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(54) **LIQUID METAL THERMAL STORAGE
SYSTEM**

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(57) **ABSTRACT**

Embodiments of this invention relate generally to high temperature thermal energy storage, and more specifically, to the use of the latent heat of fusion of melting and solidifying metals to receive from and provide heat to a gaseous medium. Embodiments of this invention are also known as the Liquid Metal Thermal Storage system or LIMETS. Also described are methods of containing the storage material, heat transfer means, and choices of metals and alloys for thermal storage materials.

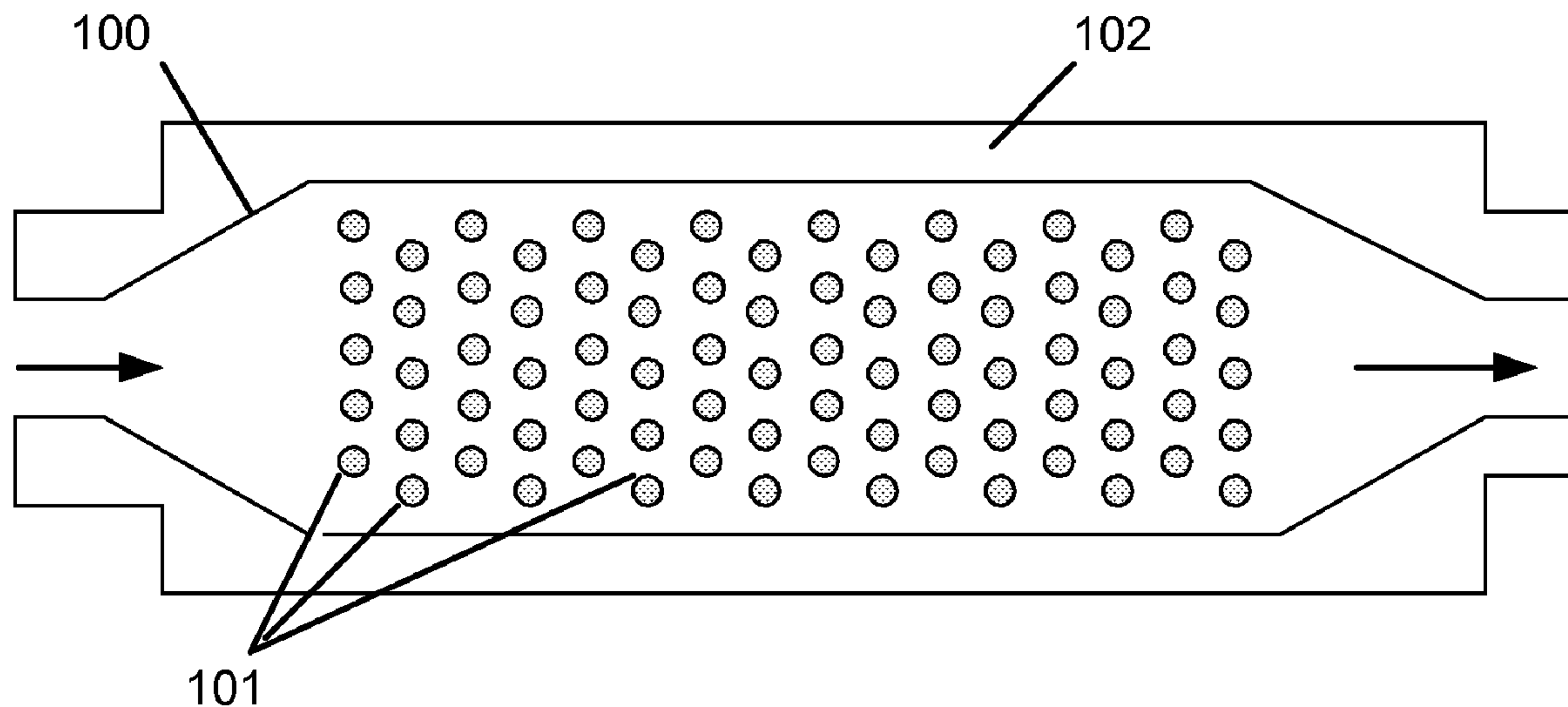
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(60) Provisional application No. 61/276,269, filed on Sep. 10, 2009.



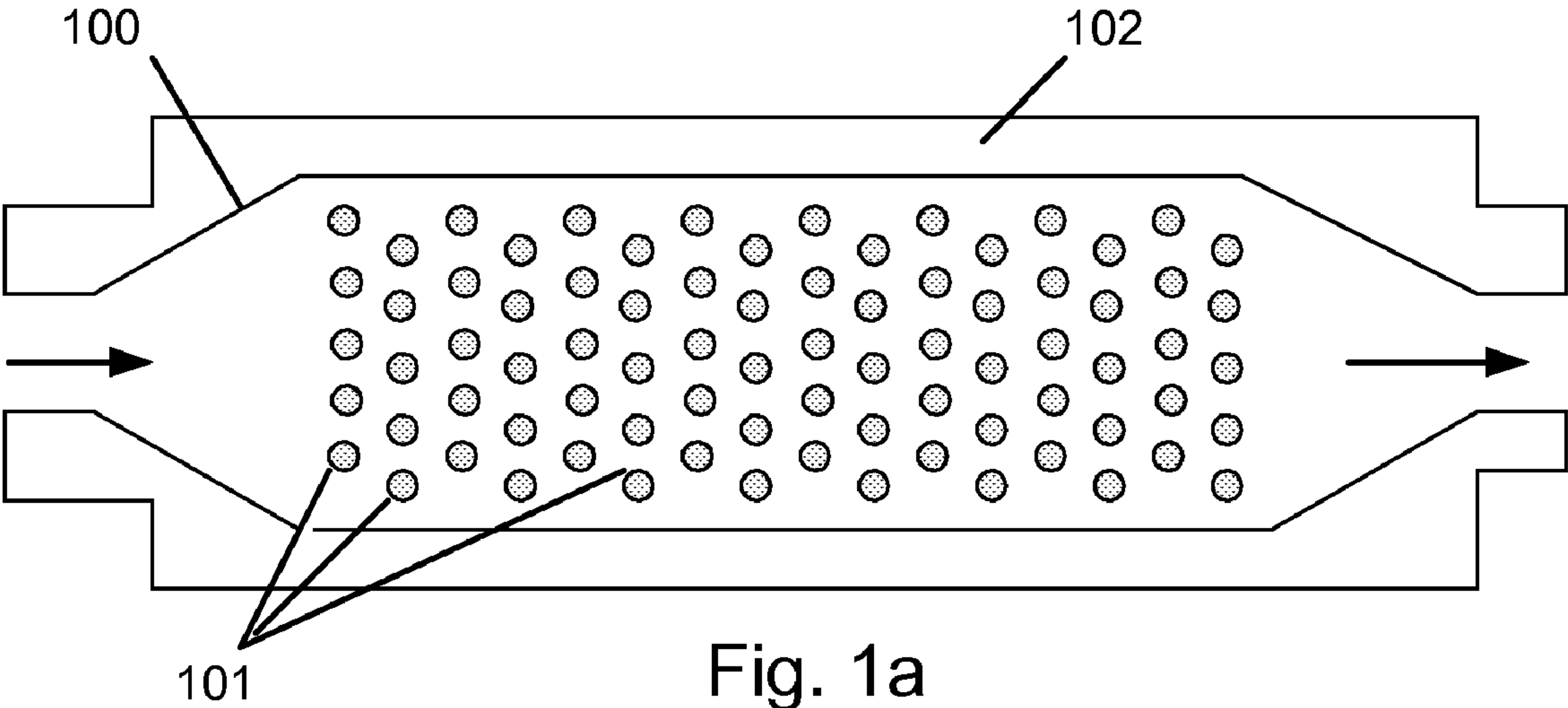


Fig. 1a

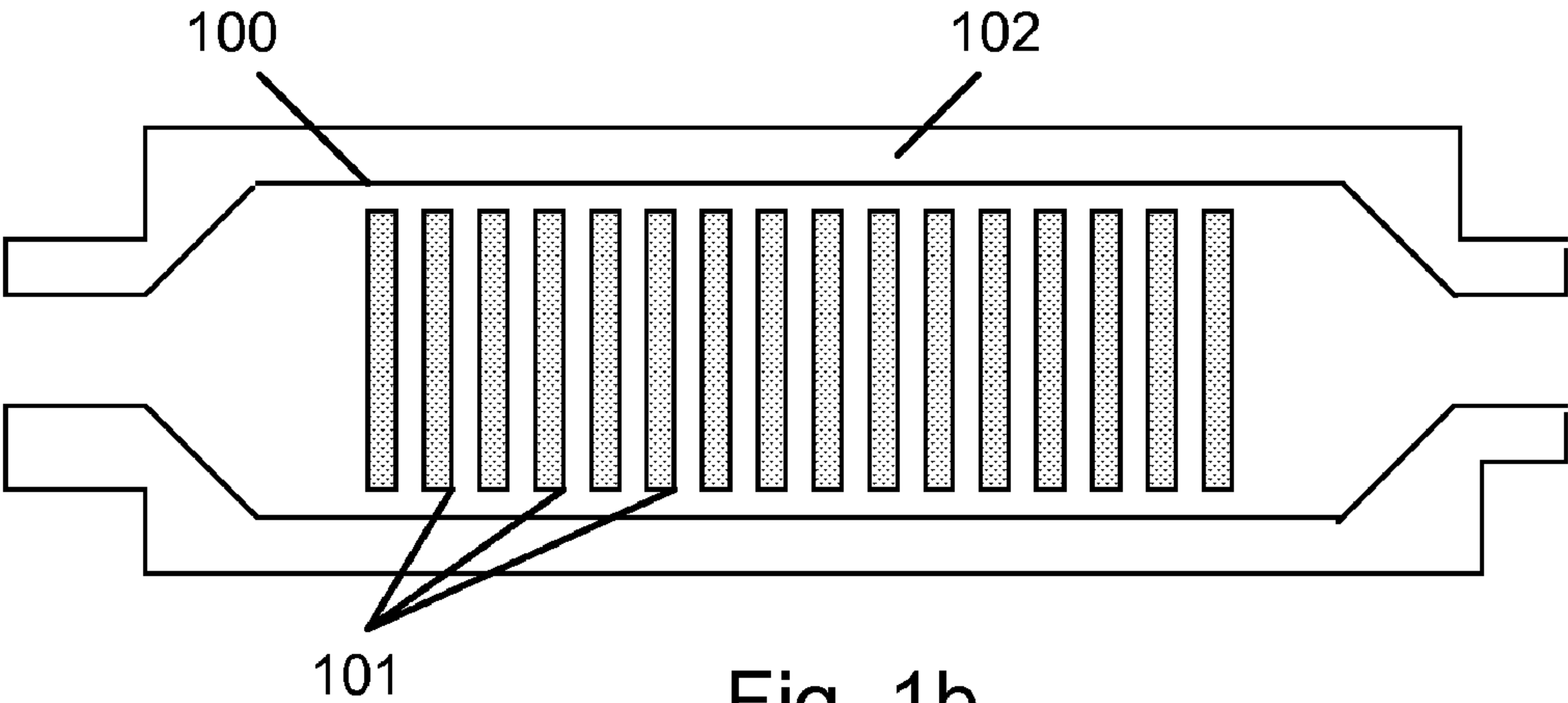


Fig. 1b

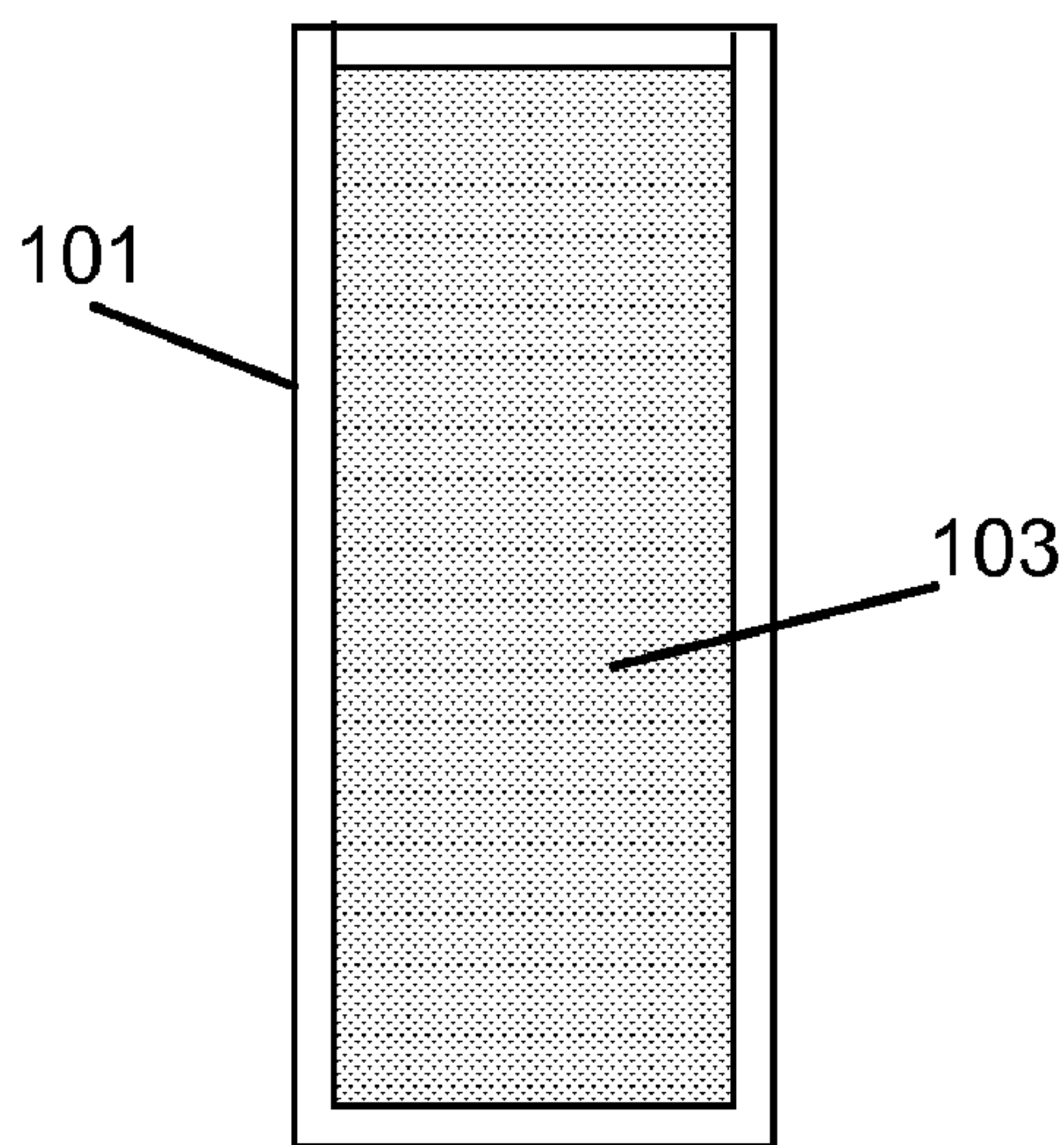


Fig 1c

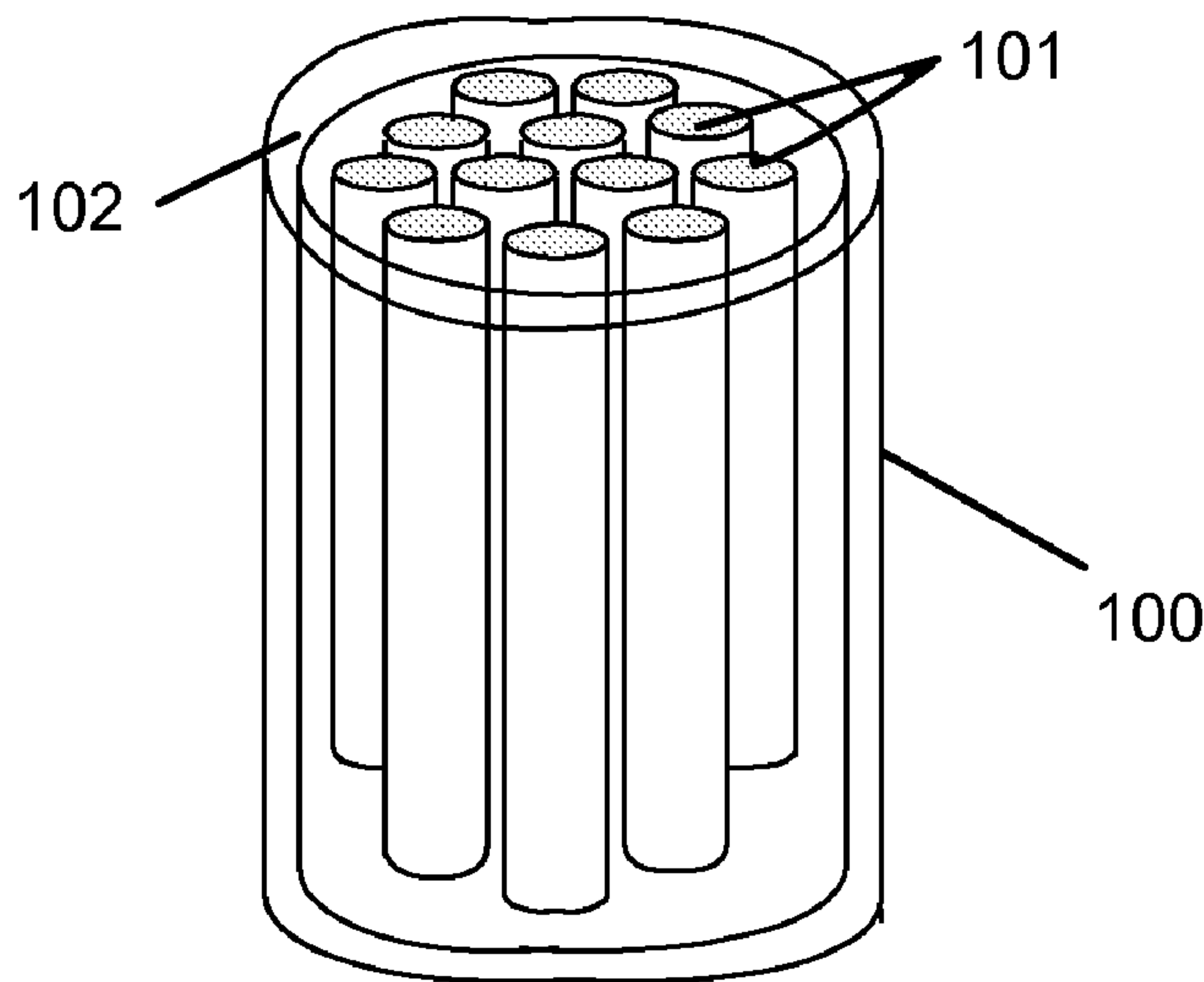


Fig. 1d

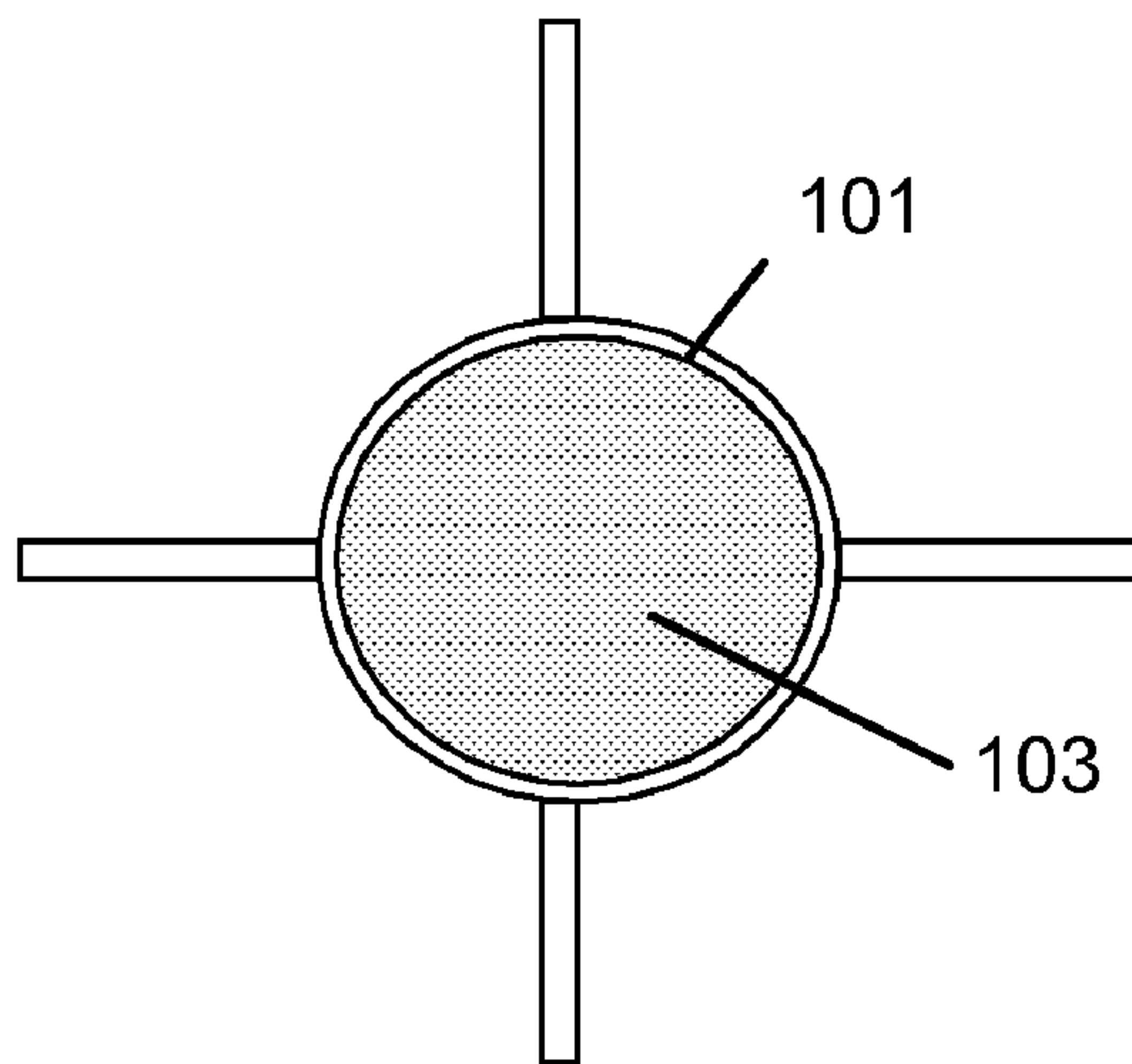


Fig 1e

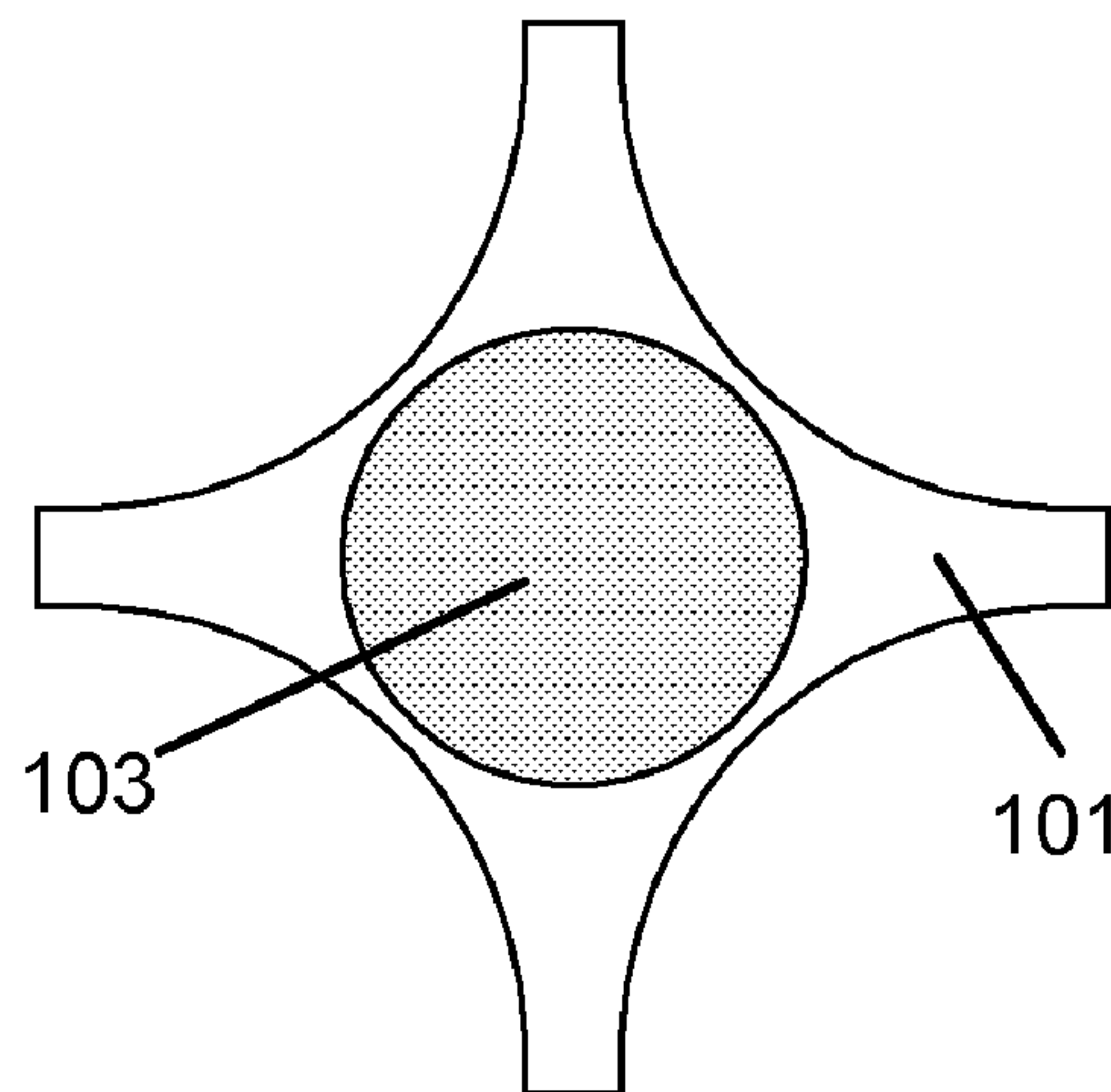


Fig 1f

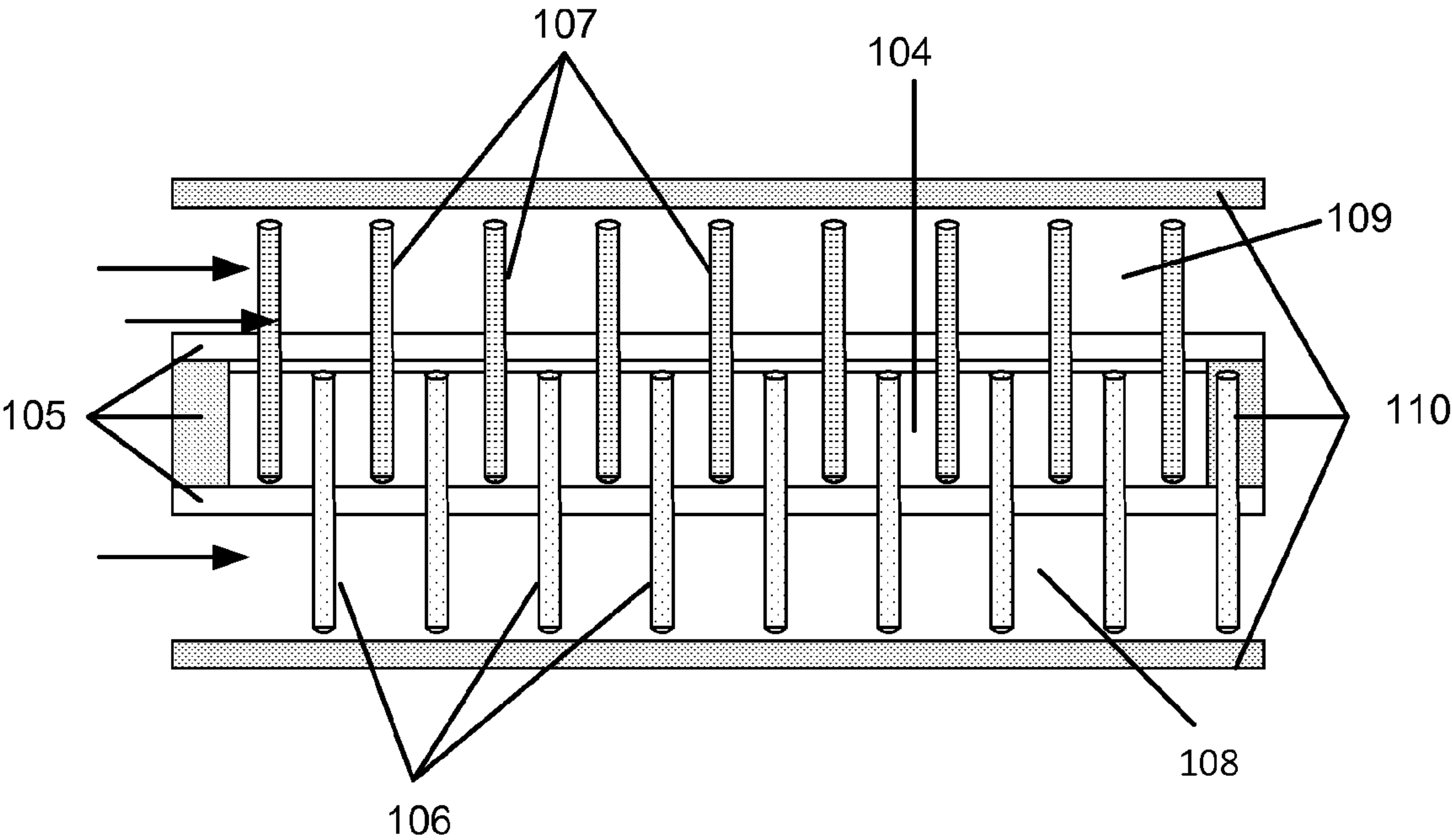


Fig. 2

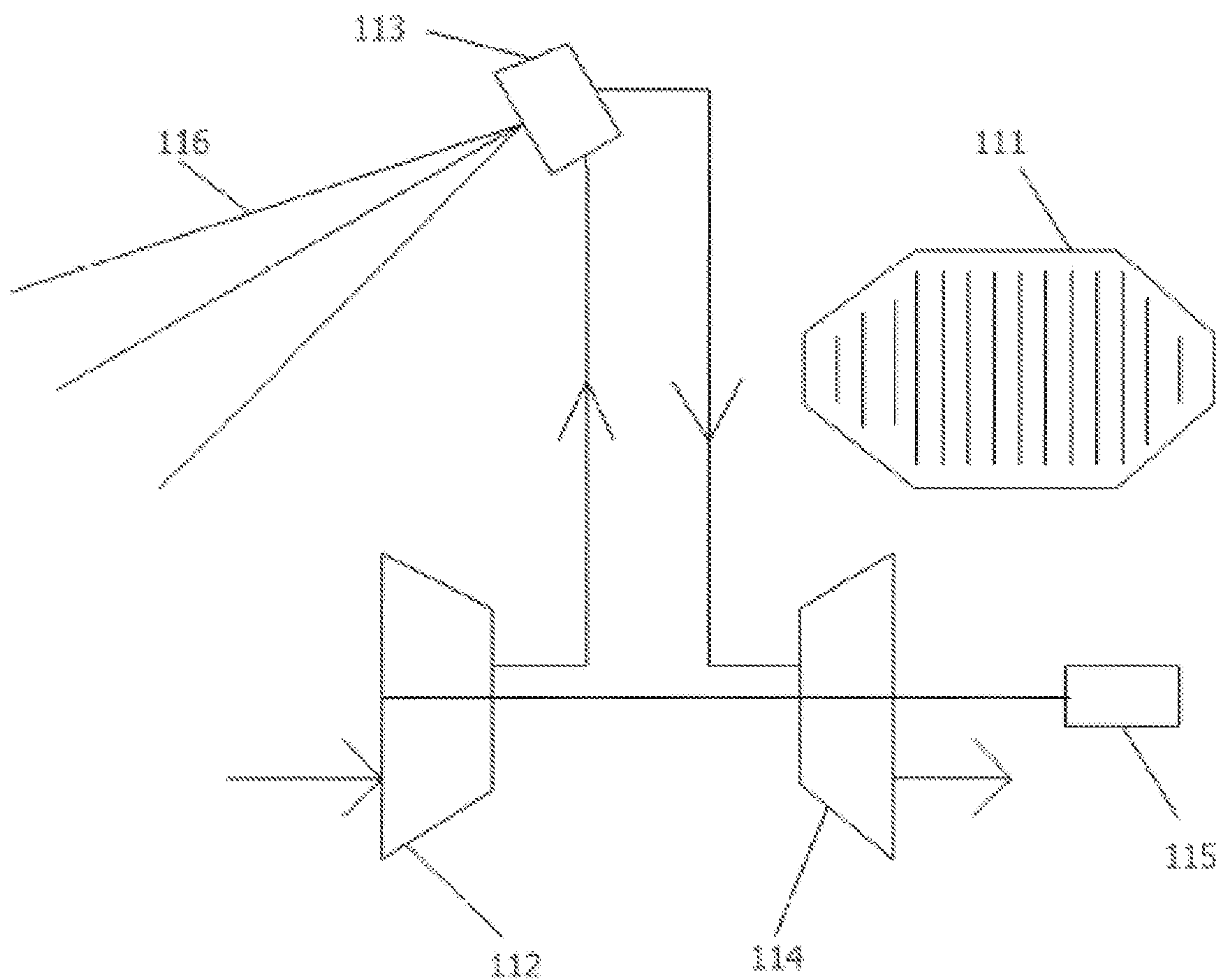


Fig. 3a

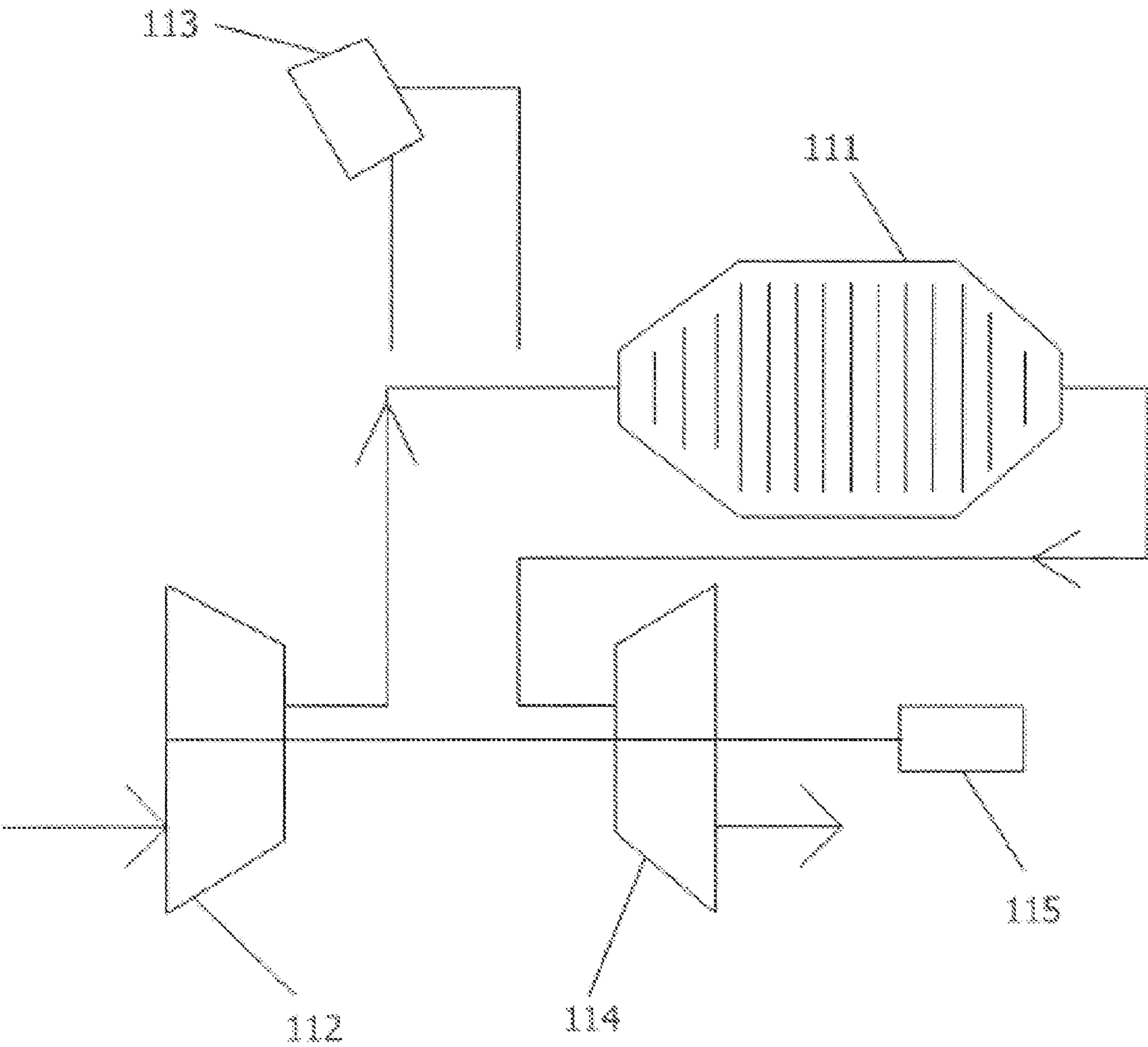


Fig 3b

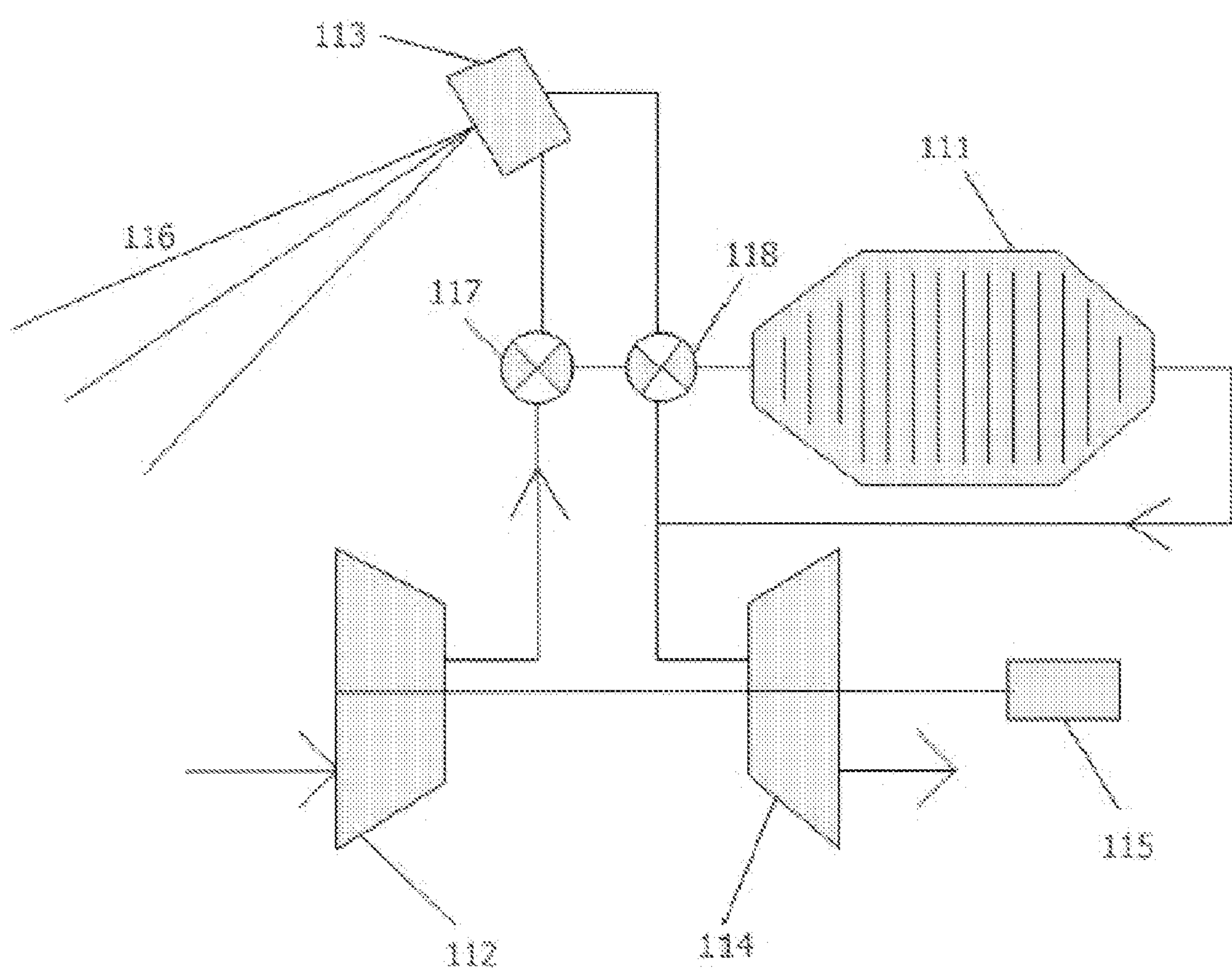
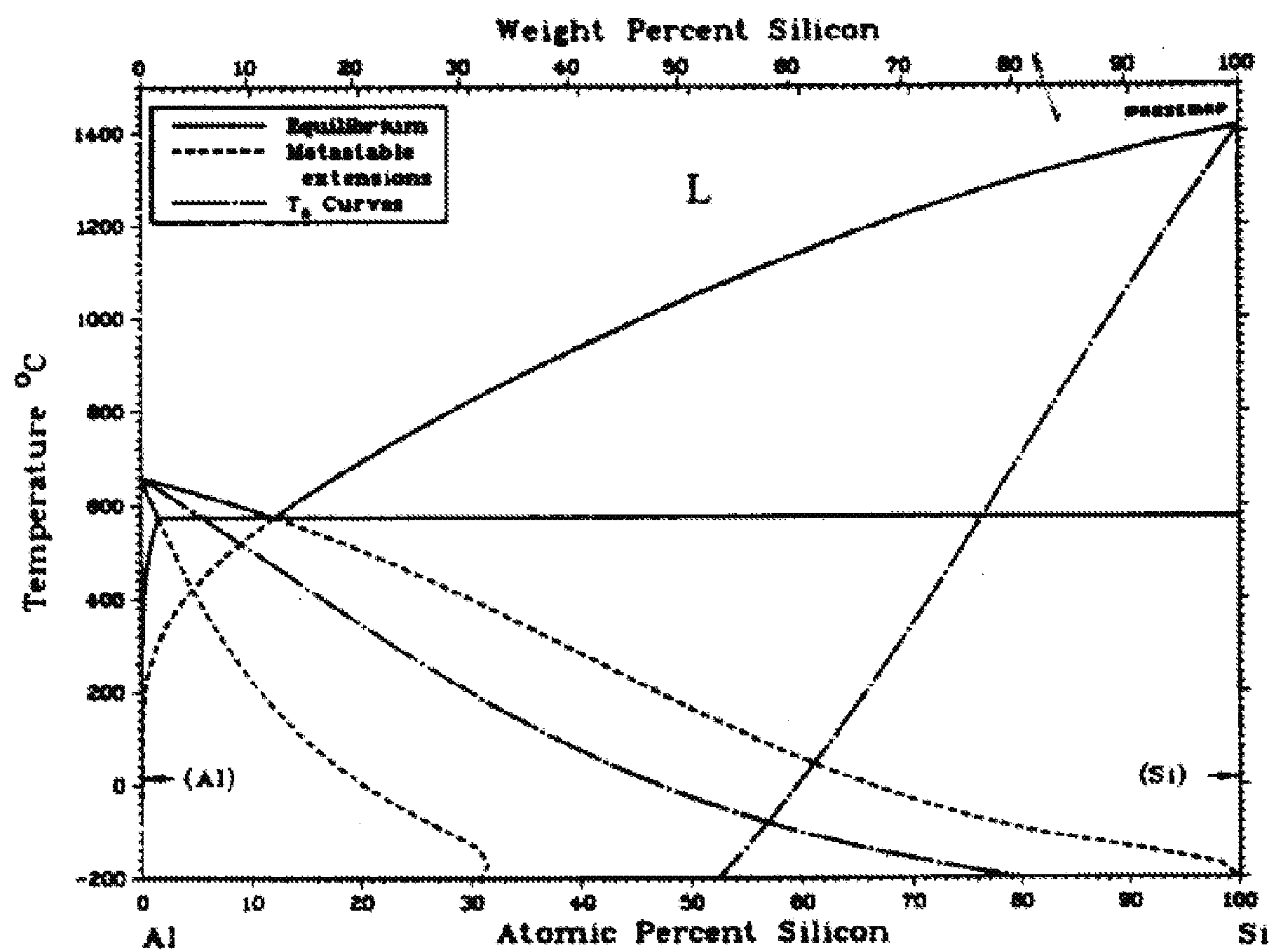


Fig 3c

Fig. 4



LIQUID METAL THERMAL STORAGE SYSTEM

CLAIM OF PRIORITY

[0001] This application claims benefit of U.S. Provisional Application No. 61/276,269, filed Sep. 10, 2009, which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] The use of solar thermal power for generating electricity on a utility scale is having a resurgence of interest in light of global warming issues caused largely by the release of carbon dioxide, methane, and absorbing particulates in the atmosphere and to the increasing of fossil fuels. The use of concentrated solar energy to heat a working fluid to a high temperature to operate Rankin, Brayton, and Sterling cycle engines to provide mechanical power to operate a generator for utility scale electric power production offers an attractive alternative to the use of fossil fuels. However, utilities are generally requesting that power production facilities provide dispatchable power on the order of 75% of the year. Since the sun is only above the horizon 50% of the time on a yearly basis, there is a need to provide some form of storage to operate the plant when there is no sunlight available.

[0003] Thermal energy storage may be accomplished by storing the energy in the form of heat, either as sensible heat or latent heat (or a combination thereof). Current solar collectors utilize heliostats, parabolic troughs or liner Fresnel reflectors to concentrate sunlight on solar receivers. These receivers are heated by the concentrated sunlight and utilize steam, oil, liquid salt, liquid alkali metal or gas as the heat collection and transfer fluid. This fluid may be used as the heat storage medium itself or the heat may be transferred to another medium to provide the storage. Thermal storage may be provided by the sensible heat in tanks of oil, oil and rock, liquid salts, or liquid alkali metals as discussed by Geyer in Winter et. al. The fluids heated by the concentrated sunlight are used to generate steam, heat a working fluid for energy conversion or they may be stored at high temperatures (or in combination). After giving up their heat for energy conversion the cooled fluids are stored separately from the hot fluids. This may be accomplished in separate hot and cold tanks or by using a thermocline configuration. In the thermocline system, the colder (denser) fluid forms the bottom layer with the hotter (less dense) fluid forms the upper layer. In any of these configurations, when the sun is not providing heat, the stored hot liquid may be pumped through the heat exchanger to heat the working fluid for power production and then to the cold side of the storage to complete the cycle.

[0004] Alternatively, the latent heat of fusion may be used to store thermal energy. Liquid salts or alkali metals that undergo a phase change to store or release heat at their melting temperature have been used in thermal storage systems. An advantage of this form of heat storage is that the heat is released at a nearly constant temperature, providing the optimum operating conditions for the energy conversion cycle. Another advantage to the use of latent heat energy storage occurs because the amount of storage material can be significantly decreased. To clarify, the amount of energy stored in specific heat is determined by the product of the specific heat and the temperature change. For example; the specific heat of water is 1 cal/gm, if the temperature is lowered by 1° C., one gram of the water releases 1 calorie of heat. Alternatively, the

latent heat of fusion of water is about 80 cal/gm so that the energy released in freezing or solidifying one gram of ice is 80 calories of heat at a nearly constant temperature. Thus, the amount of water needed to store the same amount of heat that is provided by freezing one gram of ice is 80 times greater than that to change the temperature of the water by 1° C.

[0005] In latent heat storage systems using high temperature salts, there are restrictions in the heat flow into and out of the storage material due to the low conductivity of salt. This is further aggravated by the fact that as the heat storage is discharging, the salt freezes around the pipes carrying the heat exchange fluid which stops convective heat transfer. This reduces the rate at which the heat that can be extracted from the storage system. Thus the combination of the low conductivity of the salt and the curtailment of convection due to the immobility of the salt presents obstacles to the utilization of this type of latent heat storage system.

[0006] Another consideration in the operation of a solar power system is the operating temperatures. To make concentrated solar thermal power systems as cost effective as possible, it is desirable to maximize the efficiency of the power conversion cycle. This reduces the cost of the most expensive component of the plant; the concentrating collectors. Since the maximum efficiency of a heat engine is determined by the temperature difference between the hot and cold reservoirs between which it operates, operating at the highest temperature possible is most desirable. Oils break down at temperatures above about 400° C. Most thermal storage systems using salt operate below about 570° C. No effective means have been found to store steam at the pressures and temperatures required to run efficient Rankin cycle engines. Brayton or gas cycle engines use gas as a working fluid and again it is impracticable to store gas at very high temperatures and pressures. The Brayton cycle provides the highest efficiencies for power tower concentrating systems because the operating temperatures are only limited by the turbine inlet temperatures (well over 1000° C.). Storing high temperature gas is not a realistic energy storage option.

INCORPORATION BY REFERENCE

[0007] The following references are incorporated herein in their entireties:

[0008] U.S. Pat. No. 4,512,388, issued Apr. 23, 1985, by Terry D. Claar et al., entitled "High-Temperature Direct-Contact Thermal Energy Storage Using Phase-Change Media"; Simensen "Comments on the Solubility of Carbon in Molten Aluminum" Metallurgical Transactions A Vol. 20A January 1989, p. 191;

[0009] Winter, Sizmann, @ Vant-Hull, Solar Power Plants, Chapter 6, Springer, Verlag 1991; and

[0010] Guthy and Makhlof "The aluminum-silicon eutectic reaction: mechanisms and crystallography" Journal of Light Metals Vol. 1, No. 4, November 2001, pp. 199-218.

SUMMARY OF THE INVENTION

[0011] Embodiments of the invention relate to the use of melting and solidifying or freezing metals and metal alloys to store and release the high latent heat of fusion of certain metals and alloys to store large amounts of heat energy at very high temperatures suitable for operating a gas turbine or other purposes. In particular, the alloy may consist of two or more

metals with melting and eutectic temperatures in the range that is compatible with the energy conversion device to be used.

[0012] In the first embodiment considered here, the metal or alloy is contained in an array of tubes located in an insulated channel through which the high temperature gas is circulated. The system is charged by passing gas, from the solar receiver or other heat source, past the tubes in order to heat and melt the metal/alloy contained within the tubes. The system is discharged by passing the air to be heated through the same channel until the metal or alloy has changed phase (liquid to solid) and the temperature has dropped to the optimum operating temperature for the system.

[0013] In another embodiment, the metal or alloy is contained in an insulated container equipped with heat transfer elements or tubes that thermally communicate with the heat source. In this case, the system is charged by transferring heat from a high temperature gas circulating in a channel or passageway through a wall into the chamber containing the solid/liquid metal or alloy until it melts. The system is discharged by passing heat out of the chamber with the same or different heat transfer elements or tubes that communicate with the channel carrying the gas to be heated.

[0014] In any of the embodiments above, there is a wide choice of alloys to be used. In another embodiment two elements are combined to form an alloy with a melting temperature determined by the fraction of each metal present, which is in turn chosen by the desired operating temperature. In a particular embodiment, the alloy composed of aluminum and silicon is chosen. By varying the ratio of these elements the operating point may be chosen from about 600° C. to 1411° C. This very wide temperature range provides for the operation of a variety of turbine inlet temperatures including the upper range of Rankine steam cycles.

[0015] The tubes containing the metal or metal alloy in the first embodiment may be made from ceramic, metal, or clad graphite. The graphite must be clad in metal or ceramic in the case of air or other oxidizing gas (e.g., carbon dioxide) in the heat exchanger as otherwise the graphite would be subject to oxidation at the operating temperatures considered here.

[0016] In the embodiment using the heat transfer elements or tubes that transfer the heat to and from the metal enclosed in a separate insulated chamber, the tubes may be composed of solid metal of suitably high melting temperature e.g. copper, steel, nickel, or high temperature alloys of these or other metals. The elements may also be composed of graphite in direct contact with the molten metal if there is minimum chemical reaction with the heat storage metal or metal alloy, but with appropriate cladding in the sections that they may be exposed to an oxidizing atmosphere.

[0017] In another embodiment these heat transfer elements or tubes may also be closed hollow tubes composed of a high temperature metal ceramic or graphite containing a relatively small amount of an element or compound with a boiling temperature that is above that of the melting point of the metal or metal alloy storage material. In this case the element or compound is boiled within the lower end of the tube by the gas passing through the channel below the storage tank with the upper end imbedded in the metal or metal alloy storage material. This heat pipe arrangement is very effective as a heat exchanger. In this case the thermal storage is discharged by similar tubes, but that contain an element or compound with a lower boiling temperature than the melting point of the metal or metal alloy storage material. The lower end of the

heat pipe is in the metal or alloy storage material while the upper end passes through the upper side of the storage chamber and into a separate gas carrying channel. In this case the storage is discharged by passing a gas through the upper channel.

[0018] There are several advantages to this form of latent heat storage. First, most of the heat is released at a constant temperature which allows a gas turbine to operate at its design point. This is a consideration as off-design operation of gas turbines can significantly lower their conversion efficiency. Charging the thermal storage is accomplished by the gas at any reasonable temperature above the melting point of the metal. Because all suitable metals and alloys contract on melting there is no reason for metals to break their containing tubes or storage containers. The high thermal conductivity of the metal in both liquid and solid form provides excellent heat transfer within the metal. This avoids problems encountered in using liquid salts or alkali metals wherein low conductivity regions of the solid and solidifying material slow the release of heat.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] The foregoing aspects and others will be readily appreciated by the skilled artisan from the following description of illustrative embodiments when read in conjunction with the accompanying drawings.

[0020] FIG. 1a is a schematic illustration of the top view of an embodiment of the a heat exchanger of an embodiment of the invention.

[0021] FIG. 1b is a schematic illustration of the side view of an embodiment of a heat exchanger of an embodiment of the invention.

[0022] FIG. 1c is a schematic illustration one of the tubes containing the metal or metal alloy of an embodiment of the invention.

[0023] FIG. 1d is a schematic of an embodiment of the invention using a vertical flow configuration wherein the gas is moving parallel to the alignment of the storage tubes.

[0024] FIGS. 1e and 1f depict alternative embodiments of the tubes of the invention.

[0025] FIG. 2 is a schematic of another embodiment of the invention showing the charging plenum at the bottom and the discharging plenum above the metal or metal alloy storage container.

[0026] FIG. 3a is a schematic illustration how an embodiment of the invention is implemented with a gas turbine generator in solar only mode.

[0027] FIG. 3b is a schematic illustration how an embodiment of the invention is implemented with a gas turbine generator during thermal discharging.

[0028] FIG. 3c is a schematic illustration how an embodiment of the invention is implemented with a gas turbine generator during hybrid operation wherein power for the turbine is supplied from storage and the solar receiver.

[0029] FIG. 4 is an equilibrium diagram for the Al—Si system showing metastable extensions of liquidus and solidus line.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0030] The embodiments of the invention are illustrated in the context of a Brayton cycle solar thermal electric power plant. The skilled artisan will readily appreciate, however that

the materials and methods disclosed herein will have application in a number of other contexts where high temperature thermal storage is desirable.

[0031] One embodiment of the invention, also known as a Liquid Metal Thermal Storage system (LIMETS) consists of substantially four items; the metal or metal alloy thermal storage material, the tubes or a compartment containing the metal or metal alloy, the insulated cavity enclosing the tubes, and the heat transfer medium (gas). FIG. 1*a* is a top view of a schematic drawing of the system showing the insulated cavity **100**, the ceramic or clad graphite tubes **101** containing the metal or metal alloy and the insulated container **102**. FIG. 1*b* is a side view of the same components. FIG. 1*c* is a cross sectional view of the tube and metal showing one tube **101** and metal **103** with the open top. FIG. 1*d* depicts a perspective view of this embodiment. By way of example only, tubes **101** can include fins or other appendages or structures that increase the surface area of the tubes and the rate of heat transfer to and/or from the tubes (FIG. 1*e*). The tubes also have cross-sections that increase the rate of heat transfer (FIG. 1*f*). Such cross-sections increase the surface area of the cross-section by including, for example, a star-shaped cross-section. The tubes and enclosure are to be arranged so as to maximize the heat transfer considering the temperature and nature of the gas transfer medium. The Reynolds number is determined by the properties of the gas and the characteristic dimensions of the tubes and the design should be optimized for these factors to maximize the heat transfer to and from the tubes.

[0032] FIG. 2 illustrates another embodiment utilizing the tubes. A vertical orientation of the tubes is useful so as to utilize the down corner from the solar receiver located at the top of tower and to provide an alternative design to optimize the heat transfer to the tubes. Ducting arrangements can allow flow of the gas in either up or down past the vertical tubes. In both of these arrangements the system is charged by passing hot gas from the solar receiver over the tubes until melting takes place. Since most metals and metal alloys expand when melting the lower density melt will rise to the top, leaving the bottom to melt last. This has a consequence of encouraging good mixing to ensure that the metal or metal alloy is nearly isothermal. In this embodiment the metal or metal alloy **104** is contained in a separate insulated container **105** that thermally communicates to the heated air via either high conductivity metal or metal clad graphite rods, or preferably by using hollow heat pipes or tubes **106** and **107**. In this embodiment there are two channels, one channel **108** for the hot (charging) gas below the metal or metal alloy container and one channel **109** above. The hot gas passes through the lower channel **108** and the heat pipes or tubes or rods **106** and carry the heat to the metal or metal alloy to melt the storage material **104**. To discharge the storage, a similar set of heat pipes or tubes or rods **107** carries the heat to the upper channel when cooler gas is pumped through the upper channel. The heat transfer may be substantially improved by using heat pipes in which an element or compound with a suitable boiling point is encapsulated within the tubes. As an example only, such element or compound can include potassium that may be used from about 500° C. to 1000° C., sodium from 500° C. to 1000° C., and lithium from 900° C. to 1700° C.

[0033] Because heat pipes carry heat most efficiently in an upward direction, in this embodiment there are two sets **106** and **107**. The element or compound within the lower pipes or tubes **106** is preferably chosen to have a operating point above

the melting temperature of the metal or metal alloy storage material. The element or compound within the upper pipes or tubes **107** is preferably chosen to have a operating point below the meeting temperatures of the metal or metal alloy storage material.

[0034] The hot gas passing through the lower channel heats the lower end of the tubes and the element or compound in the tubes vaporizes and moves upward and condense at the cooler end in the storage material. When the storage material has melted and heat is needed to run a turbine, the gas to be heated is pumped through the upper channel. The upper heat pipes contain an element or compound that has an operating temperature below that of the melting temperature of the storage material. Therefore, when cooler air is pumped through the upper channel, the element or compound in the upper heat pipes condenses on the upper end transferring the heat to the gas to operate the turbine. The heat transfer is controlled by the flow of gases, moving upwards when heat is needed. There is an added advantage to this heat pipe system because the upper and lower channel may be at different pressures and the storage material need not be in a pressure container. Thus the system can take heat from air at ambient pressure, store the heat and discharge the heat at a convenient pressure for gas turbine operation.

[0035] The choice of the metal or alloy rod or tube is determined by, for example, 1) the melting temperature, 2) latent heat of fusion, 3) heat conductivity, 4) its viscosity and thermal convection characteristics, 5) expansion and contraction upon phase change, 5) chemical reactivity with containment and heat transfer elements and 6) effects of contaminants. For any given application, the melting temperature may be determined by the choice of metal, or be more finely tuned by the selection of alloy. Other considerations include crystallite size, effects of contaminants and alloy separation during the solidifying or freezing and re-melting. Another consideration is the price of the metal or metal alloy in current metal markets and what its future price will be at the decommissioning of the plant as this is likely to represent a significant investment.

[0036] Pure non-alkali metals that may be used for thermal storage include aluminum (m.p. 660° C., I.h. 95 cal/gm), copper (m.p. 1084° C., I.h. 49 cal/gm), iron (m.p. 1536° C., I.h. 65 cal/gm), and magnesium (m.p. 650° C., I.h. 88 cal/gm) (m.p.=melting point, I.h.=latent heat). The other pure metals have impractically high or low melting temperatures, are rare, expensive, radioactive, or toxic. However, alloys of the above mentioned and other metals form a very large class of possible alternatives for thermal storage materials. One reason for this is that two metals with differing melting temperatures often form a eutectic mixture when melted together that has a lower melting point than either metal by itself. Sometimes these effects can significantly lower the melting point in a range of materials that could be useful for new metal alloy storage materials.

[0037] Another embodiment of the invention includes the specific choice of aluminum and silicon as a thermal storage material. Silicon is a common component of aluminum alloys; particularly at the composition of AlSi12 (approximately 88% aluminum and 12% silicon with a small amount of impurities such as iron). This is a particularly advantageous combination of materials, because of the physical properties resulting therein. While aluminum has a melting point of about 660° C., and silicon has a melting point of 1411° C., the melting point at the eutectic mixture of AlSi12 is about 600° C. Thus, it can be seen that by varying the composition, the

melting point of the resulting alloy ranges from 600° C. at the eutectic point to 1411° C. for a pure Si composition. This is illustrated in FIG. 4 which depicts a graph of melting temperatures vs. compositions. This is a very wide and convenient range for high temperature latent heat storage materials.

[0038] There is another beneficial advantage of this combination of materials. While the latent heat of aluminum is relatively quite high at 95 cal/gm compared to other metals, the latent heat of fusion of silicon is amongst the highest known at 430 cal/gm. For example, it can be seen from the figure that at approximately a 50-50 atomic percentages, the melting temperature of the mixture is about 1000° C. If a linear interpolation between the latent heats of fusion of aluminum and silicon is used, the latent heat of the resulting mixture is about 263 cal/gm. This may be compared to value for sodium which has been used for a latent heat storage medium at 27 cal/gm. (about 1/10th that of the mixture—requiring 10 times the storage mass). Other potential storage materials include zinc with a latent heat of fusion of 27 cal/gm, copper at 49 cal/gm or lead of 5.5 cal/gm. Thus, it can be seen that there is a very substantial reduction in required material in using the AlSi combination.

[0039] Another advantage of the combination of silicon and aluminum is the relatively low cost of these materials in the industrial grades sufficient for this purpose compared to other metals with suitable melting temperatures.

[0040] Yet another consideration is the selection of the containment tubes. The size and shape of the tubes should be chosen to maximize the heat transfer with the gas and optimize the melting rates and patterns of the enclosed metal. In some circumstances radial or axial fins can be added to improve heat transfer to the tubes. High temperature ceramic materials are suitable because of the high melting temperatures of the metals involved (600-1200° C.). However, certain high temperature alloy tubes may be considered for containment in the lower part of that temperature range. Another choice of materials is graphite. Graphite has high thermal conductivity and low reactivity with aluminum as discussed by Simensen and is widely used in aluminum refining for electrodes and containment materials. However, graphite may not be used in the presence of oxidization gases such as air or carbon dioxide because it will oxidize to carbon dioxide and fail as a containment or heat transfer means. The graphite may be clad with metals or ceramics to prevent its oxidation. The choice of the tube material should be guided by the desired operating temperatures and potential metal—containment tube interactions. The tubes may be closed or open depending on the choice of gas and metals. If air is the heat transfer medium the tubes should be closed to eliminate possible oxidation or other reactions between the metal and the components of the air. If helium, nitrogen or carbon dioxide is used the tubes may be open at the top if there are no interactions between the metal and gasses. For other gasses the potential interactions must be taken into consideration.

[0041] To illustrate the operation of a liquid metal thermal storage system embodiment of the invention in conjunction with a heat source and turbine, an embodiment of the overall system is illustrated in FIGS. 3a, 3b, and 3c. FIG. 3a illustrates the components of the system without the heat storage system 111 being connected or in the “pure solar” mode Air enters the turbo compressor 112 and is compressed before arriving at the heat source 113. This may be a high temperature solar receiver heating a gas by direct or indirect of absorption of sunlight or a non-solar high temperature heat

source. Further, the heat source 113 can be a windowed high temperature solar receiver that uses small particles to absorb concentrated sunlight 116 and heats the gas in which they are entrained. An example of such a receiver is discussed in “Solar Test Results of an Advanced Direct Absorption High Temperature Gas Receiver (SPHER),” by

[0042] A. J. Hunt and C. T. Brown, Proc. of the 1983 Solar World Congress, International Solar Energy Society, Perth, Australia, Aug. 15-19, 1983, LBL-16947, and “Heat transfer in a directly irradiated solar receiver/reactor for solid-gas reactions” by Klein, H. H., Karni, J., Ben-Zvi, R. and Bertocchi, R. Solar Energy 81 (2007) 1227-1239. which are incorporated herein by reference. After being heated to a high temperature the gas is routed into the expansion turbine 114 that provides power to run the compressor and turn the generator 115 before being exhausted or recycled. FIG. 3b illustrates the arrangement for charging the storage wherein all the gas is routed through the storage system before passing through the expansion turbine. FIG. 3c illustrates operation of the system in “hybrid” mode in which the gas is selectively routed both through the storage and through the turbine, in parallel, adjusted with the controlling valves 117 and 118. Valve 117 can divert gasses directly to the solar receiver or heat source 113 (for the operation of the embodiment of FIG. 3a) or directly to the heat storage system 111 for the operation of the embodiment of FIG. 3b). Valve 118 can divert gasses to the heat storage system 111 or to the expansion turbine 114. Various positions of the valves 117 and 118 can allow the expansion turbine 114 to run directly on energy provided by the receiver or heat source 113, or alternatively on energy provided by the heat storage system 111, or both.

What is claimed is:

1. A system for storing and retrieving thermal energy from gas heated by a high temperature source comprising:
 - a chamber containing heat exchanger elements wherein the heated gas is passed through the chamber containing the heat exchanger elements which heat exchanger elements are in thermal communication with a non-alkali metal or metal alloy that melts at a specified temperature between 600° C. and 1400° C. to stores thermal energy; and
 - the same or a different chamber containing the same or different heat exchanger elements wherein a gas to be heated is passed through the same or the different chamber containing the same or different heat exchanger elements that are in thermal communication with the same metal or metal alloy that at least partially solidifies, giving up the thermal energy stored.
2. The system of claim 1 including the metal alloy composition for a latent heat thermal storage system that melts at a specified temperature by varying the fraction of each component.
3. The system in claim 1 wherein the heat exchanger elements are tubes which tubes are composed of a high temperature ceramic material.
4. The system in claim 1 wherein the heat exchanger elements are tubes and the tubes are composed of a high temperature metal alloy with a substantially higher operating temperature than the melting temperatures of the metal or metal alloy.
5. The system in claim 1 wherein the heat exchanger elements are tubes and the tubes are composed of graphite.
6. The system in claim 1 wherein the heat exchanger tubes are tubes and the tubes are composed of graphite that is clad

in a metal or ceramic to prevent oxidation when using oxidizing gasses as the heat transfer medium.

7. The system in claim 1 wherein the heat exchanger elements are tubes and the tubes are solid metal or solid graphite with a cladding.

8. The system in claim 1 wherein the heat exchanging elements are tubes and the tubes are hollow and contain an element or compound with a boiling temperature above the metal or metal alloy to carry the heat from the solar source into the metal or metal alloy.

9. The system in claim 1 wherein the heat exchanging elements are tubes and the tubes are hollow and contain an element or compound with a boiling temperature below the metal or metal alloy to carry the heat from the metal or metal alloy to the gas stream to be heated.

10. The system in claim 1 wherein the heat exchanging elements are tubes and the tubes are arranged in such a fashion so as to maximize the heat transfer between the tubes and heat transfer gas.

11. The system in claim 1 wherein the heat exchanging elements are tubes and the tubes are one of hollow or solid rods have radial or axial fins to improve the heat transfer.

12. The system in claim 1 wherein the heat exchanging elements are tubes and the cross section of the tubes is designed so as to maximize the heat transfer between the tubes and the heat transfer gas.

13. The system in claim 1 that uses air, carbon dioxide, argon, helium, or nitrogen as the heat transfer gas.

14. The system in claim 7 wherein the source including a solar receiver to heat the gas to provide heat to melt the metal or metal alloy.

15. The system in claim 1 including a gas turbine that uses the stored heat to operate a gas turbine to provide mechanical power.

16. The system in claim 14 wherein the source including a windowed high temperature solar receiver that uses small particles to absorb concentrated sunlight and heat gases including at least one of air, carbon dioxide, helium or nitrogen in which they are entrained.

17. The system in claim 1 including a metal alloy that is made from two or more elements whose melting temperature is determined by the choice of the fraction of the two or more elements.

18. The system in claim 1 wherein the metal alloys including aluminum and silicon with a melting temperature from 600° C. to 1400° C.

19. A method for storing and retrieving thermal energy from and to a gas heated by a high temperature source including the steps of:

passing the heated gas through a chamber containing heat exchanger elements that are in thermal communication with a non-alkali metal or metal alloy that melts at a specified temperature between 600° C. and 1400° C. to store thermal energy in the form of the latent heat of fusion of the metal or metal alloy; and

passing the gas to be heated through the same or a different chamber containing the same or different heat exchanger elements that are in thermal communication with the same metal or metal alloy that at least partially solidifies, giving up the thermal energy stored in the form of the latent heat of fusion.

20. The method of claim 19 including choosing the metal alloy composition for a latent heat thermal storage system so that the metal alloy melts at a specified temperature by varying the fraction of each component of the metal alloy.

21. A system for storing and retrieving thermal energy from a gas heated by a high temperature source comprising:
a chamber containing heat exchanger elements; and
a non-alkali metal or metal alloy contained in the heat exchanger elements adapted for storing heat from the heated gases.

22. The system of claim 1 wherein the metal or metal alloy melts at a specified temperature of between about 600° C. and 1400° C.

23. A system for storing and retrieving thermal energy from a gas heated by a high temperature source comprising:
a first channel having first heat exchanger elements;
a second channel having second heat exchange elements;
a chamber containing a non-alkali metal or metal alloy that is adapted for storing heat from the heated gas; and
the first and the second heat exchanger elements in part extending into the chamber.

24. The system of claim 1 wherein the metal or metal alloy melts at a specified temperature of between about 600° C. and 1400° C.

25. A method for storing and retrieving thermal energy from gas heated by a high temperature source including the steps of:

passing the heated gas through a chamber containing heat exchanger elements that are in thermal communication with a non-alkali metal or metal alloy that melts to store thermal energy; and

passing the gas to be heated through the same or a different chamber containing the same or different heat exchanger elements that are in thermal communication with the same metal or metal alloy that at least partially solidifies, giving up the thermal energy stored.

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