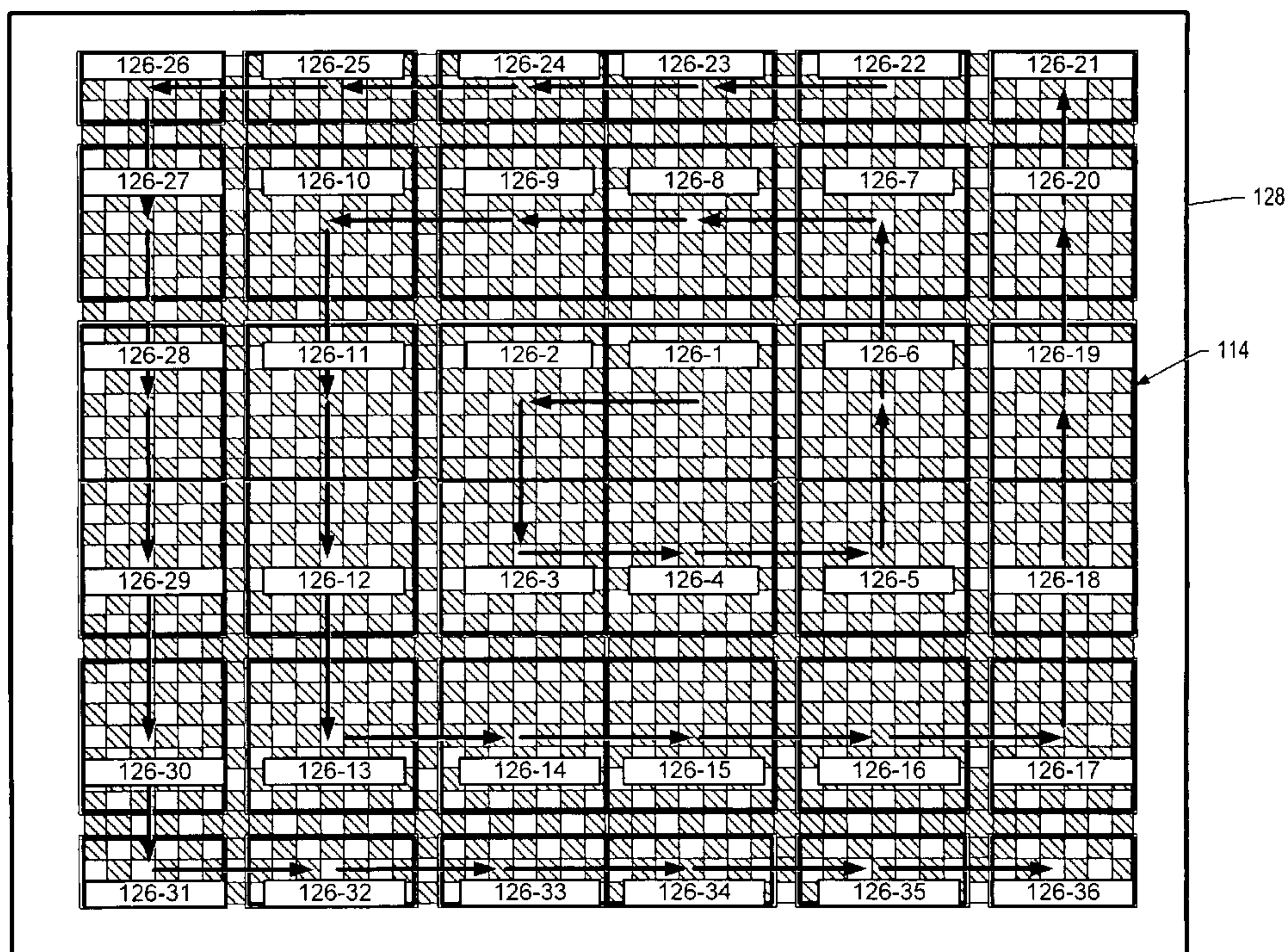




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(57) **Abrégé/Abstract:**

A method for treating a hydrocarbon containing formation includes treating a first zone of the formation. Treatment of a plurality of zones of the formation is begun at selected times after the treatment of the first zone begins. The treatment of at least two successively treated zones begins at a selected time after treatment of the previous zone begins. At least two of the successively treated zones are adjacent to the zone treated previously. The successive treatment of the zones proceeds in an outward, substantially spiral sequence from the first zone so that the treatment of the zones moves substantially spirally outwards towards a boundary of the treatment area.

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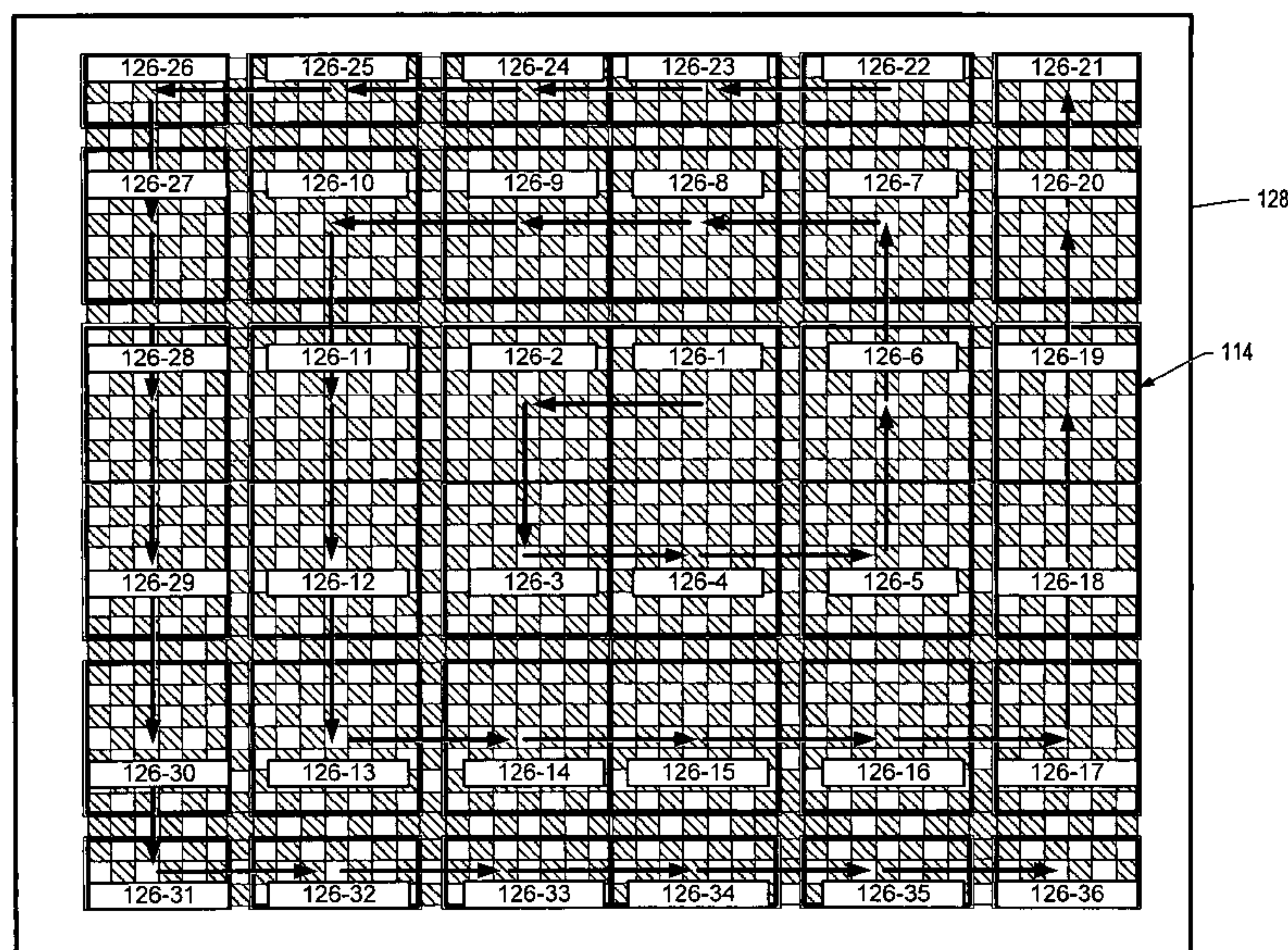
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(57) Abstract: A method for treating a hydrocarbon containing formation includes treating a first zone of the formation. Treatment of a plurality of zones of the formation is begun at selected times after the treatment of the first zone begins. The treatment of at least two successively treated zones begins at a selected time after treatment of the previous zone begins. At least two of the successively treated zones are adjacent to the zone treated previously. The successive treatment of the zones proceeds in an outward, substantially spiral sequence from the first zone so that the treatment of the zones moves substantially spirally outwards towards a boundary of the treatment area.

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HEATING HYDROCARBON CONTAINING FORMATIONS IN A SPIRAL STARTUP STAGED SEQUENCE

BACKGROUND

5 1. Field of the Invention

[0001] The present invention relates generally to methods and systems for production of hydrocarbons, hydrogen, and/or other products from various subsurface formations such as hydrocarbon containing formations. Certain embodiments relate to treatment of formations in controlled or staged processes.

10

2. Description of Related Art

[0002] Hydrocarbons obtained from subterranean formations are often used as energy resources, as feedstocks, and as consumer products. Concerns over depletion of available hydrocarbon resources and concerns over declining overall quality of produced hydrocarbons have led to development of processes for more efficient recovery, processing and/or use of available hydrocarbon resources. In situ processes may be used to remove hydrocarbon materials from subterranean formations. Chemical and/or physical properties of hydrocarbon material in a subterranean formation may need to be changed to allow hydrocarbon material to be more easily removed from the subterranean formation. The chemical and physical changes may include in situ reactions that produce removable fluids, composition changes, solubility changes, density changes, phase changes, and/or viscosity changes of the hydrocarbon material in the formation. A fluid may be, but is not limited to, a gas, a liquid, an emulsion, a slurry, and/or a stream of solid particles that has flow characteristics similar to liquid flow.

25 [0003] Heaters may be placed in wellbores to heat the formation during an in situ process. Examples of in situ processes utilizing downhole heaters are illustrated in U.S. Patent Nos. 2,634,961 to Ljungstrom; 2,732,195 to Ljungstrom; 2,780,450 to Ljungstrom; 2,789,805 to Ljungstrom; 2,923,535 to Ljungstrom; and 4,886,118 to Van Meurs et al.

30 [0004] As outlined above, there has been a significant amount of effort to develop methods and systems to economically produce hydrocarbons, hydrogen, and/or other products from hydrocarbon containing formations. There is a need for improved methods and systems for production of hydrocarbons, hydrogen, and/or other products from various hydrocarbon

containing formations that reduce energy input to the formation and more efficiently treat these formations.

SUMMARY

5 [0005] Embodiments described herein generally relate to systems, methods, and heaters for treating a subsurface formation. Embodiments described herein also generally relate to heaters that have novel components therein. Such heaters can be obtained by using the systems and methods described herein.

[0006] In certain embodiments, the invention provides one or more systems, methods,
10 and/or heaters. In some embodiments, the systems, methods, and/or heaters are used for treating a subsurface formation.

[0007] In some embodiments, the invention provides a method for treating a hydrocarbon containing formation, comprising: treating a first zone of the formation; beginning
15 treatment of a plurality of zones of the formation at selected times after the treatment of the first zone begins, the treatment of at least two successively treated zones beginning at a selected time after treatment of the previous zone begins; wherein at least two of the successively treated zones are adjacent to the zone treated previously; wherein the successive treatment of the zones proceeds in an outward, substantially spiral sequence from the first zone so that the treatment of the zones moves substantially spirally outwards
20 towards a boundary of the treatment area; wherein treatment of at least two of the zones comprises: providing heat from one or more heaters located in two or more first sections of the zone; allowing some of the heat to transfer from at least two of the first sections to two or more second sections of the zone; wherein the first sections and the second sections are arranged in a checkerboard pattern within the zone, the checkerboard pattern having at
25 least one of the first sections substantially surrounded by three or more of the second sections and at least one of the second sections substantially surrounded by three or more of the first sections; producing at least some hydrocarbons from the second sections, wherein at least some of the hydrocarbons produced in the second sections comprise fluids initially in the first sections.

30 [0008] In further embodiments, features from specific embodiments may be combined with features from other embodiments. For example, features from one embodiment may be combined with features from any of the other embodiments.

[0009] In further embodiments, treating a subsurface formation is performed using any of the methods, systems, or heaters described herein.

[0010] In further embodiments, additional features may be added to the specific embodiments described herein.

5

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Advantages of the present invention may become apparent to those skilled in the art with the benefit of the following detailed description and upon reference to the accompanying drawings in which:

10 [0012] FIG. 1 depicts an illustration of stages of heating a hydrocarbon containing formation.

[0013] FIG. 2 shows a schematic view of an embodiment of a portion of an in situ heat treatment system for treating a hydrocarbon containing formation.

15 [0014] FIG. 3 depicts a side view representation of an embodiment for an in situ staged heating and producing process for treating a tar sands formation.

[0015] FIG. 4 depicts a top view of a rectangular checkerboard pattern embodiment for the in situ staged heating and production process.

[0016] FIG. 5 depicts a top view of a ring pattern embodiment for the in situ staged heating and production process.

20 [0017] FIG. 6 depicts a top view of a checkerboard ring pattern embodiment for the in situ staged heating and production process.

[0018] FIG. 7 depicts a top view an embodiment of a plurality of rectangular checkerboard patterns in a treatment area for the in situ staged heating and production process.

25 [0019] While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and may herein be described in detail. The drawings may not be to scale. It should be understood, however, that the drawings and detailed description thereto are not intended to limit the invention to the particular form disclosed, but on the contrary, the intention is to cover all modifications, equivalents and alternatives of the present invention as defined by the
30 appended claims.

DETAILED DESCRIPTION

[0020] The following description generally relates to systems and methods for treating hydrocarbons in the formations. Such formations may be treated to yield hydrocarbon products, hydrogen, and other products.

5 [0021] “Cracking” refers to a process involving decomposition and molecular recombination of organic compounds to produce a greater number of molecules than were initially present. In cracking, a series of reactions take place accompanied by a transfer of hydrogen atoms between molecules. For example, naphtha may undergo a thermal cracking reaction to form ethene and H₂.

10 [0022] “Fluid pressure” is a pressure generated by a fluid in a formation. “Lithostatic pressure” (sometimes referred to as “lithostatic stress”) is a pressure in a formation equal to a weight per unit area of an overlying rock mass. “Hydrostatic pressure” is a pressure in a formation exerted by a column of water.

[0023] A “formation” includes one or more hydrocarbon containing layers, one or more
15 non-hydrocarbon layers, an overburden, and/or an underburden. “Hydrocarbon layers” refer to layers in the formation that contain hydrocarbons. The hydrocarbon layers may contain non-hydrocarbon material and hydrocarbon material. The “overburden” and/or the “underburden” include one or more different types of impermeable materials. For example, the overburden and/or underburden may include rock, shale, mudstone, or
20 wet/tight carbonate. In some embodiments of in situ heat treatment processes, the overburden and/or the underburden may include a hydrocarbon containing layer or hydrocarbon containing layers that are relatively impermeable and are not subjected to temperatures during in situ heat treatment processing that result in significant characteristic changes of the hydrocarbon containing layers of the overburden and/or the underburden.
25 For example, the underburden may contain shale or mudstone, but the underburden is not allowed to heat to pyrolysis temperatures during the in situ heat treatment process. In some cases, the overburden and/or the underburden may be somewhat permeable.

[0024] “Formation fluids” refer to fluids present in a formation and may include pyrolyzation fluid, synthesis gas, mobilized hydrocarbons, and water (steam). Formation
30 fluids may include hydrocarbon fluids as well as non-hydrocarbon fluids. The term “mobilized fluid” refers to fluids in a hydrocarbon containing formation that are able to flow as a result of thermal treatment of the formation. “Produced fluids” refer to fluids removed from the formation.

[0025] A “heat source” is any system for providing heat to at least a portion of a formation substantially by conductive and/or radiative heat transfer. For example, a heat source may include electric heaters such as an insulated conductor, an elongated member, and/or a conductor disposed in a conduit. A heat source may also include systems that generate
5 heat by burning a fuel external to or in a formation. The systems may be surface burners, downhole gas burners, flameless distributed combustors, and natural distributed combustors. In some embodiments, heat provided to or generated in one or more heat sources may be supplied by other sources of energy. The other sources of energy may directly heat a formation, or the energy may be applied to a transfer medium that directly
10 or indirectly heats the formation. It is to be understood that one or more heat sources that are applying heat to a formation may use different sources of energy. Thus, for example, for a given formation some heat sources may supply heat from electric resistance heaters, some heat sources may provide heat from combustion, and some heat sources may provide heat from one or more other energy sources (for example, chemical reactions, solar energy,
15 wind energy, biomass, or other sources of renewable energy). A chemical reaction may include an exothermic reaction (for example, an oxidation reaction). A heat source may also include a heater that provides heat to a zone proximate and/or surrounding a heating location such as a heater well.

[0026] A “heater” is any system or heat source for generating heat in a well or a near
20 wellbore region. Heaters may be, but are not limited to, electric heaters, burners, combustors that react with material in or produced from a formation, and/or combinations thereof.

[0027] “Heavy hydrocarbons” are viscous hydrocarbon fluids. Heavy hydrocarbons may include highly viscous hydrocarbon fluids such as heavy oil, tar, and/or asphalt. Heavy
25 hydrocarbons may include carbon and hydrogen, as well as smaller concentrations of sulfur, oxygen, and nitrogen. Additional elements may also be present in heavy hydrocarbons in trace amounts. Heavy hydrocarbons may be classified by API gravity. Heavy hydrocarbons generally have an API gravity below about 20°. Heavy oil, for example, generally has an API gravity of about 10-20°, whereas tar generally has an API
30 gravity below about 10°. The viscosity of heavy hydrocarbons is generally greater than about 100 centipoise at 15 °C. Heavy hydrocarbons may include aromatics or other complex ring hydrocarbons.

[0028] “Hydrocarbons” are generally defined as molecules formed primarily by carbon and hydrogen atoms. Hydrocarbons may also include other elements such as, but not limited to, halogens, metallic elements, nitrogen, oxygen, and/or sulfur. Hydrocarbons may be, but are not limited to, kerogen, bitumen, pyrobitumen, oils, natural mineral waxes, and asphaltites. Hydrocarbons may be located in or adjacent to mineral matrices in the earth. Matrices may include, but are not limited to, sedimentary rock, sands, silicilytes, carbonates, diatomites, and other porous media. “Hydrocarbon fluids” are fluids that include hydrocarbons. Hydrocarbon fluids may include, entrain, or be entrained in non-hydrocarbon fluids such as hydrogen, nitrogen, carbon monoxide, carbon dioxide, hydrogen sulfide, water, and ammonia.

[0029] An “in situ conversion process” refers to a process of heating a hydrocarbon containing formation from heat sources to raise the temperature of at least a portion of the formation above a pyrolysis temperature so that pyrolyzation fluid is produced in the formation.

[0030] An “in situ heat treatment process” refers to a process of heating a hydrocarbon containing formation with heat sources to raise the temperature of at least a portion of the formation above a temperature that results in mobilized fluid, visbreaking, and/or pyrolysis of hydrocarbon containing material so that mobilized fluids, visbroken fluids, and/or pyrolyzation fluids are produced in the formation.

[0031] “Pyrolysis” is the breaking of chemical bonds due to the application of heat. For example, pyrolysis may include transforming a compound into one or more other substances by heat alone. Heat may be transferred to a section of the formation to cause pyrolysis.

[0032] “Pyrolyzation fluids” or “pyrolysis products” refers to fluid produced substantially during pyrolysis of hydrocarbons. Fluid produced by pyrolysis reactions may mix with other fluids in a formation. The mixture would be considered pyrolyzation fluid or pyrolyzation product. As used herein, “pyrolysis zone” refers to a volume of a formation (for example, a relatively permeable formation such as a tar sands formation) that is reacted or reacting to form a pyrolyzation fluid.

[0033] “Rich layers” in a hydrocarbon containing formation are relatively thin layers (typically about 0.2 m to about 0.5 m thick). Rich layers generally have a richness of about 0.150 L/kg or greater. Some rich layers have a richness of about 0.170 L/kg or greater, of about 0.190 L/kg or greater, or of about 0.210 L/kg or greater. Lean layers of the

formation have a richness of about 0.100 L/kg or less and are generally thicker than rich layers. The richness and locations of layers are determined, for example, by coring and subsequent Fischer assay of the core, density or neutron logging, or other logging methods. Rich layers may have a lower initial thermal conductivity than other layers of the formation. Typically, rich layers have a thermal conductivity 1.5 times to 3 times lower than the thermal conductivity of lean layers. In addition, rich layers have a higher thermal expansion coefficient than lean layers of the formation.

[0034] "Superposition of heat" refers to providing heat from two or more heat sources to a selected section of a formation such that the temperature of the formation at least at one location between the heat sources is influenced by the heat sources.

[0035] "Thermal fracture" refers to fractures created in a formation caused by expansion or contraction of a formation and/or fluids in the formation, which is in turn caused by increasing/decreasing the temperature of the formation and/or fluids in the formation, and/or by increasing/decreasing a pressure of fluids in the formation due to heating.

[0036] "Thickness" of a layer refers to the thickness of a cross section of the layer, wherein the cross section is normal to a face of the layer.

[0037] "Upgrade" refers to increasing the quality of hydrocarbons. For example, upgrading heavy hydrocarbons may result in an increase in the API gravity of the heavy hydrocarbons.

[0038] The term "wellbore" refers to a hole in a formation made by drilling or insertion of a conduit into the formation. A wellbore may have a substantially circular cross section, or another cross-sectional shape. As used herein, the terms "well" and "opening," when referring to an opening in the formation may be used interchangeably with the term "wellbore."

[0039] Hydrocarbons in formations may be treated in various ways to produce many different products. In certain embodiments, hydrocarbons in formations are treated in stages. FIG. 1 depicts an illustration of stages of heating the hydrocarbon containing formation. FIG. 1 also depicts an example of yield ("Y") in barrels of oil equivalent per ton (y axis) of formation fluids from the formation versus temperature ("T") of the heated formation in degrees Celsius (x axis).

[0040] Desorption of methane and vaporization of water occurs during stage 1 heating. Heating of the formation through stage 1 may be performed as quickly as possible. For example, when the hydrocarbon containing formation is initially heated, hydrocarbons in

the formation desorb adsorbed methane. The desorbed methane may be produced from the formation. If the hydrocarbon containing formation is heated further, water in the hydrocarbon containing formation is vaporized. Water may occupy, in some hydrocarbon containing formations, between 10% and 50% of the pore volume in the formation. In other formations, water occupies larger or smaller portions of the pore volume. Water typically is vaporized in a formation between 160 °C and 285 °C at pressures of 600 kPa absolute to 7000 kPa absolute. In some embodiments, the vaporized water produces wettability changes in the formation and/or increased formation pressure. The wettability changes and/or increased pressure may affect pyrolysis reactions or other reactions in the formation. In certain embodiments, the vaporized water is produced from the formation. In other embodiments, the vaporized water is used for steam extraction and/or distillation in the formation or outside the formation. Removing the water from and increasing the pore volume in the formation increases the storage space for hydrocarbons in the pore volume.

[0041] In certain embodiments, after stage 1 heating, the formation is heated further, such that a temperature in the formation reaches (at least) an initial pyrolyzation temperature (such as a temperature at the lower end of the temperature range shown as stage 2). Hydrocarbons in the formation may be pyrolyzed throughout stage 2. A pyrolysis temperature range varies depending on the types of hydrocarbons in the formation. The pyrolysis temperature range may include temperatures between 250 °C and 900 °C. The pyrolysis temperature range for producing desired products may extend through only a portion of the total pyrolysis temperature range. In some embodiments, the pyrolysis temperature range for producing desired products may include temperatures between 250 °C and 400 °C or temperatures between 270 °C and 350 °C. If a temperature of hydrocarbons in the formation is slowly raised through the temperature range from 250 °C to 400 °C, production of pyrolysis products may be substantially complete when the temperature approaches 400 °C. Average temperature of the hydrocarbons may be raised at a rate of less than 5 °C per day, less than 2 °C per day, less than 1 °C per day, or less than 0.5 °C per day through the pyrolysis temperature range for producing desired products. Heating the hydrocarbon containing formation with a plurality of heat sources may establish thermal gradients around the heat sources that slowly raise the temperature of hydrocarbons in the formation through the pyrolysis temperature range.

[0042] The rate of temperature increase through the pyrolysis temperature range for desired products may affect the quality and quantity of the formation fluids produced from the hydrocarbon containing formation. Raising the temperature slowly through the pyrolysis temperature range for desired products may inhibit mobilization of large chain molecules in the formation. Raising the temperature slowly through the pyrolysis temperature range for desired products may limit reactions between mobilized hydrocarbons that produce undesired products. Slowly raising the temperature of the formation through the pyrolysis temperature range for desired products may allow for the production of high quality, high API gravity hydrocarbons from the formation. Slowly raising the temperature of the formation through the pyrolysis temperature range for desired products may allow for the removal of a large amount of the hydrocarbons present in the formation as hydrocarbon product.

[0043] In some in situ heat treatment embodiments, a portion of the formation is heated to a desired temperature instead of slowly heating the temperature through a temperature range. In some embodiments, the desired temperature is 300 °C, 325 °C, or 350 °C. Other temperatures may be selected as the desired temperature. Superposition of heat from heat sources allows the desired temperature to be relatively quickly and efficiently established in the formation. Energy input into the formation from the heat sources may be adjusted to maintain the temperature in the formation substantially at the desired temperature. The heated portion of the formation is maintained substantially at the desired temperature until pyrolysis declines such that production of desired formation fluids from the formation becomes uneconomical. Parts of the formation that are subjected to pyrolysis may include regions brought into a pyrolysis temperature range by heat transfer from only one heat source.

[0044] In certain embodiments, formation fluids including pyrolyzation fluids are produced from the formation. As the temperature of the formation increases, the amount of condensable hydrocarbons in the produced formation fluid may decrease. At high temperatures, the formation may produce mostly methane and/or hydrogen. If the hydrocarbon containing formation is heated throughout an entire pyrolysis range, the formation may produce only small amounts of hydrogen towards an upper limit of the pyrolysis range. After all of the available hydrogen is depleted, a minimal amount of fluid production from the formation will typically occur.

[0045] After pyrolysis of hydrocarbons, a large amount of carbon and some hydrogen may still be present in the formation. A significant portion of carbon remaining in the formation can be produced from the formation in the form of synthesis gas. Synthesis gas generation may take place during stage 3 heating depicted in FIG. 1. Stage 3 may include heating a hydrocarbon containing formation to a temperature sufficient to allow synthesis gas generation. For example, synthesis gas may be produced in a temperature range from about 400 °C to about 1200 °C, about 500 °C to about 1100 °C, or about 550 °C to about 1000 °C. The temperature of the heated portion of the formation when the synthesis gas generating fluid is introduced to the formation determines the composition of synthesis gas produced in the formation. The generated synthesis gas may be removed from the formation through a production well or production wells.

[0046] Total energy content of fluids produced from the hydrocarbon containing formation may stay relatively constant throughout pyrolysis and synthesis gas generation. During pyrolysis at relatively low formation temperatures, a significant portion of the produced fluid may be condensable hydrocarbons that have a high energy content. At higher pyrolysis temperatures, however, less of the formation fluid may include condensable hydrocarbons. More non-condensable formation fluids may be produced from the formation. Energy content per unit volume of the produced fluid may decline slightly during generation of predominantly non-condensable formation fluids. During synthesis gas generation, energy content per unit volume of produced synthesis gas declines significantly compared to energy content of pyrolyzation fluid. The volume of the produced synthesis gas, however, will in many instances increase substantially, thereby compensating for the decreased energy content.

[0047] FIG. 2 depicts a schematic view of an embodiment of a portion of the in situ heat treatment system for treating the hydrocarbon containing formation. The in situ heat treatment system may include barrier wells 100. Barrier wells are used to form a barrier around a treatment area. The barrier inhibits fluid flow into and/or out of the treatment area. Barrier wells include, but are not limited to, dewatering wells, vacuum wells, capture wells, injection wells, grout wells, freeze wells, or combinations thereof. In some embodiments, barrier wells 100 are dewatering wells. Dewatering wells may remove liquid water and/or inhibit liquid water from entering a portion of the formation to be heated, or to the formation being heated. In the embodiment depicted in FIG. 2, the barrier wells 100 are shown extending only along one side of heat sources 102, but the barrier

wells typically encircle all heat sources 102 used, or to be used, to heat a treatment area of the formation.

[0048] Heat sources 102 are placed in at least a portion of the formation. Heat sources 102 may include heaters such as insulated conductors, conductor-in-conduit heaters, surface
5 burners, flameless distributed combustors, and/or natural distributed combustors. Heat sources 102 may also include other types of heaters. Heat sources 102 provide heat to at least a portion of the formation to heat hydrocarbons in the formation. Energy may be supplied to heat sources 102 through supply lines 104. Supply lines 104 may be structurally different depending on the type of heat source or heat sources used to heat the
10 formation. Supply lines 104 for heat sources may transmit electricity for electric heaters, may transport fuel for combustors, or may transport heat exchange fluid that is circulated in the formation. In some embodiments, electricity for an in situ heat treatment process may be provided by a nuclear power plant or nuclear power plants. The use of nuclear power may allow for reduction or elimination of carbon dioxide emissions from the in situ
15 heat treatment process.

[0049] Production wells 106 are used to remove formation fluid from the formation. In some embodiments, production well 106 includes a heat source. The heat source in the production well may heat one or more portions of the formation at or near the production well. In some in situ heat treatment process embodiments, the amount of heat supplied to
20 the formation from the production well per meter of the production well is less than the amount of heat applied to the formation from a heat source that heats the formation per meter of the heat source.

[0050] In some embodiments, the heat source in production well 106 allows for vapor phase removal of formation fluids from the formation. Providing heating at or through the
25 production well may: (1) inhibit condensation and/or refluxing of production fluid when such production fluid is moving in the production well proximate the overburden, (2) increase heat input into the formation, (3) increase production rate from the production well as compared to a production well without a heat source, (4) inhibit condensation of high carbon number compounds (C6 and above) in the production well, and/or (5) increase
30 formation permeability at or proximate the production well.

[0051] Subsurface pressure in the formation may correspond to the fluid pressure generated in the formation. As temperatures in the heated portion of the formation increase, the pressure in the heated portion may increase as a result of increased fluid

generation and vaporization of water. Controlling rate of fluid removal from the formation may allow for control of pressure in the formation. Pressure in the formation may be determined at a number of different locations, such as near or at production wells, near or at heat sources, or at monitor wells.

5 [0052] In some hydrocarbon containing formations, production of hydrocarbons from the formation is inhibited until at least some hydrocarbons in the formation have been pyrolyzed. Formation fluid may be produced from the formation when the formation fluid is of a selected quality. In some embodiments, the selected quality includes an API gravity of at least about 20°, 30°, or 40°. Inhibiting production until at least some hydrocarbons
10 are pyrolyzed may increase conversion of heavy hydrocarbons to light hydrocarbons. Inhibiting initial production may minimize the production of heavy hydrocarbons from the formation. Production of substantial amounts of heavy hydrocarbons may require expensive equipment and/or reduce the life of production equipment.

[0053] After pyrolysis temperatures are reached and production from the formation is
15 allowed, pressure in the formation may be varied to alter and/or control a composition of formation fluid produced, to control a percentage of condensable fluid as compared to non-condensable fluid in the formation fluid, and/or to control an API gravity of formation fluid being produced. For example, decreasing pressure may result in production of a larger condensable fluid component. The condensable fluid component may contain a larger
20 percentage of olefins.

[0054] In some in situ heat treatment process embodiments, pressure in the formation may be maintained high enough to promote production of formation fluid with an API gravity of greater than 20°. Maintaining increased pressure in the formation may inhibit formation subsidence during in situ heat treatment. Maintaining increased pressure may facilitate
25 vapor phase production of fluids from the formation. Vapor phase production may allow for a reduction in size of collection conduits used to transport fluids produced from the formation. Maintaining increased pressure may reduce or eliminate the need to compress formation fluids at the surface to transport the fluids in collection conduits to treatment facilities.

30 [0055] Maintaining increased pressure in a heated portion of the formation may surprisingly allow for production of large quantities of hydrocarbons of increased quality and of relatively low molecular weight. Pressure may be maintained so that formation fluid produced has a minimal amount of compounds above a selected carbon number. The

selected carbon number may be at most 25, at most 20, at most 12, or at most 8. Some high carbon number compounds may be entrained in vapor in the formation and may be removed from the formation with the vapor. Maintaining increased pressure in the formation may inhibit entrainment of high carbon number compounds and/or multi-ring hydrocarbon compounds in the vapor. High carbon number compounds and/or multi-ring hydrocarbon compounds may remain in a liquid phase in the formation for significant time periods. The significant time periods may provide sufficient time for the compounds to pyrolyze to form lower carbon number compounds.

[0056] Formation fluid produced from production wells 106 may be transported through collection piping 108 to treatment facilities 110. Formation fluids may also be produced from heat sources 102. For example, fluid may be produced from heat sources 102 to control pressure in the formation adjacent to the heat sources. Fluid produced from heat sources 102 may be transported through tubing or piping to collection piping 108 or the produced fluid may be transported through tubing or piping directly to treatment facilities 110. Treatment facilities 110 may include separation units, reaction units, upgrading units, fuel cells, turbines, storage vessels, and/or other systems and units for processing produced formation fluids. The treatment facilities may form transportation fuel from at least a portion of the hydrocarbons produced from the formation. In some embodiments, the transportation fuel may be jet fuel, such as JP-8.

[0057] In certain embodiments, a controlled or staged in situ heating and production process is used to in situ heat treat a hydrocarbon containing formation (for example, an oil shale formation). The staged in situ heating and production process may use less energy input to produce hydrocarbons from the formation than a continuous or batch in situ heat treatment process. In some embodiments, the staged in situ heating and production process is about 30% more efficient in treating the formation than the continuous or batch in situ heat treatment process. The staged in situ heating and production process may also produce less carbon dioxide emissions than a continuous or batch in situ heat treatment process. In certain embodiments, the staged in situ heating and production process is used to treat rich layers in the oil shale formation. Treating only the rich layers may be more economical than treating both rich layers and lean layers because heat may be wasted heating the lean layers.

[0058] FIG. 3 depicts a top view representation of an embodiment for the staged in situ heating and producing process for treating the formation. In certain embodiments, heaters

112 are arranged in triangular patterns. In other embodiments, heaters 112 are arranged in any other regular or irregular patterns. The heater patterns may be divided into one or more sections 116, 118, 120, 122, and/or 124. The number of heaters 112 in each section may vary depending on, for example, properties of the formation or a desired heating rate
5 for the formation. One or more production wells 106 may be located in each section 116, 118, 120, 122, and/or 124. In certain embodiments, production wells 106 are located at or near the centers of the sections. In some embodiments, production wells 106 are in other portions of sections 116, 118, 120, 122, and 124. Production wells 106 may be located at other locations in sections 116, 118, 120, 122, and/or 124 depending on, for example, a
10 desired quality of products produced from the sections and/or a desired production rate from the formation.

[0059] In certain embodiments, heaters 112 in one of the sections are turned on while the heaters in other sections remain turned off. For example, heaters 112 in section 116 may be turned on while the heaters in the other sections are left turned off. Heat from heaters
15 112 in section 116 may create permeability, mobilize fluids, and/or pyrolysis fluids in section 116. While heat is being provided by heaters 112 in section 116, production well 106 in section 118 may be opened to produce fluids from the formation. Some heat from heaters 112 in section 116 may transfer to section 118 and “pre-heat” section 118. The pre-heating of section 118 may create permeability in section 118, mobilize fluids in
20 section 118, and allow fluids to be produced from the section through production well 106.

[0060] In certain embodiments, a portion of section 118 proximate production well 106, however, is not heated by conductive heating from heaters 112 in section 116. For example, the superposition of heat from heaters 112 in section 116 does not overlap the portion proximate production well 106 in section 118. The portion proximate production
25 well 106 in section 118 may be heated by fluids (such as hydrocarbons) flowing to the production well (for example, by convective heat transfer from the fluids).

[0061] As fluids are produced from section 118, the movement of fluids from section 116 to section 118 transfers heat between the sections. The movement of the hot fluids through the formation increases heat transfer within the formation. Allowing hot fluids to flow
30 between the sections uses the energy of the hot fluids for heating of unheated sections rather than removing the heat from the formation by producing the hot fluids directly from section 116. Thus, the movement of the hot fluids allows for less energy input to get

production from the formation than is required if heat is provided from heaters 112 in both sections to get production from the sections.

[0062] In certain embodiments, the temperature of the portion proximate production well 106 in section 118 is controlled so that the temperature in the portion is at most a selected temperature. For example, the temperature in the portion proximate the production well may be controlled so that the temperature is at most about 100 °C, at most about 200 °C, or at most about 250 °C. In some embodiments, the temperature of the portion proximate production well 106 in section 118 is controlled by controlling the production rate of fluids through the production well. In some embodiments, producing more fluids increases heat transfer to the production well and the temperature in the portion proximate the production well.

[0063] In some embodiments, production through production well 106 in section 118 is reduced or turned off after the portion proximate the production well reaches the selected temperature. Reducing or turning off production through the production well at higher temperatures keeps heated fluids in the formation. Keeping the heated fluids in the formation keeps energy in the formation and reduces the energy input needed to heat the formation. The selected temperature at which production is reduced or turned off may be, for example, about 100 °C, about 200 °C, or about 250 °C.

[0064] In some embodiments, section 116 and/or section 118 may be treated prior to turning on heaters 112 to increase the permeability in the sections. For example, the sections may be dewatered to increase the permeability in the sections. In some embodiments, steam injection or other fluid injection may be used to increase the permeability in the sections.

[0065] In certain embodiments, after a selected time, heaters 112 in section 118 are turned on. Turning on heaters 112 in section 118 may provide additional heat to sections 116 and 118 to increase the permeability, mobility, and/or pyrolysis of fluids in these sections. In some embodiments, as heaters 112 in section 118 are turned on, production in section 118 is reduced or turned off (shut down) and production well 106 in section 120 is opened to produce fluids from the formation. Thus, fluid flow in the formation towards production well 106 in section 120 and section 120 is heated by the flow of hot fluids as described above for section 118. In some embodiments, production well 106 in section 118 may be left open after the heaters are turned on in the section, if desired. In some embodiments,

production in section 118 is reduced or turned off at the selected temperature, as described above.

[0066] The process of reducing or turning off heaters and shifting production to adjacent sections may be repeated for subsequent sections in the formation. For example, after a
5 selected time, heaters in section 120 may be turned on and fluids produced from production well 106 in section 122 and so on through the formation.

[0067] In some embodiments, heat is provided by heaters 112 in alternating sections (for example, sections 116, 120, and 124) while fluids are produced from the sections in between the heated sections (for example, sections 118 and 122). After a selected time,
10 heaters 112 in the unheated sections (sections 118 and 122) are turned on and fluids are produced from one or more of the sections as desired.

[0068] In certain embodiments, a smaller heater spacing is used in the staged in situ heating and producing process than in the continuous or batch in situ heat treatment processes. For example, the continuous or batch in situ heat treatment process may use a
15 heater spacing of about 12 m while the in situ staged heating and producing process uses a heater spacing of about 10 m. The staged in situ heating and producing process may use the smaller heater spacing because the staged process allows for relatively rapid heating of the formation and expansion of the formation.

[0069] In some embodiments, the sequence of heated sections begins with the outermost
20 sections and moves inwards. For example, for a selected time, heat may be provided by heaters 112 in sections 116 and 124 as fluids are produced from sections 118 and 122. After the selected time, heaters 112 in sections 118 and 122 may be turned on and fluids are produced from section 120. After another selected amount of time, heaters 112 in section 120 may be turned on, if needed.

[0070] In certain embodiments, sections 116-124 are substantially equal sized sections.
25 The size and/or location of sections 116-124 may vary based on desired heating and/or production from the formation. For example, simulation of the staged in situ heating and production process treatment of the formation may be used to determine the number of heaters in each section, the optimum pattern of sections and/or the sequence for heater
30 power up and production well startup for the staged in situ heating and production process. The simulation may account for properties such as, but not limited to, formation properties and desired properties and/or quality in the produced fluids. In some embodiments, heaters 112 at the edges of the treated portions of the formation (for example, heaters 112 at the

left edge of section 116 or the right edge of section 124) may have tailored or adjusted heat outputs to produce desired heat treatment of the formation.

[0071] In some embodiments, the formation is sectioned into a checkerboard pattern for the staged in situ heating and production process. FIG. 4 depicts a top view of rectangular checkerboard pattern 126 embodiment for the staged in situ heating and production process. In some embodiments, heaters in the “A” sections (sections 116A, 118A, 120A, 122A, and 124A) may be turned on and fluids are produced from the “B” sections (sections 116B, 118B, 120B, 122B, and 124B). After the selected time, heaters in the “B” sections may be turned on. The size and/or number of “A” and “B” sections in rectangular checkerboard pattern 126 may be varied depending on factors such as, but not limited to, heater spacing, desired heating rate of the formation, desired production rate, size of treatment area, subsurface geomechanical properties, subsurface composition, and/or other formation properties.

[0072] In some embodiments, heaters in sections 116A are turned on and fluids are produced from sections 116B and/or sections 118B. After the selected time, heaters in sections 118A may be turned on and fluids are produced from sections 118B and/or 120B. After another selected time, heaters in sections 120A may be turned on and fluids are produced from sections 120B and/or 122B. After another selected time, heaters in sections 122A may be turned on and fluids are produced from sections 122B and/or 124B. In some embodiments, heaters in a “B” section that has been produced from may be turned on when heaters in the subsequent “A” section are turned on. For example, heaters in section 116B may be turned on when the heaters in section 118A are turned on. Other alternating heater startup and production sequences may also be contemplated for the in situ staged heating and production process embodiment depicted in FIG. 4.

[0073] In some embodiments, the formation is divided into a circular, ring, or spiral pattern for the staged in situ heating and production process. FIG. 5 depicts a top view of the ring pattern embodiment for the staged in situ heating and production process. Sections 116, 118, 120, 122, and 124 may be treated with heater startup and production sequences similar to the sequences described above for the embodiments depicted in FIGS. 3 and 4. The heater startup and production sequences for the embodiment depicted in FIG. 5 may start with section 116 (going inwards towards the center) or with section 124 (going outwards from the center). Starting with section 116 may allow expansion of the formation as heating moves towards the center of the ring pattern. Shearing of the formation may be

minimized or inhibited because the formation is allowed to expand into heated and/or pyrolyzed portions of the formation. In some embodiments, the center section (section 124) is cooled after treatment.

[0074] FIG. 6 depicts a top view of a checkerboard ring pattern embodiment for the staged
5 in situ heating and production process. The embodiment depicted in FIG. 6 divides the ring pattern embodiment depicted in FIG. 5 into a checkerboard pattern similar to the checkerboard pattern depicted in FIG. 4. Sections 116A, 118A, 120A, 122A, 124A, 116B, 118B, 120B, 122B, and 124B, depicted in FIG. 6, may be treated with heater startup and production sequences similar to the sequences described above for the embodiment
10 depicted in FIG. 4.

[0075] In some embodiments, fluids are injected to drive fluids between sections of the formation. Injecting fluids such as steam or carbon dioxide may increase the mobility of hydrocarbons and may increase the efficiency of the staged in situ heating and production process. In some embodiments, fluids are injected into the formation after the in situ heat
15 treatment process to recover heat from the formation. In some embodiments, the fluids injected into the formation for heat recovery include some fluids produced from the formation (for example, carbon dioxide, water, and/or hydrocarbons produced from the formation). In some embodiments, the embodiments depicted in FIGS. 3-6 are used for in situ solution mining of the formation. Hot water or another fluid may be used to get
20 permeability in the formation at low temperatures for solution mining.

[0076] In certain embodiments, several rectangular checkerboard patterns (for example, rectangular checkerboard pattern 126 depicted in FIG. 4) are used to treat a treatment area of the formation. FIG. 7 depicts a top view of a plurality of rectangular checkerboard patterns 126(1-36) in treatment area 114 for the staged in situ heating and production
25 process. Treatment area 114 may be enclosed by barrier 128. Each of rectangular checkerboard patterns 126 (1-36) may individually be treated according to embodiments described above for the rectangular checkerboard patterns.

[0077] In certain embodiments, the startup of treatment of rectangular checkerboard patterns 126(1-36) proceeds in a sequential process. The sequential process may include
30 starting the treatment of each of the rectangular checkerboard patterns one by one sequentially. For example, treatment of a second rectangular checkerboard pattern (for example, the onset of heating of the second rectangular checkerboard pattern) may be started after treatment of a first rectangular checkerboard pattern and so on. The startup of

treatment of the second rectangular checkerboard pattern may be at any point in time after the treatment of the first rectangular checkerboard pattern has begun. The time selected for startup of treatment of the second rectangular checkerboard pattern may be varied depending on factors such as, but not limited to, desired heating rate of the formation, desired production rate, subsurface geomechanical properties, subsurface composition, and/or other formation properties. In some embodiments, the startup of treatment of the second rectangular checkerboard pattern begins after a selected amount of fluids have been produced from the first rectangular checkerboard pattern area or after the production rate from the first rectangular checkerboard pattern increases above a selected value or falls below a selected value.

[0078] In some embodiments, the startup sequence for rectangular checkerboard patterns 126(1-36) is arranged to minimize or inhibit expansion stresses in the formation. In an embodiment, the startup sequence of the rectangular checkerboard patterns proceeds in an outward spiral sequence, as shown by the arrows in FIG. 7. The outward spiral sequence proceeds sequentially beginning with treatment of rectangular checkerboard pattern 126-1, followed by treatment of rectangular checkerboard pattern 126-2, rectangular checkerboard pattern 126-3, rectangular checkerboard pattern 126-4, and continuing the sequence up to rectangular checkerboard pattern 126-36. Sequentially starting the rectangular checkerboard patterns in the outwards spiral sequence may minimize or inhibit expansion stresses in the formation.

[0079] Starting treatment in rectangular checkerboard patterns at or near the center of treatment area 114 and moving outwards maximizes the starting distance from barrier 128. Barrier 128 may be most likely to fail when heat is provided at or near the barrier. Starting treatment/heating at or near the center of treatment area 114 delays heating of rectangular checkerboard patterns near barrier 128 until later times of heating in treatment area 114 or at or near the end of production from the treatment area. Thus, if barrier 128 does fail, the failure of the barrier occurs after a significant portion of treatment area 114 has been treated.

[0080] Starting treatment in rectangular checkerboard patterns at or near the center of treatment area 114 and moving outwards also creates open pore space in the inner portions of the outward moving startup pattern. The open pore space allows portions of the formation being started at later times to expand inwards into the open pore space and, for example, minimize shearing in the formation.

[0081] In some embodiments, support sections are left between one or more rectangular checkerboard patterns 126(1-36). The support sections may be unheated sections that provide support against geomechanical shifting, shearing, and/or expansion stress in the formation. In some embodiments, some heat may be provided in the support sections. The heat provided in the support sections may be less than heat provided inside rectangular checkerboard patterns 126(1-36). In some embodiments, each of the support sections may include alternating heated and unheated sections. In some embodiments, fluids are produced from one or more of the unheated support sections.

[0082] In some embodiments, one or more of rectangular checkerboard patterns 126(1-36) have varying sizes. For example, the outer rectangular checkerboard patterns (such as rectangular checkerboard patterns 126(21-26) and rectangular checkerboard patterns 126(31-36)) may have smaller areas and/or numbers of checkerboards. Reducing the area and/or the number of checkerboards in the outer rectangular checkerboard patterns may reduce expansion stresses and/or geomechanical shifting in the outer portions of treatment area 114. Reducing the expansion stresses and/or geomechanical shifting in the outer portions of treatment area 114 may minimize or inhibit expansion stress and/or shifting stress on barrier 128.

[0083] Further modifications and alternative embodiments of various aspects of the invention may be apparent to those skilled in the art in view of this description.

Accordingly, this description is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the general manner of carrying out the invention. It is to be understood that the forms of the invention shown and described herein are to be taken as the presently preferred embodiments. Elements and materials may be substituted for those illustrated and described herein, parts and processes may be reversed, and certain features of the invention may be utilized independently, all as would be apparent to one skilled in the art after having the benefit of this description of the invention. Changes may be made in the elements described herein without departing from the spirit and scope of the invention as described in the following claims. In addition, it is to be understood that features described herein independently may, in certain embodiments, be combined.

CLAIMS

1. A method for treating a hydrocarbon containing formation, comprising:
treating a first zone of the formation;
5 beginning treatment of a plurality of zones of the formation at selected times after the treatment of the first zone begins, the treatment of at least two successively treated zones beginning at a selected time after treatment of the previous zone begins;
wherein at least two of the successively treated zones are adjacent to the zone treated previously;
10 wherein the successive treatment of the zones proceeds in an outward, substantially spiral sequence from the first zone so that the treatment of the zones moves substantially spirally outwards towards a boundary of the treatment area; and
wherein treatment of at least two of the zones comprises:
providing heat from one or more heaters located in two or more first
15 sections of the zone;
allowing some of the heat to transfer from at least two of the first sections to two or more second sections of the zone;
wherein the first sections and the second sections are arranged in a checkerboard pattern within the zone, the checkerboard pattern having at least one
20 of the first sections substantially surrounded by three or more of the second sections and at least one of the second sections substantially surrounded by three or more of the first sections; and
producing at least some hydrocarbons from the second sections, wherein at least some of the hydrocarbons produced in the second sections comprise fluids
25 initially in the first sections.
2. The method of claim 1, wherein the first zone is at or near a center of a treatment area.
3. The method of any of claims 1 or 2, further comprising providing heat from one or more heaters located in the second sections.
- 30 4. The method of any of claims 1-3, further comprising providing a barrier around at least a portion of the treatment area.

5. The method of any of claims 1-4, further comprising allowing outer zones of the formation to expand inwards into previously treated zones to inhibit shearing in the formation.
6. The method of any of claims 1-5, wherein the outward spiral sequence inhibits expansion stresses in the formation.
7. The method of any of claims 1-6, further comprising providing one or more support portions in the formation between one or more of the zones.
8. The method of claim 7, wherein the support portions provide support against geomechanical shifting, shearing, and/or expansion stress in the formation.
9. The method of any of claims 1-8, further comprising allowing at least some fluids to flow from the first sections to the second sections.
10. The method of any of claims 1-9, further comprising allowing at least some fluids to flow from the first sections to the second sections to convectively transfer heat from the first sections to the second sections.
11. The method of any of claims 1-10, wherein the provided heat increases the permeability of at least one of the first sections and/or at least one of the second sections.
12. The method of any of claims 1-11, wherein the provided heat mobilizes at least some hydrocarbons in the first sections and/or the second sections.
13. The method of any of claims 1-12, wherein the provided heat pyrolyzes at least some hydrocarbons in the first sections and/or the second sections.
14. The method of any of claims 1-13, further comprising dewatering at least one of the first sections and/or at least one of the second sections prior to providing heat to the formation.
15. The method of any of claims 1-14, wherein the volume of at least one of the first sections is between about 70% and about 130% of the volume of at least one of the second sections.
16. The method of any of claims 1-15, further comprising injecting a fluid into the first sections to move at least some of the hydrocarbons into the second sections.
17. The method of any of claims 1-16, wherein superposition of heat from the first heaters does not overlap a portion of at least one of the second sections proximate at least one production well.

18. The method of any of claims 1-17, further comprising controlling a temperature of a portion of at least one of the second sections proximate at least one production well so that the temperature is at most about 200 °C.
19. The method of any of claims 1-18, further comprising reducing or turning off
5 production in at least one production well in at least one of the second sections when a temperature in a portion proximate the production well reaches a temperature of about 200 °C.

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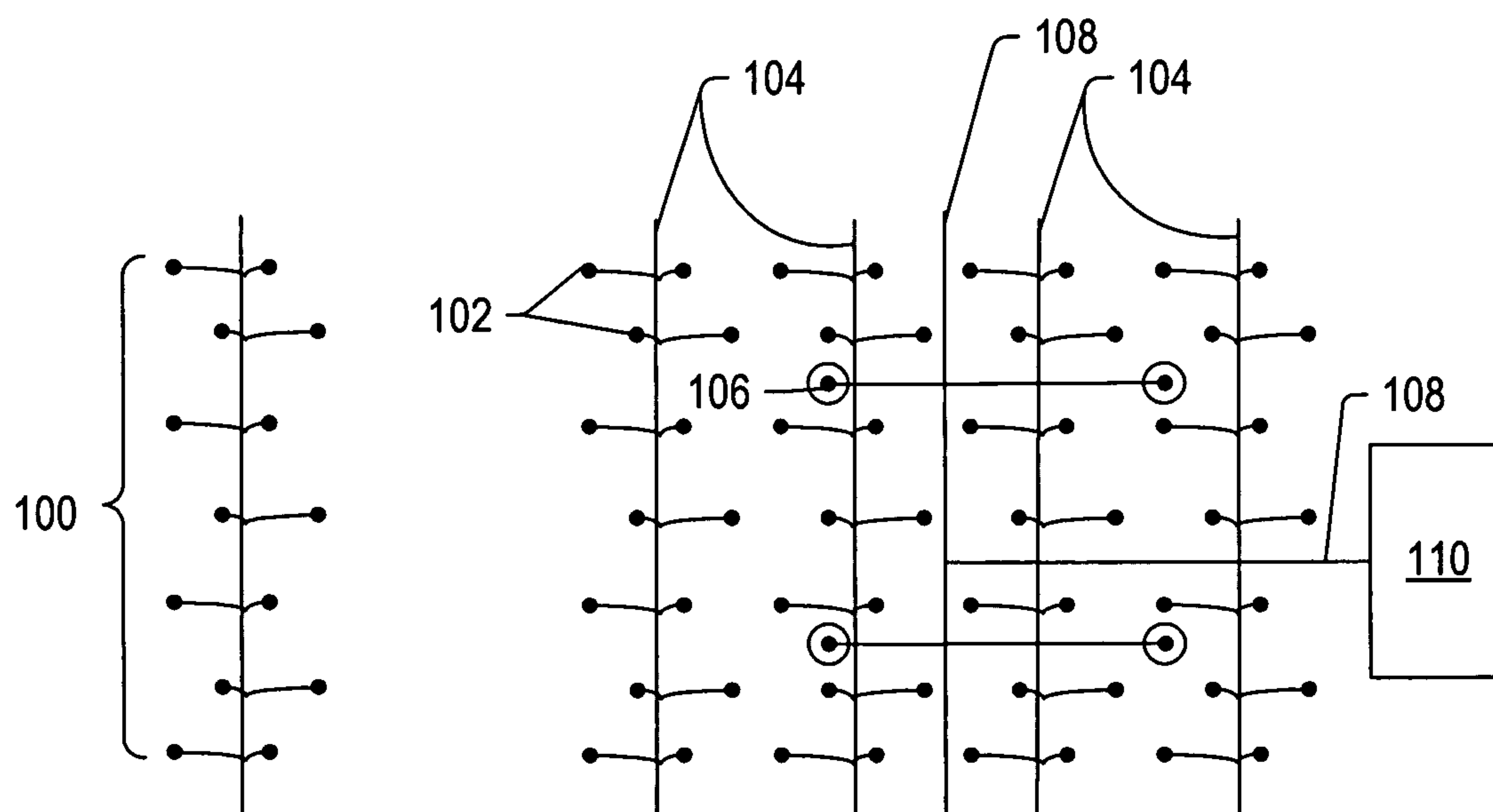
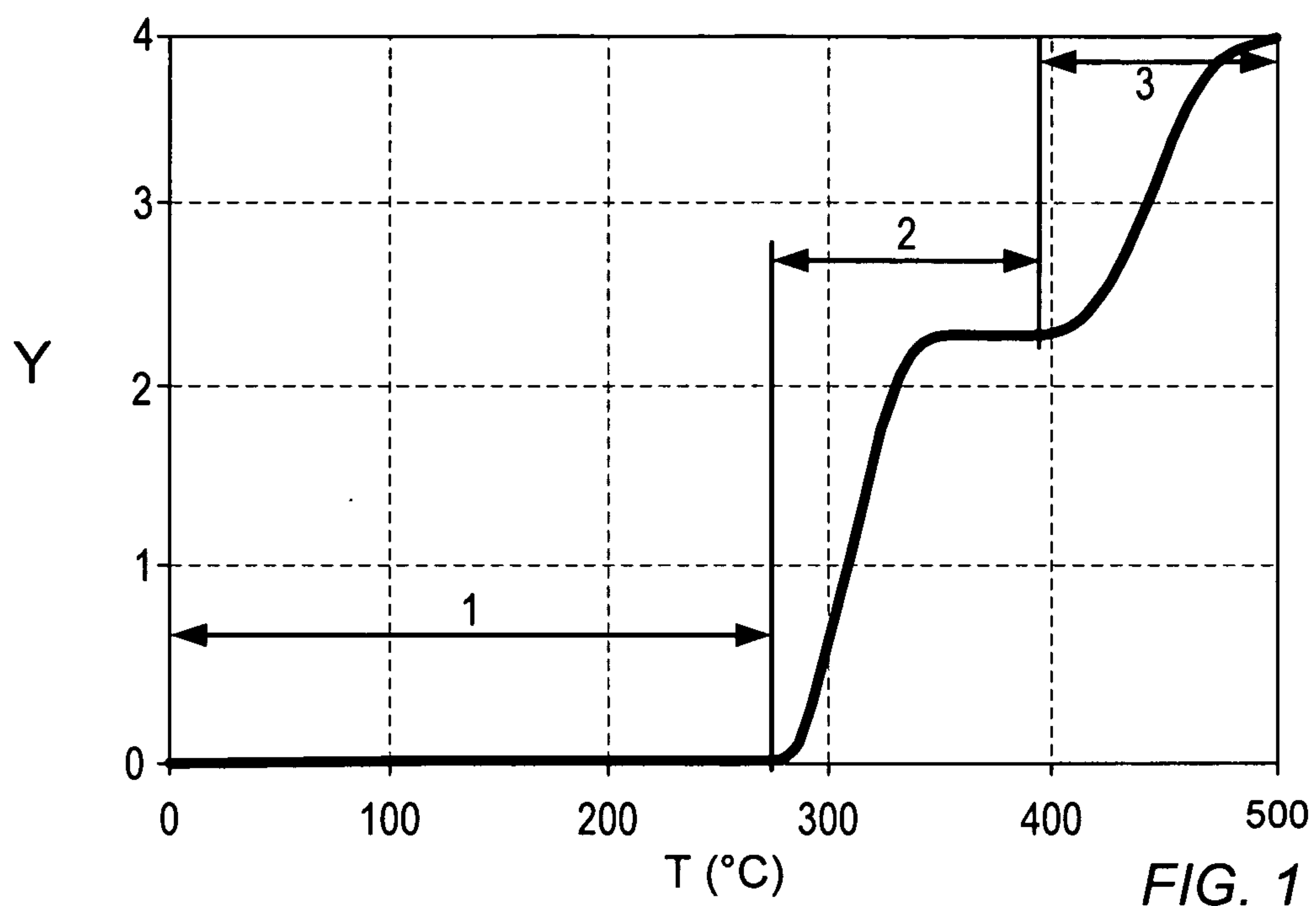


FIG. 2

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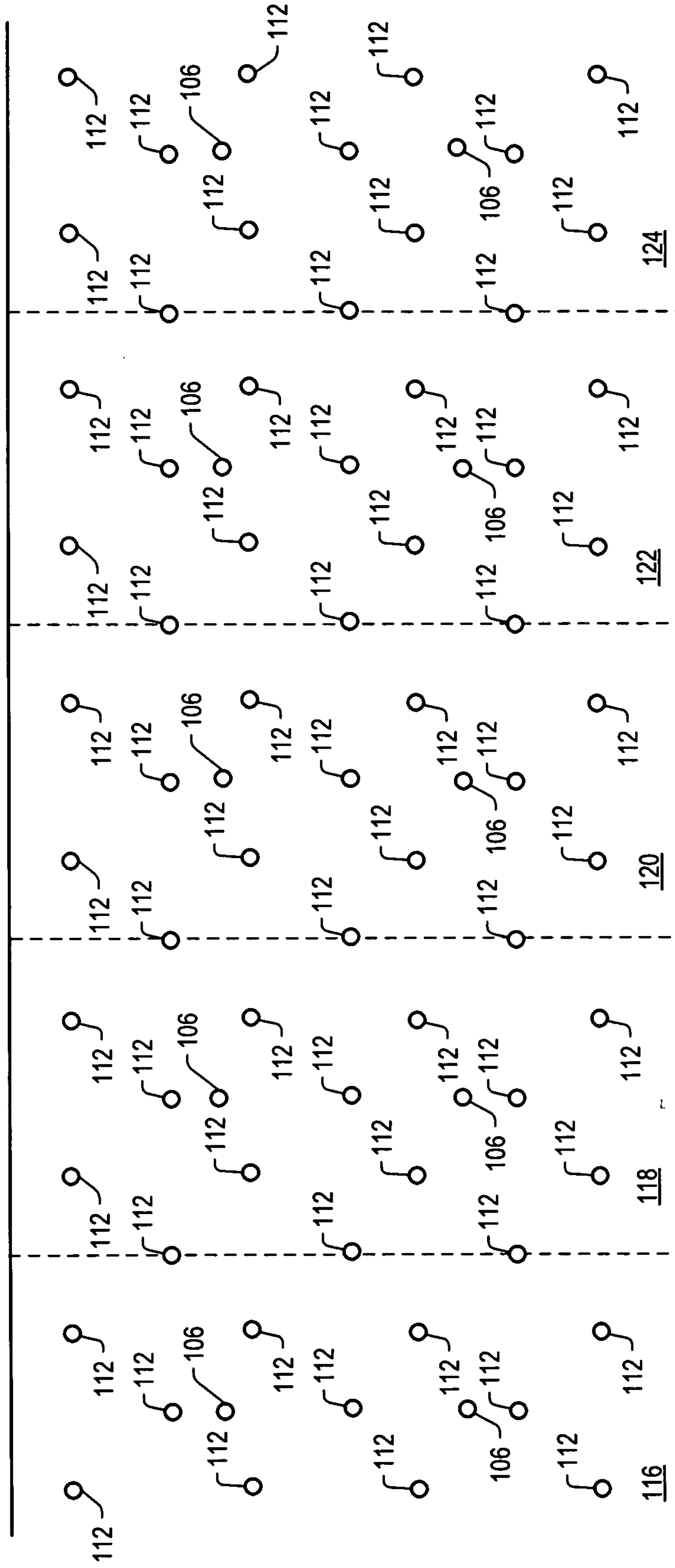


FIG. 3

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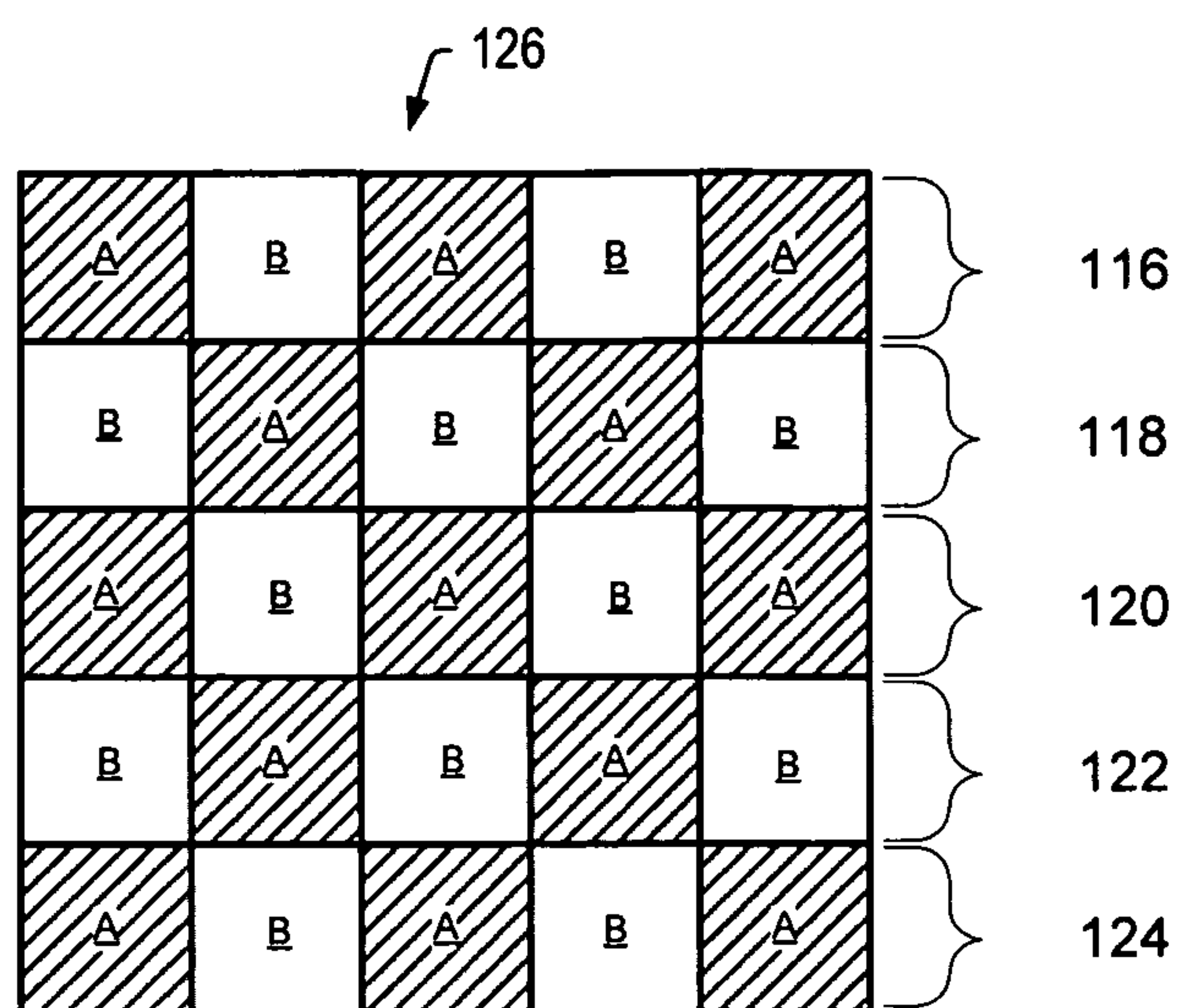


FIG. 4

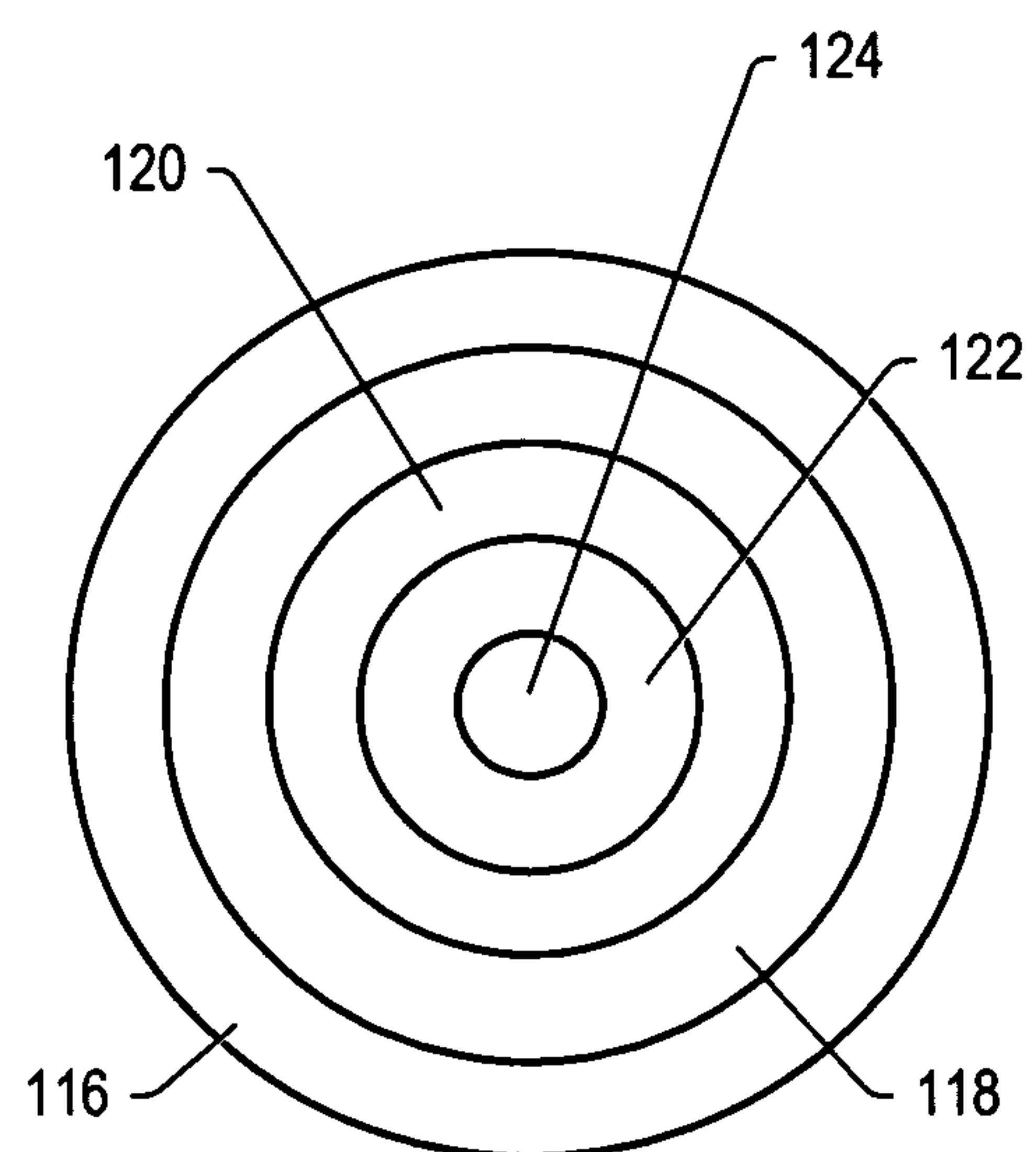


FIG. 5

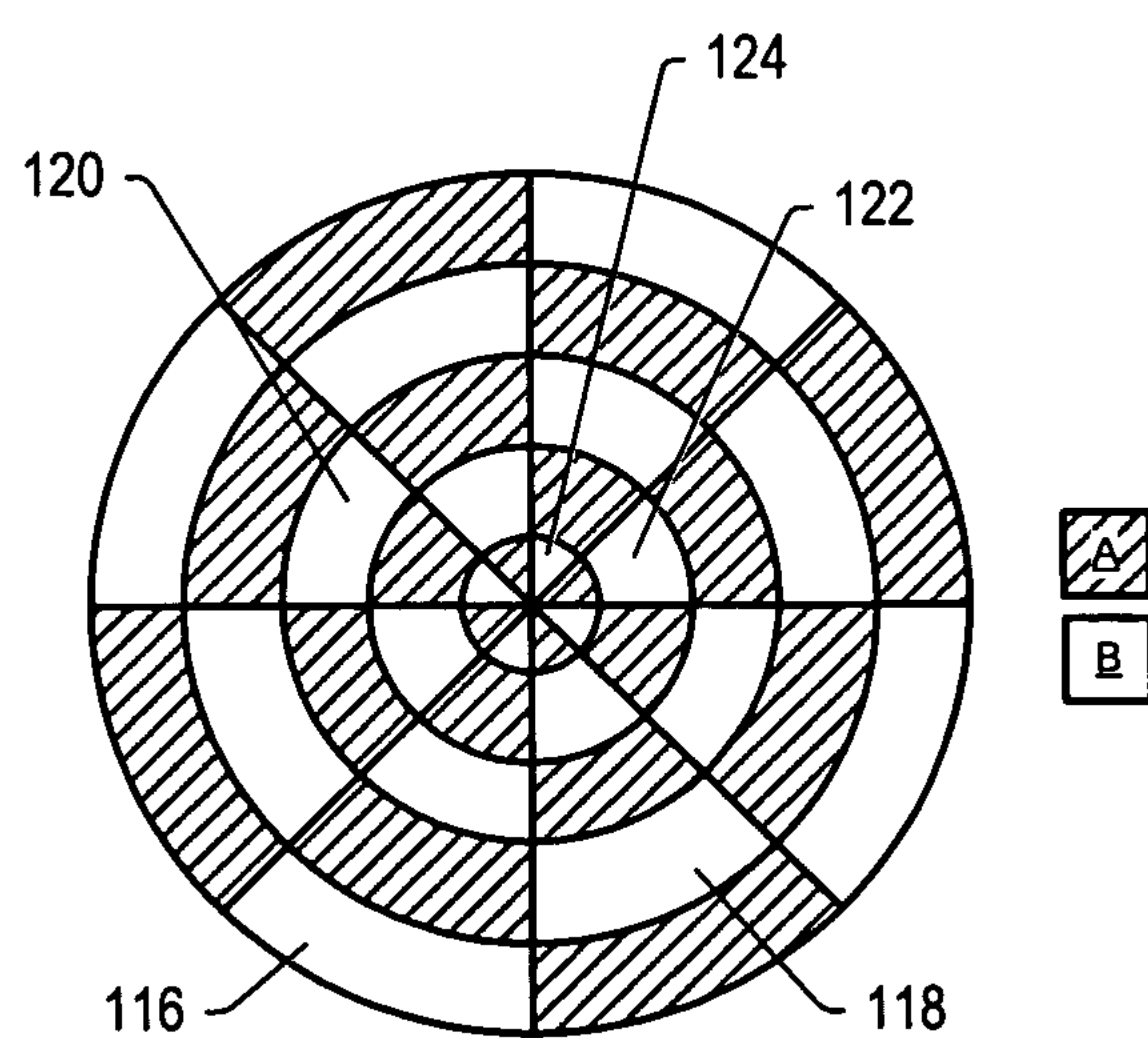


FIG. 6

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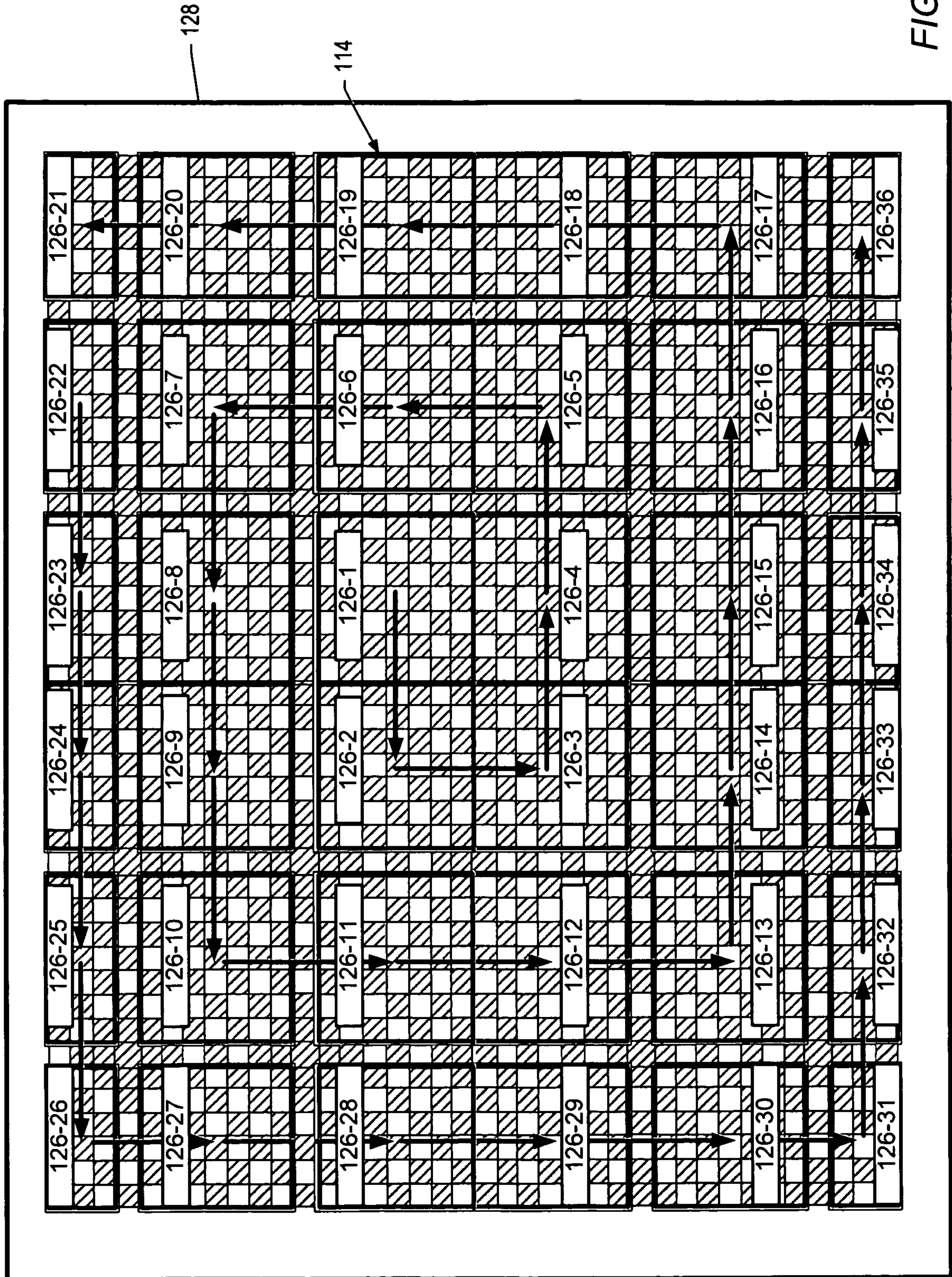
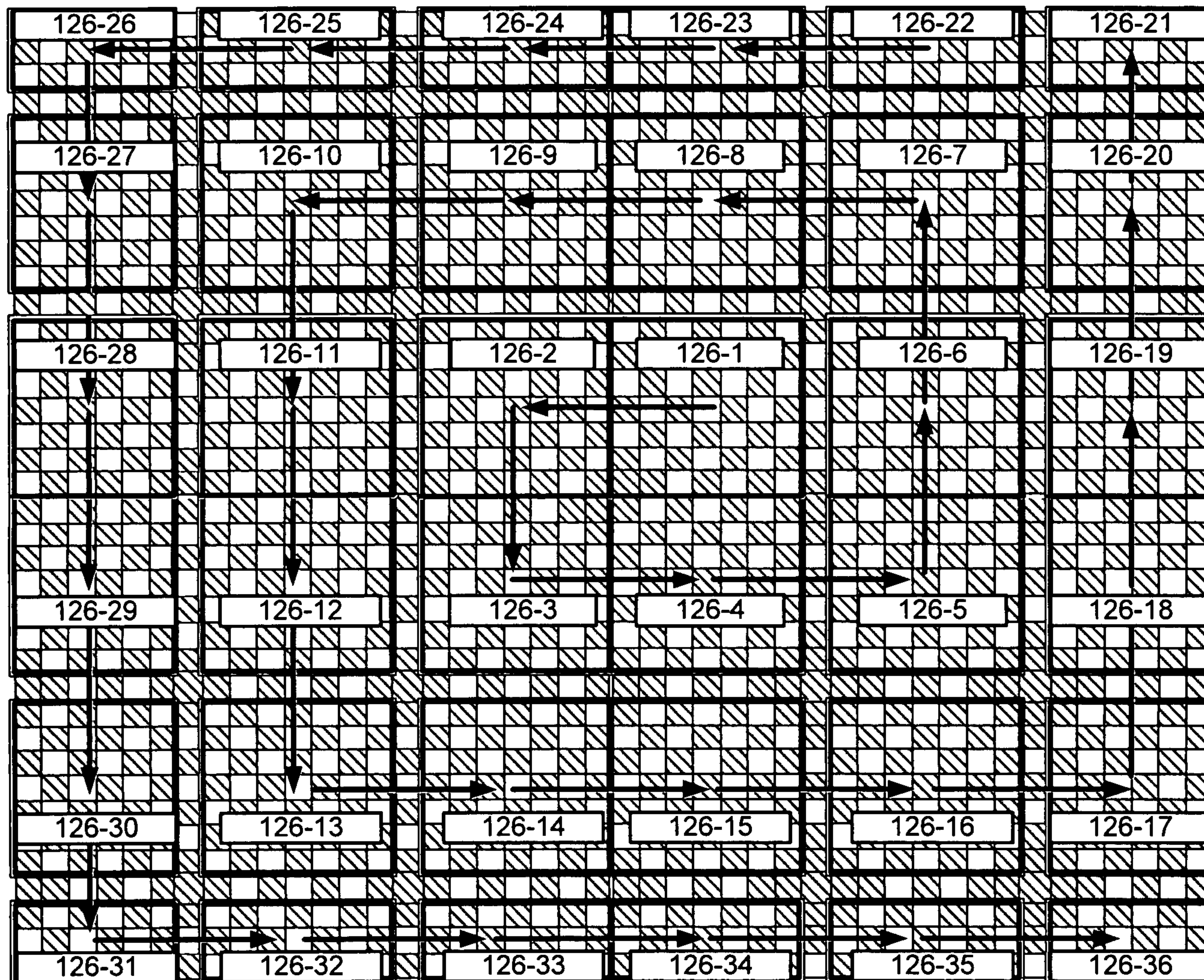


FIG. 7



128

114