 117, 319; 13/31, 22, 25

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Assistant Examiner—J. G. Smith
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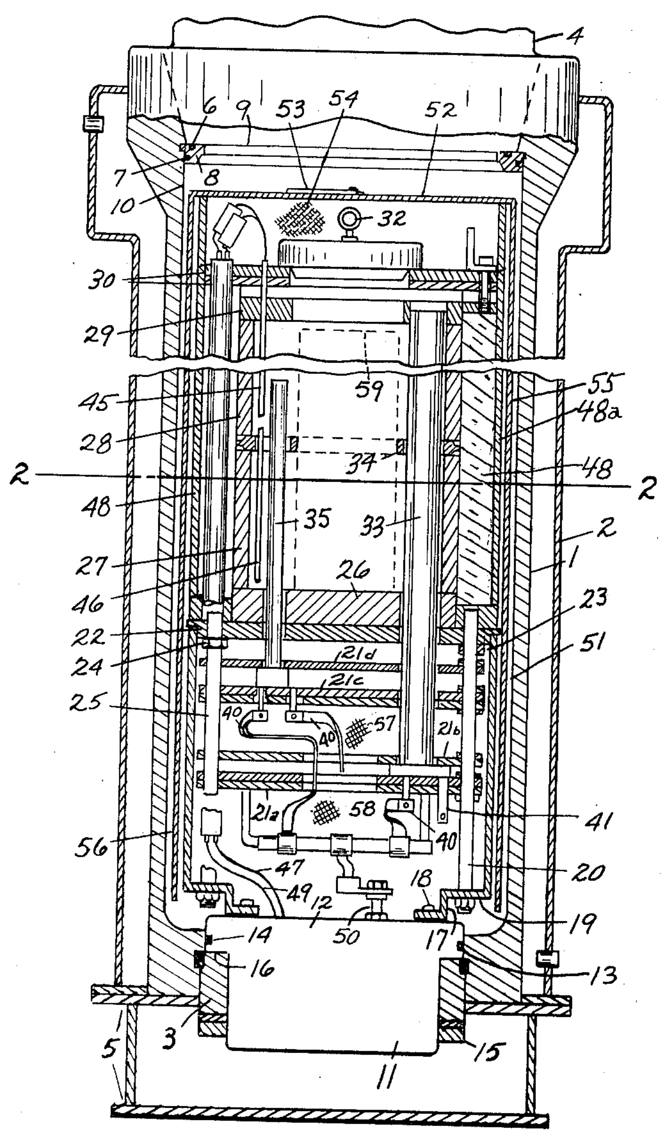
ABSTRACT: Apparatus for isostatic pressing, diffusion bonding, and the like, having a furnace designed to prevent turbulence in the hot zone so substantially the entire free space may be occupied by the work. In one form, the furnace can operate in vacuum to 100 microns and in air or inert gas at temperatures to 2,600° F. and pressures to 30,000 pounds per square inch which shortens the operating cycle by substantially eliminating the heatup and cooldown time.



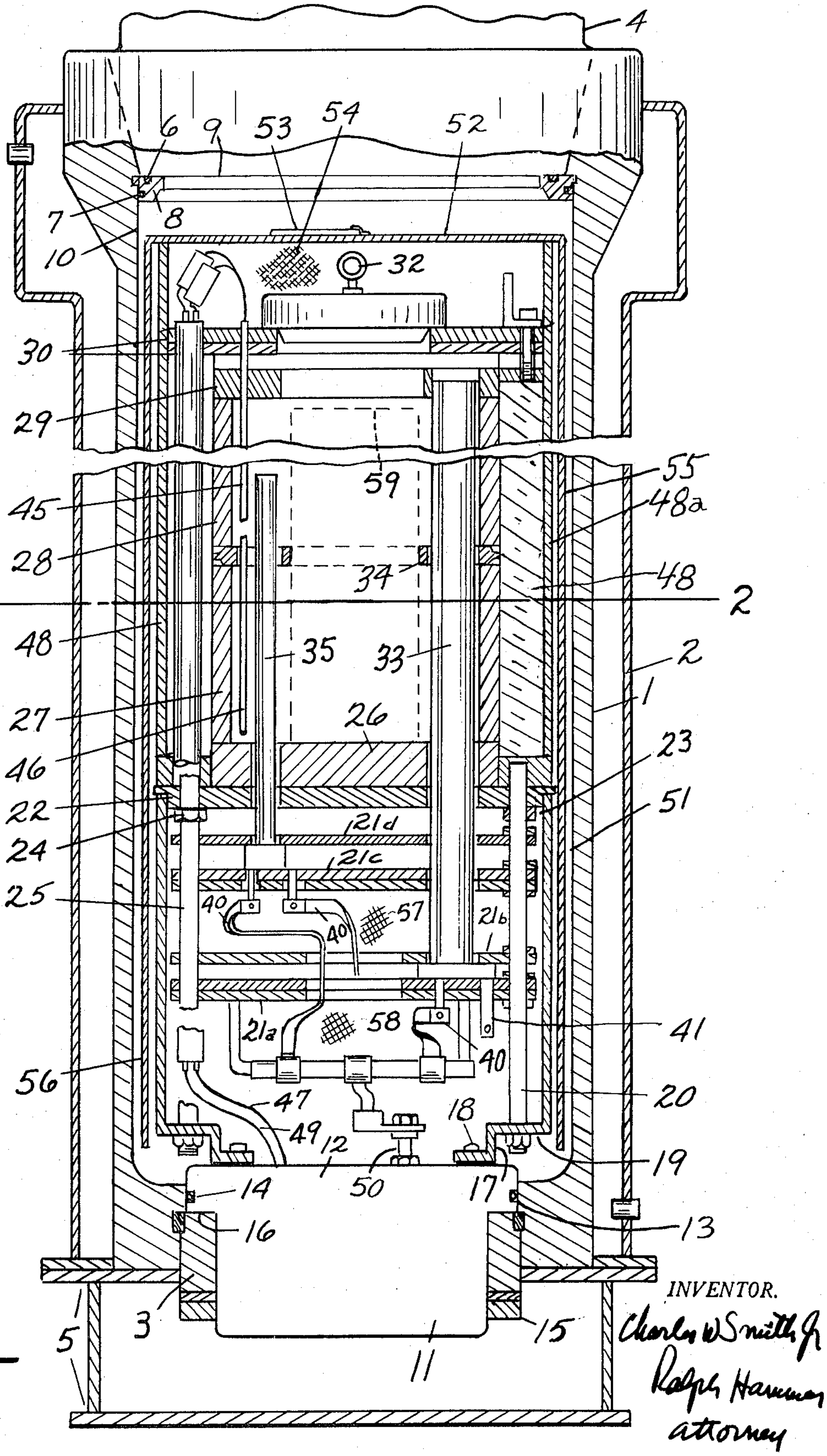

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FIG. 1

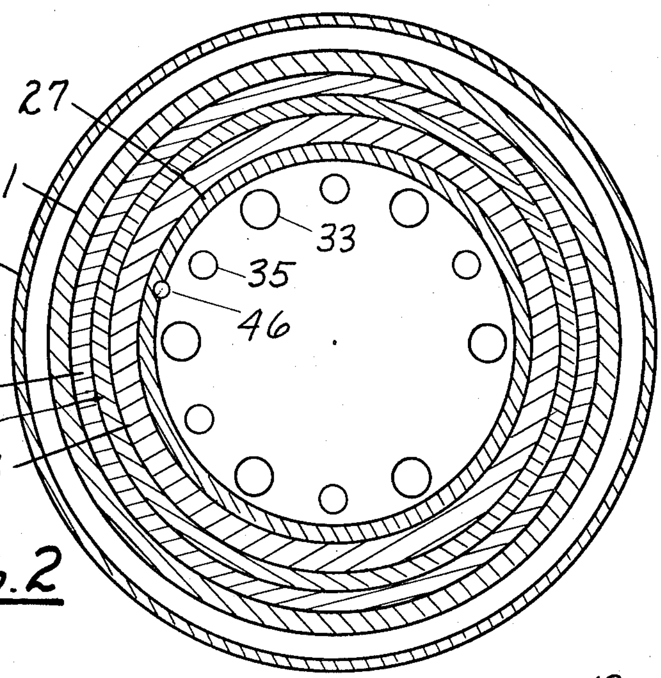
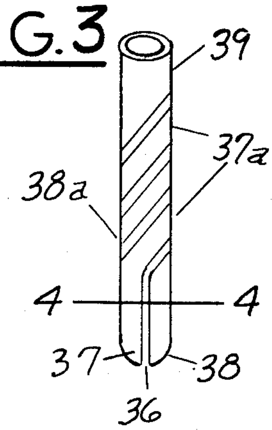


FIG. 2

FIG. 3



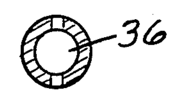


FIG. 4

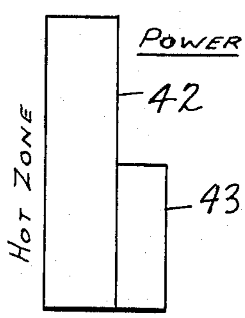


FIG. 5

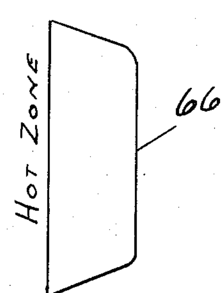


FIG. 6

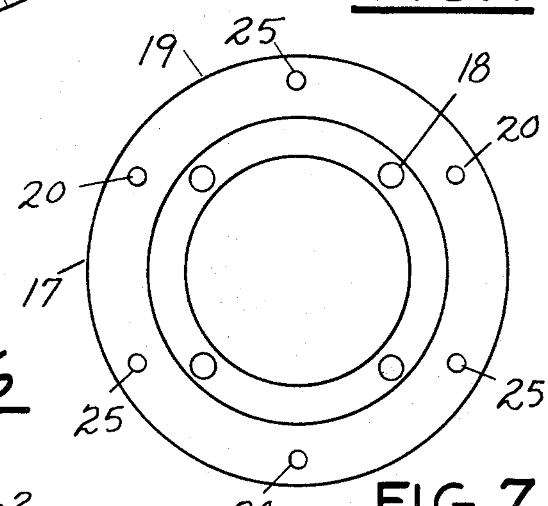


FIG. 7

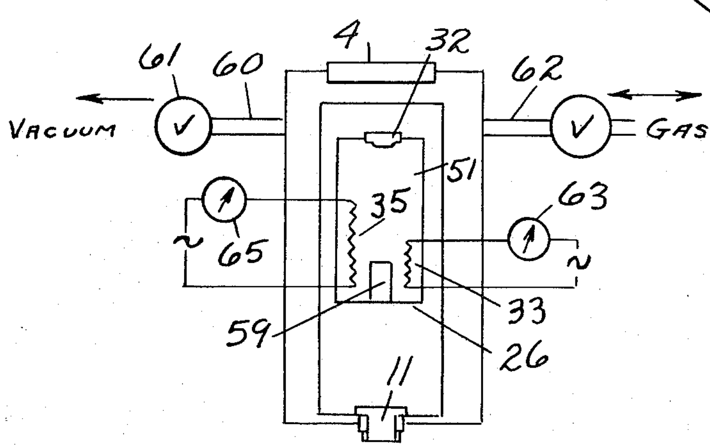


FIG. 8

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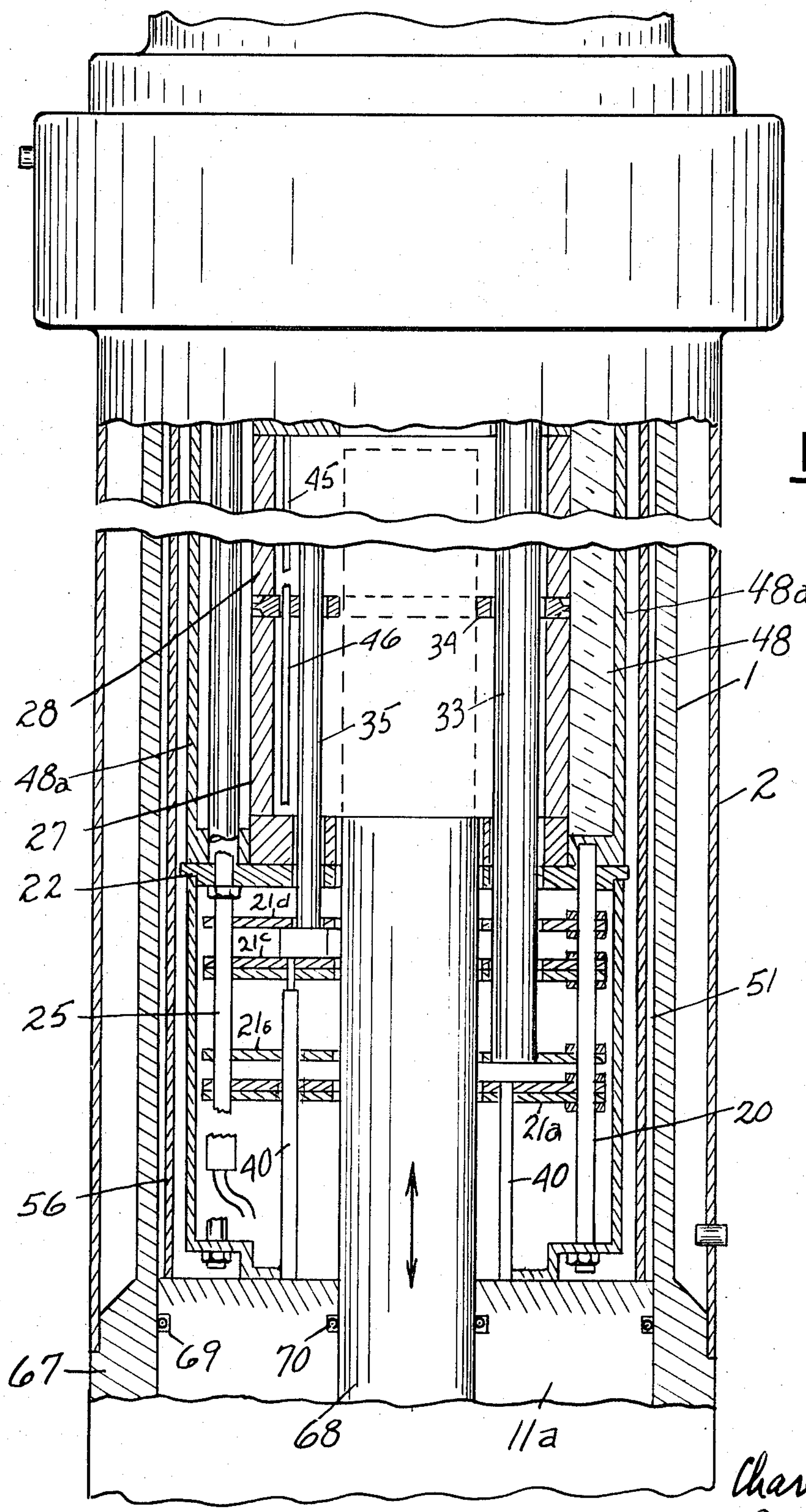

FIG. 9

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DIFFUSION BONDING APPARATUS

This invention is intended to prevent turbulence in the hot zone of diffusion bonding apparatus so substantially the entire free space may be used as a working zone.

In the drawing, FIG. 1 is a sectional elevation of diffusion bonding apparatus, FIG. 2 is a section on line 2—2 of FIG. 1, FIG. 3 is an elevation of one of the heating elements, FIG. 4 is a section on line 4—4 of FIG. 3, FIG. 5 is a diagram of the heating input, FIG. 6 is a diagram of the temperature at the hot zone, FIG. 7 is a plan view of the furnace support, FIG. 8 is a control diagram, and FIG. 9 is an elevation of the bottom loaded apparatus.

The apparatus has a pressure vessel body **1** surrounded by a water jacket **2** which cools the walls of the vessel. The lower end of the body is closed by an annular nut **3** and the upper end of the body is closed by a conical nut **4** which is adapted to quick opening and closing. The body **1** is supported on a stand **5**.

The upper end of the pressure vessel is sealed by O-rings **6** and **7** carried by a seal ring **8** and respectively making sealing engagement with the bottom surface **9** of the closure **4** and with the cylindrical sidewall **10** of the body **1**. The lower end of the pressure vessel is sealed by a plug **11** having a head **12** slidably received within a bore **13** at the lower end of the body and carrying an O-ring **14** making sealing engagement with the bore. A locknut **15** threaded on the stem of the plug **11** clamps a shoulder **16** on the underside of the head solidly against the upper end of the nut **3**. By removing the locknut **15**, the plug **11** may be lifted out of the nut **3**.

The furnace in which the diffusion bonding takes place is mounted on a support **17** fixed to the head **12** by screws **18**. As shown in FIG. **7**, the support **17** has an annular opening supporting ring **19** carrying studs **20** which carry supporting and guide plates ***21a***, ***21b***, ***21c***, ***21d*** for the furnace heating elements and for the associated electrical terminal connections. The supporting plates and the terminal connections are in the cool zone of the furnace which comprises all of the furnace below the supporting plate **22**. The supporting plate **22** is partially supported by nuts **23** on the upper ends of the studs **20** and is further supported by nuts **24** on the studs **25** carried by the supporting ring **19**. The supporting plate **22** carries a refractory disc **26** which serves as the bottom wall of the hot zone and which also supports refractory cylinders **27** and **28** serving as the sidewall of the hot zone. At the top of the hot zone of the furnace is an annular guide **29** of refractory material and a top supporting structure **30** closed by a cover **31** which may be lifted by an eye bolt **32**.

The heating elements are of two kinds. There is a set of angularly distributed heating element **33** which have their active heating surface extending substantially the full distance between the disc **26** and the top guide ring **29**. These heating elements extend through a middle guide ring **34** between the cylindrical sections **27** and **28**. The purpose of the heating elements **33** is to supply heat throughout the entire hot zone of the furnace. The other set of heating elements **35** is similarly distributed around the inner circumference of the furnace and each has its active heating length extending from the disc **26** about half way to the top of the furnace. The purpose of the heating elements **35** is to supply heat to the lower part of the hot zone. The heating elements are within the hot zone near its outer periphery and are spaced from the walls of the hot zone to prevent heat transfer by conduction. Each of the heating elements **33** and **35** is of the general structure shown in FIGS. **3** and **4** and comprises a hollow tube of silicon carbide which is split at **36** at its lower end and each side **37**, **38** of the split is connected by spiral sections ***37a*** and ***38a*** to the continuous upper end **39** of the heating element. The active heating sections of the heating elements are the spiral sections ***37a*** and ***38a***. The split lower ends are connected to power terminals **40** and **41** in the cool zone of the furnace. The actual connections to the heating elements are not shown but are diagrammatically indicated since these are well known.

FIG. **5** shows the maximum heating power output of the heating elements **33** and **35**. The power output of the heating elements **33** is indicated at **42** and the power output of the heating elements **35** is indicated at **43**.

The sets of heating elements **33** and **35** are separately controlled. The control for heating elements **33** has a thermocouple **45** which senses the temperature in the upper part of the hot zone of the furnace. The control for the heating element **35** has a thermocouple **46** which senses to the temperature in the lower part of the hot zone of the furnace. The thermocouple **45** is connected to lead wires **47** which extend up through the guide ring **29** and top supporting structure **30** and down through thermal insulation **48** surrounding the sidewalls **27**, **28** of the furnace. The thermocouple **46** is connected to a lead wire **49** which also extends up through the guide ring **29** and top supporting structure **30** and down through ceramic thermal insulation **48**, e.g. zirconia, surrounded by metal shell ***48a***. Both of the thermocouple lead wires **47** and **49** extend out through the plug **11** in the bottom closure **3** of the pressure vessel. The electrical power input lines (not shown) also extend through the plug **11** and are connected to a bus structure **50**, only part of which is shown. The furnace structure is all mounted on the plug **11** which can be assembled and tested prior to insertion in the pressure vessel.

The furnace is surrounded by a metal seal can **51** closed at its top and open at its bottom, which telescopes over substantially the full length of the furnace. The top wall **52** of the seal can is provided with a lifting ring **53**. The wall **52** is protected from the furnace heat by fibrous thermal insulation **54**. The sidewalls **55** of the seal can are adjacent the inner sidewalls of the pressure vessel, are cooled by the cooling jacket **2** and are also protected from the furnace heat by the insulation **48**. The lower end **56** of the seal can is protected from the furnace heat by insulation **57**, **58** in the spaces above and below the spacer plates ***21a***, ***21b***, ***21c***, ***21d***.

The operation of the furnace will be explained in connection with the control diagram of FIG. **8**. At the start of the operation, the workpiece **59** consisting of several parts to be diffusion bonded is placed on the bottom wall **26** of the furnace hot zone, the cover **32** and seal can **51** are installed on the furnace and the pressure vessel is closed by its top closure **4**. If desired, the interior of the pressure vessel is then evacuated through vacuum line **60**. When the desired vacuum is reached, the valve **61** is closed. Any of the usual gases is now supplied under pressure through line **62** and the heating elements **33** and **35** are turned on, each heating element being controlled by a separate control **63**, **65**. At the end of several hours, the furnace will come up to its operating temperature, for example, 2,600° F., and the parts of the workpiece **59** will be fusion bonded in a few minutes. At this point, the inert gas is withdrawn through line **62** to depressurize the furnace, the pressure vessel cover **4**, the seal can **51** and furnace cover **32** are removed exposing the open top of the furnace so that the finished workpiece **59** can be lifted out and a new workpiece substituted. When the furnace is opened, the workpiece and the heating elements **33**, **35** are exposed to air but are not oxidized because they are of silicon carbide. The heating elements and the part of the furnace do not substantially cool down while the completed workpiece **59** is being removed and another workpiece substituted. There is no substantial change in the furnace hot zone temperature which remains substantially as indicated by line **66** in FIG. **6**. It will be noted that the hot zone temperature remains substantially constant from top to bottom so that convection cannot significantly change the temperature to which the workpiece is being subjected. The time between cycles is that required for handling of the parts which must be removed and replaced. There is no need to wait for the furnace to cool down between cycles. This results in significant shortening of the average process time for the bonding operation. For example, in a prior furnace which could not be operated in vacuum, air and inert gas, it might take 3 hours for the furnace to heat up and 3 hours for the furnace to cool down.

When starting cold, both sets of heating elements are on and transfer heat by radiation and convection to all portions of the hot zone. The top, side and bottom walls of the hot zone become hot. As the furnace temperature increases, the demand for heat from the elements **33** decreases and at operating temperature little or no heat is required from the elements **33** and the heating elements **35** maintain the furnace temperature which remains substantially constant from the top to the bottom of the hot zone. This is possible because turbulence in the gas is avoided. Under operating conditions, gas under pressure permeates the entire interior of the pressure vessel, with the coldest gas adjacent the water-cooled pressure vessel body **1** and the hottest gas within the hot zone. Within the hot zone, convection is unobstructed so gas adjacent the heating elements is free to flow both toward the outer walls of the hot zone and toward the workpiece. However convection from the hot zone to the cooler gas outside the walls of the hot zone is effectively blocked by means in the form of restricted passageways provided by the seal can **51**, thermal insulation **48, 54, 57, 58**, which causes the flow of gas between the hot and cold zones to take place by diffusion rather than by ordinary hydrodynamic flow. By avoiding turbulence in the hot zone, no measurable difference in temperature in the workpiece can be measured from bottom to top. There should be a free space for convection currents within the hot zone so the temperature of the gas can equalize. Direct contact with the heating elements is avoided. The workpiece may occupy substantially all of the free space at the center of the hot zone so long as there is space for free circulation of gas about the workpiece and contact of the heating elements with the work and with cooler walls is avoided. By way of example, in a furnace having a hot zone approximately 10 inches in diameter and 20 inches high, the work can be 6 inches in diameter and from 18 to 19 inches high and the clearance between the heating elements and the work and between the heating elements and the sidewalls of the hot zone can be from one-fourth to one-half inch.

FIG. **9** shows the apparatus of FIG. **1** modified so that it may be bottom loaded. The changes necessary for bottom loading are (1) enlarge the lower end of the body of the pressure vessel as shown at **67** so that the seal can and the enclosed apparatus may be installed from the bottom, (2) change the plug on which the apparatus is supported from cylindrical to annular shape as shown at **11***a*, and (3) provide an insulating piston **68** for carrying the work. The power and control connections will now be mounted on the annular plug **11***a*. Appropriate seals **69** and **70** are provided between the plug **11***a* and the lower end of the pressure vessel body and between the insulating piston **68** and the plug **11***a*. When these changes are made, the apparatus can be used for either top or bottom loading.

The silicon carbide heating elements **33, 35** are advantageous when the apparatus is operated so as to expose the hot elements to air. Other heating elements which will not stand exposure to air while hot may be used if the apparatus is cooled down between cycles or if the heating elements are protected by an inert or nonreactive gas such as argon, by continuous purging with the gas when the apparatus is open.

The furnace is intended for operation at pressures up to 30,000 p.s.i. and temperatures up to 2,600° F. The particular furnace shown had an operating pressure of 3,000 p.s.i., and an operating temperature of 2,450° F.

What is claimed is:

1. Apparatus for diffusion bonding and the like comprising an upright pressure vessel having a filling of inert gas under pressure required for diffusion bonding, said vessel having top, bottom and sidewalls, means for cooling the pressure vessel walls while holding gas under said pressure, a furnace having a hot zone surrounded by refractory top, bottom and side walls each spaced from the corresponding part of the pressure vessel, a plurality of heating elements within the hot zone distributed to leave an open space at the center of the hot zone, means for supporting work in said open space out of contact with said heating elements and providing space for free circulation of said gas about the work, said heating elements being out of contact with each other and said furnace walls and spaced to permit free convection from the heating elements to the furnace walls and to said open space, the gas under diffusion bonding pressure permeating the entire interior of the pressure vessel with the coldest gas adjacent the cooled pressure vessel walls and the hottest gas within the hot zone, means in the form of restricted passageways for blocking convection of gas under diffusion bonding pressure from the hot zone to the coldest gas adjacent the cooled pressure vessel walls and limiting the flow of said gas from the hot and cold zones to diffusion rather than by ordinary hydrodynamic flow and thereby avoiding turbulence in the hot zone.

2. The apparatus of claim **1** in which said means for blocking convection of said gas from the hot zone comprises a seal can open at the bottom and closed at the top and sides and telescoped over the furnace between the furnace and the pressure vessel and thermal insulation between the top and sides of the furnace and the top and sides of the seal can and between the bottom wall of the hot zone of the furnace and the sides of the seal can and the bottom wall of the pressure vessel.

3. The apparatus of claim **1** in which the heating elements comprise a plurality of sets and one set of heating elements is wholly in the lower part of the hot zone.

4. The apparatus of claim **1** in which the pressure vessel has a removable bottom closure and the furnace is mounted on said removable bottom closure.

5. The apparatus of claim **1** in which the pressure vessel has an annular bottom closure with a removable closure at the center of the annular closure and the furnace is mounted on the annular closure.

6. The apparatus of claim **5** in which an insulated piston having means for carrying a workpiece on its upper end extends from said removable bottom closure up through the bottom wall of the furnace.

7. The apparatus of claim **3** in which another set of heating elements has a height substantially equal to the full height of the hot zone.

8. The apparatus of claim **7** having separate control means for each set of heating elements.

* * * * *