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Ignatiev et al.(10) **Pub. No.: US 2012/0318196 A1**(43) **Pub. Date: Dec. 20, 2012**(54) **SYSTEM FOR FORMING
SUPERCONDUCTOR MATERIAL ON A TAPE
SUBSTRATE****Publication Classification**

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(21) **Appl. No.: 13/364,549**(22) **Filed: Feb. 2, 2012****Related U.S. Application Data**

- (60) Division of application No. 11/038,569, filed on Jan. 19, 2005, now Pat. No. 8,124,170, which is a continuation of application No. 10/206,123, filed on Jul. 26, 2002, now abandoned.
- (60) Provisional application No. 60/539,055, filed on Jan. 23, 2004.

(57) **ABSTRACT**

There is disclosed a system for forming a superconductor material on a substrate. The system may comprise a dispensing reel; a spooling reel; and at least two modular reaction chambers, wherein at least one modular reaction chamber is connected to a supply of buffer precursor material and at least one other modular reaction chamber is connected to a supply of superconductor precursor material. The modular reaction chambers may include connections capable of being modified to add or remove adjacent components. It is understood that at least one of the spooling reel and/or the dispensing reel are exposed to normal atmosphere. The deposition chamber may also comprise a distribution head that provides a laminar flow of precursor materials onto the substrate, as well as at least one lamp comprising a reflector that directs UV and/or visible light towards the tape substrate to enhance a growth rate of material.

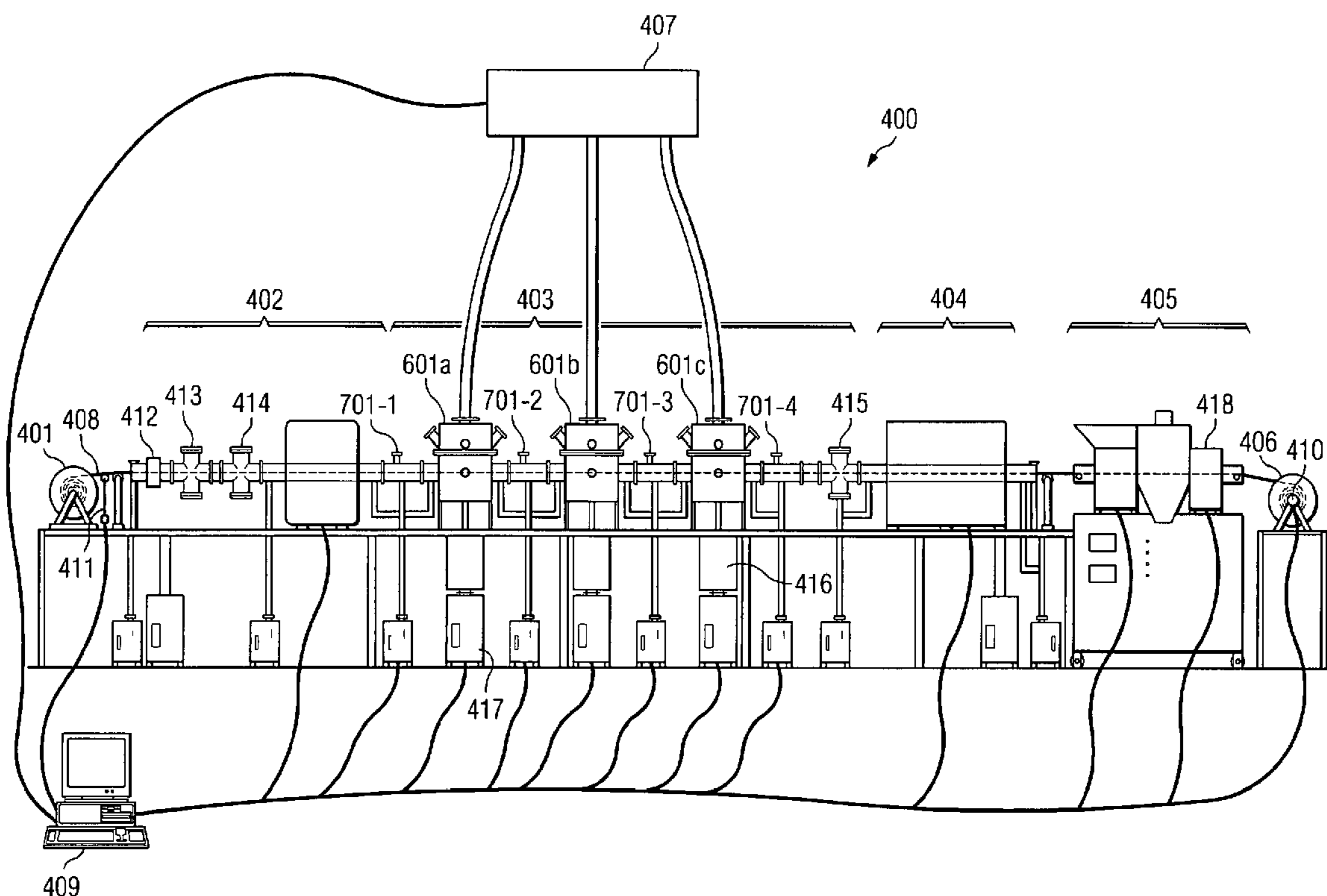


FIG. 1
(PRIOR ART)

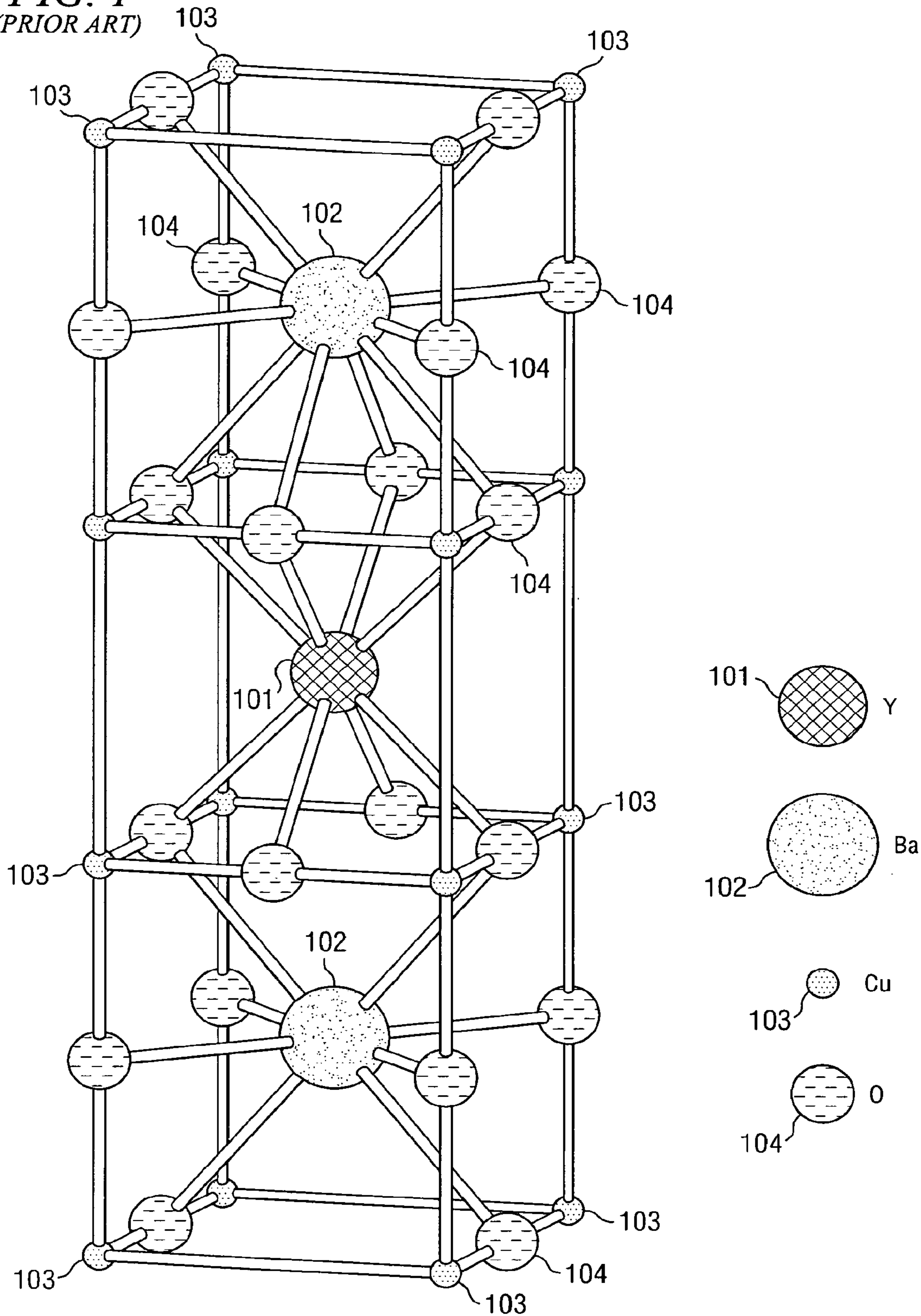


FIG. 2
(PRIOR ART)

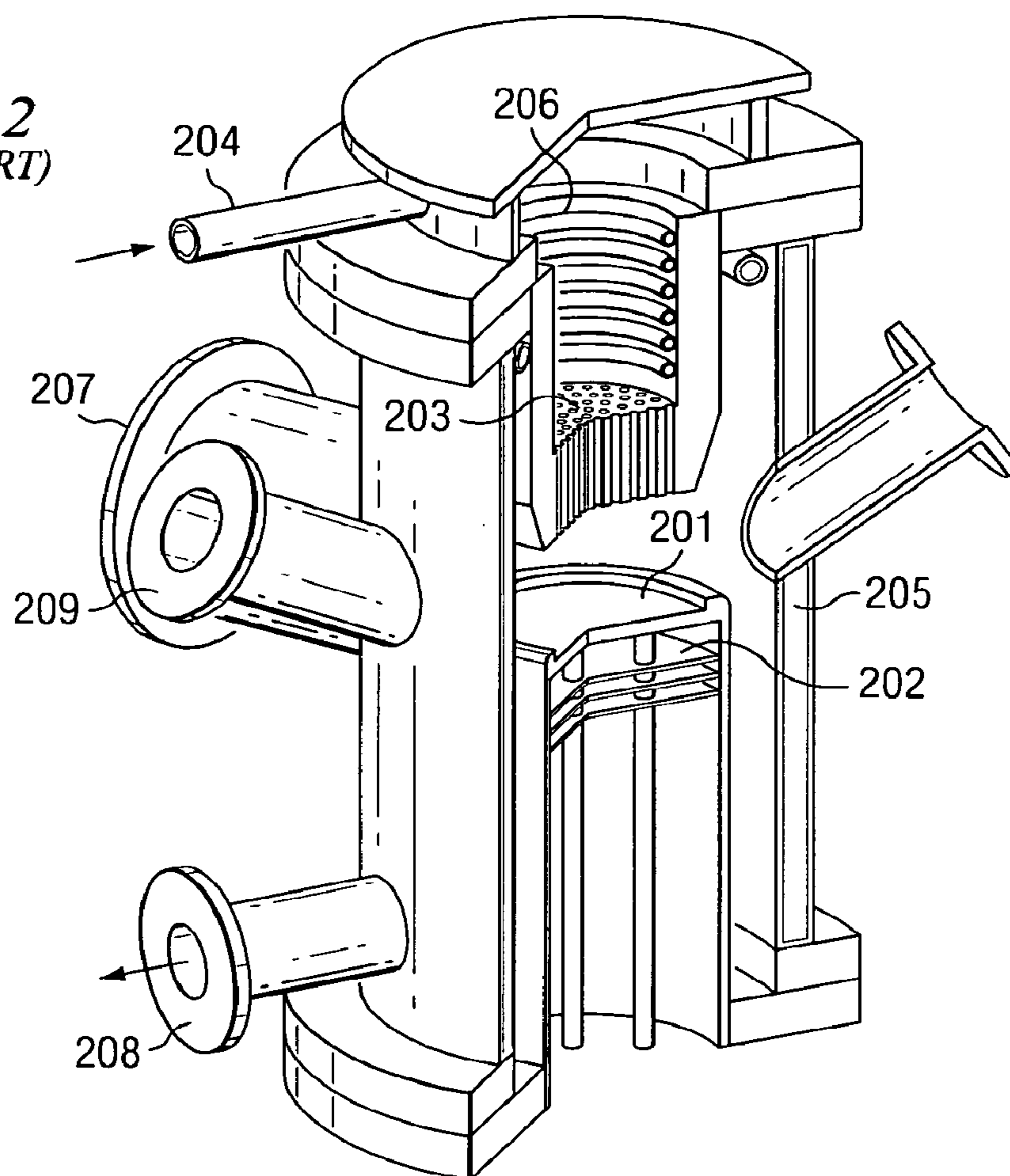
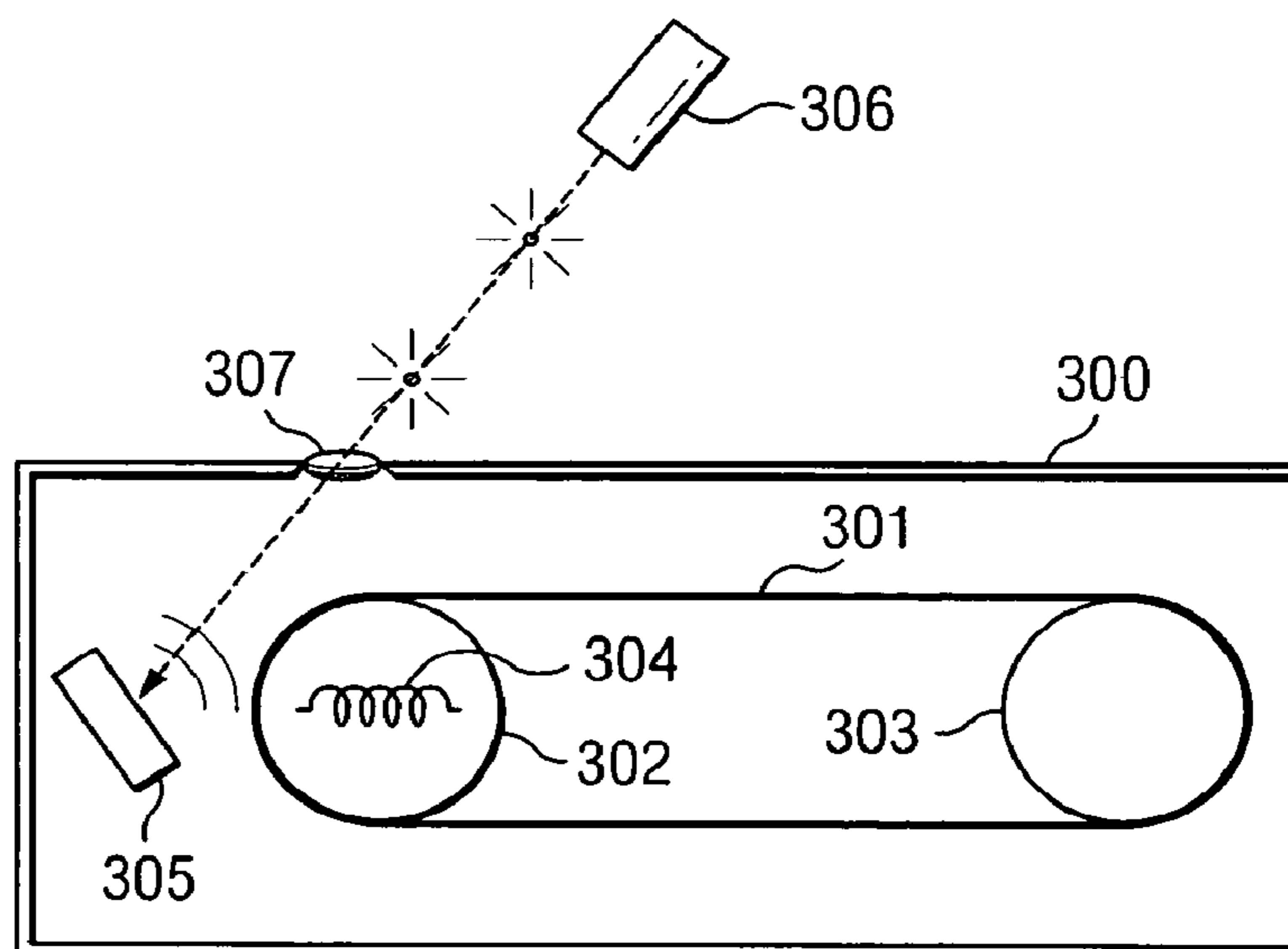
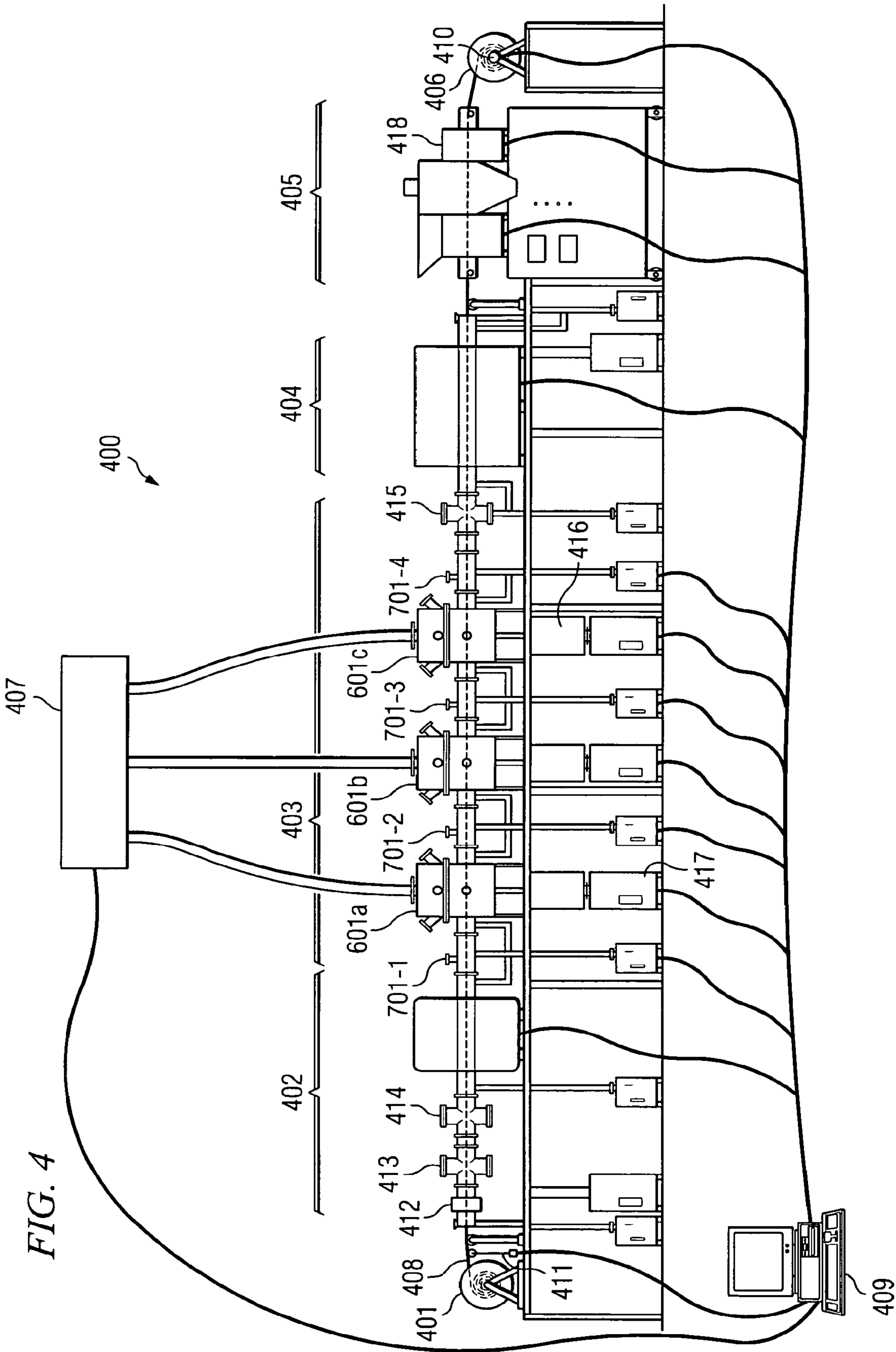


FIG. 3
(PRIOR ART)





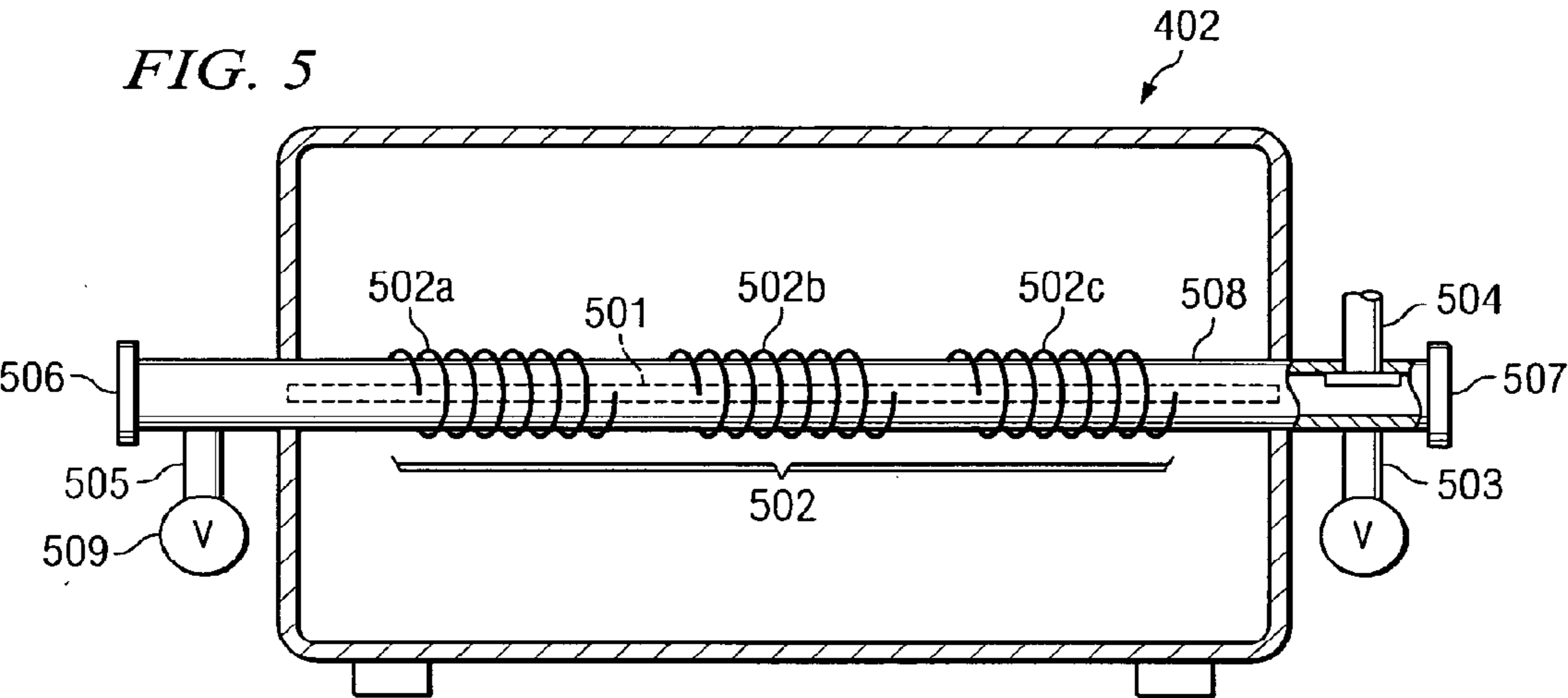
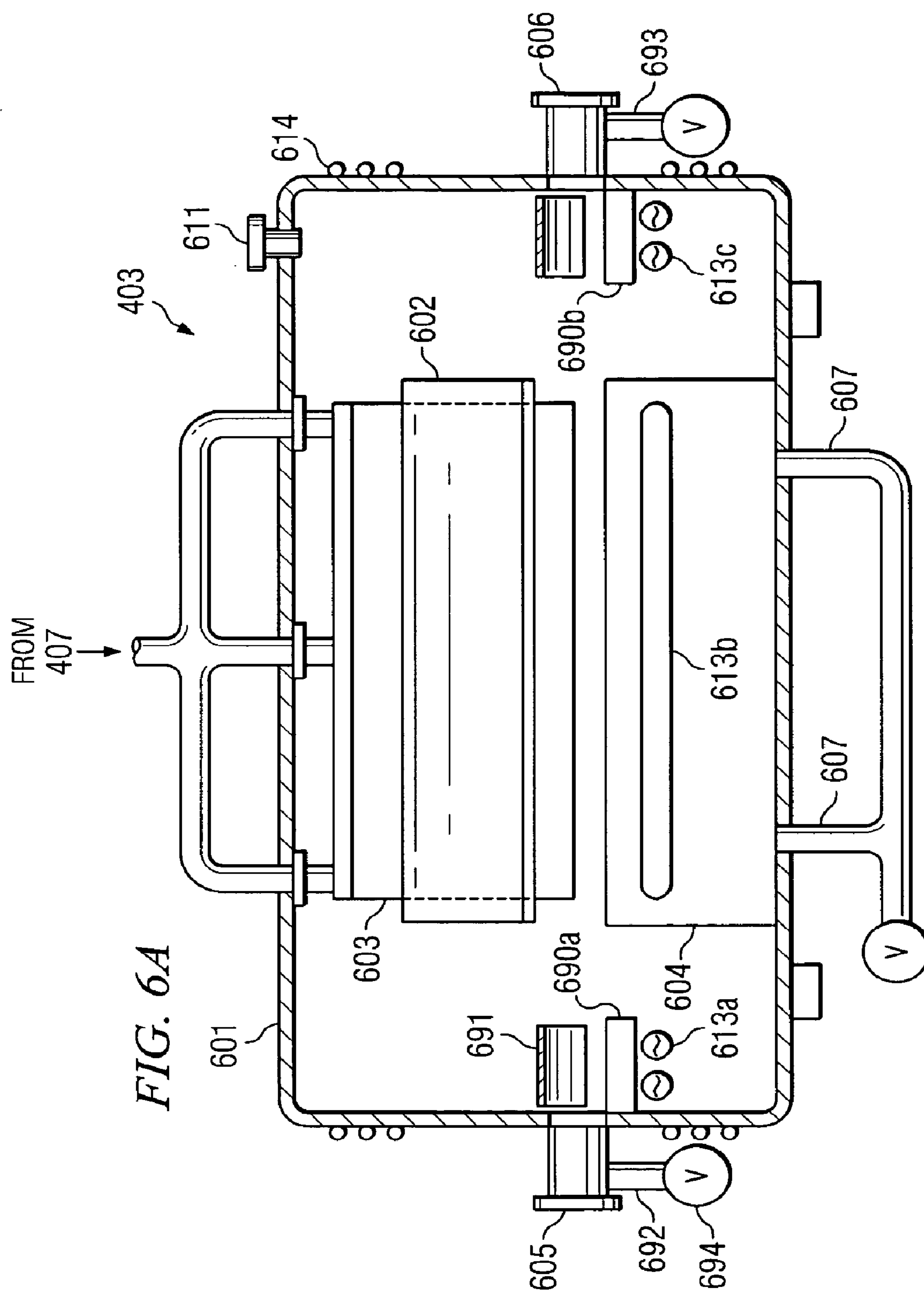


FIG. 6A



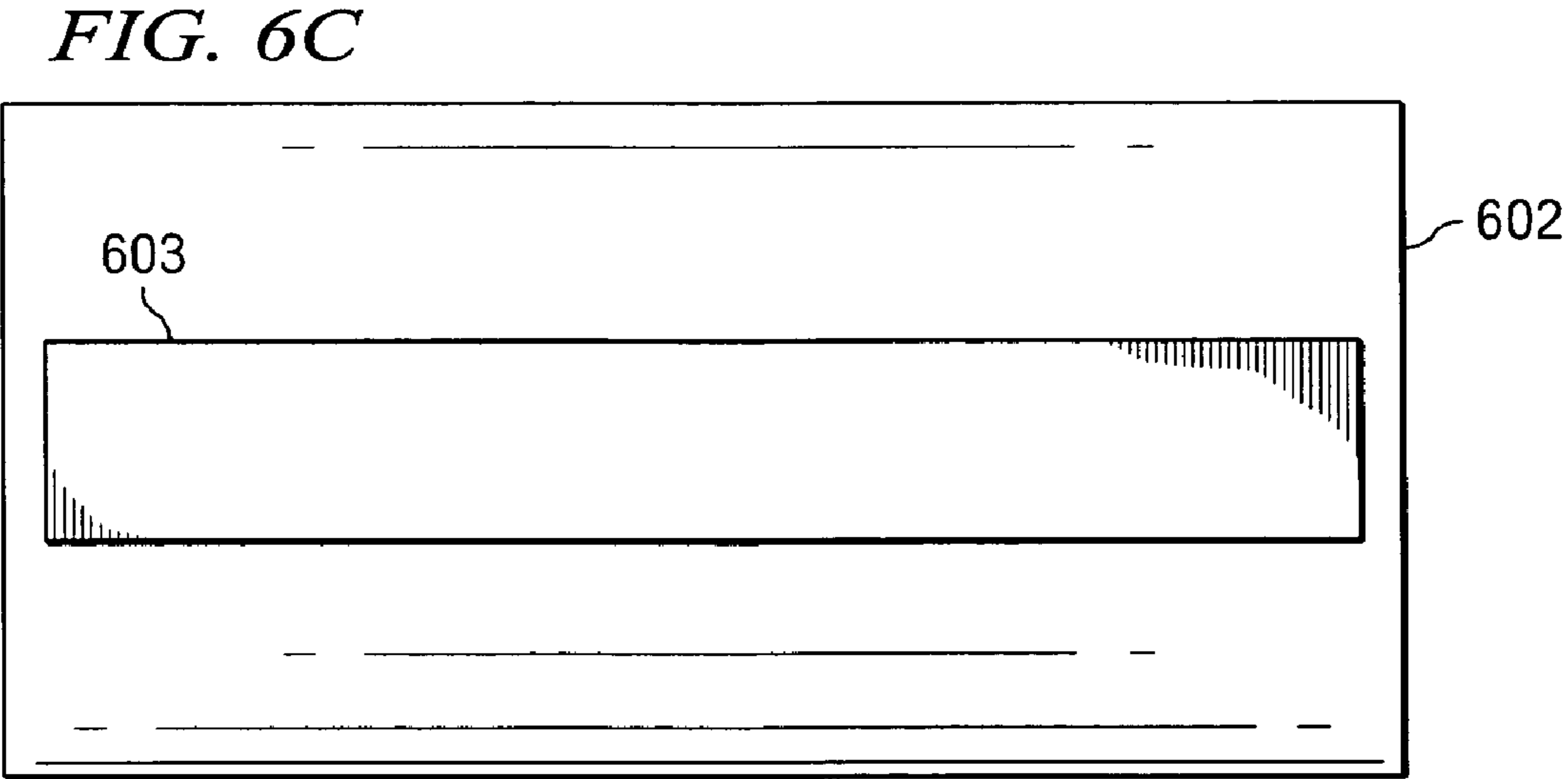
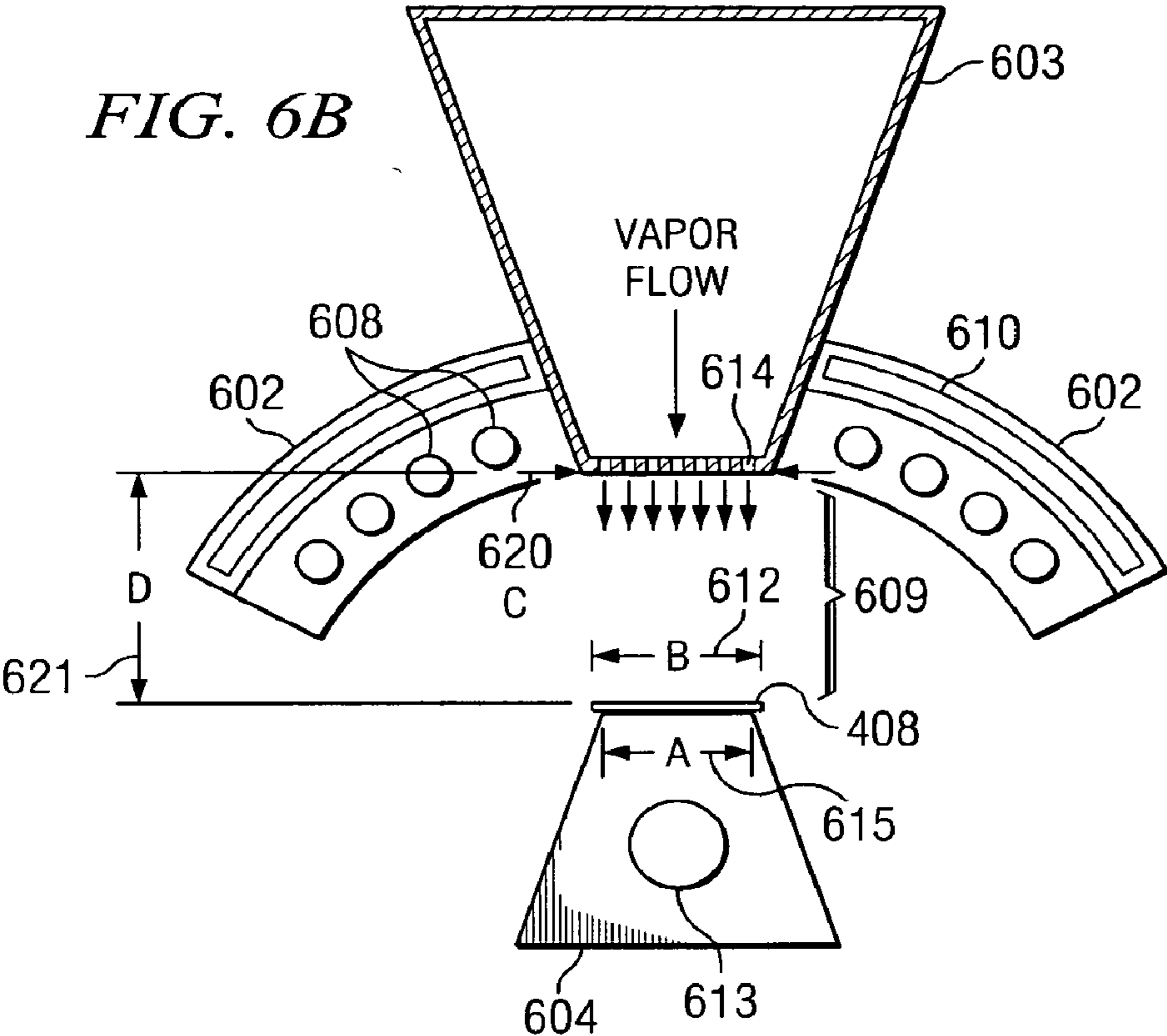


FIG. 6D

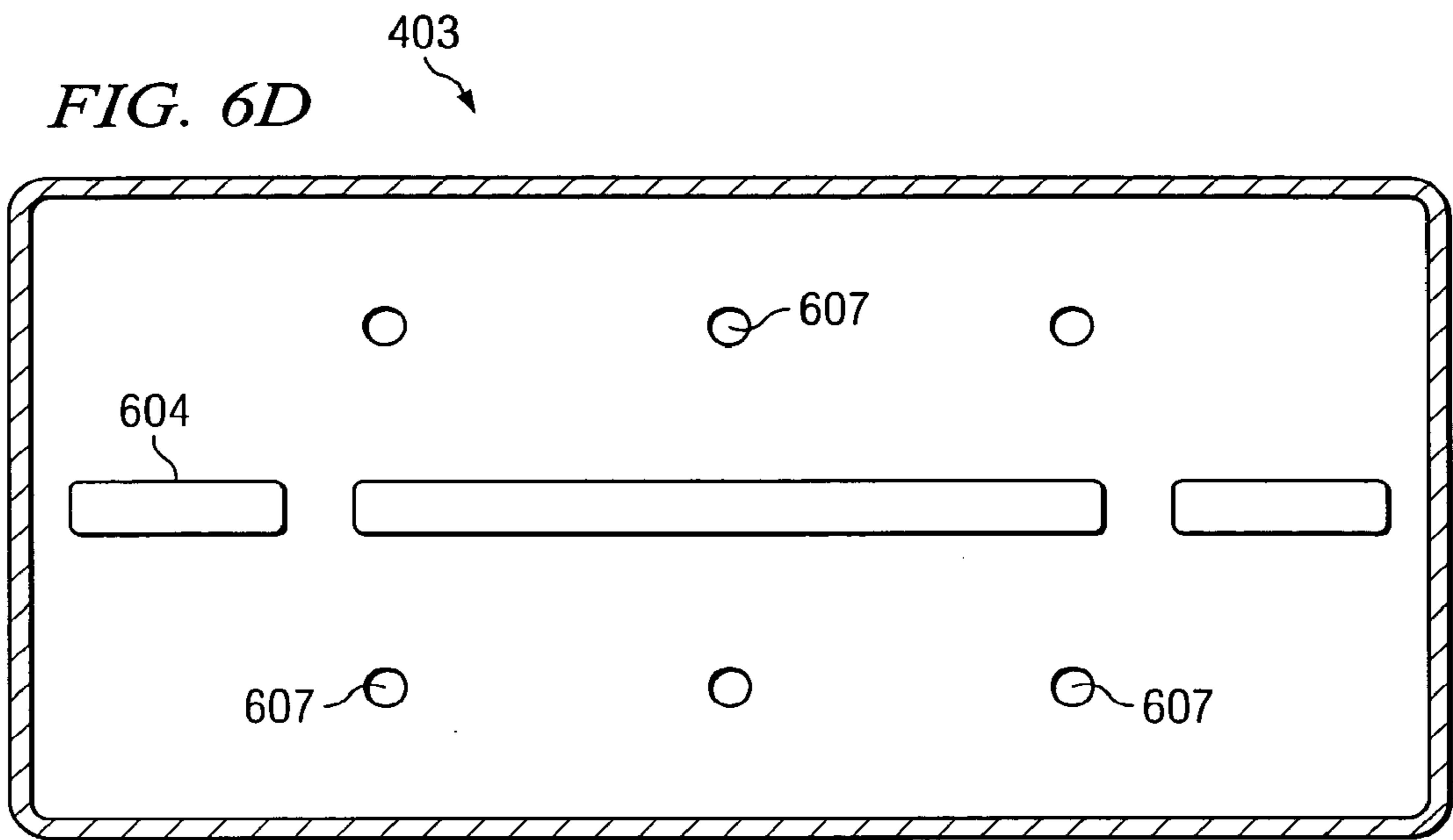


FIG. 6E

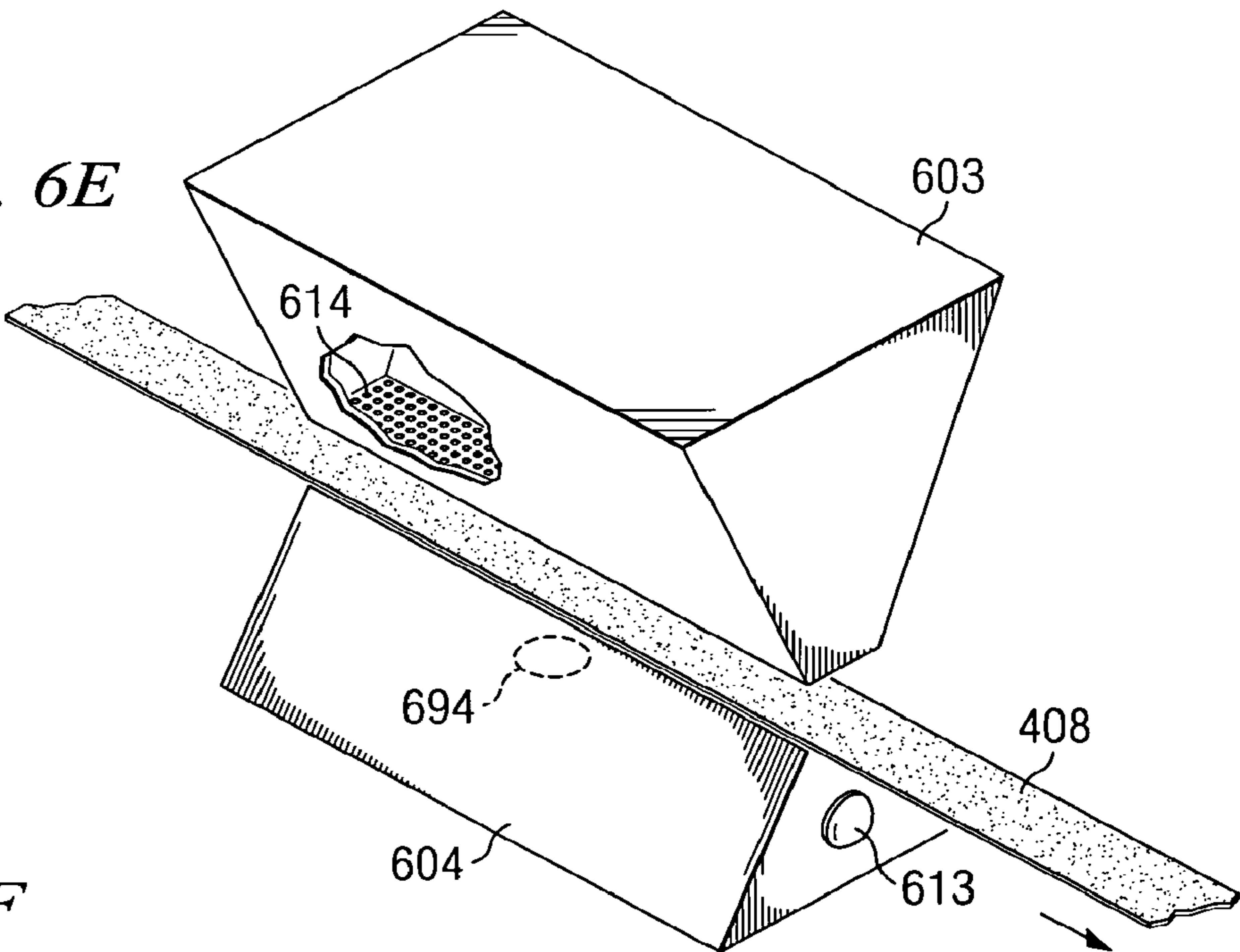
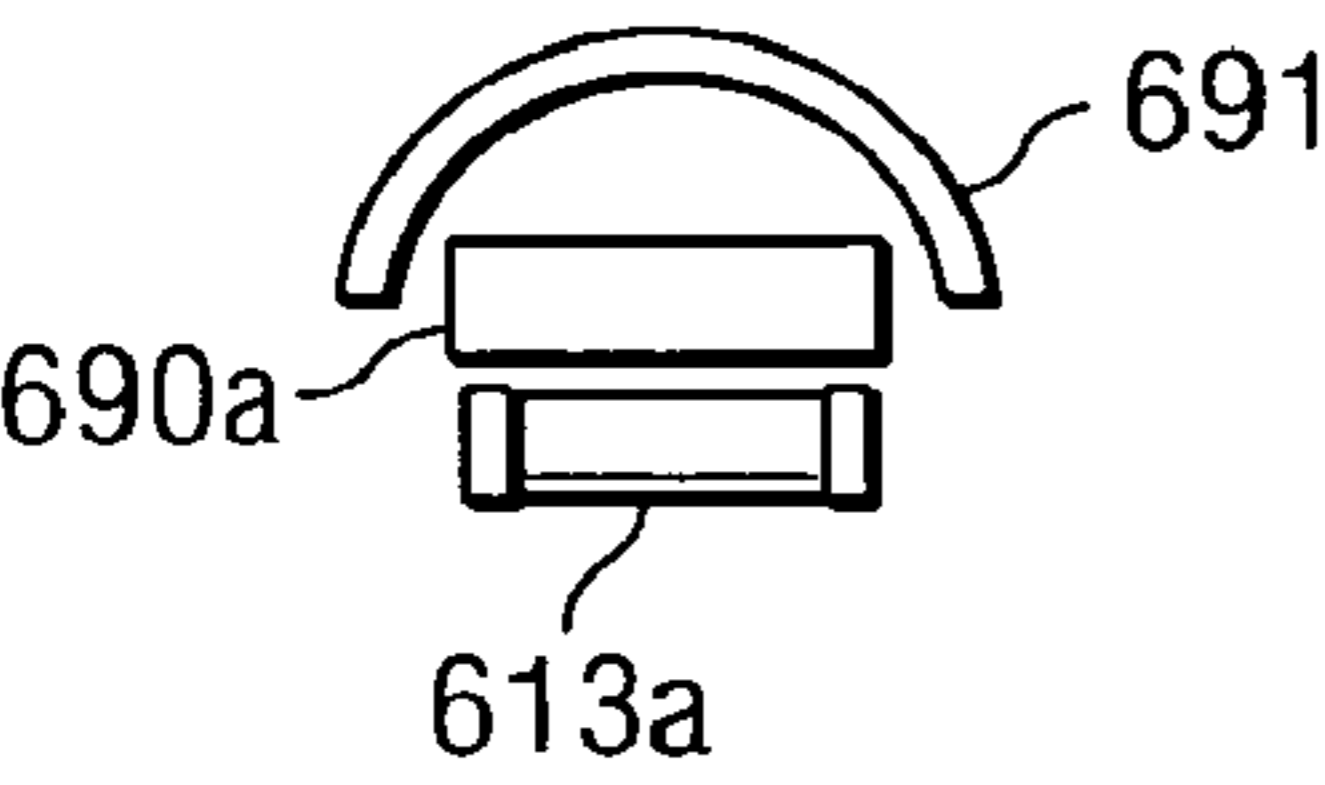


FIG. 6F



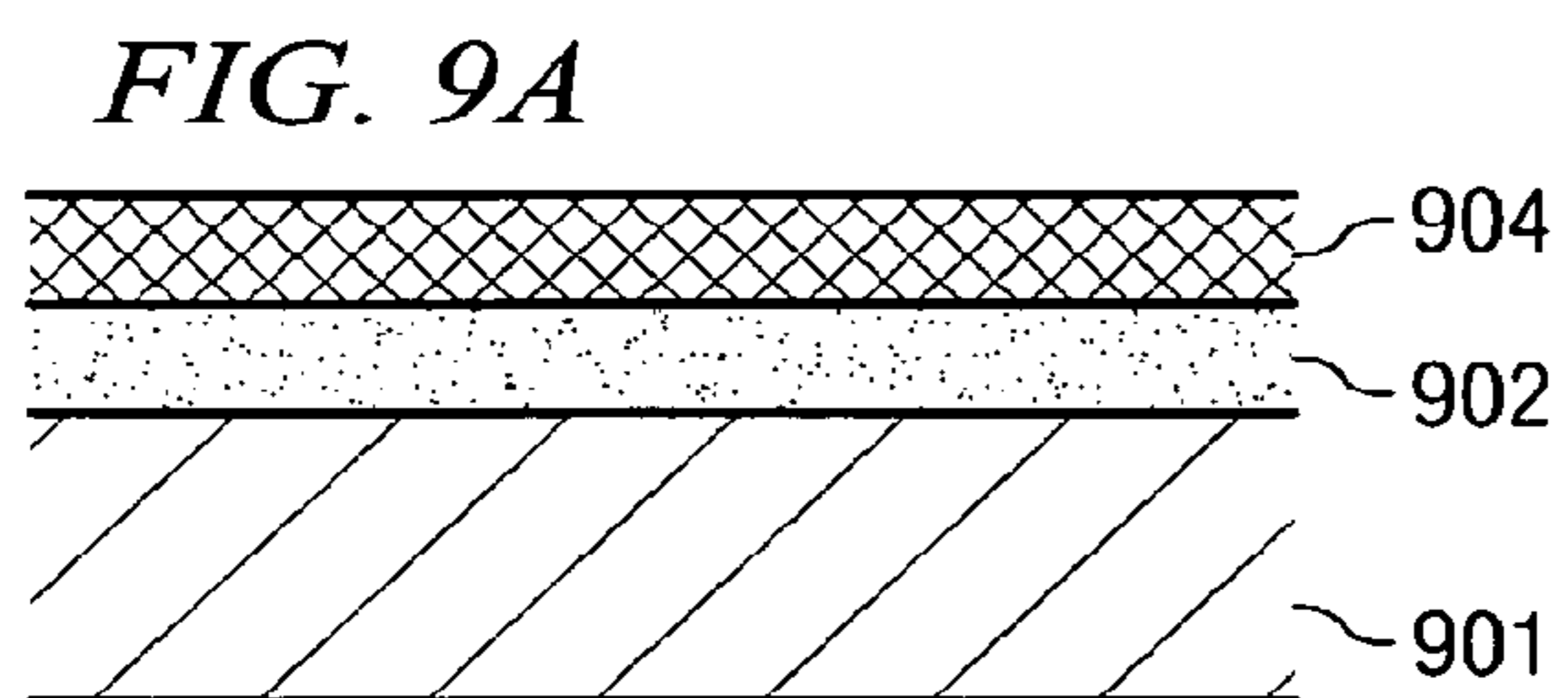
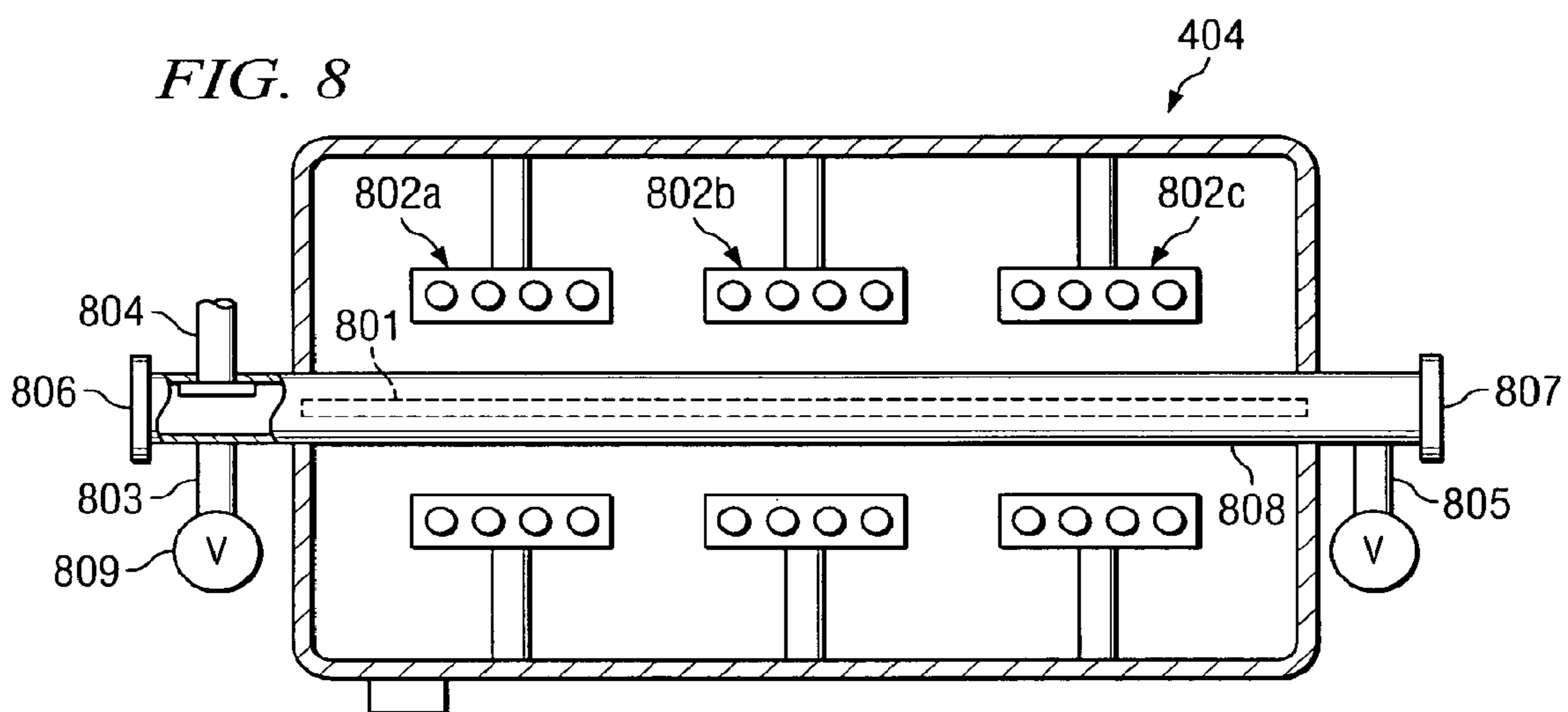
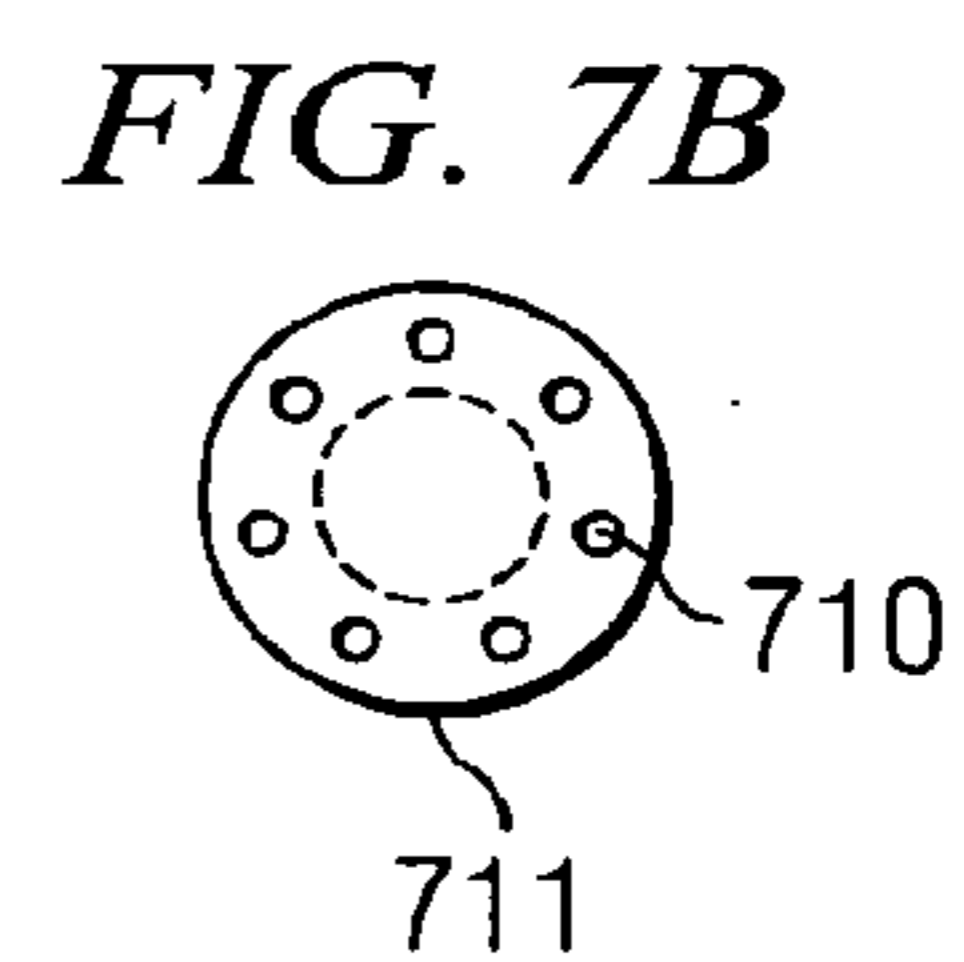
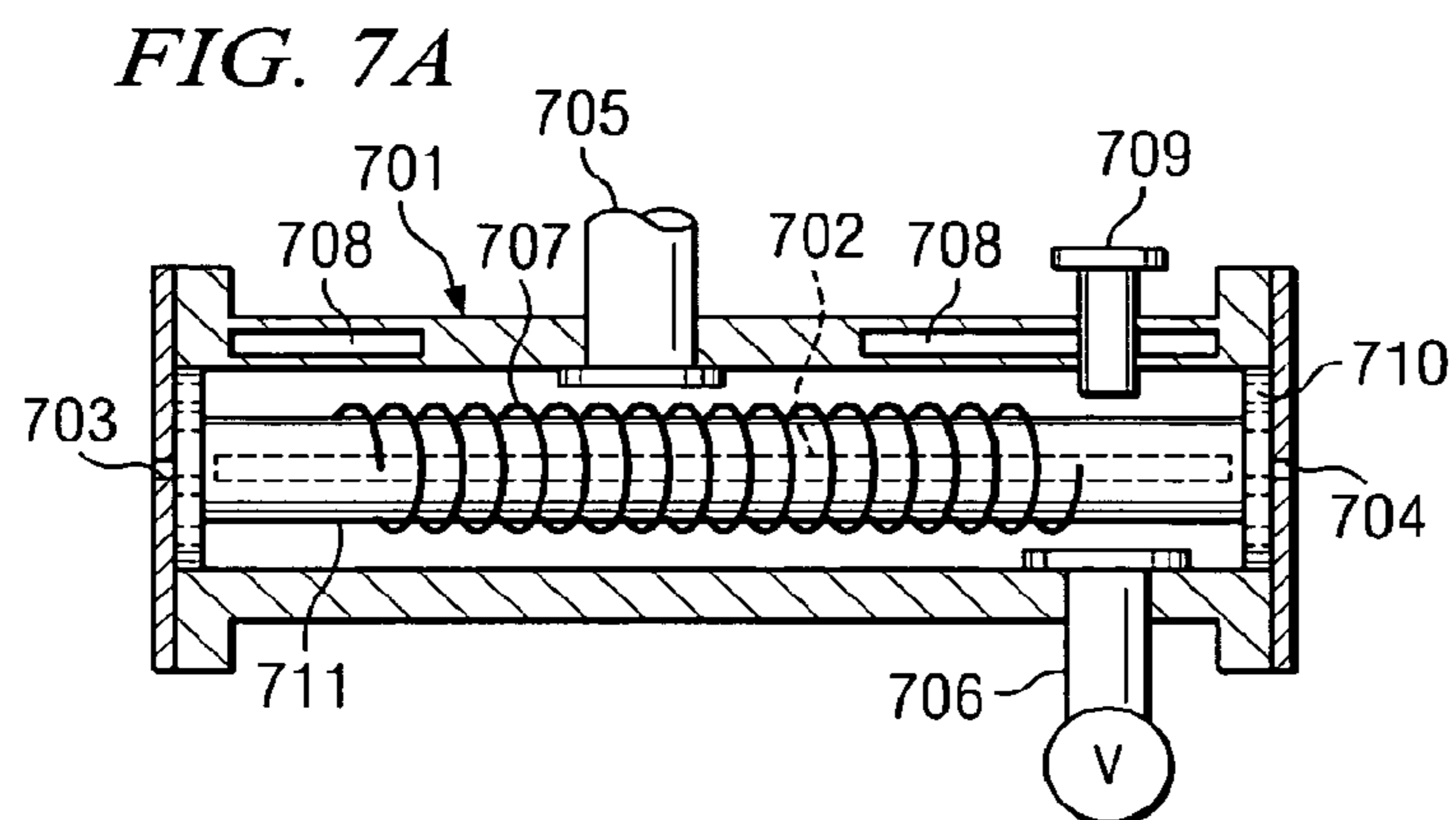


FIG. 9B

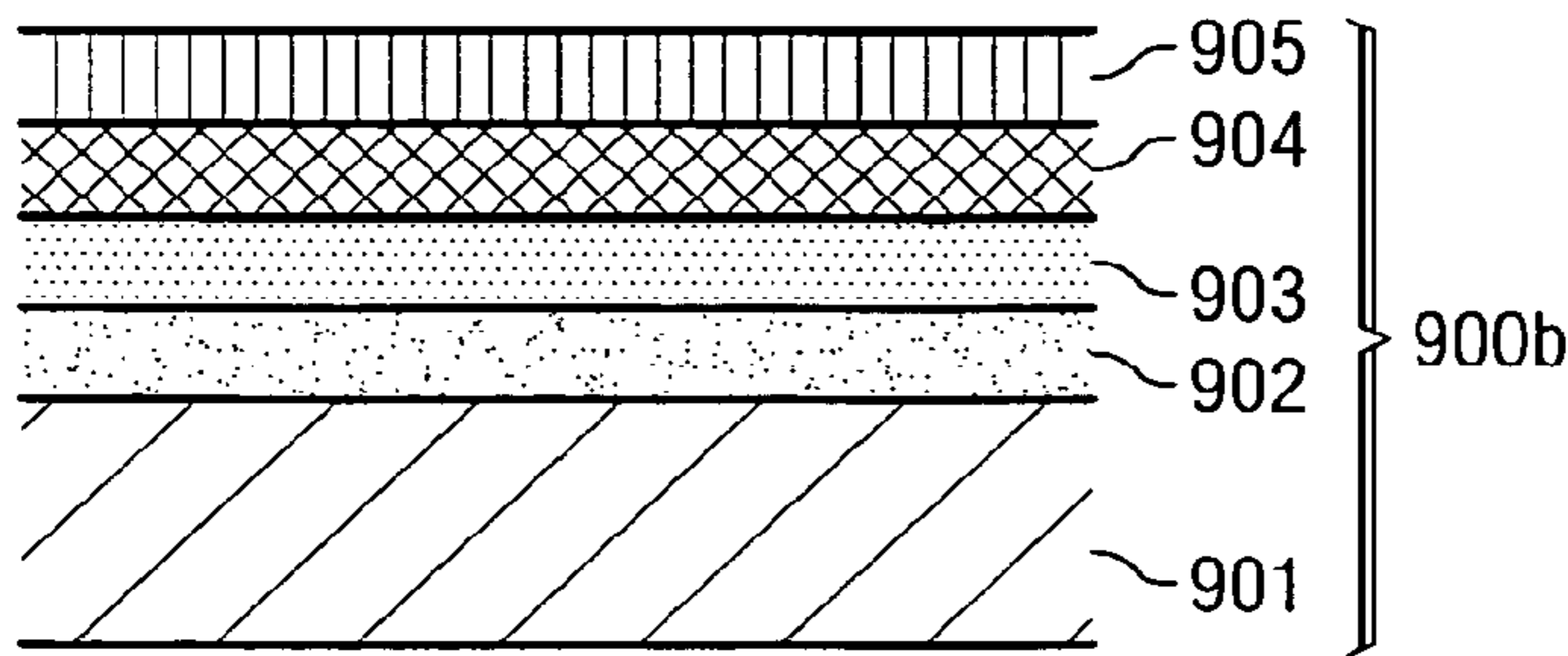


FIG. 9C

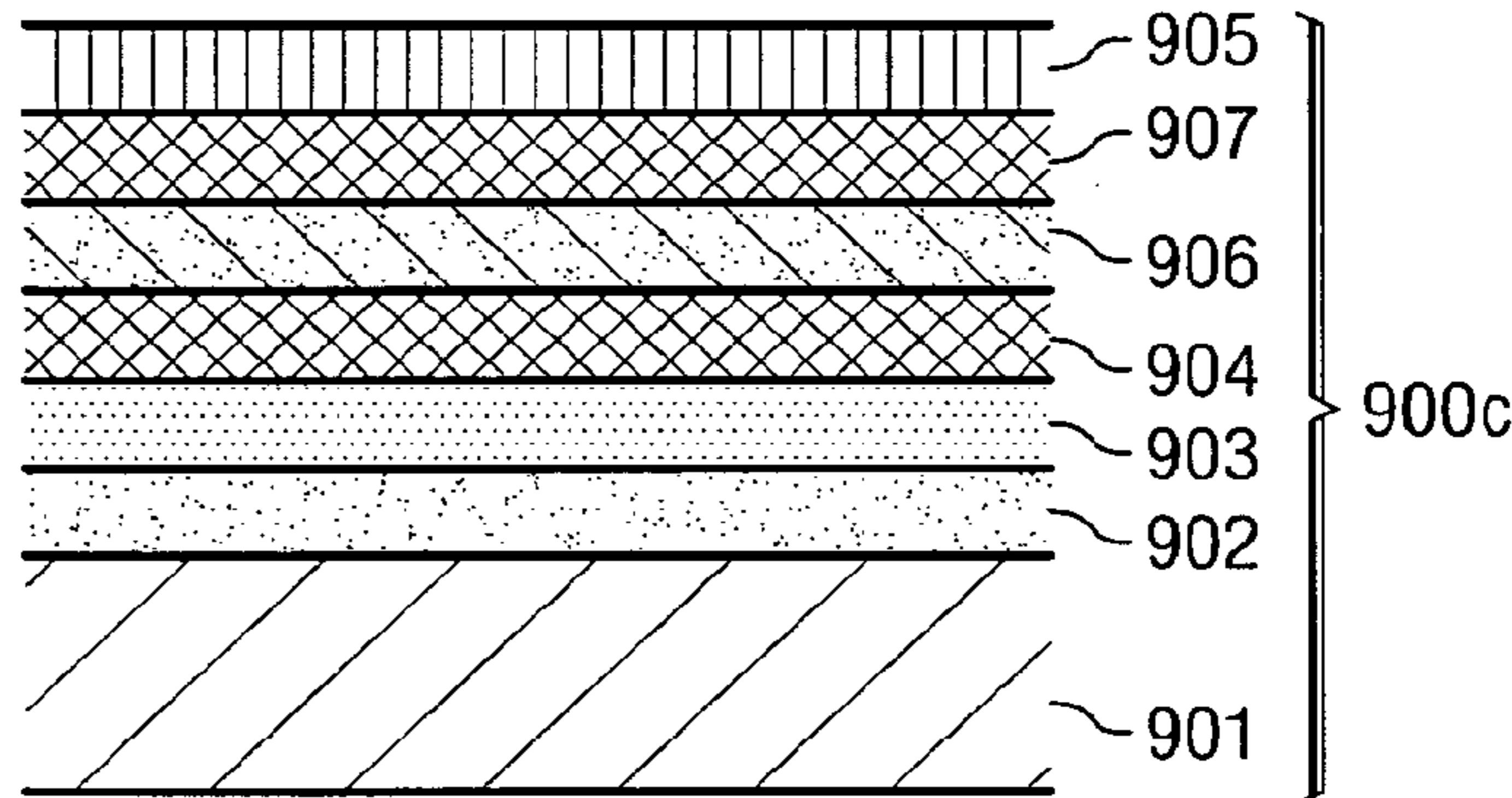
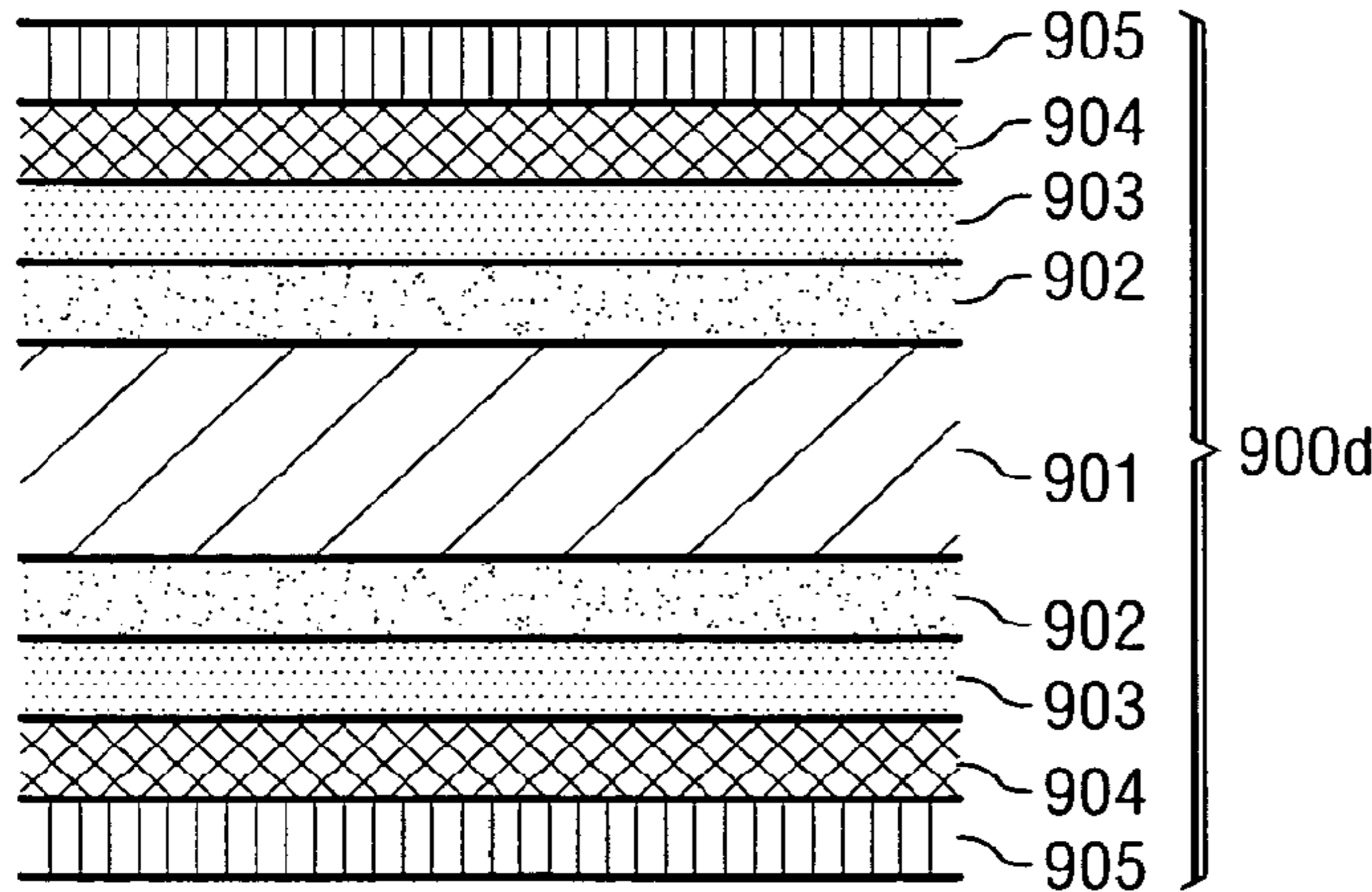


FIG. 9D



SYSTEM FOR FORMING SUPERCONDUCTOR MATERIAL ON A TAPE SUBSTRATE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 60/539,055, the disclosure of which is hereby incorporated herein by reference. This application is related to co-pending and commonly assigned U.S. patent application Ser. No. 10/206,123, entitled "METHOD AND APPARATUS FOR FORMING SUPERCONDUCTOR MATERIAL ON A TAPE SUBSTRATE," filed Jul. 26, 2002, to co-pending and commonly-assigned U.S. patent application Ser. No. 10/206,900, entitled "SUPERCONDUCTOR MATERIAL ON A TAPE SUBSTRATE," filed Jul. 26, 2002, and concurrently filed and commonly assigned U.S. patent application Ser. No. 10/206,783, entitled "METHOD AND APPARATUS FOR FORMING A THIN FILM ON A TAPE SUBSTRATE," filed Jul. 26, 2002, to U.S. patent application Ser. No. _____ [attorney docket no. 5837-P004US-10311281] filed concurrently herewith and entitled "SYSTEM AND METHOD FOR PROVIDING PRECURSORS," to U.S. patent application Ser. No. _____ [attorney docket no. 5837-P005US-10311282] filed concurrently herewith and entitled "SYSTEM AND METHOD FOR JOINING SUPERCONDUCTIVITY TAPE," and to U.S. patent application Ser. No. _____ [attorney docket no. 5837-P006US-10311283] filed concurrently herewith and entitled "SYSTEM AND METHOD FOR QUALITY TESTING OF SUPERCONDUCTIVITY TAPE," the disclosures of which are hereby incorporated herein by reference.

TECHNICAL FIELD

[0002] This invention relates in general to superconductors, and in specific to a method and apparatus for forming superconductor material on tape substrate

BACKGROUND OF THE INVENTION

[0003] Electrical resistance in metals arises because electrons that are propagating through the solid are scattered because of deviations from perfect translational symmetry. These deviations are produced either by impurities or the phonon lattice vibrations. The impurities form the temperature independent contribution to the resistance, and the vibrations form the temperature dependent contribution.

[0004] Electrical resistance, in some applications, is very undesirable. For example, in electrical power transmission, electrical resistance causes power dissipation, i.e. loss. The power dissipation grows in proportion to the square of the current, namely $P=I^2R$ in normal wires. Thus, wires carrying large currents dissipate large amounts of energy. Moreover, the longer the wire used in either larger transformers, bigger motors or larger transmission distances, the more dissipation, since the resistance in a wire is proportional to its length. Thus, as wire lengths increase more energy is lost in the wires, even with a relatively small currents. Consequently, electric power plants produce more energy than that which is used by consumers, since a portion of the energy is lost due to wire resistance.

[0005] In a superconductor that is cooled below its transition temperature T_C , there is no resistance because the scattering mechanisms are unable to impede the motion of the

current carriers. The current is carried, in most known classes of superconductor materials, by pairs of electrons known as Cooper pairs. The mechanism by which two negatively charged electrons are bound together is described by the BCS (Bardeen Cooper Schrieffer) theory. In the superconducting state, i.e. below T_C , the binding energy of a pair of electrons causes the opening of a gap in the energy spectrum at E_F , which is the Fermi energy or the highest occupied level in a solid. This separates the pair states from the "normal" single electron states. The size of a Cooper pair is given by the coherence length which is typically 1000 Å, although it can be as small as 30 Å in the copper oxides. The space occupied by one pair contains many other pairs, which forms a complex interdependence of the occupancy of the pair states. Thus, there is insufficient thermal energy to scatter the pairs, as reversing the direction of travel of one electron in the pair requires the destruction of the pair and many other pairs due to the complex interdependence. Consequently, the pairs carry current unimpeded. For further information on superconductor theory please see "Introduction to Superconductivity," by M. Tinkham, McGraw-Hill, New York, 1975.)

[0006] Many different materials can become superconductors when their temperature is cooled below T_C . For example, some classical type I superconductors (along with their respective T_C 's in degrees Kelvin (K)) are carbon 15K, lead 7.2K, lanthanum 4.9K, tantalum 4.47K, and mercury 4.47K. Some type II superconductors, which are part of the new class of high temperature superconductors (along with their respective T_C 's in degrees K), are $Hg_{0.8}Tl_{0.2}Ba_2Ca_2Cu_3O_{8.33}$ 138K, $Bi_2Sr_2Ca_2Cu_3O_{10}$ 118k, and $YBa_2Cu_3O_{7-x}$ 93K. The last superconductor is also well known as YBCO superconductor, for its components, namely Yttrium, Barium, Copper, and Oxygen, and is regarded as the highest performance and highest stability high temperature superconductor, especially for electric power applications. YBCO has a Perovskite structure. This structure has a complex layering of the atoms in the metal oxide structure. FIG. 1 depicts the structure for $YBa_2Cu_3O_7$, that include Yttrium atoms **101**, Barium atoms **102**, Copper atoms **103**, and Oxygen atoms **104**. For further information on oxide superconductors please see "Oxide Superconductors", Robert J. Cava, J. Am. Ceram. Soc., volume 83, number 1, pages 5-28, 2000.

[0007] A problem with YBCO superconductors specifically, and the oxide superconductors in general, is that they are hard to manufacture because of their oxide properties, and are challenging to produce in superconducting form because of their complex atomic structures. The smallest defect in the structure, e.g. a disordering of atomic structure or a change in chemical composition, can ruin or significantly degrade their superconducting properties. Defects may arise from many sources, e.g. impurities, wrong material concentration, wrong material phase, wrong processing temperature, poor atomic structure, and improper delivery of materials to the substrate, among others.

[0008] Thin film YBCO superconductors can be fabricated in many ways including pulsed laser deposition, sputtering, metal organic deposition, physical vapor deposition, and chemical vapor deposition. Two typical ways for the deposition of thin film YBCO superconductors are described here as example. In the first way, the YBCO is formed on a wafer substrate in a reaction chamber **200**, as shown in FIG. 2 by metal organic chemical vapor deposition (MOCVD). This manner of fabrication is similar to that of semiconductor devices. The wafer substrate is placed on holder **201**. The

substrate is heated by heater **202**. The wafer substrate is also rotated which allows for more uniform deposition on the substrate wafer, as well as more even heating of the substrate. Material, in the form of a gas, is delivered to the substrate by shower head **203**, via inlet **204**. The shower head **203** provides a laminar flow of the material onto the substrate wafer. The material collects on the heated wafer substrate to grow the superconductor. Excess material is removed from the chamber **200** via exhaust port **208**, which is coupled to a pump. To prevent undesired deposition of material onto the walls of the chamber **200**, coolant flows through jackets **205** in the walls. To prevent material build up inside the shower head **203**, coolant flows through coils **206** in the shower head. The flanges port **207** allows access to the inside of the chamber **200** for insertion and removal of the film/substrate sample. Processing of the film may be monitored through optical port **209**.

[0009] In the second way, YBCO is formed by pulsed laser deposition on a substrate, including the possibility of using a continuous metal tape substrate **301**. The tape substrate **301** is supported by two rollers **302**, **303** inside of a reaction chamber **300**. Roller **302** includes a heater **304**, which heats the tape **301** up to a temperature that allows YBCO growth. The material **305** is vaporized in a plume from a YBCO target by irradiation of the target by typically an excimer laser **306**. The vapor in the plume then forms the YBCO superconductor film on the substrate **301**. The rollers **302**, **303** allow for continuous motion of the tape past the laser target thus allowing for continuous coating of the YBCO material onto the tape. Note that the laser **306** is external to the chamber **300** and the beam from the laser **306** enters the chamber **300** via optical port **307**. The resulting tape is then cut, and forms a tape or ribbon that has a layer of YBCO superconductive material.

[0010] Neither of the above described methods for forming thin film high temperature superconductors can produce a long length tape or ribbon of YBCO which can be used to replace copper (or other metal) wires in electric power applications. The first way only allows for the production of small pieces of superconductor material on the wafer, e.g. a batch process. The second way can only be used to make tape that is a few feet in length and uses multiple passes to generate a superconducting film of several microns thickness. The second way has a practical limitation of about 5 feet. Larger pieces of tape would require a larger heating chamber. A larger heating roller will also be needed. The tape will cool down after leaving roller **302**, and thus will need more time to heat back up to the required temperature. Heating on one side of the chamber, with a cool down on the other side of the chamber may also induce thermal cracks into the YBCO layer and other layers formed on the metal substrate. The smaller pieces of tape produced by the second method may be spliced together to form a long length tape, but while the pieces may be superconducting, splice technology is not yet at the point of yielding high quality high temperature superconductor splices. Consequently, current arrangements for forming superconductors cannot form a long, continuous tape of superconductor material.

BRIEF SUMMARY OF THE INVENTION

[0011] Embodiments of the present invention are directed to a system and method where there is a need in the art for an arrangement that would allow for the formation of a superconductor, preferably YBCO, onto a metal ribbon or tape or wire, in a continuous manner, so as to form a continuous,

long-length superconductor ribbon or tape or wire. Note that the term superconducting wire, as used herein, includes any superconducting element used for transporting current.

[0012] These and other objects, features, and technical advantages are achieved by a system and method which continuously deposits materials used to grow a superconductor layer onto a moving tape. The embodiments use a pay-out reel to dispense the tape substrate at a constant rate. Embodiments then use an initialization stage to preheat and/or pretreat the tape substrate before growing the additional layers required for a superconducting wire. Preheating is desirable to lessen thermal shock of the tape substrate. Pretreating is desirable to reduce contaminants from the tape substrate before growing the additional layers required for a superconducting wire. Embodiments then use at least one reactor or reaction chamber to deposit one or more materials onto the tape substrate that is used to form the superconducting wire. The number of reactors needed depends upon the type superconductor material that is being formed, the type and number of buffer layers that are needed (if any) between the superconductor material and the tape substrate, and the type of tape substrate that is used to support the superconductor material. In addition, multiple reactors can be used to form a superconducting wire with multiple buffer layer/superconducting layer groups. Embodiments of the invention are modular such that reactors may be added or removed as needed. Embodiments use an anneal stage to finalize the superconductor layer and cool down the superconducting tape. Embodiments use a take-up reel to spool the superconducting tape. Embodiments may optionally use a coating stage that deposits a protective coating onto the superconducting tape and/or applies a protective interleaving layer to the tape. The interleaving layer is used in the storage, transportation, and packaging of the superconductor tape. This prevents the tape from sticking to itself when stored in reel form. Embodiments also may optionally use a quality control stage that ensures the proper characteristics of the superconducting tape. The embodiments may further optionally use a precleaning stage that removes grease and/or other contaminants from the tape prior to entry into the initialization stage.

[0013] Embodiments use transition chambers between the initialization stage and the reaction chamber, between the reaction chamber and the anneal stage, and between reaction chambers if more than one chamber is used. Additional reaction chambers or reactors may be used to provide buffer layers between the substrate and the high temperature superconducting (HTS) film, or coating layers on top of or in between layers of the HTS film. The transition chambers isolate each stage or reactor from the other stages and/or reactors, and thereby prevent cross-contamination of materials from one stage or reactor to another stage or reactor. The transition chamber is differentially pumped with narrow slits at either end through which the tape substrate is passed. The transition chamber includes a heating element that allows the temperature of the tape to be maintained and/or adjusted. The transition chamber includes at least one port to allow the introduction of at least one gas to control the environment in the transition chambers for optimal maintenance of the superconductor or buffer layers, and can incorporate tape monitoring for process control. The transition chamber may include at least one support that holds the tape during its transit through the transition chamber.

[0014] The reactor includes at least one support that holds the tape during its transit through the reactor. The reactor also includes a heating system that has a length in the direction of tape movement that is associated with the speed of the tape and the deposition of the material and/or growth rate of the superconductor layer. Thus, a portion of tape will be heated long enough so that a desired thickness of material (preferably, from 1 μm up to more than 10 μm) is achieved, as the portion of the tape is moved through the reaction region (thin film growth region) of the reactor. The reactor also uses a shower-head to provide a laminar flow of material onto the tape. The reactor further uses a cooling system to reduce the build up of material in undesired locations.

[0015] Embodiments of the invention may be used to form superconducting tape from different superconducting materials, including, but not limited to $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$, YBCO, $\text{NdBa}_2\text{Cu}_3\text{O}_{7-x}$, $\text{LaBa}_2\text{Cu}_3\text{O}_{7-x}$, $\text{Bi}_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$, $\text{Pb}_{2-x}\text{Bi}_x\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$, $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_z$, $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_x$, $\text{Tl}_2\text{Ba}_2\text{Ca}_2\text{Cu}_3\text{O}_y$, $\text{Tl}_2\text{Ba}_2\text{Ca}_2\text{Cu}_3\text{O}_z$, $\text{Bi}_x\text{Sr}_{2-y}\text{Ba}_y\text{Ca}_2\text{Cu}_4\text{O}_z$, $\text{TlBa}_2\text{CaCu}_2\text{O}_z$, $\text{HgBa}_2\text{CaCu}_2\text{O}_y$, $\text{HgBa}_2\text{Ca}_2\text{Cu}_3\text{O}_y$, MgB_2 , copper oxides, rare earth metal oxides, and other high temperature superconductors. Furthermore, the embodiments may operate for many different thin film deposition processes, including but not limited to metal-organic chemical vapor deposition (MOCVD), pulsed laser deposition, dc/rf sputtering, vapor deposition, metal organic deposition, molecular beam epitaxy, and sol gel processing.

[0016] The foregoing has outlined rather broadly the features and technical advantages of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims. The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages will be better understood from the following description when considered in connection with the accompanying figures. It is to be expressly understood, however, that each of the figures is provided for the purpose of illustration and description only and is not intended as a definition of the limits of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] For a more complete understanding of the present invention, reference is now made to the following descriptions taken in conjunction with the accompanying drawing, in which:

[0018] FIG. 1 depicts a known atomic structure for a YBCO superconductor;

[0019] FIG. 2 depicts a first prior art arrangement for producing a YBCO superconductor;

[0020] FIG. 3 depicts a second prior art arrangement for producing a YBCO superconductor;

[0021] FIG. 4 depicts an example of an embodiment of the invention;

[0022] FIG. 5 depicts an embodiment of an initialization stage of the invention;

[0023] FIGS. 6A-6F depict an embodiment of a reactor of a deposition stage of the invention;

[0024] FIGS. 7A and 7B depict an embodiment of a transition chamber of the invention;

[0025] FIG. 8 depicts an embodiment of an anneal stage of the invention; and

[0026] FIGS. 9A-9D depict different embodiments of the inventive superconductivity wire.

DETAILED DESCRIPTION OF THE INVENTION

[0027] FIG. 4 is a schematic diagram of an embodiment of a system 400 that produces a continuous tape of high temperature super-conducting (HTS) material. The system 400 includes several stages that operate together to deposit superconducting material onto a metallic substrate, such that the HTS material is atomically ordered with large, well-oriented grains and principally low angle grain boundaries. The atomic ordering allows for high current densities, e.g. J_c greater than or equal to 100,000 amps per cm^2 .

[0028] The metallic substrate may be a metal foil tape 408 that is from $10/1000$ to $1/1000$ of an inch thick. The tape may be as wide as desired. For example, the tape may be wide so that the resulting HTS tape can carry a large amount of current, or the tape may be wide so that the resulting HTS tape can be cut into narrower strips.

[0029] The tape 408 may be composed of nickel and/or a nickel alloy, and has a predetermined atomic ordering which will promote growth of the HTS material. The tape may also comprise nickel, silver, palladium, platinum, copper, aluminum, iron, tungsten, tantalum, vanadium, chromium, tin, zinc, molybdenum, and titanium. Such a tape has been described by Oak Ridge National Laboratories. The tape 408 supports the HTS layer, and thus should be ductile or flexible, as well as strong. Note that as described herein, only one side of the tape is being coated with a HTS layer, however, both sides may be coated with a HTS layer.

[0030] The tape 408 is dispensed by pay-out reel 401. The pay-out reel 401 is a continuous feed reel which provides the tape at a constant speed. The pay-out reel (along with take-up reel 406) is tension controlled to prevent sagging of the tape (too little tension) or stretching or breaking of the tape (too much tension). Either sagging or stretching the tape during processing (e.g. when the tape is heated to high temperature) can damage or destroy the HTS layer. A computer 409 may control the tension of tape, via tension controller 411, as the tape transits from the pay-out reel 401 to the take-up reel 406. Note that pay-out reel 401 is exposed to the room environment. Similarly, the take-up reel 406 is also exposed to the room environment. Thus, system 400 embodies air-to-air processing, which makes processing much easier.

[0031] The speed of the tape depends upon a number of factors, e.g. size of the reaction chambers, desired thickness of the deposited materials, growth rate of the layers, temperature of the reaction, photo/flux, etc. A speed of about 3 cm per minute is suitable to continuously grow a YBCO HTS layer of about 0.5 to 5 micrometers in thickness. However, a speed of from 1 to 20 cm per minute may be used, depending on factors such as (but not limited to) desired thickness, growth rates, materials being used, material concentrations, etc. A speed controller 410 that comprises a stepper motor, which can be adjustable set, is used to control the speed of the tape. A computer 409 may control the speed of tape, via speed con-

troller **410**, as the tape transits from the pay-out reel **401** to the take-up reel **406**. Note that pay-out reel may also comprise a speed controller that may also be connected to the computer **409**.

[0032] The tape **408** should be clean and free of grease and/or other contaminants. Such contaminants can prevent deposition of materials, can chemically contaminate deposited materials, and can distort the resulting thin film structure, in most cases adversely affecting superconducting properties. A vapor degreaser or cleaner can be used in pre-clean stage **412** to clean the tape prior to its entry into the initialization stage **402**. Alternatively, a mechanical cleaner, e.g. a roller wiper can be used to clean the tape. Another alternative is to use an ultrasonic bath, with a liquid cleaner, e.g. acetone, to clean the tape. Residual cleaning agents would be evaporated and/or burned off of the tape by initialization stage **402**. Note that pre-clean stage **412** may comprise multiple applications of vapor, mechanical, or bath treatments, as well as combinations of vapor, mechanical, and/or bath treatments. Further note that this stage may be operated separately from system **400**. The resulting cleaned tape could then be re-spooled and used in system **400** as tape **408**.

[0033] Initialization stage **402** pre-heats and/or pre-treats the tape substrate **408** before growing the additional layers required for a superconducting tape. This stage raises the temperature of the tape **408** to about 500° C. This temperature is between room temperature and the temperature of the next stage. This will reduce thermal shock of the tape substrate. Pre-treating will reduce contaminants from the tape substrate before growing surface layers including the top superconductor layer. This stage also removes the native oxide that covers metals. This stage has a reducing atmosphere that preferably comprises an oxygen scavenger, e.g. hydrogen (H₂), and for ammonia (NH₃), and argon (and/or other non-reacting gas e.g. nitrogen). The scavenger reacts with the metal surface oxide to reduce it to bare metal. The surface metal oxide could disrupt the atomic order of the HTS layer, affecting its superconducting properties, and thus should be removed.

[0034] An example of an embodiment of the initialization stage **402** is shown in FIG. 5. This stage includes at least one support **501**, and is composed of stainless steel. Other materials could include quartz, gold, platinum, aluminum oxide, LaAlO₃, SrTiO₃, and/or other metal oxide materials. The support should be polished smooth, so as not to snag or kink the tape, which would damage the atomic ordering of the substrate, and result in reduced quality HTS film. Also, the support should only be as large as necessary to prevent sag, this will minimize contact with the tape and prevent contamination. Heater **502** is used to heat the tape. Heater **502** may comprise a plurality of stages, e.g. **502a**, **502b**, **502c**, wherein each stage incrementally heats the tape to a desired temperature. This will reduce thermal shock of the tape substrate. Note that in this embodiment, the heater includes supporting pipe **508**. This pipe has a plurality of ports (not shown), which allows the passage of gases and/or other materials into and/or out of the pipe. The tape feeds into this stage via tape port **506** and passes out of this stage via tape port **507**. Note that tape ports **506** and **507** are not required to be narrow slits, like those on the transition chambers **701**. Alternatively, the narrow slits may not be part of the transition chambers, and instead tape ports **506** and **507** may comprise narrow slits. Material port **504** provides an inlet for the gases (if any) that are to be used to define the environment in this stage. Ports **503**, **505** may be connected to one or more vacuum sources

509 to prevent leakage of the atmosphere into an adjacent stage and/or leakage of the atmosphere of an adjacent stage into stage **402**. Note that instead of using coil heater(s), lamp heater(s) similar to those shown in FIG. 8 may be used.

[0035] The following table provides a working example of the environment of the initialization stage. The values are preferred values, as well as useable values, that are provided by way of example only. Note that SCCM is standard cubic centimeters per minute.

TABLE I

INITIALIZATION STAGE 402		
Variable	Preferred	Operating
Input Tape Temperature	Room Temperature	Room Temperature
Output Tape Temperature	600° C.	200-650° C.
Pressure	5-30 Torr	1-700 Torr
Gas Flow Rate	500-1000 SCCM	100-2000 SCCM
Gas Composition: H ₂	5%	3%-30%
Ar	95%	97%-70%

[0036] The next stage is the deposition stage **403**. This stage preferably comprises at least one reactor or reaction chamber **601** to deposit one or more materials onto the tape substrate onto which the superconductor layer is deposited. The number of reactors needed depends upon the type superconductor material that is being formed, the type and number of buffer layers that are needed (if any) between the superconductor material and the tape substrate, and the type of tape substrate that is used to support the superconductor material. This system is modular such that reactors may be added or removed as needed. For example, suppose that the superconductor material is YBCO and the tape substrate is nickel. Further suppose that two buffer layers are going to be used, e.g. cerium oxide and yttria stabilized zirconia. Thus, a total of three reactor chambers would be needed, one for the YBCO, and one for each of the buffer layers. As another example, if only one buffer layer was to be used, e.g. Sm-doped or "Samarium-doped ceria," then only two reactor chambers would be needed, i.e. one for the superconductor material and one for the buffer material. As a further example, if the superconductor material were to be directly formed on the tape substrate, then only one reactor chamber would be needed. In any event, the system is modular, such that the system may be modified to add or remove reactor chambers as needed.

[0037] Further note that an unused reactor chamber does not have to be physically removed from the system. For example a system may comprise three reactor chambers, however only two chambers are needed to produce the superconductor material. Thus, one reactor chamber may be physically removed from the system. Alternatively, one reactor may be set to a neutral operating mode. This mode would have the reactor not in an off mode, but rather would maintain the tape at a predetermined temperature and provide a non-reactive atmosphere to the tape substrate. Thus the tape would pass through the neutral reactor and not be changed by the reactor, and would exit the neutral reactor with essentially the same characteristics with which it entered the neutral reactor.

[0038] As shown in FIG. 4, this section may comprise multiple reaction chambers **601a**, **601b**, **601c** which may be separated by transition chamber **701** in FIG. 7A. Particular superconductors may require the deposition of different materials, different concentrations, different temperatures,

different pressures, and/or combinations thereof that would require more than one different operating environment. Each reaction chamber is preferably similar, however the reaction chambers may be made larger or smaller in the direction of tape travel if a particular environment needs a particularly longer or shorter growing time, and/or the layer needs to be thicker or thinner. Note that since the tape is moving at a constant speed, time can be equated to distance, such that if a longer deposition time is needed (and/or a thicker film is needed), then the reactive zone would be longer or the film grows thicker, higher, and vice versa. Similarly, changing the tape speed will also change the deposition time, e.g. slowing the tape will result in longer deposition times and thicker films, and vice versa.

[0039] FIG. 6A depicts an example of an embodiment of a reactor 601. The reactor includes at least one support 604, preferably composed of stainless steel. Other materials could include quartz, gold, platinum, aluminum oxide, LaAlO_3 , SrTiO_3 , and/or other metal oxide materials. The support should be polished smooth, so as not to snag or kink the tape, which would damage the atomic ordering of the substrate, and result in reduced quality HTS film. Also, the support should only be as large as necessary to prevent sag, this will minimize contact with the tape and prevent contamination. The support may include a heater to supplement heat provided by the heating element 613b, e.g. a lamp. This prevents the support from acting as a heat sink. The sides of the reactor may comprise stainless steel or may comprise some other material, such as quartz, e.g., gold, platinum, aluminum oxide, LaAlO_3 , SrTiO_3 , and/or other metal oxide materials. Note that various sensors may be placed throughout the system to provide data regarding the operation of the system, e.g. environmental data, speed of the tap, tape temperature, etc. For example, temperature sensor 694 may be located in the support 604 as shown in FIG. 6E.

[0040] The tape feeds into this stage via tape port 605 and passes out of this stage via tape port 606. Note that tape ports 605 and 606 are not required to be narrow slits, like those on the transition chambers 701. Alternatively, the narrow slits may not be part of the transition chambers, and instead tape ports 605 and 606 may comprise narrow slits. Material ports 607 provide an outlet for the materials that are to be used in this stage and are connected to vacuum pumps with gauging and valve control. As shown in the bottom view of a reactor 601 of FIG. 6D, the ports 607 are arranged to facilitate a laminar flow of materials in the reactor 601. In other words, material flows in from the shower head 603 and then out through ports 607.

[0041] As shown in FIG. 6F, the tape ports 605 and 606 may have adjacent supports 690a and 690b, preferably composed of stainless steel. Other materials could include quartz, gold, platinum, aluminum oxide, LaAlO_3 , SrTiO_3 , and/or other metal oxide materials. The support should be polished smooth, so as not to snag or kink the tape, which would damage the atomic ordering of the substrate, and result in reduced quality HTS film. Also, the support should only be as large as necessary to prevent sag, this will minimize contact with the tape and prevent contamination. The support may include a heater to supplement heat provided by the heating element(s) 613a, e.g. a lamp. This prevents the support from acting as a heat sink.

[0042] The reactor 601 includes a lamp housing 602 and shower head (or distribution head) 603. FIGS. 6B and 6C depict a side view and a top view, respectively, of the lamp

housing 602 and shower-head 603 arrangement shown in FIG. 6A. FIG. 6E depicts a perspective view of the shower head, substrate, and support (note that the lamp housing 602 has been omitted in this view). Lamps 608 in the lamp housing 602 heats the tape to a desired temperature, which will allow for the deposition of materials. The lamp also provides ultraviolet and visible light which significantly enhances the growth rate, i.e. increases the speed of growth through enhanced surface diffusion of the reacting species, which in turn allows for rapid growth of thick layers, and faster tape speeds and/or smaller reactors. The lamp housing 602 uses a reflector to direct the light onto the reaction area 609, which is the area immediately beneath the shower-head 603. This reduces heat flux to the chamber walls. The lamp 608 is preferably a quartz halogen lamp with the light source in the reactor comprising a plurality of lamps 608 that extend along the length of the lamp housing 602. Note that other ultraviolet/visible (UV/V) light sources may be used, for example xenon discharge, mercury vapor, or excimer laser light. The shower-head 603 provides a laminar flow of the reactant vapors mixed with a carrier gas to the deposition region of the reactor at the substrate tape 408. The shower-head 603 is preferably made from stainless steel, but may also be another non-reacting material such as quartz, gold, platinum, aluminum oxide, LaAlO_3 , SrTiO_3 , and/or other metal oxide materials.

[0043] The area below the shower-head is the deposition region of the reactor. The size of this region is selected with respect to other system characteristics, e.g. the tape speed, deposition rate, chamber pressure, etc. to produce a film of a desired thickness. When not in the deposition region, the tape 408 is covered by shields 691 to prevent material from coating the tape.

[0044] The dimensions and placement of the distribution head 603 depend on the width of the substrate 408. For example, as shown in FIG. 6B, for a substrate 408 having a width B 612, the width A 615 of the support 604 is preferably slightly smaller than B, e.g. B minus 2 mm. However, A may be operative for values in the range of B plus 2 mm to B minus 2 mm. The width C 620 of the shower head is preferably larger than B, e.g. B plus 10 mm. However, C may be operative for values in the range of B plus 15 mm to B minus 2 mm. The spacing D 621 between the shower head and the substrate is preferably greater than or equal to B. However, D may be operative for values of greater than or equal to B/2.

[0045] The lamp housing 602 also preferably includes a cooling jacket 610 as part of the lamp reflector. Different coolants may be used in the jackets, e.g. water, oil, glycol, etc. The sides of the reactor may also include cooling jackets and/or cooling pipes 614. The cooling jacket(s) not only reduce the reaction chamber external temperature to a safe range, but also reduce unwanted buildup of deposition materials on the walls by reducing the wall temperature to a point where chemical reaction of species does not occur.

[0046] The reactor also may preferably include one or several quality control ports 611. This port would allow viewing of the tape during the deposition process, and/or permit access for testing the quality of the tape.

[0047] The deposition materials (reactant chemicals) or precursors that react at the substrate to form the deposited film, e.g. HTS, buffer layer or overcoat layer, are provided by precursor system 407. Known systems include gas, liquid, solid and slurry preparation systems. Solid precursor delivery systems typically volatilize the solid precursor in a separate

heated vessel, pass a carrier gas through the vessel, and then pass the carrier gas/precursor vapor to the reaction chamber. The solid precursors could be separate or mixed as solids into one mass for vaporization. Slurry precursor delivery systems vaporize, in a separate chamber equipped with a hot zone, small amounts of a thick slurry containing all or a subset of all of the precursors dissolved in a solvent to form the slurry. The liquid precursor delivery system, vaporizes in a separate chamber equipped with a hot zone, small amounts of a liquid solution containing all or a subset of all of the precursors dissolved in a solvent. The vaporized precursors may then be injected into the reactor shower head for delivery to the tape **408**. A liquid precursor solution can also be atomized and then vaporized for injection into the reactor shower head.

[0048] For the integration of YBCO superconductors with continuous metal foil substrates, three reactors may be used. The first two reactors provide buffer layers, and the third reactor provides the YBCO layer. The first reactor **601a** deposits a thin layer of buffer, preferably cerium oxide (CeO_2). The buffer layers suffice to prevent other diffusion of speed between the metal substrate and the superconducting layer, as well as provide an atomically ordered template onto which to grow atomically ordered subsequent buffer layers or superconductor layers. This layer is deposited at relatively low temperature, as compared to the next two reactors, and prevents the nickel from oxidizing, which would destroy the atomic structure of the nickel substrate surface on which the follow-on layers are grown. Note that this reactor may operate in a reducing environment of forming gas, e.g. hydrogen, but also grows an oxide layer, which means that oxygen may be also provided into the reactor. Because of the relatively low concentrations and pressures (as compared with a standard atmosphere), there is no risk of explosion. The following table provides a working example of the environment of the first reactor. The values are preferred values, as well as useable values, which are provided by way of example only.

TABLE 2

CeO ₂ BUFFER LAYER BY REACTOR 601A		
Variable	Preferred	Operating
Reactor Temperature	600-700° C.	550-750° C.
Reactor Pressure	2-4 Torr	1-10 Torr
Carrier Gas Flow Rate	100-400 SCCM	100-400 SCCM
Oxygen Flow Rate	250-700 SCCM	200-1000 SCCM
Reducing Gas	H ₂ 22-26% Ar 78-74%	3-30% 97-70%
Reducing Gas Flow Rate	200-600 SCCM	100-1000 SCCM

[0049] The second reactor **601b** deposits a higher deposition temperature buffer layer, preferably yttria stabilized zirconia (YSZ) buffer. This buffer layer prevents the inter-diffusion of the first buffer layer and the metal substrate into the YBCO layer. This reactor operates in an oxidizer-rich environment composed of O₂, N₂O, O₃, combinations thereof, or other oxidizing agents at a pressure of from 1 to 5 Torr, and at a temperature of 600-850° C. The following table provides a working example of the environment of the second reactor. The values are preferred values, as well as useable values, which are provided by way of example only.

TABLE 3

YSZ BUFFER LAYER BY REACTOR 601B		
Variable	Preferred	Operating
Reactor Temperature	780-830° C.	750-850° C.
Reactor Pressure	2-4 Torr	1-10 Torr
Oxygen Flow Rate	300-600 SCCM	100-750 SCCM
Argon Flow Rate	500-8000 SCCM	200-2000 SCCM

[0050] The third reactor **601c** deposits the YBCO layer also in an oxidizer-rich environment. The thickness of the YBCO layer and its chemical purity and crystalline quality determine the critical current of the fabricated superconducting tape. The critical current is the current beyond which the superconductor is no longer superconducting. The following table provides a working example of the environment of the third reactor for precursors in solid form. The values are preferred values, as well as useable values, which are provided by way of example only.

TABLE 4

YBCO LAYER BY REACTOR 601C USING SOLID FORM PRECURSORS		
Variable	Preferred	Operating
Reactor Temperature	780-835° C.	750-850° C.
Reactor Pressure	2-4 Torr	1-10 Torr
Precursor B _a Temperature	270-280° C.	265-285° C.
Precursor C _a Temperature	165-185° C.	150-190° C.
Precursor Y Temperature	165-185° C.	150-190° C.
Oxygen Flow Rate	100-500 SCCM	100-1000 SCCM
N ₂ O Flow Rate	100-300 SCCM	100-1000 SCCM
Argon Flow Rate	500-800 SCCM	300-2000 SCCM

[0051] The following table provides a working example of the environment of the third reactor for precursors in liquid (Table 5) forms. The values are preferred values, as well as useable values, which are provided by way of example only. Note that M is molality.

TABLE 5

YBCO LAYER BY REACTOR 601C USING LIQUID FORM PRECURSORS		
Variable	Preferred	Operating
Reactor Temperature	780-830° C.	700-900° C.
Reactor Pressure	2-3 Torr	1-10 Torr
Precursor Temperature	270-280° C.	260-310° C.
Precursor Concentration	0.05-0.1M	0.01-0.5M
Argon Flow Rate	400-500 SCCM	200-1000 SCCM
Oxygen Flow Rate	300-500 SCCM	200-1000 SCCM
N ₂ O Flow Rate	200-500 SCCM	100-1000 SCCM

[0052] Note that system **400** may be configured for a two reactor version, namely, one reactor for a single buffer layer and the other reactor for the superconductor layer. The first reactor would be configured as described in Table 2, but use a SM-doped CeO₂ as the buffer material. The second reactor may be configured as in either Table 4 or Table 5 for either solid form precursor or liquid form precursor, respectively, for the YBCO superconductor material.

[0053] The deposition stage **403** also includes transition chambers **701** between stage **402** and the first reactor, between reactors, and between the last reactor and stage **404**. FIG. 7A depicts an example of an embodiment of a transition chamber. The tape feeds into the transition chamber via narrow slit **703** and passes out of the transition chamber via narrow slit **704**. The slits are used to minimize the passage of gases and other materials from reactor chamber to transition chamber, and vice versa. Therefore, the transition chambers isolate each stage or reactor from the other stages and/or reactors, and thereby prevent cross-contamination of materials and/or gases from one stage or reactor to another stage or reactor. The transition chamber has a vacuum system **706** that controls any materials or gases leaking in from either end of the transition chamber, and may be operated at a pressure that is either higher or lower than the nominal reaction chamber pressure.

[0054] The transition chamber may include at least one support **702** for the moving tape substrate, preferably composed of stainless steel or a non-reactive material such as quartz, gold, platinum, aluminum oxide, LaAlO_3 , SrTiO_3 , and/or other metal oxide materials. The support should be polished smooth, so as not to snag or kink the tape, which would damage the atomic ordering of the substrate, and result in reduced quality HTS film. Also the support should only be as large as necessary to prevent sag, this will minimize contact with the tape and prevent contamination.

[0055] The transition chamber may include one or more heating elements **707** that allow the temperature of the tape to be maintained and/or adjusted while in the transition chamber. The heater **707** may maintain the temperature of the tape, or it may adjust the temperature (either higher or lower) to a point, e.g. midpoint, between the two stages connected to it. For example, if one reactor has a temperature of 550°C . and the other reactor has a temperature of 700°C ., then the transition chamber may be set to have a temperature of 625°C . This will reduce thermal shock of the tape, as it moves between stages and/or reactors. Note that in this embodiment, the heating element **707** includes supporting pipe **711**. This pipe **711** has a plurality of ports **710**, which allows the passage of gases and/or other materials into and/or out of the pipe. FIG. 7B depicts a side view of the pipe **711** with ports **710**.

[0056] The transition chamber preferably includes at least one port **705** to allow the introduction of at least one gaseous specie into the transition chamber that could stabilize or enhance the buffer layer (s) or the superconductor layer(s) formed on the substrate, or enhance the formation of follow-on layers on the tape. For example, a transition chamber may provide oxygen to the tape, which would help maintain oxygen stoichiometry in the deposited films. Any introduced gaseous materials would be removed by vacuum system **706**.

[0057] The transition chamber also preferably includes a cooling jacket **708**. Different coolants may be used in the jackets, e.g. water, oil, glycol, etc. The cooling jacket not only reduce the external temperature to a safe range, but also may reduce unwanted buildup of deposition materials on the walls by reducing the wall temperature to a point where chemical reaction of species does not occur.

[0058] The transition chamber also may preferably include one or more quality control ports **709**. This port would allow viewing of the tape during the deposition process, and/or permit access for testing or monitoring the quality of the tape.

[0059] The following table provides working examples of the environments of the transition chambers 701-1, 701-2, 701-3, and 701-4. The values are preferred values, as well as useable values, which are provided by way of example only.

TABLE 6

TRANSITION CHAMBER ENVIRONMENTS			
Chamber	Variable	Preferred	Operating
701-1	Temperature	500°C .	$400\text{-}700^\circ\text{C}$.
	Pressure	3 Torr	1-10 Torr
	Gas Composition: H_2	22-26%	3-30%
	Ar	78-74%	97-70%
	Gas Flow Rate	500 SCCM	100-1000 SCCM
701-2	Temperature	600°C .	$450\text{-}800^\circ\text{C}$.
	Pressure	3 Torr	1-10 Torr
	Gas Composition: O_2	100%	100%
	Gas Flow Rate	500 SCCM	100-2000 SCCM
701-3	Temperature	700°C .	$650\text{-}850^\circ\text{C}$.
	Pressure	3 Torr	1-10 Torr
	Gas Composition: O_2	100%	100%
	Gas Flow Rate	500 SCCM	100-1500 SCCM
701-4	Temperature	650°C .	$600\text{-}800^\circ\text{C}$.
	Pressure	10 Torr	2-100 Torr
	Gas Flow: O_2	500 SCCM	300-2000 SCCM
	N_2O	300 SCCM	300-2000 SCCM

[0060] The next stage is the anneal stage **404**. This stage allows for increasing the oxygen stoichiometry in the superconducting layer on the substrate tape, and cools down the complete processed tape. After this stage, the tape can be exposed to normal air with no degradation of the superconducting layer, and thus no further transition chambers are required. The tape is in this stage for about 30-60 minutes. The tape is at about $800\text{-}650^\circ\text{C}$. when it enters this stage and is about 300°C . or lower when it exits this stage. The tape is in an oxygen atmosphere in this stage.

[0061] FIG. 8 depicts an example of an anneal stage. This stage includes at least one support **801**, preferably composed of stainless steel or a non-reactive material such as quartz, gold, platinum, aluminum oxide, LaAlO_3 , SrTiO_3 , and/or other metal oxide materials. The support should be polished smooth, so as not to snag or kink the tape, which would damage the atomic ordering of the substrate, and result in reduced quality HTS film. Also, the support should only be as large as necessary to prevent sag, this will minimize contact with the tape and prevent contamination. Heater **802** is used to heat the tape. Heater **802** may comprise a plurality of stages, e.g. **802a**, **802b**, **802c**, wherein each stage decrements the temperature of the tape to a desired temperature. This will reduce thermal shock of the tape substrate. Note that in this embodiment, the heater includes supporting pipe **808**. This pipe may have a plurality of ports (not shown), which allows the passage of gases and/or other materials into and/or out of the pipe. The tape feeds into this stage via tape port **806** and passes out of this stage via tape port **807**. Note that tape ports **806** and **807** are not required to be narrow slits, like those on the transition chambers **701**. Alternatively, the narrow slits may not be part of the transition chambers, and instead tape ports **806** and **807** may comprise narrow slits.

[0062] Material port **804** provides an inlet for the gases (if any) that are to be used to define the environment in this stage. Ports **803**, **505** may be connected to one or more vacuum sources **809** to prevent leakage of the atmosphere into an adjacent stage and/or leakage of the atmosphere of an adja-

cent stage into stage **404**. Note that instead of using lamp heater(s), coil heater(s) similar to those shown in FIG. **5** may be used.

[0063] The following table provides a working example of the environment of the anneal stage. The values are preferred values, as well as useable values, that are provided by way of example only.

TABLE 7

ANNEAL STAGE ENVIRONMENTS			
Stage	Variable	Preferred	Operating
Stage I 802a	Temperature	550° C.	500-700° C.
	Pressure	760 Torr	100-1500 Torr
	O ₂ Flow	500 SCCM	100-2000 SCCM
Stage II 802b	Temperature	350° C.	300-500° C.
	Pressure	760 Torr	100-1500 Torr
	O ₂ Flow	500 SCCM	100-2000 SCCM
Stage III 802c	Temperature	200° C.	≤300° C.
	Pressure	760 Torr	100-1500 Torr
	O ₂ Flow	500 SCCM	100-2000 SCCM

[0064] Optional sealing stage **405** may coat the tape with a protective coating, e.g. lacquer, plastic, polymer, cloth, metal (e.g. silver, gold, or copper). This materials are cited by way of example only as other coatings could be used.

[0065] Optional stage **418** performs quality control testing that ensures the proper characteristics of the final superconducting tape, as well as the tape under process. Note that this stage may use the ports **611** and/or **709**. Further note that quality control testing may be incorporated at any of the reactors **601a, b, c**, in any of the transition chamber chambers **701**, and/or at the pre-treat or post anneal stages. Further note that quality control testing may be performed separately from system **400**. This quality control may incorporate direct or indirect measurement of YBCO properties including atomic order, temperature, reflectivity, surface morphology, thickness, microstructure, T_c , J_c , microwave resistivity, etc., or the direct or indirect measurement of the properties of the buffer layers or the coating layers of the tape including atomic order, temperature, reflectivity, surface morphology, thickness, microstructure, etc. Note that J_c is the critical current density or the maximum amount of current that the wire can handle before breakdown. Some superconductor elements may have a J_c of 100,000 amps/cm² or greater. Good superconductor elements may have a J_c of 500,000 amps/cm² or greater.

[0066] The system uses a take-up reel **406** to spool the superconducting tape. Note that the length of the wire tape **408** is limited only by the size of the pay-out and take-up reels. Thus, the tape may be any desired length, depending on the length of the input/output reels. For example, the system may produce 1 or 2 kilometer (km) long wire tapes, or even longer.

[0067] Note that computer **409** can be used to control the different aspects of the system. For example, it can control the concentration of materials flowing into the reactors, the temperature of the reactors and/or the transition chambers the pressure in the reactors and/or transition chambers, the tape speed, the tape tension, the flow rate of the materials into the different reactors or stages, etc. This would allow feedback from the quality control testing to improve the characteristics of the wire tape.

[0068] The system **400** also may optionally include pressure control chambers **414** and **415**, which assist in controlling the pressure in the initialization stage **402** and the anneal

stage **404**, respectively. A transition chamber **701** may be used as a pressure control chamber. In such a case, the heating element **707**, supporting pipe **711**, and/or water jacket **708** may not be needed. Also narrow slits may not be used between chamber **414** and stage **402**, and/or between chamber **415** and stage **404**. The system may also use an additional transition chamber **413** between initialization stage **402** and normal atmosphere, or between chamber **414** (if used) and normal atmosphere. Chamber **413** prevents the mixing of normal atmosphere and the environment of the initialization stage **402**. For example, chamber **413** prevents oxygen from the normal atmosphere from entering initialization stage **402**, as well as preventing hydrogen from the initialization stage from entering the normal atmosphere.

[0069] The system uses vacuum pumps **417** to achieve the desired pressure in the various components of the system. Liquid nitrogen traps and filters **416** are used to remove materials from the exhaust of the reactors **601** to prevent damage to the pumps **417**. The other components may also use such traps and/or filters to prevent damage to their associated pumps.

[0070] FIGS. 9A-9D depict examples of different embodiment of the inventive superconducting wire produced by the system of FIG. 4. FIG. 9A depicts tape substrate **901** with buffer layer **902** and HTS layer **904**. FIG. 9B depicts tape substrate **901** with buffer layers **902, 903**, HTS layer **904**, and sealing layering **905**.

[0071] FIG. 9C depicts a two HTS layer wire that includes substrate **901** with buffer layers **902, 903** and sealing layer **905**. Buffer layer **906** separates first HTS layer **904** and second HTS layer **907**. Note that the buffer layer **906** may be used here, and **906** is not necessarily equivalent to either **902** or **903**. This wire may be made by using additional reactors, transition chambers, and/or other components in the system of FIG. 4 to form the additional layers. This wire may also be made by repeating the processing with the system of FIG. 4. In other words, after completion of the first HTS layer, the wire is spooled without adding the sealing layer. The spool is then moved to the pay-out reel **401**. Selected ones of the components of the system of FIG. 4 are then used to form the subsequent layers including the second HTS layer.

[0072] FIG. 9D depicts another example of a two HTS layer wire that has an HTS layer on each side of the substrate. This wire may be made by using additional reactors, transition chambers, and/or other components in the system of FIG. 4 to form the additional layers. In order to form layers on the opposite side, additional pieces of equipment would be added to the system of FIG. 4 that twists or flips the tape as needed to process the bottom side of the tape. This wire may also be made by repeating the processing with the system of FIG. 4. In other words, after completion of the first HTS layer, the wire is spooled without adding the sealing layer. To reverse the side of the tape, the take-up reel **406** would wind the tape from the bottom of the reel (counter-clockwise), instead of the top of the reel (clock-wise), as shown in FIG. 4. The spool is then moved to the pay-out reel **401**. The system of FIG. 4 then processes the tape to form the subsequent layers including the second HTS layer.

[0073] The inventive wire may be used in the transporting of current, the distribution of power, in an electric motor, in an electric generator, in a transformer, in a fault current limiter, in superconducting magnetic energy storage (SMES) system, and a variety of magnets (including, but not limited to, MRI

systems, magnetic levitation transport systems, particle accelerators, and magnetohydrodynamic power systems).

[0074] The inventive system may be used to form the inventive superconducting wire from different superconducting materials, including, but not limited to $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$, YBCO, $\text{NdBa}_2\text{Cu}_3\text{O}_{7-x}$, $\text{LaBa}_2\text{Cu}_3\text{O}_{7-x}$, $\text{Bi}_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$, $\text{Pb}_{2-x}\text{Bi}_x\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$, $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_z$, $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_x$, $\text{Tl}_2\text{Ba}_2\text{Ca}_2\text{Cu}_3\text{O}_y$, $\text{TlBa}_2\text{Ca}_2\text{Cu}_3\text{O}_z$, $\text{Tl}_{1-x}\text{Bi}_x\text{Sr}_{2-y}\text{Ba}_y\text{Ca}_2\text{Cu}_4\text{O}_z$, $\text{TlBa}_2\text{Ca}_1\text{Cu}_2\text{O}_z$, $\text{HgBa}_2\text{CaCu}_2\text{O}_y$, $\text{HgBa}_2\text{Ca}_2\text{Cu}_3\text{O}_y$, MgB_2 , copper oxides, rare earth metal oxides, and other high temperature superconductors. The invention may also include different buffer materials, including but not limited to CeO_2 (or CEO), Y_2O_3 — ZrO_2 (or YSZ), Gd_2O_3 , Eu_2O_3 , Yb_2O_3 , RuO_2 , $\text{La}_1\text{Sr}_x\text{CoO}_3$, MgO , SiN , BaCeO_2 , NiO , Sr_2O_3 , SrTiO_3 , and $\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$.

[0075] Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the invention as defined by the appended claims. Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure of the present invention, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the present invention. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

1-9. (canceled)

10. A system for forming a superconductor material on a tape substrate, the system comprising:

a dispensing reel;
a spooling reel; and

at least two modular reaction chambers, wherein at least one modular reaction chamber is connected to a supply of buffer precursor material and at least one other modular reaction chamber is connected to a supply of superconductor precursor material, wherein the at least two modular reaction chambers include connections capable of being modified to add or remove adjacent components; and

wherein the spooling reel and the dispensing reel are exposed to normal atmosphere.

11. The system of claim 10, further comprising:

a pre-clean stage to remove oil-based contaminants from the tape substrate, wherein the pre-clean stage comprises

a vapor treatment, a mechanical treatment, a bath treatment, or a combination thereof.

12. The system of claim 10, further comprising:

an initialization stage comprising at least one reducing material for treating the tape substrate prior to delivery to the modular reaction chambers.

13. The system of claim 10, wherein each modular reaction chamber comprises: a heating element that heats the tape substrate.

14. The system of claim 13, wherein the heating element comprises a lamp housing with a length dimension parallel to the path of the tape substrate such that light from the lamp housing is directed to the path of the tape substrate.

15. The system of 10, wherein each modular reaction chamber comprises:

at least one distribution head to provide a laminar flow of material to form the layer of superconductor material on the tape substrate, wherein the distribution head has a length dimension parallel to a path of the tape substrate and wherein the distribution head is positioned over the path of the tape substrate.

16. The system of claim 15, wherein the length dimension of the at least one distribution head is parallel to the length dimension of the heating element, wherein the shape of the heating element is substantially a half-pipe, and wherein the distribution head bisects the width of the heating element.

17. The system of claim 10, further comprising:

at least one transition chamber that isolates at least one of the modular reaction chambers from at least one other modular reaction chamber.

18. The system of claim 17, wherein the at least one transition chamber comprises a vacuum system.

19. The system of claim 10, further comprising an anneal stage between the at least two modular reactors and the spooling reel, wherein the anneal stage has an atmosphere that allows for increasing the oxygen stoichiometry in the layer of superconducting material on the substrate tape.

20. (canceled)

21. A system for forming a superconductor wire with a tape substrate, the system comprising:

a device for moving a continuous tape substrate through a deposition system;

a device for forming at least one buffer layer on the tape substrate;

a device for forming at least one layer of superconductor material on the at least one buffer layer to form the superconductor wire; and

a device for spooling the tape substrate with the at least one buffer layer and the at least one layer of superconductor material in normal atmosphere, wherein the spooling means are exposed to normal atmosphere.

22. The system of claim 21, wherein the tape substrate is at least one kilometer in length and the superconductor wire is continuous.

23. The system of claim 21, further comprising a process controller for monitoring the tape substrate.

24. The system of claim 23, wherein the process controller comprises at least one environmental sensor, at least one speed sensor, at least one temperature sensor, or any combination thereof.

25. The system of claim 21, further comprising a device for maintaining the tape substrate at a predetermined temperature while providing a non-reactive atmosphere.

26. The system of claim 21, wherein the tape substrate is longer than one-half kilometer.

27. (canceled)

28. The system of claim 21, further comprising a device for providing a protecting layer to the superconductor wire.

29. The system of claim 21, further comprising a device for controlling a concentration of materials in the deposition system and/or means for controlling at least one of pressure and temperature in the deposition system.

30-34. (canceled)

35. A system for forming a superconductor wire on a tape substrate, the system comprising:

a first reel under ambient conditions that dispenses the tape substrate;

at least one deposition chamber that receives the tape substrate from the first reel, wherein the first reel is outside the at least one deposition chamber, the at least one deposition chamber comprising:

at least one distribution head that provides a laminar flow of precursor materials onto the tape substrate; and

at least one lamp comprising a reflector that directs UV and/or visible light towards the tape substrate to enhance a growth rate of material on the tape substrate surface;

at least one precursor system to inject at least one precursor material into the deposition chamber;

at least one transition chamber comprising at least one heating element to adjust the temperature of the tape substrate; and

a second reel under ambient conditions outside the at least one deposition chamber and the at least one transition chamber that spools the tape substrate comprising the layer of superconductor material.

36. The system of claim **35**, further comprising at least one stage chosen from:

a pre-clean stage that removes oil-based contaminants from the tape substrate.

an initialization stage that pre-treats and/or pre-heats the tape substrate to delivery to the at least one deposition chamber.

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