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(54) **METHANE EXTRACTION METHOD AND APPARATUS USING HIGH-ENERGY DIODE LASERS OR DIODE-PUMPED SOLID STATE LASERS**

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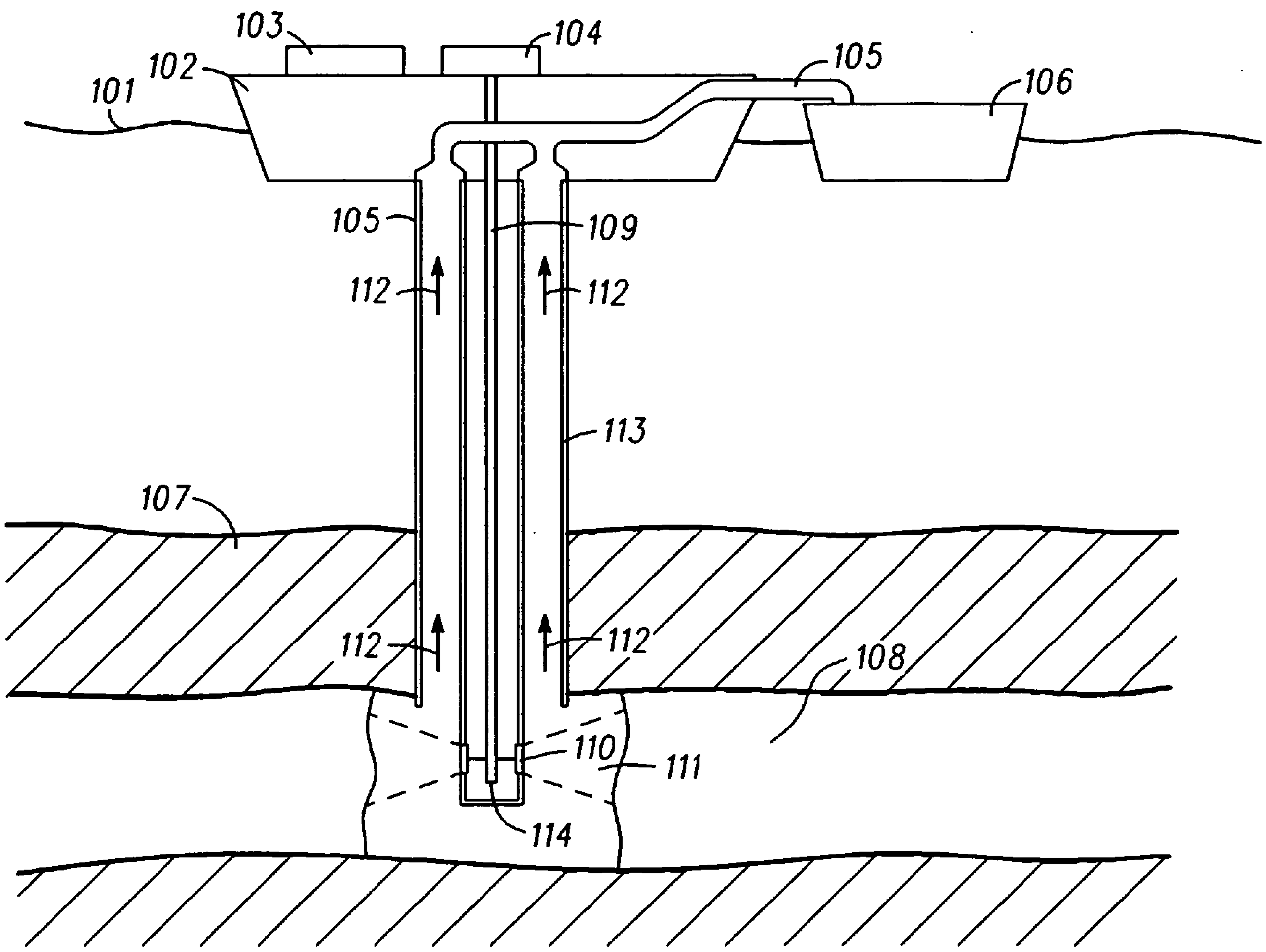
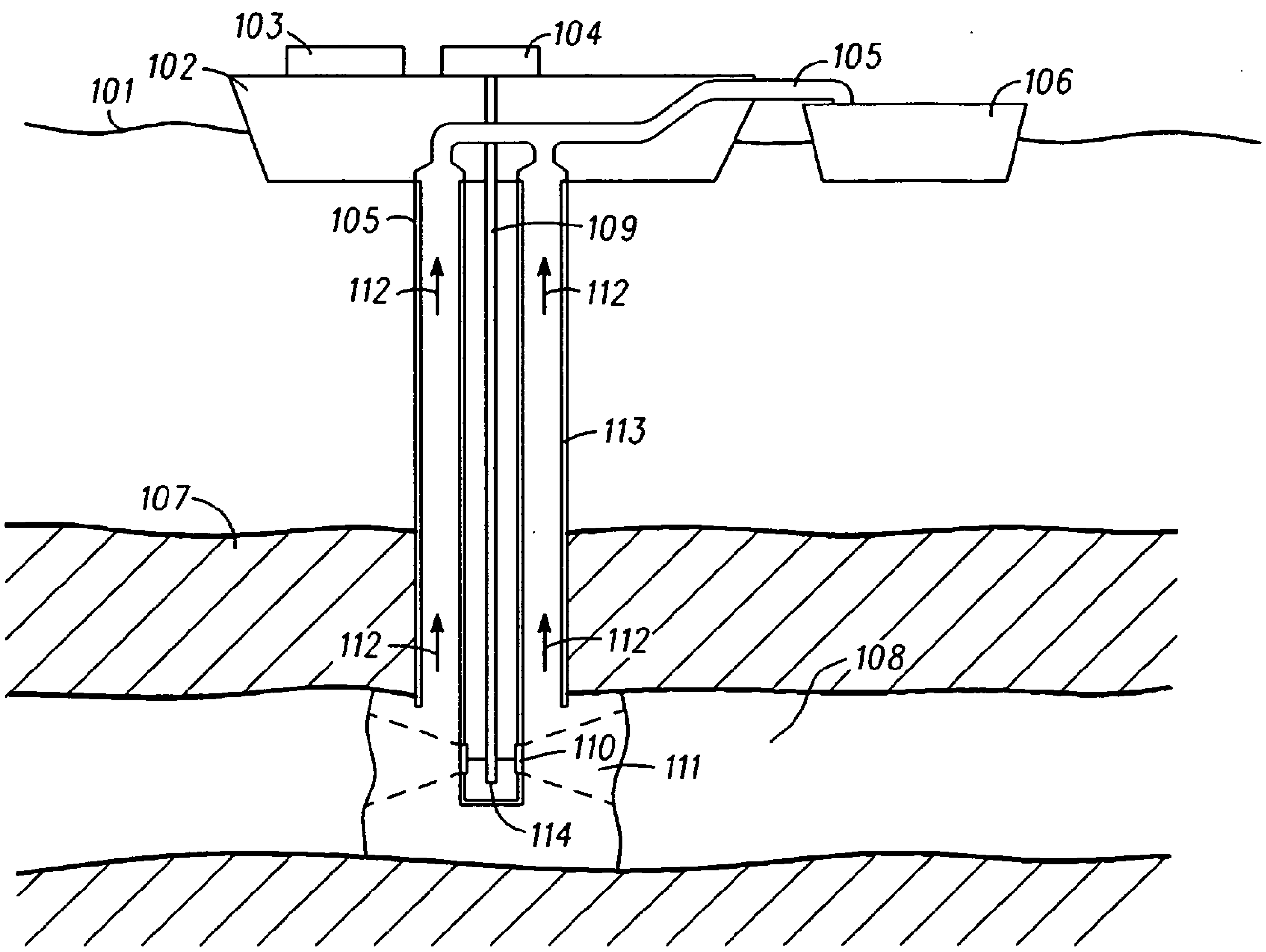
(57) **ABSTRACT**

A method and apparatus for extracting methane gas from methane hydrate. The method includes heating the methane hydrate with a laser apparatus. The laser apparatus includes a diode laser or a solid state laser that is pumped with a diode laser. The laser is guided to a working end of a tool with a fiber optic bundle. The tool is guided to heat the methane hydrate with the laser, which emanates from a beam expander at the working end of the tool. The tool can be modified for removing obstructions of methane hydrate in pipelines. Also, the tool can be modified for extracting methane from mined methane hydrate, which is in a container. The characteristics of diode lasers or diode-pumped solid state lasers such as efficiency, size, nature of operation, environmental impact and durability, make methane gas extraction from methane hydrate economically feasible.




103
104
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106
102
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113
107
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108
110
111
114

FIG. 1

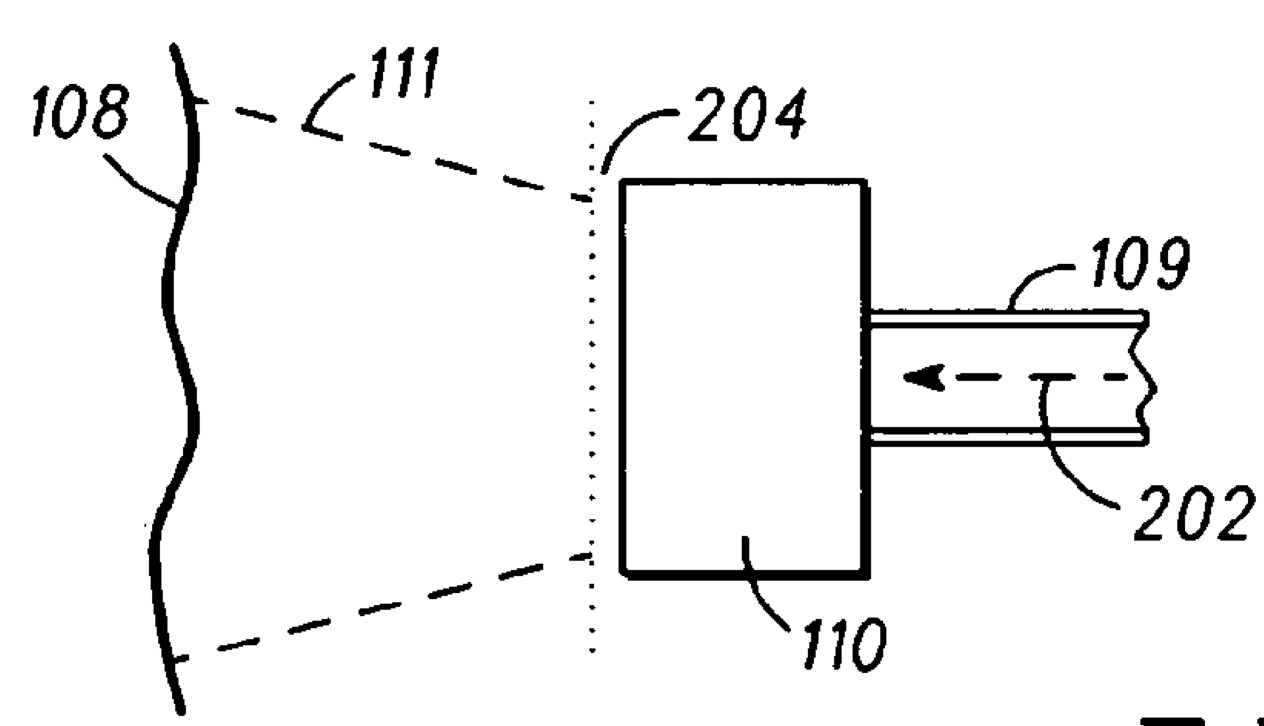
108
111
204
109
202
110

FIG. 2

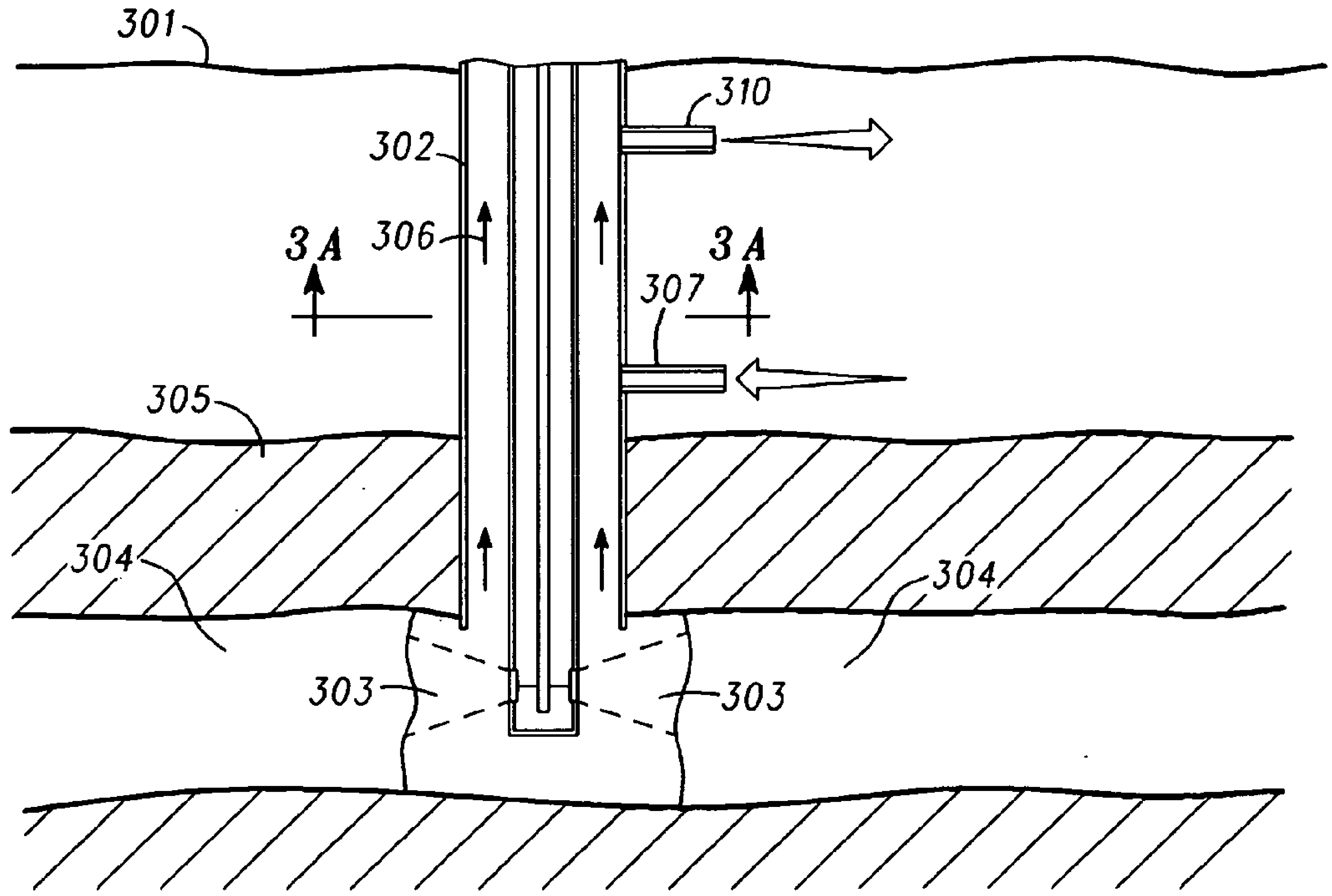
301
310
302
306
3A
3A
307
305
304
304
303
303

FIG. 3

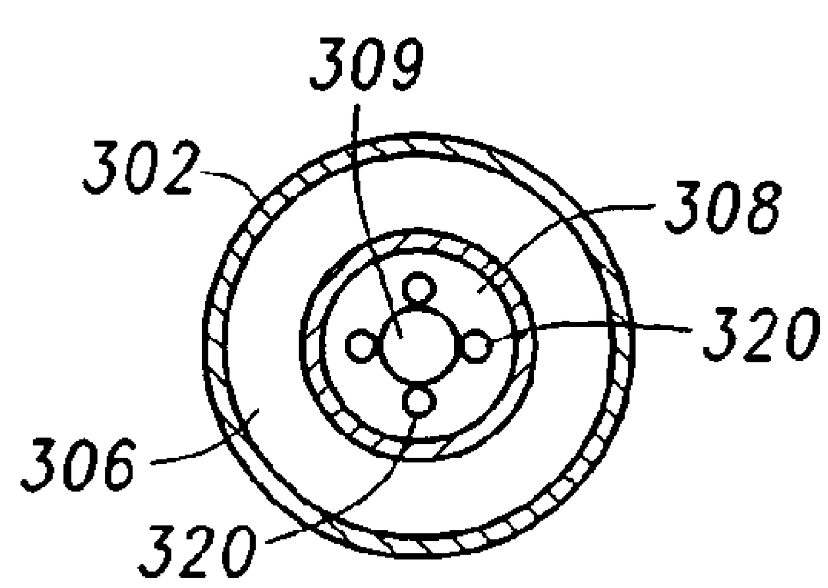
309
302
308
320
306
320

FIG. 3A

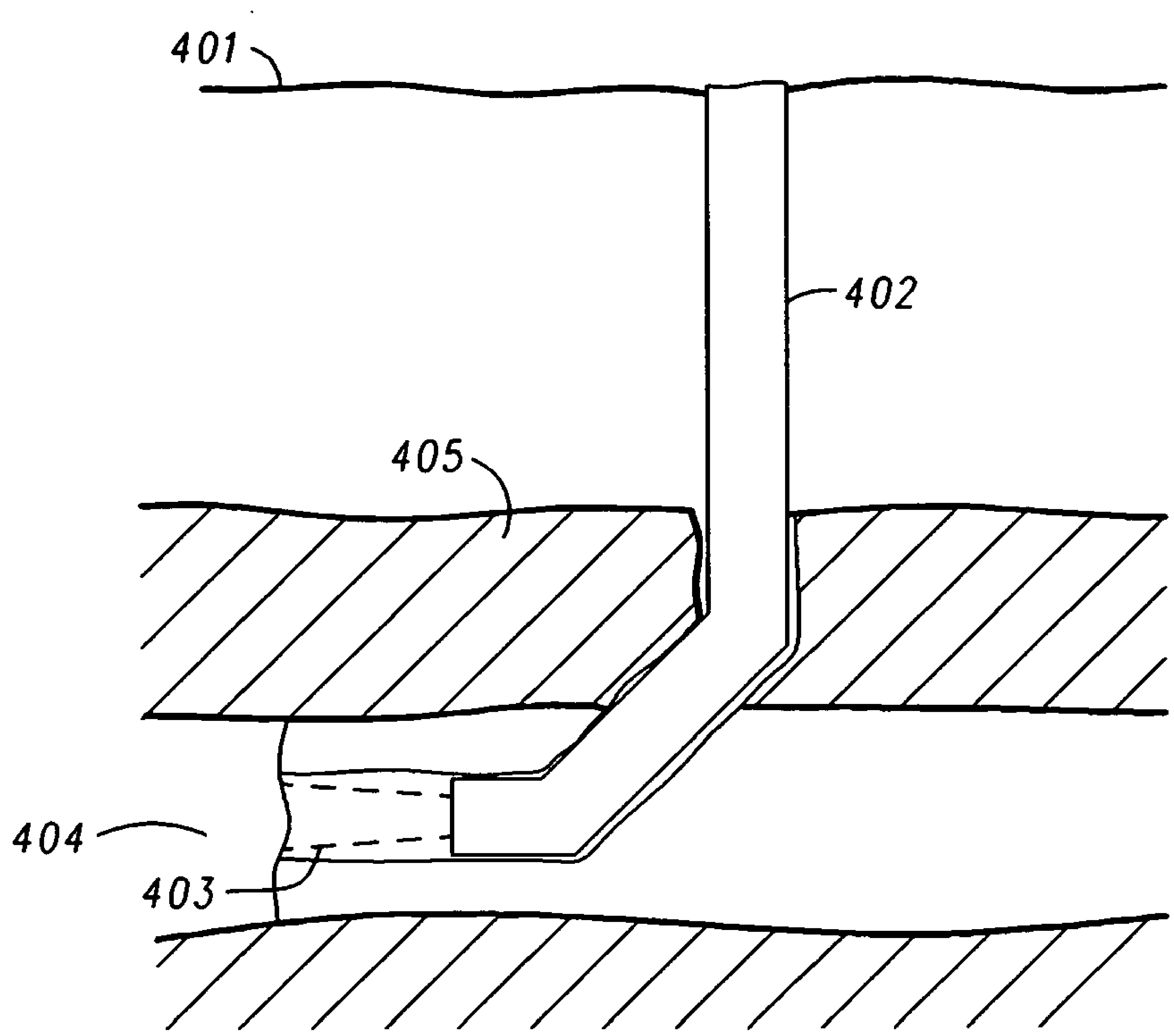

FIG. 4

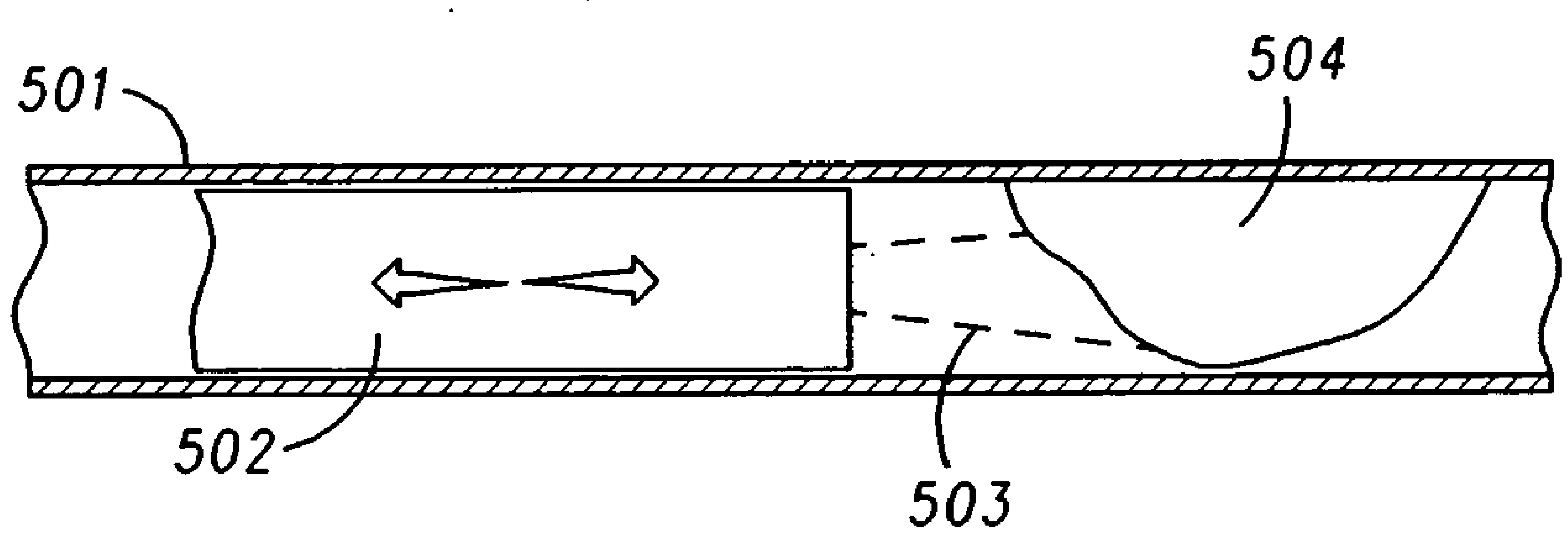

FIG. 5

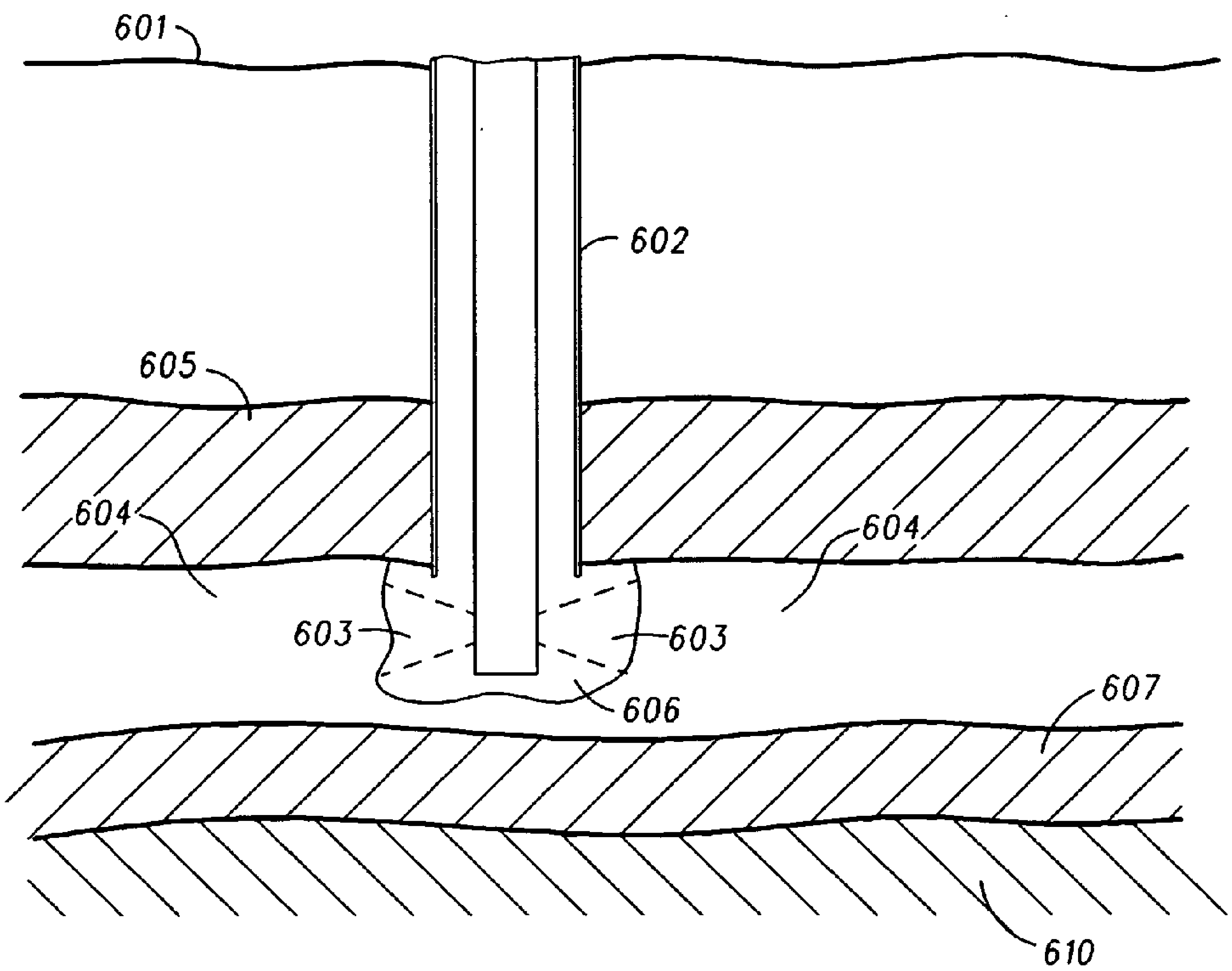
601
602
605
604
604
603
603
606
607
610

FIG. 6

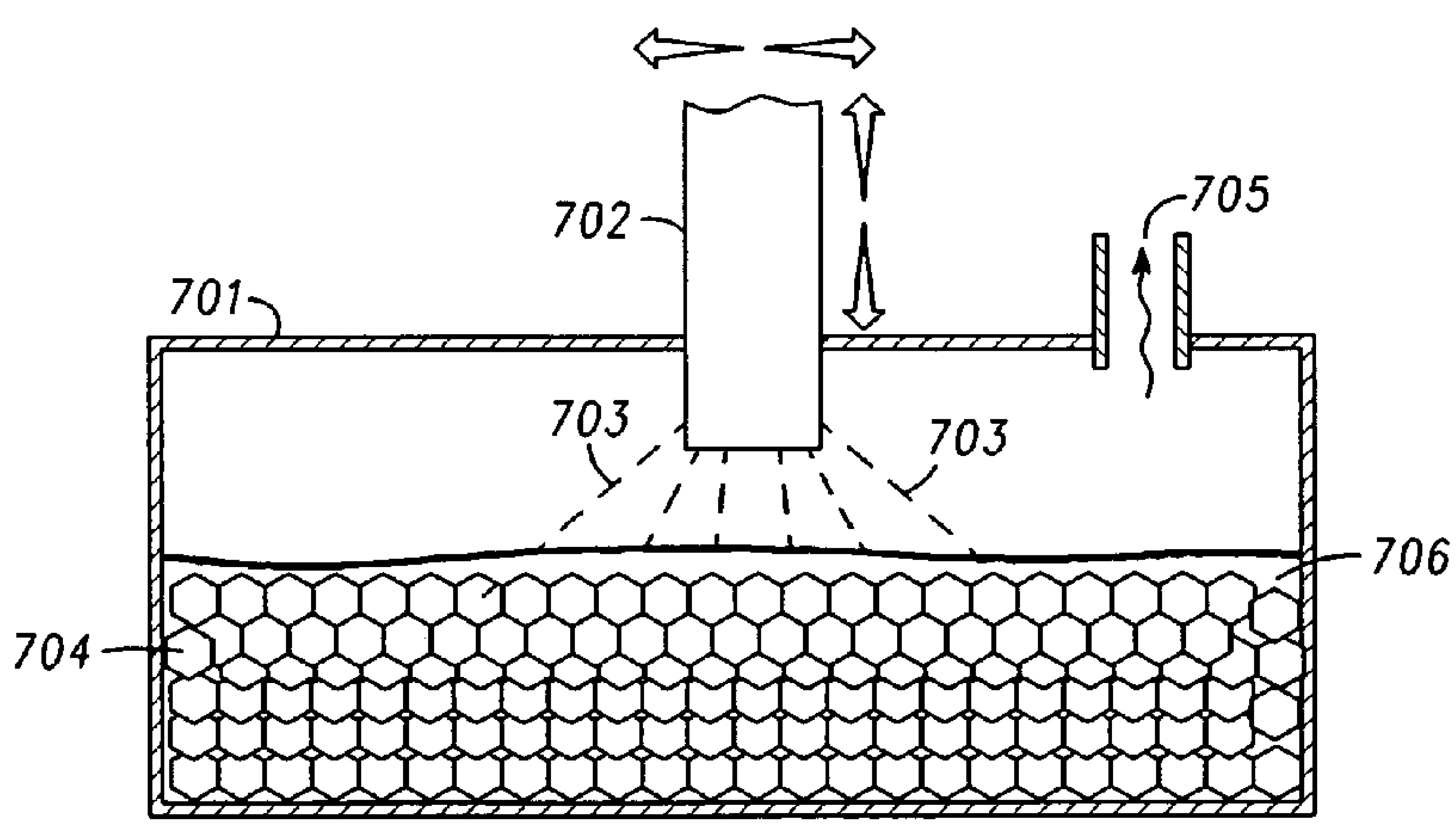
705
702
701
703
703
706
704

FIG. 7

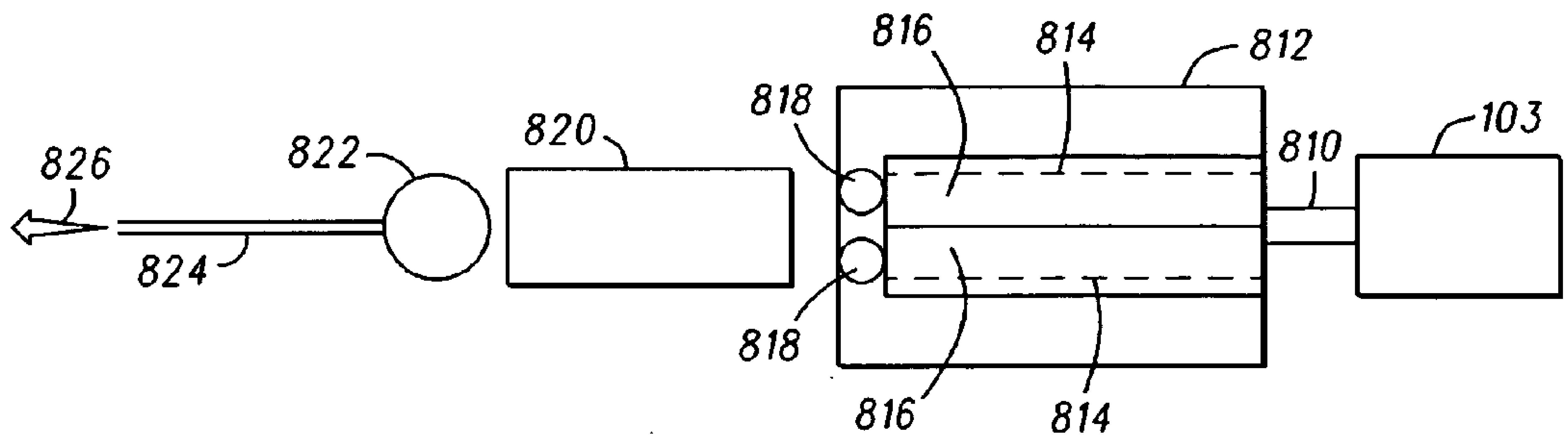
816
814
812
818
820
810
103
826
822
824
818
816
814

FIG. 8

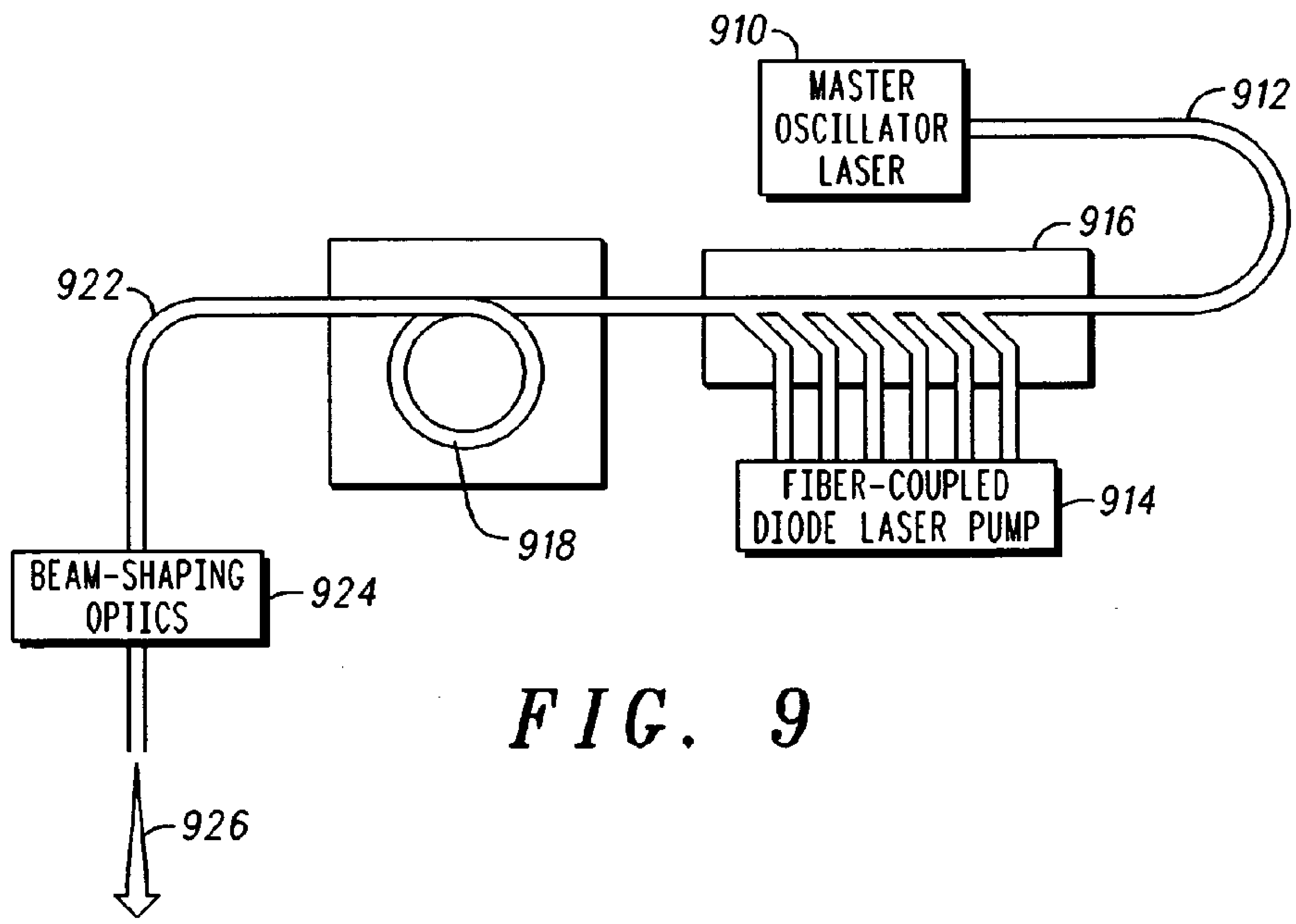
910
MASTER OSCILLATOR LASER
912
916
922
FIBER-COUPLED DIODE LASER PUMP
914
918
BEAM-SHAPING OPTICS
924
926

FIG. 9

METHANE EXTRACTION METHOD AND APPARATUS USING HIGH-ENERGY DIODE LASERS OR DIODE-PUMPED SOLID STATE LASERS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of the filing date of U.S. provisional application No. 60/800,408, which was filed on May 16, 2006 and which is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] This invention relates in general to a method and apparatus for methane extraction, and more particularly, to a method and apparatus for extracting methane from methane hydrate using high-energy diode lasers or solid state lasers that are pumped with diode lasers.

BACKGROUND OF THE INVENTION

[0003] At various locations around the world, there are large supplies of methane gas in the solid, frozen form of methane hydrate. Beneath the ocean bed, at various depths, methane hydrate deposits are estimated at many trillions of cubic meters. Currently, there is no cost-effective method of extracting methane from methane hydrate. However, as the cost of energy increases, extraction of methane from methane hydrate may become cost-effective. However, there is a need for an efficient method of extracting the methane from the methane hydrate.

[0004] Several proposals for extraction have been put forth. These include thermal stimulation, depressurization, and the use of chemicals, or inhibitors. However, currently proposed methods have various drawbacks that reduce their cost-effectiveness. Currently, none of these methods is considered to be commercially viable.

[0005] In particular, it has been proposed to use a chemically pumped oxygen-iodine energy transfer laser (COIL) to thermally stimulate the methane hydrate. However, such a method would require large storage structures for the chemicals that fuel the laser. Also, exhaust from the laser would create a significant environmental hazard. Therefore, large scale scrubbing equipment would be required. Further, current COILs operate continuously for only a few minutes, which is insufficient for large-scale methane extraction.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The accompanying figures where like reference numerals refer to identical or functionally similar elements throughout the separate views and which together with the detailed description below are incorporated in and form part of the specification, serve to further illustrate various embodiments and to explain various principles and advantages all in accordance with the present invention.

[0007] FIG. **1** is a schematic block diagram of a vertical methane gas extraction operation using a high energy semiconductor laser or a solid state laser that is pumped with a semiconductor laser according to the present invention;

[0008] FIG. **2** is an enlarged schematic block diagram of a self-cleaning beam expander of the apparatus of FIG. **1**;

[0009] FIG. **3** is a schematic block diagram of a vertical methane gas extraction operation using a high energy semiconductor laser or a solid state laser that is pumped with a semiconductor laser according to a further embodiment of the present invention;

[0010] FIG. **3**A is a cross sectional schematic view taken along the plane indicated by line **3**A-**3**A in FIG. **3**;

[0011] FIG. **4** is a schematic diagram of a horizontal drilling operation using a semiconductor laser tool for extracting methane gas from a methane hydrate deposit;

[0012] FIG. **5** is a schematic block diagram showing removal of a methane hydrate obstruction in a gas pipeline with a high energy laser tool that employs a high energy semiconductor laser or a solid state laser that is pumped with a semiconductor laser;

[0013] FIG. **6** is a schematic block diagram showing a laser drill forming a bore in a methane hydrate formation;

[0014] FIG. **7** is a schematic block diagram showing a laser tool heating methane hydrate stored in a container.

[0015] FIG. **8** is a schematic block diagram showing a fiber-coupled diode laser; and

[0016] FIG. **9** is a schematic block diagram showing a fiber laser that is pumped by fiber-coupled diode lasers.

SUMMARY OF THE INVENTION

[0017] Basically, the present disclosure concerns a method and apparatus for extracting methane gas from methane hydrate. The method includes heating the methane hydrate with a laser beam of a high energy diode laser or a solid state laser that is pumped with a diode laser to release methane gas from the methane hydrate. The end of the tool is placed in the methane hydrate, and the laser is guided with an optic fiber to the end of the tool.

[0018] Preferably, the laser beam is produced with a diode laser, which is more efficient.

[0019] The laser can be operated in a pulsed mode or a continuous mode.

[0020] In a further embodiment, the invention includes a method of removing a methane hydrate obstruction in a gas pipeline by heating the methane hydrate with a laser beam of a diode laser or a laser that is pumped with a diode laser to change the phase of the obstruction.

[0021] In a further embodiment, the invention includes a method of boring through a methane hydrate formation to access a natural gas pocket that is located beneath the methane hydrate formation. The boring method includes forming a bore hole through the methane hydrate with a laser beam of a diode laser or a solid state laser that is pumped with a diode laser and placing a conventional drill in the bore hole to drill beneath the methane hydrate formation to form a second bore, which leads into the gas pocket.

[0022] The invention includes an apparatus for extracting methane from methane hydrate. The apparatus includes an extraction tool; a diode laser or a solid state laser that is pumped with a diode laser; and an optic fiber for leading a laser beam generated by the laser to a working end of the extraction tool.

[0023] The apparatus may further include a conduit for conducting extracted methane from a methane formation toward a proximal end of the extraction tool.

[0024] The apparatus may further include a beam expander for expanding the laser beam before the laser beam strikes the methane hydrate.

[0025] The apparatus may further include apparatus for forming an air curtain adjacent to a lens of the beam expander so that the lens is self-cleaning.

[0026] The apparatus may further include an air passage for delivering air to the air curtain.

[0027] The extraction tool may include a water cooling passage for cooling the optic fiber.

[0028] The extraction tool may be supported by a platform, which carries the high energy diode laser or diode-pumped solid state laser, its power source and thermal management system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0029] FIG. **1** shows a methane extraction apparatus performing a vertical extraction operation in a body of water **101**. A platform **102** is located at the water level of the body of water **101**, such as the ocean. Beneath a crust **107**, which forms the floor of the body of water **101** is a layer, or strata, of methane hydrate **108**. An electric power plant **103** is located on the platform **102**. A high-power laser **104** (diode laser or solid state laser that is pumped by a diode laser) is located on the platform as shown. Although FIG. **1** shows an extraction operation on water, the extraction can take place on dry land or ice with a drilling rig (not illustrated) that includes equipment similar to that located on the platform **102**.

[0030] Extending from the platform **102** to the methane hydrate strata is a laser extractor tool **113**, which includes a laser light-carrying optic fiber bundle **109**, a laser head assembly **114** and a conduit **105**, for transporting gas mixture **112** (methane and steam) to the platform **102**. The extractor tool **113** is formed by concentric pipes, as shown. The conduit **105** is formed between the inner surface of an outer pipe and the outer surface of an inner pipe. The gas mixture **112** is delivered to a gas separator apparatus **106**, which separates methane from steam and stores the separated methane in gas, liquid or solid form, as desired. Although not illustrated in FIG. **1**, apparatus for cooling the fiber bundle is incorporated in the laser tool **113**.

[0031] The laser head **114** can include a self-cleaning beam expander **110** from which an expanded laser beam **111** is projected. The laser beam **111** interacts with the solid methane hydrate **108** and causes a phase change. That is, the laser beam **111** heats the methane hydrate **108** and converts the methane hydrate into steam and methane gas. The beam expander **110** increases the diameter of the laser beam, which increases the area of the methane hydrate **108** to be heated, which facilitates large scale production of methane gas.

[0032] In the example of FIG. **1**, the methane hydrate is located below a crust **107** of the earth. Prior to the extraction process illustrated in FIG. **1**, a bore is drilled through the crust **107** with a conventional drill (not illustrated). The well can then be capped until the extractor tool **113** is inserted. The extractor tool **113** may be equipped to break a cap on a capped bore; however, such equipment is not illustrated.

[0033] FIG. **2** shows the self-cleaning laser beam expander **110** in more detail. The fiber bundle **109** is coupled to the beam expander **110** as shown. At a light exit lens of the beam expander **110** is an air curtain **204**. Although it is not required to employ a self-cleaning beam expander, it is considered advantageous to maintain high production rates by reducing equipment maintenance and idle time.

[0034] Conventional equipment such as valves and pumps to control the pressure and flow inside the conduit **105** are not illustrated for simplicity. However, such equipment is well understood to those in the field of gas drilling and will not be described here.

[0035] To minimize the loss of laser energy, it is preferred to minimize the separation between the beam expander **110** and the solid methane hydrate. That is, it is desired to minimize the size of the gas pocket surrounding the end of the extractor tool **113**. Horizontal drilling can facilitate positioning the end of the drill to minimize the gas pocket and the separation distance.

[0036] The laser **104** is a high-power semiconductor laser, or diode laser, which is very efficient. In this application, “high power” means approximately one hundred kilowatts or more. Alternatively, the laser **104** can be a solid state laser that is pumped with a diode laser. Such lasers are particularly suitable for methane extraction from methane hydrate because of their extended on-time (time of continuous operation), durability, efficiency, size, power requirements, and maintenance and supply requirements. For example, the life-expectancy of diode lasers or solid state lasers that are pumped with diode lasers is approximately a few years, which is favorable for methane gas extraction, and diode lasers or solid state lasers that are pumped with diode lasers require only electricity to operate, which is favorable for methane gas extraction. Further, diode lasers or solid state lasers that are pumped with diode lasers do not produce waste materials at the work site. Therefore, diode lasers or solid state lasers that are pumped with diode lasers have little environmental impact on drilling sites.

[0037] The characteristics of diode lasers or solid state lasers that are pumped with diode lasers make them particularly suitable for extracting methane from methane hydrate. Prior to this disclosure, methane extraction from methane hydrate was generally considered to be uneconomic. However, the present method and apparatus is considered likely to render methane extraction from methane hydrate a commercially viable operation.

[0038] It is preferred that the laser beam of the methane extraction apparatus is a diode laser. Diode lasers currently have an efficiency of approximately 55-80%. Such relatively high efficiencies are required for economic methane gas production. The efficiency discussed herein is the so-called wall-plug efficiency, which is the energy in the output beam divided by the energy input to the laser.

[0039] As used in this application, the phrase “solid state laser pumped with a diode laser” refers to a laser that uses a gain medium that is a solid, rather than a liquid or a gas, and is pumped with laser diodes. Currently, such lasers have efficiencies of approximately 10-20%.

[0040] A fiber laser is one type of solid state laser that is pumped with diode lasers. In a fiber laser, the optical fiber core serves as the medium. Currently, fiber lasers have an efficiency of approximately 30-35%.

[0041] The term “solid state laser” includes diode lasers, fiber lasers, and rod or slab lasers.

[0042] Diode lasers are generally considered separately from diode-pumped lasers. Thus, in this application, the terms “diode laser” and “diode-pumped laser” refer to separate types of lasers. That is, in this application, the term “diode laser” excludes diode-pumped lasers.

[0043] Most preferably, the laser **104** is a diode laser, which more efficient than lasers that are pumped by diode lasers. Assuming an average overall efficiency of an electricity generator to be approximately 40%, the ratio of energy in extracted methane to energy input is expected to be approximately 3 to 5 for a diode laser. Co-generating power plants, which generate both power and heat, have higher overall efficiencies (50-70%) and would improve the energy ratio.

[0044] Diode lasers or diode-pumped solid state lasers require no supplies of chemicals or fuel other than electricity, which can be produced at the drilling site. The electricity can be generated from a fraction of the methane gas produced by the well or from another energy source. In contrast, for example, a COIL requires chemical supply tanks, which greatly increase the size and cost of the platform and associated equipment. A diode laser or a diode-pumped solid state laser requires only electricity and is thus more compact and less costly. Thus, a drilling rig that uses a diode laser or a diode-pumped solid state laser is more cost effective and can tip the balance of an operation that would otherwise be economically unsound toward commercial viability.

[0045] Commercially viable gas production would require a laser that operates continually for relatively long periods of time. COILs, for example, can operate for only short periods of a few minutes, which is insufficient for economic gas production. A diode laser or a diode-pumped solid state laser can operate for sustained periods that render methane extraction by the method disclosed above economically sound.

[0046] It is contemplated that the laser **104** will be operated in either of a pulsed mode and a continuous mode. The pulsed mode may be advantageous for breaking ice, which is the naturally occurring state of methane hydrate.

[0047] The beam parameter product (BPP) of a laser beam is defined as the product of beam radius (measured at the beam waist) and the beam divergence half-angle (measured in the far field). The usual units are mm mrad (millimeters times milliradians). The BPP is often used to specify the beam quality of a laser beam: the higher the beam parameter product, the lower the beam quality. Although there is equipment available for improving the beam quality of laser beams, the beam quality is not an important consideration in heating methane hydrate. Thus, high beam quality (low BPP) is not required, which reduces the costs.

[0048] FIGS. **3** and **3**A show a vertical extraction tool **302** including an air conduit **309** and a water cooling passage **308**. In the embodiment of FIG. **3**, an extraction is shown in a body of water **301**. The extraction tool **302** includes a conduit **306** for carrying extracted methane and steam toward a platform, which is not illustrated in FIG. **3** but is like the platform shown in FIG. **1**. Beneath a crust **305** is a layer of methane hydrate **304**. An expanded laser beam **303** heats the methane hydrate **304** to release steam and methane gas.

[0049] As shown in FIG. **3**A, optical fibers **320** are located within a cooling passage **308** of the extraction tool **302**. Cooling water is pumped into the cooling passage **308** through an input passage **307**. The cooling water is discharged through an output passage **310**. The locations of the input passage **307** and output passage **310** are arbitrarily selected and are not necessarily as shown.

[0050] The apparatus of FIG. **3** includes a beam expander **203** as shown in FIG. **2**. Located within the cooling passage **308** is the air conduit **309** for supplying air to the self-cleaning expander **203**. As shown in FIG. **2**, the air, which is under pressure, is used to form an air curtain **204** for cleaning an outer surface or lens of the beam expander **203**.

[0051] FIG. **4** shows a horizontal drilling operation that on a body of water **401**. For simplicity, the platform and associated equipment is not illustrated. A horizontal extraction tool **402** extends from the platform and through an opening in the crust of the earth **405**. The distal end of the horizontal extraction tool **402** is located in a layer of methane hydrate **404**. An expanded laser beam **403** converts the methane hydrate **404** into steam and methane gas as in the method illustrated in FIG. **1**.

[0052] A mixture of steam and methane hydrate is conducted through a conduit in the horizontal extraction tool **402** to a separator, as in the method of FIG. **1**. The horizontal drilling method is advantageous in that the tool **402** can be moved along the length of the layer of methane hydrate **404** by extending the tool **402** in the horizontal direction to increase production. Thus, horizontal movement extends the reach of the tool **402** within a horizontal layer of methane hydrate **404** to increase the efficiency of gas production.

[0053] In another embodiment, as shown in FIG. **5**, a laser tool **502** can be used to remove a methane hydrate blockage, or formation, **504** in a natural gas pipeline or a methane gas and steam carrying pipeline **501**. In cold climates, methane hydrate formations **504** can cause obstructions in such pipelines. The laser tool **502** includes a beam expander **203** like that shown in FIG. **2**. A laser beam is directed to the beam expander through optic fibers (not illustrated in FIG. **2**). Through an opening in the pipeline **501** (not illustrated) the tool **502** is guided to an obstruction of methane hydrate. The expended laser beam **503** is then used to heat the methane hydrate **504**, which converts the methane hydrate to steam and methane gas thus removing the obstruction. As in the first embodiment, the laser used in this embodiment is a diode laser or a solid state laser that is pumped by a diode laser.

[0054] As shown in FIG. **6**, in another embodiment, a laser head drill **602** can be used to form a bore in a layer of methane hydrate **604** so that a conventional well drill can reach a pocket of natural gas **610** that is located below the methane hydrate layer **604**. The laser head drill **602** incorporates a laser light-carrying fiber bundle, and a laser head assembly that includes a self-cleaning beam expander, like that shown in FIG. **2**. The laser head drill **602** includes a conduit for carrying methane gas and steam away from a bore **606**. As in the first embodiment, the laser beam **603** heats the methane hydrate **604** and converts the solid methane hydrate **604** to methane gas and steam, which is carried away through the conduit in the laser head drill **602**. As in the first embodiment, the laser used in this embodiment is a diode laser or a solid state laser that is pumped by a diode laser.

[0055] Initially, a conventional drill is used to form a bore through a first crust layer **605**. Then, the laser head drill **602** is deployed in the bore formed by the conventional drill to form the bore **606** through the methane hydrate layer **604**. Then, a conventional drill is used again to bore through a second crust layer **607** to reach the pocket of natural gas **610**.

[0056] In a further embodiment, as shown in FIG. **7**, a laser tool **702** can be used to extract methane gas from methane hydrate **704** that has been mined and is located in a container **701**. The laser tool **702** is preferably movable horizontally and vertically to optimize the reach of the tool **702**. In this embodiment, the expanded laser beams **703** heat the methane hydrate **704** to release methane gas **705** from an opening in the container **701**, as shown. As in the first embodiment, the laser used is a diode laser or a solid state laser that is pumped with a diode laser. Also, as in the first embodiment, the laser tool **702** includes a bundle of optic fibers for carrying the laser beam from the laser to a beam expander at the distal end of the tool **702**.

[0057] Water **706** will collect in the container **701** as a result of the heat from the laser beams **703**. Thus, in this embodiment, a separator may not be required to separate steam from the methane gas **705**. Since methane gas is lighter than steam, it will collect at the top of the container **701**. Also, since methane gas exits the container through the opening in the container, it is not necessary to form a conduit in the laser tool **702** for conducting methane gas.

[0058] FIG. **8** shows a diode laser, which is the preferred type of laser for the laser **104** or the source laser of any of the illustrated embodiments. FIG. **8** illustrates a known fiber-coupled diode laser module **812**. The electrical power plant **103** is coupled to the laser module **812** by a cable **810**. Although FIG. **8** shows only two laser diode bars **816** any number of laser diode bars **816** may be arranged in the laser module **812** depending on the circumstances and output needs. In the illustrated embodiment, one cooling channel **814**, which carries coolant, is associated with each laser diode bar **816**. However, any number of cooling channels may be arranged in various configurations as long as heat is transferred from the diode laser bars.

[0059] As shown in FIG. **8**, a pair of lenses **818** direct laser light to coupling and conditioning optics **820**. For example, the coupling and conditioning optics can include a containing lens, half-wave plates, beam compression prisms, a polarization beam combiner, and spatial filters. A fiber port coupler **822** couples the coupling and conditioning optics **820** to a fiber **824**. Laser light **826** emanates from the end of the fiber **824**. Depending on the capacity, a bundle of fibers **824** may be employed.

[0060] FIG. **9** shows an alternative known fiber laser that may be used as the laser **104** in FIG. **1** or as the source laser in any of the illustrated embodiments. In FIG. **9**, a master oscillator laser **910**, which may be any of several types of known lasers, is coupled to an optical fiber **912**. A fiber-coupled diode laser pump **914** is coupled to a light coupler **916**, as illustrated. Within the laser pump **914** is an array of diode laser modules, such as that illustrated in FIG. **8**, each of which is coupled to one of the illustrated optical fibers extending between the laser pump **914** and the light coupler **916**.

[0061] Downstream from the light coupler **916** is an active fiber **918** that is being pumped by the fiber-coupled diode laser modules. Further downstream from the active fiber **918** are beam shaping optics **924**. Laser light **926** emanates from the beam shaping optics **924** or a fiber coupled to the beam shaping optics **924**.

[0062] The apparatuses and methods discussed above and the inventive principles thereof are intended to and will alleviate problems with conventional methane extraction methods and apparatuses. It is expected that one of ordinary skill given the above described principles, concepts and examples will be able to implement other alternative procedures and constructions that offer the same benefits. It is anticipated that the claims below cover many such other examples.

1. A method of extracting methane gas from methane hydrate comprising heating the methane hydrate with a laser beam of a diode laser or a solid state laser that is pumped with a diode laser to release methane gas from the methane hydrate.

2. The method of claim **1** including;

guiding the laser beam with an optic fiber to and end of a tool; and

placing the end of the tool in the methane hydrate.

3. The method of claim **1** including expanding the laser beam with a beam expander at the end of the tool.

4. The method of claim **1**, wherein the laser is a diode laser.

5. The method of claim **1** including operating the laser in a pulsed mode.

6. The method of claim **1** including operating the laser in a continuous mode.

7. A method of removing a methane hydrate obstruction in a gas pipeline comprising heating the methane hydrate with a laser beam of a diode laser or a solid state laser that is pumped with a diode laser to change the phase of the obstruction.

8. The method of claim **7** including:

providing a tool for supporting an optic fiber; and

directing the laser beam with an optic fiber toward a working end of the tool; and

guiding the tool to direct the laser beam toward the obstruction.

9. A method of boring through a methane hydrate formation to access a natural gas pocket that is located beneath the methane hydrate formation comprising:

forming a bore hole through the methane hydrate with a laser beam of a diode laser or a laser that is pumped with a diode laser; and

placing a drill in the bore hole to drill beneath the methane hydrate formation to access the natural gas pocket.

10. An apparatus for extracting methane from methane hydrate comprising:

an extraction tool;

a diode laser or a laser that is pumped with a diode laser; and

an optic fiber for leading a laser beam generated by the laser to a working end of the extraction tool.

11. The apparatus of claim **10** further comprising a conduit for conducting extracted methane from a methane formation toward a proximal end of the extraction tool.

12. The apparatus of claim **10** further comprising a beam expander for expanding the laser beam before the laser beam strikes the methane hydrate.

13. The apparatus of claim **12**, wherein the beam expander includes apparatus for forming an air curtain adjacent to a lens of the beam expander so that the lens is self-cleaning.

14. The apparatus of claim **13**, wherein the extraction tool includes an air passage for delivering air to the apparatus for forming an air curtain.

15. The apparatus of claim **10**, wherein the laser is a diode laser.

16. The apparatus of claim **10**, wherein the extraction tool includes a water cooling passage for cooling the optic fiber.

17. The apparatus of claim **10**, wherein the extraction tool is supported by a platform, which carries the laser.

* * * * *