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(54) Titre : SYSTEME DE REFRIGERATION PASSIVE DESTINE AU SECTEUR DE LA CHAINE DE FROID
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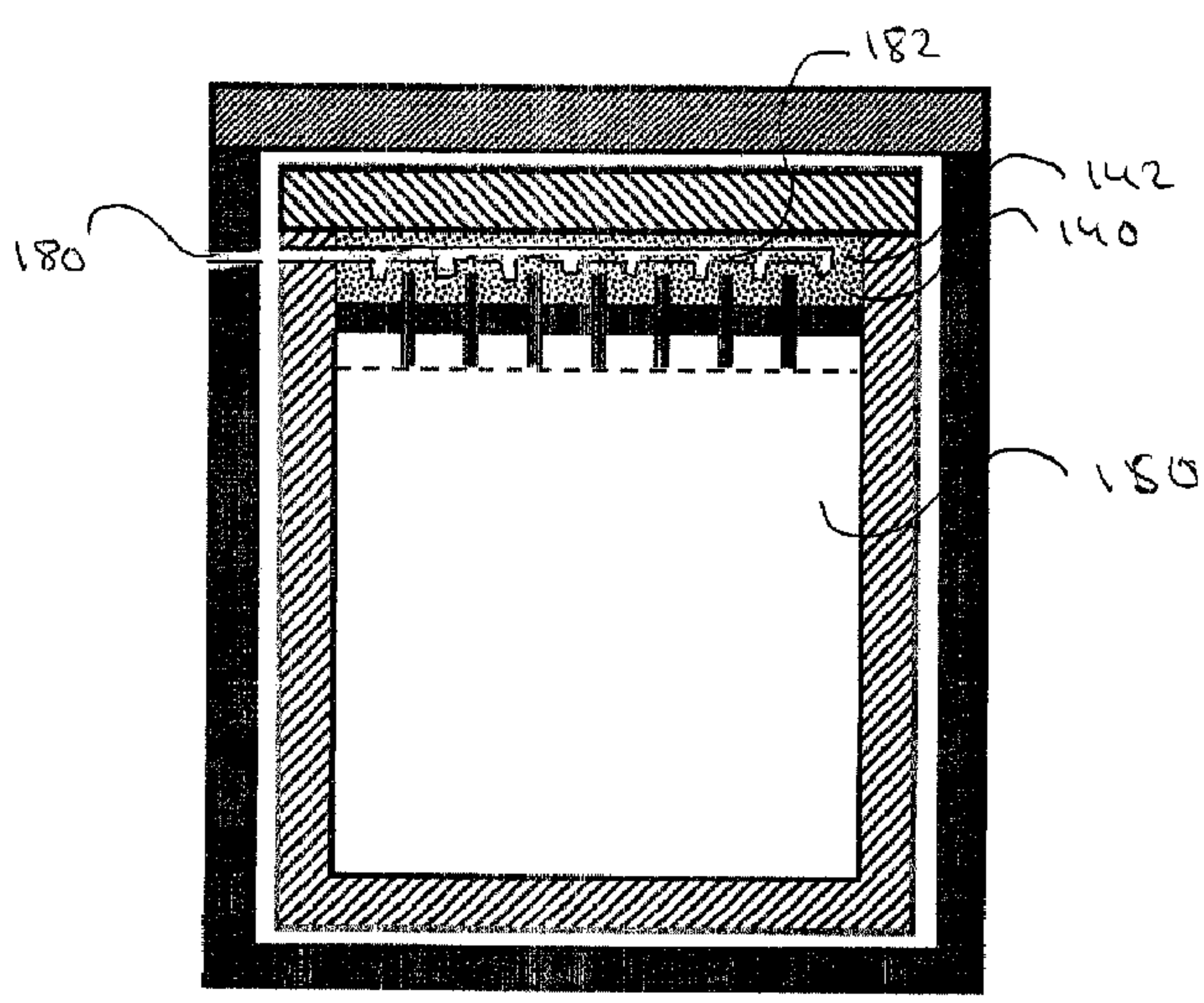

(57) Abrégé/Abstract:
A passive refrigeration box for controlled refrigeration of a product is provided, the refrigeration box comprising: an outer box, the outer box including an outer insulation layer; an inner box, the inner box including an inner insulation layer, and a thermal shield on

(57) Abrégé(suite)/Abstract(continued):
an outside of the inner insulation layer, the inner box and the outer box defining a vapour channel therebetween; and a thermal link, the thermal link including an thermal layer and a plurality of heat pipes or thermosyphons, the thermal layer and a top section of the inner box defining a coolant chamber, the coolant chamber including a coolant chamber access, the thermal layer and a bottom section of the inner box defining a load chamber, the load chamber including a load chamber access, each heat pipe or thermosyphon having a condenser section disposed in the coolant chamber and an evaporator section disposed in the load chamber and extending through the thermal layer.

ABSTRACT

A passive refrigeration box for controlled refrigeration of a product is provided, the refrigeration box comprising: an outer box, the outer box including an outer insulation layer; an inner box, the inner box including an inner insulation layer, and a thermal shield on an outside of the inner insulation layer, the inner box and the outer box defining a vapour channel therebetween; and a thermal link, the thermal link including an thermal layer and a plurality of heat pipes or thermosyphons, the thermal layer and a top section of the inner box defining a coolant chamber, the coolant chamber including a coolant chamber access, the thermal layer and a bottom section of the inner box defining a load chamber, the load chamber including a load chamber access, each heat pipe or thermosyphon having a condenser section disposed in the coolant chamber and an evaporator section disposed in the load chamber and extending through the thermal layer.

PASSIVE REFRIGERATION SYSTEM FOR THE COLD CHAIN INDUSTRY

FIELD

The present technology is directed to a passive system for refrigerating perishable products during shipping and storage. More specifically, the technology is directed to a system that uses carbon-dioxide free cooling in the load chamber, and which has a high degree of temperature regulation. The system is designed both for pallet sized loads and trailer sized loads and stationary cold storage facilities and is therefore scalable.

BACKGROUND

The cold chain industry is responsible for shipping and storing refrigerated temperature sensitive food and pharmaceutical products. Losses can be incurred because of insufficient refrigeration or improper temperatures. Currently, companies involved in shipping perishable foods must either have expensive electro-mechanical refrigeration trucks with multiple refrigerated compartments that can be set to different temperatures, or place all items at a single temperature and hope the frozen product does not melt and spoil before delivery.

United States Patent 4,891,954 discloses a refrigeration system (10) consisting of an insulated railcar (12) that utilizes sublimated carbon dioxide to maintain the integrity of stored products. The insulated railcar (12) includes a divider (22) that partitions the insulated railcar (12) into a lower storage area (26) and an upper bunker (24). The bunker (24) contains a distribution manifold (28) for forming carbon dioxide snow and distributing the formed snow throughout the bunker (24). Sublimation ports (30) along each sidewall (18) and end wall (20) allow the sublimated carbon dioxide to pass to the lower storage area (26) to refrigerate the stored products during transit. A plenum (42) and emission vent (44) is provided at each end of the insulated railcar (12) to vent sublimated carbon dioxide to the exterior atmosphere. The insulated railcar (12) also includes pressure relief ports (32) located substantially below the distribution manifold (28) to vent flash gas generated during the snow forming process. This technology does not allow for temperature control over time, nor is there a consistent temperature throughout the chamber. Further, CO_2 is added to the chamber.

United States Patent 5,460,013 discloses a refrigerated, thin-walled shipping container (8) including a horizontal dividing element (20) forming a compartment (22) for holding CO_2 snow created by passing liquid CO_2 through manifold (24) along at least one side of the compartment and spraying the CO_2 snow against the opposite wall. The charging of the cooling compartment generates gas pressure, and the combination design of the charging manifold and pressure release vents allows the operation to be performed without excessive structural damaging pressure buildup. This technology does not allow for temperature control over time, or in different regions of the container. Further, gaseous CO_2 is added to the chamber.

United States Patent 7,310,967 discloses a cryogenic shipping and storage container, with an on-board cooling unit in the form of a bunker for holding solid refrigerant. The unit can be configured for different sizes, and to refrigerate rather than freeze product. While this system allows for better temperature control in the chamber, it requires power and fans, and therefore is not a passive system. Further, gaseous CO_2 is added to the chamber.

United States Patent 8,191,380 discloses a portable active cryo container for maintaining product at refrigerated and/or cryogenic temperatures. Said container comprising a control system to monitor and control the flow of cooling air from a bunker section to at least one material storage section wherein temperature sensitive product is contained. The control system is coupled to a fan which enhances heat transfer through forced convection when the system moves outside thermal tolerance. The cryo container is powered using battery packs or by being plugged into a vehicle's 12-volt power supply. While this system allows for better temperature control in the chamber, it requires power and fans, and therefore is not a passive system. Further, gaseous CO_2 is added to the chamber. The coolant, which is liquid nitrogen, travels through a liquid vaporizing heat exchanger. Unlike a heat pipe, it has an open end. The open end discharges the coolant into the ambient environment in the chamber.

United States Patent 3714793 discloses a liquefied gas vaporizer in the bottom portion of the freeze-sensitive product storage chamber with thermal insulation around the liquid vaporizing conduit and thermally conductive metal floor means contiguously associated with and in heat transfer relation to the thermal insulation. The coolant, which is liquid nitrogen, travels through a liquid vaporizing heat exchanger. Unlike a heat pipe, it has an open end. The open end discharges the coolant into the ambient environment in the chamber.

United States Patent 3421336 discloses a system for more uniform distribution of refrigerant in long-haul trailers and railcars by intermittently spraying cold fluid into the product chamber and continuously expanding vaporised cold liquid into the same chamber with the production of external work which is recovered to circulate the sprayed cold fluid.

United States Patent 7891575 discloses a thermal storage and transfer system that includes a cooling system and method using ice or other frozen material with heat pipes to produce a cool airstream. Preferably, the ice is disposed in a container with the condensers and evaporators of the heat pipes respectively inside and outside the container. A fan blows air across the evaporator sections through a duct to circulate within an enclosed airspace to be cooled. A separate refrigeration system which may be used to independently cool the airspace also freezes water or another liquid to produce the ice or other frozen material in the container. The cooling system is broadly applicable, including use on motor vehicles to provide cooling for several hours when the vehicle engine is off. A heating system includes an adsorbent heat exchanger for extracting heat from exhaust gases of an engine and heating an enclosed airspace. This is not a passive system, as it requires fans.

United States Patent Application 20040226309 discloses a portable, temperature-controlled container for storing and transporting temperature-sensitive materials. The portable, temperature-controlled container includes a container having a bottom wall, four side walls, and a top wall defining a cargo space. The container includes a temperature regulating unit connected to the container. The temperature regulating unit comprising a refrigeration unit. The temperature regulating unit being in communication with the cargo space of the container. The container includes a temperature controller connected to the container. The temperature controller comprising a temperature control unit and a temperature sensor positioned in the cargo space of the container. The container also includes a power supply. The temperature regulating unit can include a heating unit. This is not a passive system.

United States Patent 8,162,542 discloses a cargo container that includes a cargo box affixed atop a hollow base, with the base including forklift tunnels extending therethrough with elongate bays disposed parallel thereto. Each bay includes a removable tray for receiving electrical batteries. And, a temperature control system is disposed on a sidewall adjoining the base. The cargo container has both an electrical heater and vapor compression refrigeration. Onboard batteries provide power during shipping. This is not a passive system.

United States Patent Application 20130008188 discloses a cryogen heat exchanger that includes a container having a sidewall defining a chamber in the container for containing a cryogen, and at least one heat exchange assembly having a first portion disposed in the chamber and extending through the sidewall to a second portion disposed in an atmosphere of a space external to the chamber and at an opposite side of the sidewall for providing heat transfer to the atmosphere. The system uses heat pipes, but also includes at least one fan, and therefore is not a passive system. Temperature can be adjusted by varying the pressure of the cryogen (liquid nitrogen or liquid carbon dioxide) in the tank, presumably with a pump or adjusting fan speed. Again, neither being passive. Other methods of adjusting temperature do not allow for temperature adjustment on the fly, but rather involve use of a variable volume liquid reservoir to the evaporator section of each heat pipe. The heat pipes are stainless steel or copper.

A refrigerated container that can hold a pallet of product would be useful for both shipping and storage of perishable products. It would be preferably if carbon dioxide or other coolant was not added to the storage compartment, either directly or indirectly. Carbon dioxide displaces oxygen and in high concentrations will asphyxiate a person. Discharging carbon dioxide vapour directly into the load space compromises temperature control and because of its very rapid temperature pulldown, compromises the load unit's structural elements. Further, the expansion effect caused by phase change requires significant volumes of the cryogen vapour to vent the atmosphere, which increases operating costs by increasing the amount cryogen needed. It would be more preferably if it had a passive heat transfer system with no requirement for forced convention. It would be of further advantage if the system allowed for delivery and storage of cargo at various selected and controlled temperatures.

SUMMARY

The present technology provides a refrigerated container for both shipping and storage of perishable products. In one embodiment, it is sized to hold a pallet of product. Carbon dioxide is not added or released to the storage compartment, either directly or indirectly. The system has a passive heat transfer system with no requirement for forced convention. The system allows for delivery and storage of cargo at various selected and controlled temperatures.

In one embodiment, a passive refrigeration box for controlled refrigeration of a product is provided, the refrigeration box comprising: an outer box, the outer box including an outer insulation layer; an inner box, the inner box including an inner insulation layer, and a thermal shield on an outside of the inner insulation layer, the inner box and the outer box defining a vapour channel therebetween; and a thermal link, the thermal link including an thermal layer and a plurality of heat pipes or thermosyphons, the thermal layer and a top section of the inner box defining a coolant chamber, the coolant chamber including a coolant chamber access, the thermal layer and a bottom section of the inner box defining a load chamber, the load chamber including a load chamber access, each heat pipe or thermosyphon having a condenser section disposed in the coolant chamber and an evaporator section disposed in the load chamber and extending through the thermal layer.

The passive refrigeration box may further comprise a mesh header below the heat pipes or thermosyphons.

The passive refrigeration box may further comprise an outer skin on the outer insulation and an inner liner on the inner insulation.

In the passive refrigeration box the thermal shield may be an aluminum shield.

In the passive refrigeration box the coolant chamber access may include an outer lid and an inner lid.

In the passive refrigeration box the inner lid may be seated on a step in the inner box.

The passive refrigeration box may further comprise a gasket between the inner lid and the step.

In the passive refrigeration box the heat pipes may be weld-free heat pipes.

In the passive refrigeration box the heat pipes may include a working fluid, the working fluid being one of pentane, propylene, acetone and methanol.

In the passive refrigeration box the thermal link may be a reconfigurable thermal link.

The passive refrigeration box may further comprise a check valve in the outer lid.

In another embodiment, a passive refrigeration system for the cold-chain industry is provided, the system including a box and a solid coolant, the box comprising: an outer box, the outer box including an outer insulation layer; an inner box, the inner box including an inner insulation layer, and a thermal shield on an outside of the inner insulation layer, the inner box and the outer box defining a vapour channel therebetween; and a thermal link, the thermal link including a thermal layer and a plurality of heat pipes or a plurality of thermosyphons, the thermal layer and a top of the inner box defining a coolant chamber, the coolant chamber including a coolant chamber access, the thermal layer and a bottom of the inner box defining a load chamber, the load chamber including a load chamber access, each heat pipe or thermosyphon having a condenser section disposed in the coolant chamber and an evaporator section disposed in the load chamber and extending through the thermal layer, and the solid coolant is solid carbon dioxide.

In the system, the thermal link may be a reconfigurable thermal link.

In the system, the system includes the heat pipes.

In the system, the heat pipes may be weld-free heat pipes.

In the system, the heat pipes may include a working fluid, the working fluid being one of pentane, propylene, acetone and methanol.

In the system, the thermal shield may be an aluminum shield.

In another embodiment, a passive refrigeration box for controlled refrigeration of a product is provided, the refrigeration box comprising: a bottom, four side attached to the bottom, an inner lid and an outer lid, the sides including an outer insulation layer and an inner insulation layer, the layers and the inner and outer lids defining a vapour channel therebetween, an aluminum shield adjacent the vapour channel and abutting an outer side of the inner insulation layer and a top of the inner lid, a thermal layer, the thermal layer disposed below the inner lid and between the inner insulation layers to define a coolant chamber, the coolant chamber for retaining a coolant, a load chamber, the load chamber defined by the inner insulation, and the thermal layer, and a plurality of heat pipes or a plurality of thermosyphons, each heat pipe or thermosyphon having a condenser section disposed in the coolant chamber and an evaporator section disposed in the load chamber and extending through the thermal layer.

In another embodiment, a method of refrigerating a load passively is provided, using the refrigeration box described above, the method comprising loading the load into the load chamber and charging the coolant chamber with a solid coolant.

The method may further comprise configuring the thermal link to regulate the temperature of the load.

In the method, the solid coolant is solid carbon dioxide.

FIGURES

Figure 1 is a longitudinal sectional view of a heat pipe of the present technology.

Figure 2 is a longitudinal sectional view of an end cap and tube end of the heat pipe of Figure 1.

Figure 3 is a perspective sectional view of the passive refrigeration box of the present technology.

Figure 4 is a longitudinal sectional view of Figure 3.

Figure 5 is a longitudinal sectional view an alternative embodiment of Figure 3.

Figure 6 is a longitudinal sectional view of an alternative embodiment of Figure 3.

DESCRIPTION

Except as otherwise expressly provided, the following rules of interpretation apply to this specification (written description, claims and drawings): (a) all words used herein shall be construed to be of such gender or number (singular or plural) as the circumstances require; (b) the singular terms "a", "an", and "the", as used in the specification and the appended claims include plural references unless the context clearly dictates otherwise; (c) the antecedent term "about" applied to a recited range or value denotes an approximation within the deviation in the range or value known or expected in the art from the measurements method; (d) the words "herein", "hereby", "hereof", "hereto", "hereinbefore", and "hereinafter", and words of similar import, refer to this specification in its entirety and not to any particular paragraph, claim or other subdivision, unless otherwise specified; (e) descriptive headings are for convenience only and shall not control or affect the meaning or construction of any part of the specification; and (f) "or" and "any" are not exclusive and "include" and "including" are not limiting. Further, the terms "comprising," "having," "including," and "containing" are to be construed as open ended terms (i.e., meaning "including, but not limited to,") unless otherwise noted.

To the extent necessary to provide descriptive support, the subject matter and/or text of the appended claims is incorporated herein by reference in their entirety.

Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. Where a specific range of values is provided, it is understood that each intervening value, to the tenth of the unit of the lower limit unless the context clearly dictates otherwise, between the upper and lower limit of that range and any other stated or intervening value in that stated range, is included therein. All smaller sub ranges are also included. The upper and lower limits of these smaller ranges are also included therein, subject to any specifically excluded limit in the stated range.

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the relevant art. Although any methods and materials similar or equivalent to those described herein can also be used, the acceptable methods and materials are now described.

DEFINITIONS

Heat pipe – in the context of the present technology, a heat pipe consists of a sealed pipe that unreleasably retains a working fluid. A wick is present in the bore of the pipe.

Thermosyphon – in the context of the present technology, a thermosyphon is similar in components and construction to a heat pipe, except it contains a larger amount of working fluid and it does not contain a wick structure. It unreleasably retains a working fluid.

Weld-free heat pipe – in the context of the present technology, a weld-free heat pipe is one that has barbed end caps and barbs on the inside of the tube of the heat pipe proximate the ends. The end caps and tube are press fit together.

Weld-free, soldered heat pipe – in the context of the present technology, a copper heat pipe will be soldered to close the end caps to the tube.

Weld-free soldered thermosyphon – in the context of the present technology, a thermosyphon will be soldered to close the end caps to the tube.

Working fluid – in the context of the present technology, a working fluid is one that is present as both a saturated liquid phase and a vapour phase in the heat pipe. The liquid is evaporated to a vapour at the evaporator region of the heat pipe, and the vapour is condensed to a liquid at the condenser region of the heat pipe.

Wick – in the context of the present technology, a wick is a material that lines the bore of the heat pipe and exerts a capillary action on the liquid phase of the working fluid.

Thermal link – in the context of the present technology, a thermal link is an interface for the management of heat flow (thermal energy flow). The design and the material used determines the thermal conduction of the thermal linkage. The thermal linkage includes the heat pipes and an insulating or conducting layer (the thermal layer).

Reconfigurable thermal link – in the context of the present technology, a reconfigurable thermal link refers to a thermal link that can be altered to change or optimize the thermal conductivity for a given application (temperature requirement).

Solid coolant – in the context of the present technology, charging the coolant chamber with a solid coolant means that a solid coolant is added, or a liquid coolant is injected which then changes phase from a liquid to a solid coolant.

DETAILED DESCRIPTION

A heat pipe, generally referred to as 8 is shown in Figure 1. It is a tube 10 that has a first end 12, with a first end cap 14, and a second end 16, with a second end cap 18. The second end cap 18 has a fill tube 20 extending therefrom. A bore 22 extends from the first end cap 14 to the second end cap 18. The fill tube 20 has a crimping end 24 distal to the second end cap 18 and a fill tube bore 26. The second end cap 18 has a central aperture 28. The wall 30 of the central aperture 28 has a step 32 upon which the proximal end 32 of the fill tube 20 is seated (Figure 2). A solder bead 34 attaches the fill tube 20 to the second end cap 18. In Figure 1, the crimping end 24 is crimped, after the working fluid has been added to the pipe. A bead of solder 40 seals the crimped end 24. The heat pipe 8 has a wick 42 in the bore 22.

As shown in Figure 2, and using the second end cap as an example, the first end 12 and the second end 16 and the end caps 14, 18 are barbed 50, with the end cap 14, 18 preferably being the male mating member 52 and the ends 12, 16 being the female mating member 54 and also having barbs 56. An O-ring 60 is seated in the mating pair. This provides a weld-free heat pipe.

As noted above, the thermosyphon is weld-free and is soldered closed.

A passive refrigeration box, generally referred to as 80 is shown in Figure 3. The refrigeration box 80 provides passive cooling through the use of heat pipes 8 and with no release of coolant into the load chamber 82. The outer box 81 includes a bottom 84 attached to four walls 86, and an outer lid 88. The box is preferably constructed to provide sufficient strength and support for the load and to be moved using a fork lift. An outer skin 90 of aluminum or steel or plastic is optionally supported by a metal frame 92 in the bottom 84 and four walls 86. A layer of outer insulation 94 lines the inside 96 of the skin 90 and frame 92. The outer insulation 94 is preferably closed cell, extruded or expanded polystyrene or the like. The bottom 84 includes slots 97 for accepting forks of a forklift.

An inner box 98 includes four inner walls 100, an inner bottom 102, and an inner lid 104. A layer of inner insulation 110 lines the inner liner 112 of the walls 100 and the skin 114 of the inner lid 104. The inner insulation 110 is preferably closed cell, extruded or expanded polystyrene or the like. The inner liner 112 and skin 114 are aluminum or plastic. The inner liner 112 includes stand-offs 116 that extend a short distance into the load chamber 150 to ensure that an air gap 116 is maintained between the inner liner

112 and the load. The outer lid 88 is similarly constructed of a skin which is aluminum or plastic and insulation that is preferably closed cell, extruded or expanded polystyrene or the like.

Abutting the upper surface 118 of the insulation 110 of the inner lid 104 and the outer surface 120 of the inner insulation 100 is a thermal shield 122 which in the preferred embodiment is an aluminum shield 122. The aluminum shield 122 and both the layer of outer insulation 94 on the walls 86 and the outer lid 88 define a space referred to as vapour channel 124. The thermal shield 122 helps to manage heat leaks and maintain the temperature of the cold space. It also decreases the time to cool a load from its initial higher temperature to steady-state while consuming less dry-ice.

As shown in Figure 4, the inner lid 104 sits on a step 126 in the inner liner 112. A gasket 128 fits between the inner lid 104 and the step 126 in the inner liner 112. The vapour channel 124 is sealed from the ambient and from the coolant chamber 140. However, there is a check valve 125 mounted in the outer lid 88 so that a small over pressure can be maintained inside the vapour channel 124. This prevents the ingress of external moist air when the dry ice charge is depleted. A coolant 142 which is preferably solid carbon dioxide, is loaded and retained in the coolant chamber 140. Once closed, the coolant chamber 140 does not communicate with the ambient environment. The coolant chamber 140 has a plurality of heat pipes 8 extending into the chamber through a base 143 of the coolant chamber 140. The base 143 and the heat pipes 8 form a reconfigurable thermal link 144. The reconfigurable thermal link 144 allows for customization and optimization of thermal energy transfer between the coolant 142 in the coolant chamber 140 and the load chamber 150. The coolant chamber 140 is in a top section 146 of the inner box 98. The load chamber 150 is in a bottom section 148 of the inner box 98.

The construction of the heat pipes 8 assist in providing this customization. The portion of the heat pipes 8 extending into the coolant chamber 140 includes the condenser section 152. Below the base 143 and the inner liner 112 is the load chamber 150. The portion of the heat pipes 8 extending into the load chamber 150 includes the evaporator section 156. A mesh header 160 protects the heat pipes 8 from damage in case the load in the load chamber 150 shifts. The mesh is aluminum, steel or plastic and additionally functions to ensure sufficient space for air circulation. It extends across the load chamber 150 in the vicinity of the top 162 of the load chamber 150. The load chamber 150 is an enclosed space.

An inner door 170 and an outer door 172 are constructed in the same manner and with the same materials as the lids 88, 104. These doors do not impede the vapour channel 124. At least one temperature sensor

176 is located in the load chamber 150 and is in electronic communication with a display 178 that is remote to the refrigerator box 80 or is on an outer surface 178 of the refrigerator box 80.

In one embodiment, the refrigeration box 80 is sized to accept a pallet load of product. The load is placed in the refrigeration box and then the refrigeration box can be moved into and out of a storage facility or a truck for transport. Different refrigeration boxes operating at different temperatures can be placed side by side and can be delivered together or independently of other refrigeration boxes in the truck. This increases the flexibility in the truck load to be delivered, allows for optimization of storage conditions for product, and reduces energy consumption and the associated pollution caused by running a generator to cool a truck load.

In an alternative embodiment, a side access allows the coolant chamber 140 either to be slid out and charged with solid coolant 142, or simply accessed on the side and charged.

In another embodiment, shown in Figure 5, the passive refrigeration box 80 of Figures 3 and 4 further includes a liquid injection port 180 and a distribution manifold 182 in the coolant chamber 140 for the addition of liquid carbon dioxide. This liquid carbon dioxide flashes into solid carbon dioxide snow (solid coolant 142), hence charging the coolant chamber with solid coolant 142.

In another embodiment, shown in Figure 6, the refrigeration box is sized to fit as a single unit in an ISO container 200, hence it is slightly smaller than the inside dimensions of an ISO container 200. The load chamber 150 has a load chamber access 202 that is an inner 204 and an outer door 206. The coolant chamber access 208 may be through lids or an access 208 on the side, as shown in Figure 5. The construction and relationship between the doors is the same as the lids – there is a thermal shield 206 on the outer side 208 of the inner door 202 and the vapour channel 210 has an unimpeded path between the doors 202, 204.

In another embodiment, the refrigeration box is a container for transport on a trailer or a flat bed. It again has doors and is as described and shown in Figure 5.

In another embodiment, the refrigeration box 80 is a trailer. It again has doors and is as described and shown in Figure 5.

In another embodiment, the heat pipes are replaced with thermosyphons.

While example embodiments have been described in connection with what is presently considered to be an example of a possible most practical and/or suitable embodiment, it is to be understood that the descriptions are not to be limited to the disclosed embodiments, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the example embodiment. Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, many equivalents to the specific example embodiments specifically described herein. Such equivalents are intended to be encompassed in the scope of the claims, if appended hereto or subsequently filed.

CLAIMS

1. A passive refrigeration box for controlled refrigeration of a product, the refrigeration box comprising: an outer box, the outer box including an outer insulation layer; an inner box, the inner box including an inner insulation layer, and a thermal shield on an outside of the inner insulation layer, the inner box and the outer box defining a vapour channel therebetween; and a thermal link, the thermal link including an thermal layer and a plurality of heat pipes or a plurality of thermosyphons, the thermal layer and a top section of the inner box defining a coolant chamber, the coolant chamber including a coolant chamber access, the thermal layer and a bottom section of the inner box defining a load chamber, the load chamber including a load chamber access, each heat pipe or thermosyphon having a condenser section disposed in the coolant chamber and an evaporator section disposed in the load chamber and extending through the thermal layer.

2. The passive refrigeration box of claim 1, further comprising a mesh header below the heat pipes or thermosyphons.

3. The passive refrigeration box of claim 1 or 2, further comprising an outer skin on the outer insulation and an inner liner on the inner insulation.

4. The passive refrigeration system of any one of claims 1 to 3, comprising the plurality of heat pipes.

5. The passive refrigeration box of any one of claims 1 to 4, wherein the thermal shield is an aluminum shield.

6. The passive refrigeration box of any one of claims 1 to 5, wherein the coolant chamber access includes an outer lid and an inner lid.

7. The passive refrigeration box of claim 6, wherein the inner lid is seated on a step in the inner box.

8. The passive refrigeration box of any one of claims 1 to 7, further comprising a gasket between the inner lid and the step.

9. The passive refrigeration box of claim 1, wherein the heat pipes are weld-free heat pipes.

10. The passive refrigeration box of claim 9, wherein the heat pipes include a working fluid, the working fluid selected from the group consisting of acetone, methanol, pentane and propylene.

11. The passive refrigeration box of claim 1, wherein the thermal link is a reconfigurable thermal link.

12. The passive refrigeration box of any one of claims 6 to 11 further comprising a check valve in the outer lid.

13. A passive refrigeration system for the cold-chain industry, the system including a box and a solid coolant, the box comprising: an outer box, the outer box including an outer insulation layer; an inner box, the inner box including an inner insulation layer, and a thermal shield on an outside of the inner insulation layer, the inner box and the outer box defining a vapour channel therebetween; and a thermal link, the thermal link including a thermal layer and a plurality of heat pipes or a plurality of thermosyphons, the thermal layer and a top of the inner box defining a coolant chamber, the coolant chamber including a coolant chamber access, the thermal layer and a bottom of the inner box defining a load chamber, the load chamber including a load chamber access, each heat pipe or thermosyphon having a condenser section disposed in the coolant chamber and an evaporator section disposed in the load chamber and extending through the thermal layer, and the solid coolant is solid carbon dioxide.

14. The system of claim 13, wherein the thermal link is a reconfigurable thermal link.

15. The system of claim 13 or 14, wherein the system includes the plurality of heat pipes.

16. The system of any one of claims 13 to 15, wherein the heat pipes are weld-free heat pipes.

17. The system of claim 16, wherein the heat pipes include a working fluid, the working fluid selected from the group consisting of acetone, methanol, pentane and propylene.

18. The system of any one of claims 13 to 17, wherein the thermal shield is an aluminum shield.

19. A passive refrigeration box for controlled refrigeration of a product, the refrigeration box comprising: a bottom, four side attached to the bottom, an inner lid and an outer lid, the sides including an outer insulation layer and an inner insulation layer, the layers and the inner and outer lids defining a vapour channel therebetween, a aluminum shield adjacent the vapour channel and abutting an outer side of the inner insulation layer and a top of the inner lid, a thermal layer, the thermal layer disposed below the inner lid and between the inner insulation layers to define a coolant chamber, the coolant chamber for retaining a coolant, a load chamber, the load chamber defined by the inner insulation, and the thermal layer, and a plurality of heat pipes, each heat pipe having a condenser section disposed in the coolant chamber and an evaporator section disposed in the load chamber and extending through the thermal layer.

20. A method of refrigerating a load passively, using the refrigeration box of claim 1, the method comprising loading the load into the load chamber and charging the coolant chamber with a solid coolant.

21. The method of claim 20 further comprising configuring the thermal link to regulate the temperature of the load.

22. The method of claims 20 or 21, wherein the solid coolant is solid carbon dioxide.

FIGURE 1

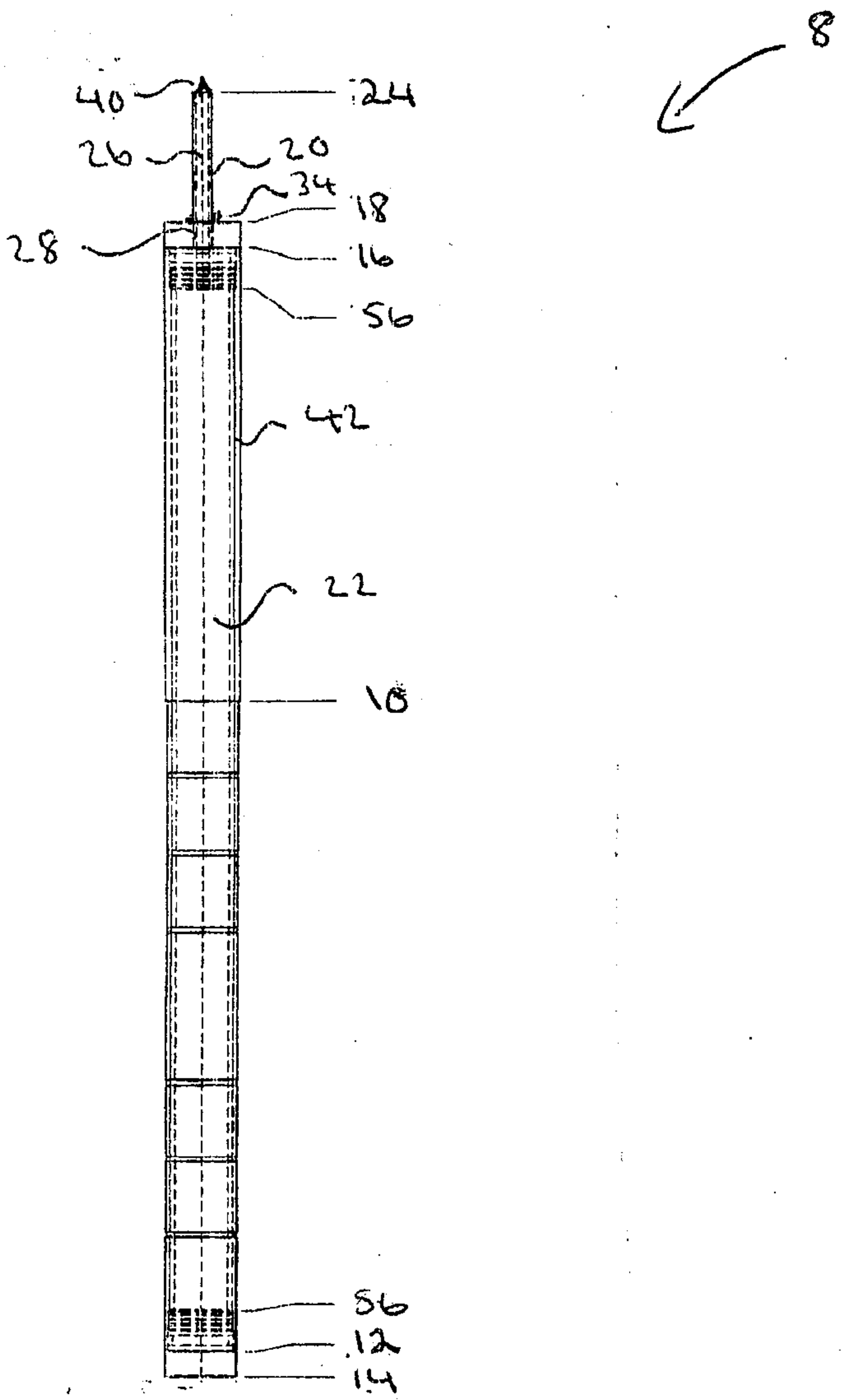

FIGURE 2

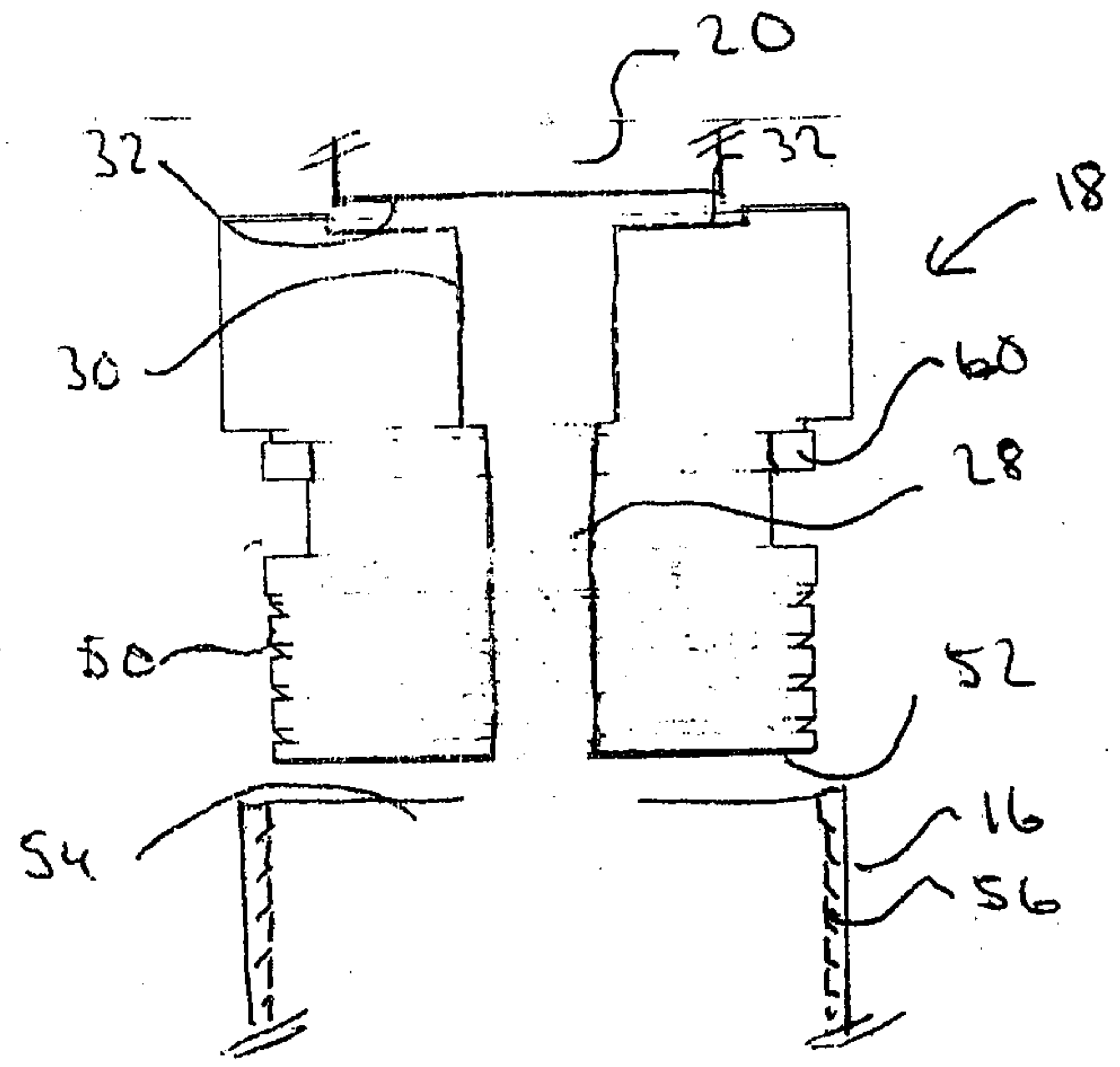

FIGURE 3

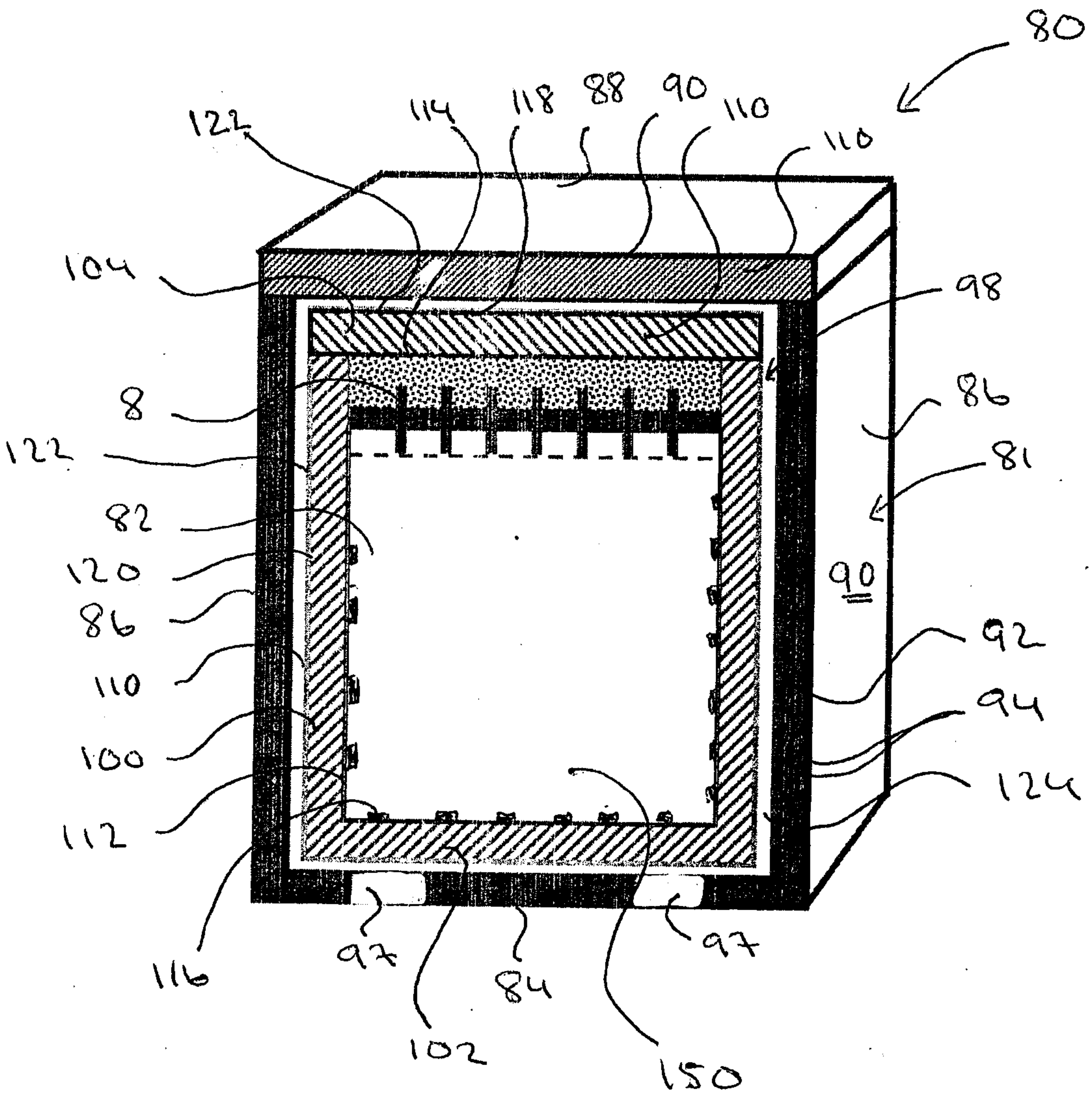
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FIGURE 4

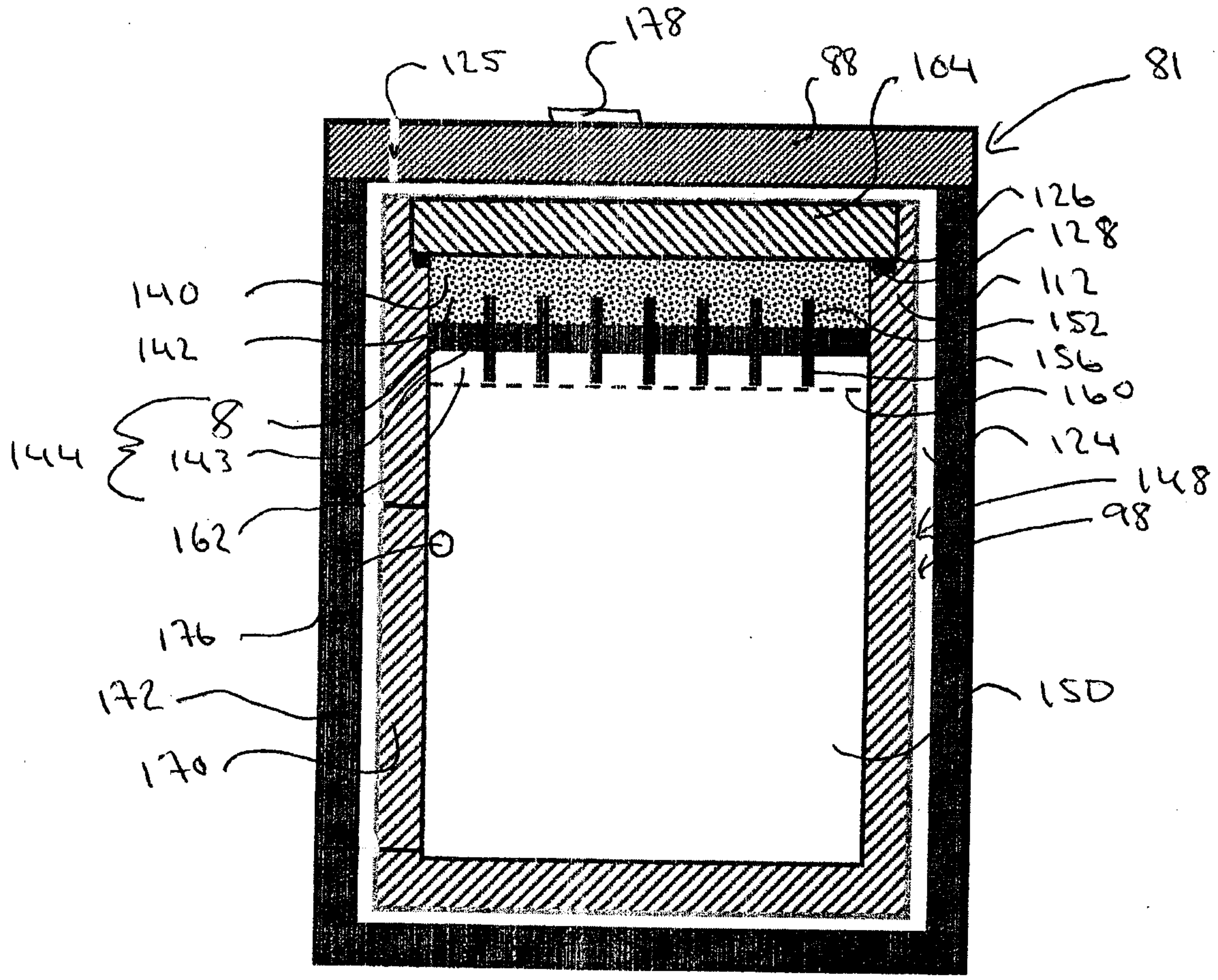
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FIGURE 5

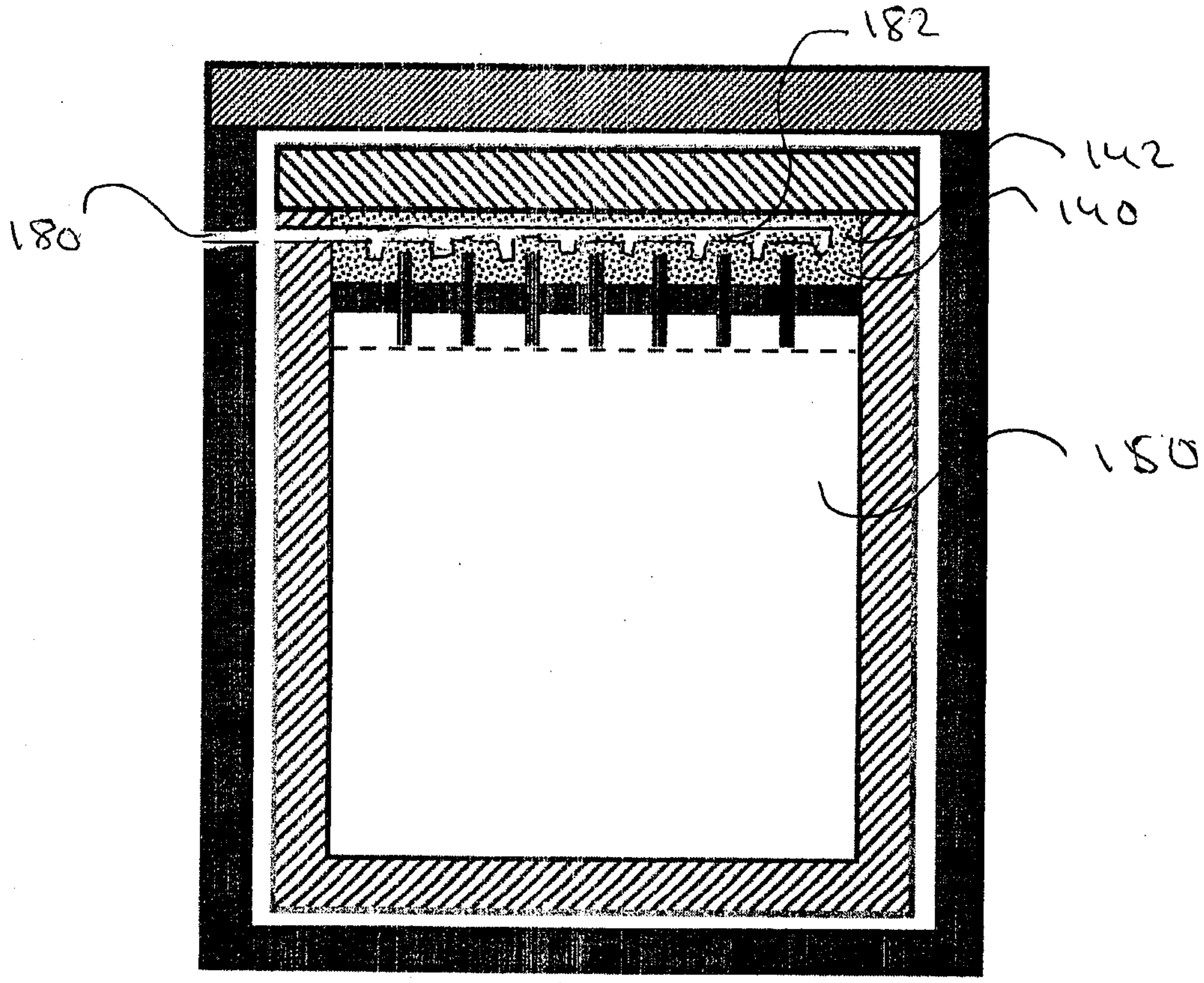
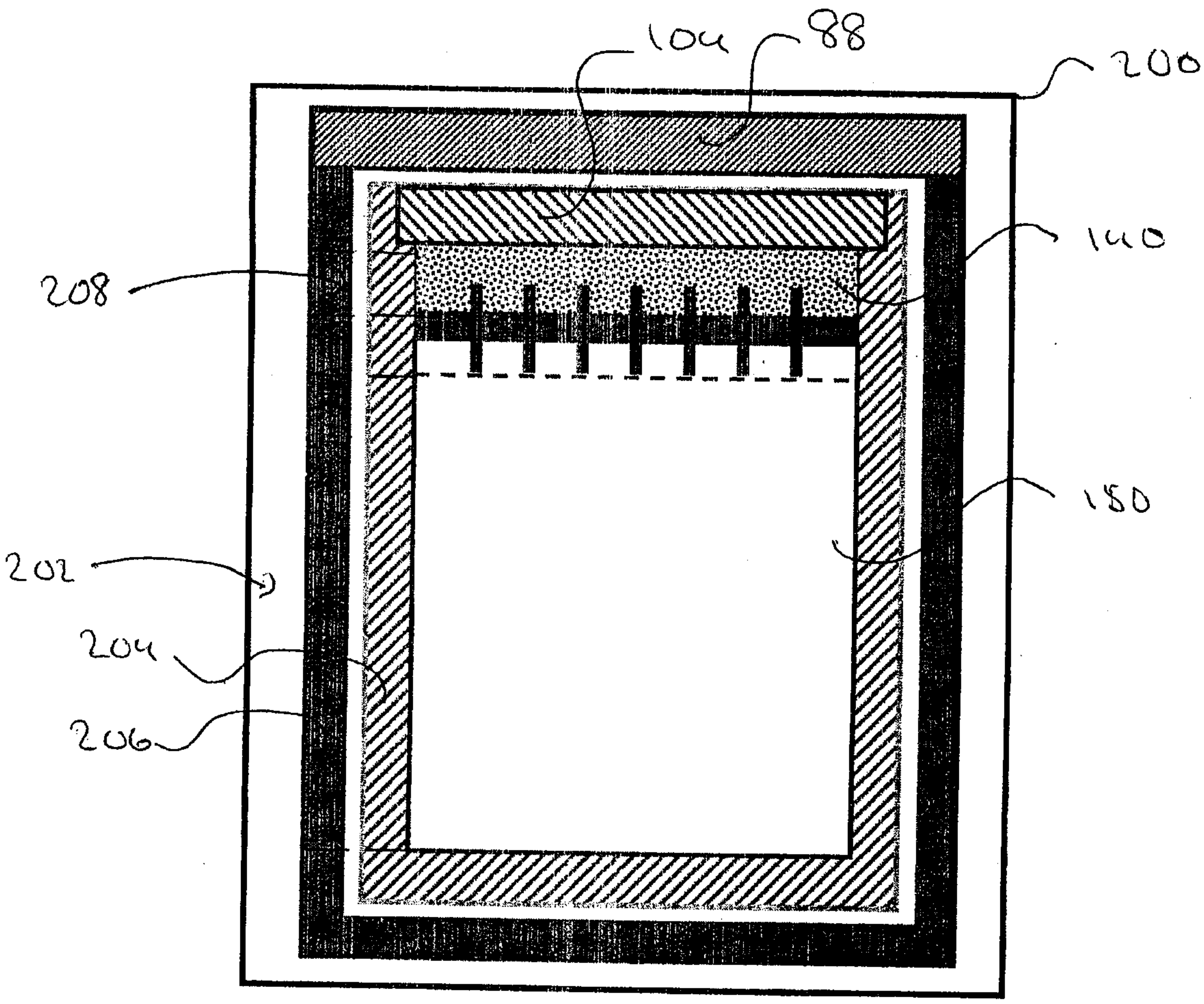
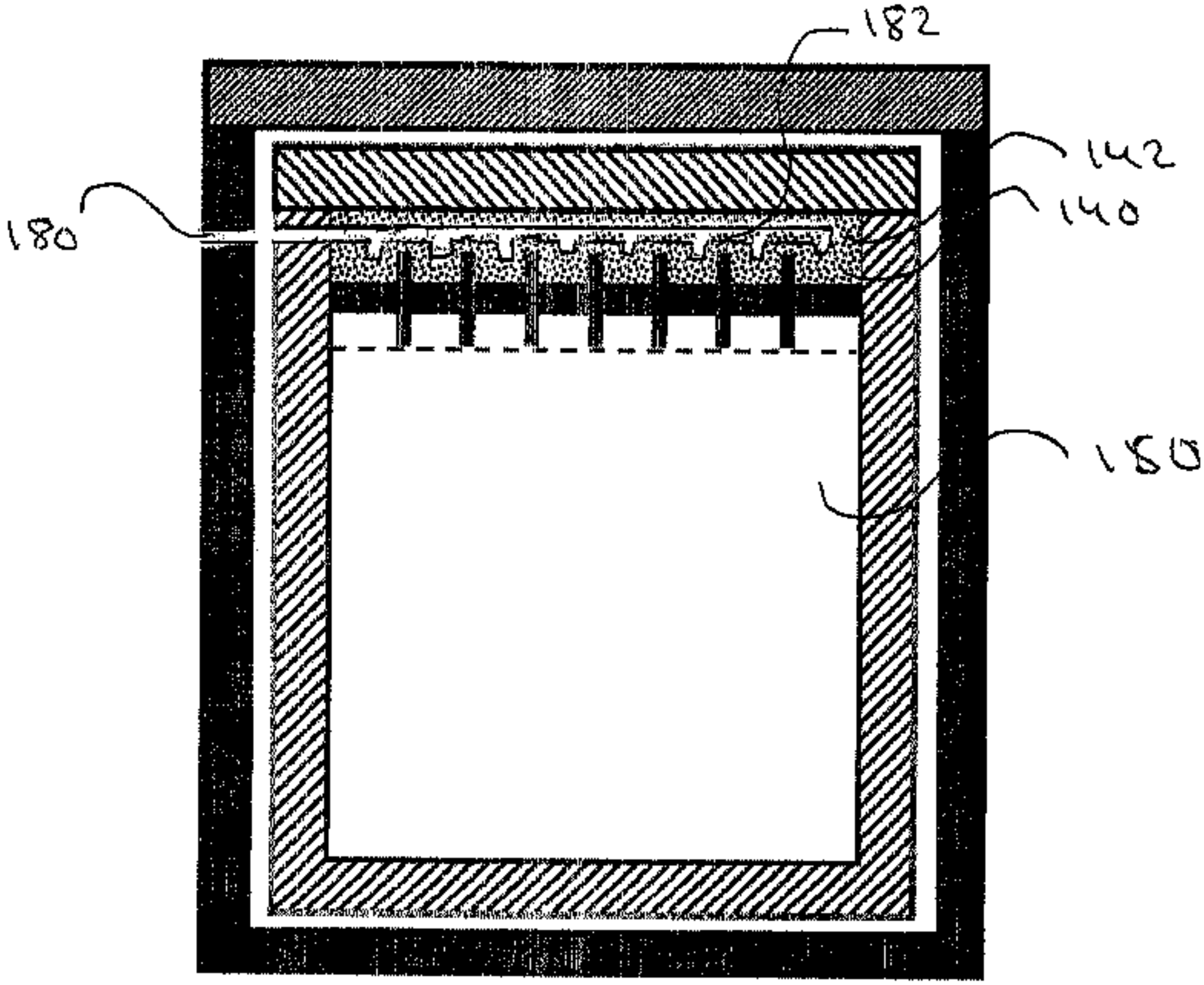


FIGURE 6

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